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Hydro-geophysical characterization for groundwater resources potential of fractured limestone reservoirs in Amdoun Monts (North-western Tunisia)

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ABSTRACT

This study has led to the identification of the Upper Cretaceous and Lower Eocene (Abiod, Boudabbous/El Gueria Formations) fractured and karstic aquifers in the Amdoun region (Northwestern Tunisia). Geological information (litho-stratigraphy and fractures network study) and geophysical (gravity, wells analysis, seismic reflection, Electrical Resistivity Tomography (ERT)) investigations performed in the area have highlighted, with some detail, images of structures of carbonate aquifers near anticline flanks and along perched synclines. Some factors such as fracture intensity, karsts evolution and structural position have an important influence on the hydrologic productivity of Abiod and Boudabbous/El Gueria reservoirs. Different methodologies were used to characterize the geological and hydro-geological perched aquifers and produce the 3D geo-electrical model of near surface karstic features and cavities of the carbonate limestone in the Aïn Sallem site. This study integrates the geological and geophysical information available and can serve as a representative example in the description of the most important hydraulic reserves in the North-western Tunisia.

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1. Introduction

Recharge and discharge of groundwater of carbonate systems in NW Tunisia depend highly on climate conditions (Hamed and Dhahri, 2013; Inoubli, 2014; Redhaounia et al., 2014a; Ayadi et al., 2014a). Carbonate aquifers in Northern Tunisia are the primary source of water for a rapidly growing population. Geophysical methods are commonly applied to detect the presence of karst in carbonate aquifers, because there is a high contrast with the host rock in terms of properties such as rock density, electrical conductivity as well as seismic properties. Single geophysical prospecting methods such as gravimetry (Chico, 1964; Beres et al., 2001; Jacob et al., 2010), Electrical Resistivity Tomography (ERT) (Loke et al., 2003; Jardani et al., 2006; Martínez-Pagán et al., 2013), ground penetrating radar (GPR) (Robert and De Bosset, 1994; McMechan et al., 1998) or seismic methods (Rechtien and Stewart, 1975; Benderitter, 1997; Grandjean, 2006) have been used to provide possible answers in the delineation and determination of karst geometry and in characterizing the sub-surface geological structures and the hydrodynamics of groundwater in these aquifers. Moreover, spatial heterogeneities in permeability and porosity, related to lithology and/or geologic history, can accentuate the effects of climate- or human-induced changes on groundwater availability and residence time, even for large aquifers. The study of the fractured and karstified limestone aquifers in the Amdoun area needs the compilation of several new approaches.

The objective of this study is to integrate gravity, seismic, ERT and geological data to better understand the hydrodynamics and characteristics of carbonate aquifers in NW Tunisia (Amdoun: Béja region). The characterization of the limestone reservoirs (Abiod and Boudabbous/El Gueria Formations) with a compilation of these geophysical approaches at different scales shows a good comprehension of the subsurface structural architecture and allows deducing the importance of this structure in the dynamic control within the aquifer.

2. Geological setting

The Amdoun area is located in North-western Tunisia (Fig. 1a), which represents the southern segment of the Alpine arc. The study

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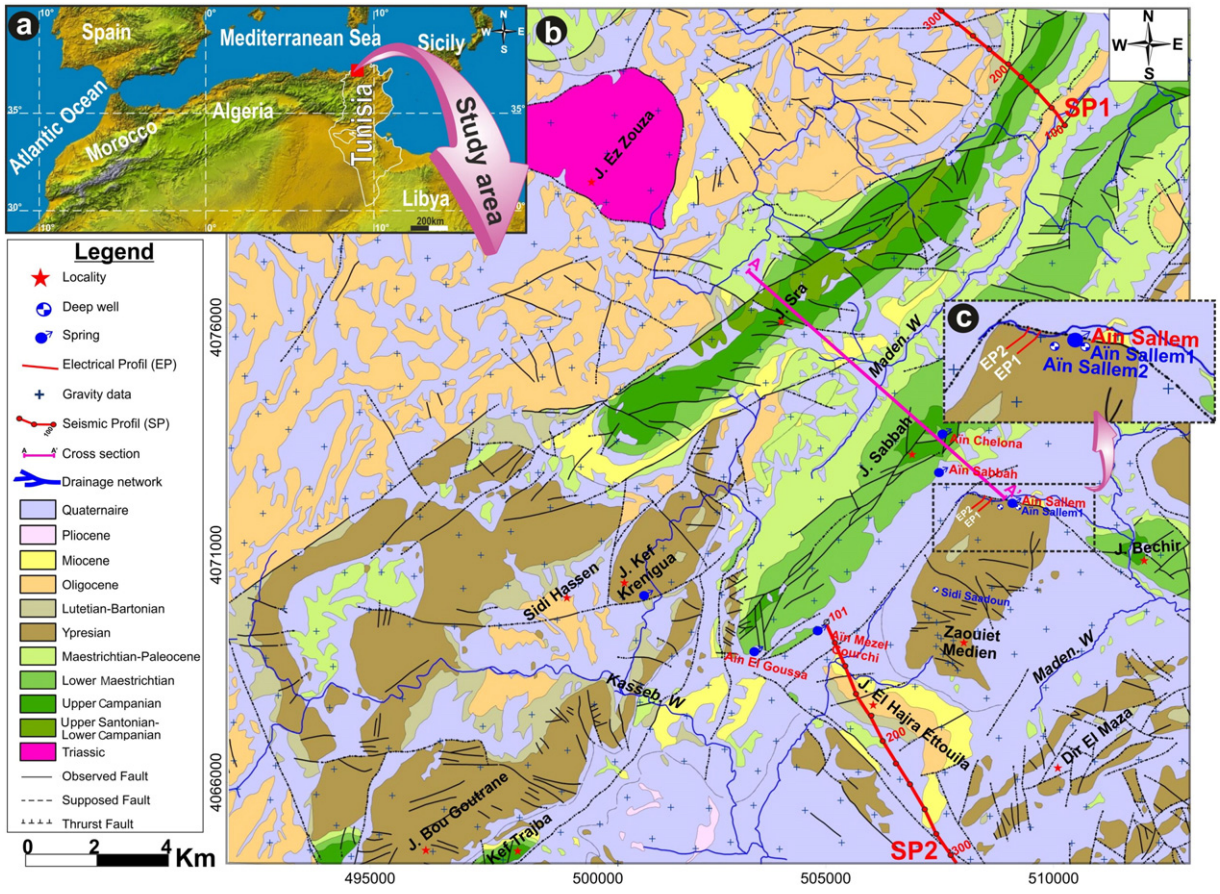

Fig. 1. a) Geographical location of the study area in Northern Tunisia, **b)** geological map of Amdoun study area (Gottis and Sainfeld, 1956), **c)** positioning plan of ERT profiles 1 and 2.

area has a complex topography and geological structure, characterized by successive NE–SW trending folds, such as Jebel Sra, Jebel Sabbah and Jebel Bougoutrane (Fig. 1b). The study area is subdivided from North-West to South-East into two major domains: the Alpine thrust belt zone (*allochtonous* overthrusting domain) and the imbricated zone (*parautochtonous* domain) (Rouvier, 1985; El Euchi et al., 1998; El Euchi et al., 2004; ETAP, 2006). These zones were affected by normal, reverse and transverse faults related to a compressional regime associated with to convergence between the Eurasiatic and African plates during the Tertiary (Rouvier, 1985; Zargouni, 1985; Bobier et al., 1991; Ben Ayed, 1993; Bédir, 1995; El Euchi et al., 1998; Khomsi, 1998; Bouaziz et al., 2002; Jallouli et al., 2002; El Euchi et al., 2004; Khomsi et al., 2009; Boukhalfa et al., 2009; Riahi et al., 2010; Laaridhi, 2012; Gabtni et al., 2013). Except for the E–W Triassic outcrop of the Jebel Ez Zouza, the lithological sequences in this study area vary in age from Upper Cretaceous to Quaternary (Fig. 1).

The Digital Elevation Model (DEM) superimposed with a geological map of the study area shows a succession of NE–SW trending structures and folds (Redhaounia et al., 2012). From NW to SE (from 1 to 6), we can distinguish the following structures, illustrated in Fig. 2.

3. Hydrogeological characteristics of carbonate aquifers

The lower and upper members of the Abiod Formation (Campanian–Lower Maastrichtian) composed of fractured and chalky limestones show a significant potential aquifer confirmed by the location of many springs like Aïn Sabbah spring and Aïn El Goussa… (Fig. 3a–f). The petrophysical and geochemical analyses of Aïn El Goussa spring show excellent drinking and irrigation water characteristics (Ca–Mg–HCO_3 water) (ONT, 2008; Redhaounia et al., 2015a,b). The Abiod Formation can be subdivided into three distinctive units, composed by the carbonate limestone series with thickness and facies variations (Gottis and Sainfeld, 1956; El Euchi et al., 1998; ETAP, 2006; Redhaounia et al., 2015b; Redhaounia, 2016).

These chalky limestones are fractured under tectonic influence and their petrophysical characteristics are enhanced, giving a good fractured reservoir. The petrophysical parameters of these reservoirs fluctuate with porosity between 8 and 20%, permeability from 100 to 200 md and have an average thickness of 250 m. The upper Abiod member is sealed by the overlying El Haria Formation shales (Upper Maastrichtian–Paleocene) (El Euchi et al., 1998; ETAP, 2006). The Ypresian fracturated limestones are represented by the Boudabbous (Globigerina)/El Gueria (Nummilitic) Formations with a thickness average of 250 m, sealed by the Souar Formation shales (Upper Lutetian–Bartonian). It exhibits several types of lithological facies corresponding to petrophysical parameters variations of porosity from 5 to 12% and permeability from 100 to 700 md (El Euchi et al., 1998; ETAP, 2006).

Small-scale fractures of different style and multiple directions have been identified, for example, open fracture direction, of NW–SE, NE–SW and N–S. This is confirmed often by the relatively location of many springs near faulted and fractured zones as Aïn Sallem and Aïn Saddek (Fig. 3b, c, d). The study area may have high groundwater potential of the limestones bodies (Abiod and Boudabbous/El Gueria) due to the high density and concentration of fault/fracture lineaments and their orientations (Redhaounia et al., 2012, 2013a, 2013b, 2014c; Anene et al., 2013).

Fig. 4 shows a NW–SE geological cross section A–A′, perpendicular to geological structures (Jebel Sra and Jebel Sabbah anticlines and Maden Wady syncline), illustrating the structural configuration of the Upper Cretaceous and the Eocene limestone aquifer beds. This geological cross section (A–A′) is accompanied by the hydro-geological data and provides a two-dimensional view of the hydrodynamic system near

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