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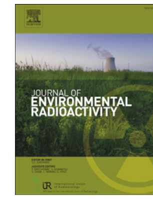

Investigation of uranium geochemistry along groundwater flow path in the Continental Intercalaire aquifer (Southern Tunisia)

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Environmental tracers (^{2}H, ^{18}O, isotopes of Uranium) and geochemical processes occurring within groundwaters from the Continental Intercalaire (CI) in Southern Tunisia were used to understand the hydrodynamics and the recharge conditions of this aquifer. This study investigates the chemical and isotopic compositions of the CI groundwater. The water types are dominated by Na^{+}, SO_4^{2-}, Cl^{-} throughout most of the basin with a general increase in total dissolved solids from the Saharan Platform margins towards the Chotts region. Large scale groundwater flow paths are toward the Chotts region. The stable isotopes composition of the analyzed groundwater ranges from −8.8 to −6‰ *vs* V-SMOW for $\delta^{18}O$ and from −67 to −40‰ *vs* V-SMOW for $\delta^{2}H$. The relatively enriched stable isotopes contents suggest the contribution of the Dahar sandstones outcrops in the current recharge of the CI aquifer in an arid context. However, the most depleted values in heavy isotopes indicate a paleorecharge of the aquifer under wetter conditions revealing a long residence time of groundwaters. The results from water samples using alpha spectrometry method indicate a range in ^{238}U concentrations and $^{234}U/^{238}U$ activity ratios (AR) of 0.044–1.285 μg kg^{-1} and 1.2 to 8.84 respectively. The geochemistry of uranium isotopes in groundwater is controlled by many factors, essentially, the influence of water rock interactions, the preferential dissolution of ^{234}U relative to ^{238}U due to alpha recoil and the mixing processes between different waters with distinct AR as well as ^{238}U concentrations.

1. Introduction

The deep Continental Intercalaire (CI) aquifer is one of the world largest groundwater reservoirs extending from the Moroccon borders to Libya from West to East. In Southern Tunisia the CI is one of the most important natural groundwater resources for water demand supply. It may be considered as a type area for large artesian basins (Edmunds et al., 2003). Over exploitation of this aquifer has occurred due to the excessive increase of water request of the different economic sectors (agriculture, tourism, industry …) with preponderance of the agricultural needs. Hence, it seems fundamental for these groundwater resources management to better understand the hydrodynamics and the recharge conditions. The CI aquifer has been the subject of numerous studies whose synthesis was conducted as part of a project supported by UNESCO (ERESS, 1972). It has been established during this project that the Chott region forms the discharge area of the CI aquifer (ERESS, 1972). It was also shown that the CI aquifer consists of several horizons with strong artesian pressure (5–25 bars) and with temperatures from 65 to 75 °C (ERESS, 1972 in Edmunds et al., 2003). ERESS study has been pursued by several authors and over different projects, for instance Gonfiantini et al. (1974), Mamou (1990), Guendouz (1985), Yahyaoui (1996), OSS 2003, Abid et al., 2010. It has been shown that the $\delta^{18}O$ and $\delta^{2}H$ values indicate a cooler recharge regime with rainfall having lower primary evaporation than today (Edmunds et al., 2003). The combined evidence shows that the recharge coincides with cooler humid periods during the late Pleistocene which exists across the whole of Saharan Africa (Guendouz et al., 1997). The main objective of this paper is to provide a further understanding of the groundwater flow pattern and the induced geochemical processes occurring in the CI aquifer system. The mechanisms controlling the groundwater geochemistry and the

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transport processes in the CI water rock system were investigated using different environmental tracers (^{18}O, ^{2}H, isotopes of Uranium). The radionuclides of uranium constitute the novelty of the present approach relative to previous related contributions.

2. Study area

The study area is located at the Southern boundary of the Atlas Saharan mountains and at the Northern boundary of the Saharan Platform. It is limited in the East by the Golf of Gabes and Libyan frontier and in the West by the Algerian frontier (Fig. 1). From South to North, it represents the geographic space that extends from the extreme South to the Northern chain of Chotts. The mean annual temperature is 21 °C with a potential evapotranspiration of 1700 mm/year. The mean annual precipitation is less than 100 mm indicating therefore an arid type climate.

3. Geological and hydrogeological settings

In Southern Tunisia, a large extension of sedimentary deposits of Mesozoic age was highlighted from the Chotts area in the North to the Libyan frontier in the South (Bouaziz, 1995). The Cretaceous, main resource of water wells in Southern Tunisia is largely outcropping along the northern chains of Chotts as well as in the Dahar upland. The Lower Cretaceous is characterized by significant variations in facies and thickness from the Saharan Platform to the Chott area. This period corresponds to an episode of continental sedimentation continued until the Vraco-Cenomanian (Mamou, 1990). Therefore, it is also known as Continental Intercalaire presenting a succession of detrital sediments separated by clay-rich strata and gypsum intercalations leading to an extent of heterogeneity within this aquifer. In Southern Tunisia, tectonic processes have generated several geological provinces with different stratigraphic and structural particularities from one province to another. The Dahar upland which consists of a N–S trending (Zargouni et al., 1985; Bouaziz, 1995; Bouaziz et al., 2002; Gabtni et al., 2009), is located between the plain of Djeffara in the East and the Saharan Platform in the West. The Chotts depression constitutes its Northern boundary (Fig. 1). The overthrow faults consist of a NW–SE trending in relay from the northern chain of chotts up to El Hamma region. This set of faults extends towards the SE across the faults of Ben Gerdane and Djerba-Zarzis constituting therefore the continuity of the NW–SE trending faults of El Hamma region whose role in the communication between the CI aquifer and the Djeffara aquifer of Gabes is determining (ERESS, 1972; Trabelsi et al., 2009; Abid et al., 2009; OSS, 2003). These faults are responsible for the subsidence of the Eastern flank of the Djeffara dome under the Mediterranean Sea (Mamou, 1990) and are part of a complex called the South Tunisian accident (Castany, 1954). In Southern Tunisia, the consequent structure of these sets of faults corresponds to successive outcrops of compartments with some local complications leading to the individualization of horsts and grabens. This structure is of a great interest on the hydrogeological scheme and obviously in the hydraulic communications between aquifers (Mamou, 1990). Groundwater flows in the CI aquifer converge towards the Chotts region (Fig. 1). The principal W–E groundwater flow line in the Continental Intercalaire aquifer comes from the Algerian frontier towards the discharge zone in the Gulf of Gabes. It has been shown that the hydraulic gradient increases at El Hamma region, which explains the discharge effect through vertical leakage (drainage) of waters from the Kebeur El Hadj series of the CI. The fault of El Hamma is responsible of this configuration which makes of the Chott region the single discharge zone of the CI aquifer in Southern Tunisia (ERESS, 1972; Trabelsi et al., 2009; Abid et al., 2009; OSS, 2003). The S–N flow direction highlights the flow line coming from the Lower Cretaceous outcrops located on the Dahar reliefs. The piezometric lines indicate that these outcrops represent a local recharge area of the CI aquifer through water runoff. The SSW-NNE direction comes from the Algerian-Libyan frontier towards the discharge area of the aquifer. Lithostratigraphic correlation along a SE–NW cross section (Fig. 2) has been established to study the geometry and the lateral extension of the aquifer system and to show the main aquifer levels.

As shown in Fig. 2, the multilayer CI aquifer is characterized by i)

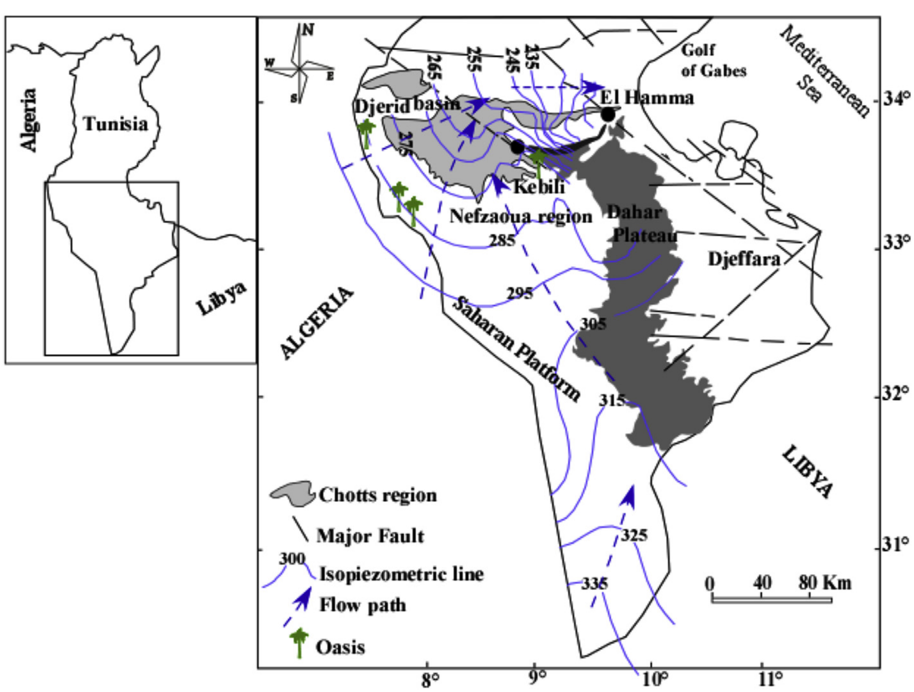

Fig. 1. Location map of the study area including the piezometric lines of the CI aquifer.