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HYDROGEOLOGICAL CHARACTERIZATION OF A FRACTURED BEDROCK AQUIFER IN THE OUGARTA CHAIN SOUTHWESTERN ALGERIA

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ABSTRACT

The Ougarta Mountains, located in southwestern Algeria, correspond to an imposing geological entity that corresponds to the center of interest in the geology of the Saharan platform. It is a vast area of elongated NW–SE reliefs, covering an area of 400 x 200 km². The Cambro-Ordovician represents the largest aquifer in the Ougarta region. The cracked type is still poorly known; it is located on a cracked base, and is composed of quartzite sandstone and shale forming a multilayer system, the details of which still remain to be sought and constitute a perennial aquifer for the supply of drinking water for the population.

The present study is an attempt to better comprehend the structure and functioning of these basement aquifers. It mainly focuses on the description of soil profiles, structural investigations, and hydrogeological characterization improving knowledge on the hydrodynamic functioning of fractured base reservoirs (geometry of aquifers, hydrodynamic parameters, recharge, resource availability) with a view to the installation of catchment works to optimize, secure and sustain its exploitation in view of its strategic importance for the water supply of this region of Beni Abbes. This contribution is based on field observations and the use of several methods. Various joint approaches have been implemented to locate and characterize aquifers, zones favorable to hydraulic catchments. These are geology, hydrodynamics, piezometry and hydrochemistry.

The «Ougarta sandstone» layer of the Cambro-Ordovician is free at the edge, captive toward the center of the basin, and is characterized by a transmissivity varying from 10^{-3} to 4.10^{-4} m²/s. Its piezometry shows a northeasterly southwesterly direction of flow in the direction of the general slope, under a hydraulic gradient of 0.04 to 0.005. The water table flows toward the southeast. The static level of the Paleozoic aquifer oscillates between 06 and 31 m relative to the soil elevation.

Over 30 years, this system has remained stationary, however, the structures installed in the north show a drawdown of 0.1m east indicating large flows (plus 3000 m^3/day), with high hydraulic productivity of the catchment works is related to heterogeneity factors.

From a hydrochemical point of view, the groundwater of the volcano-sedimentary base is, in general, poorly mineralized and predominantly chlorinated; it is rapidly charged with sulfates on the limits of the free surface area.

Keywords: Aquifer, hydrogeology, structure, Ougarta, cracked Socle, Paleozoic, Saoura, southwestern Algeria.

INTRODUCTION

Basement rocks, or crystalline rocks, are plutonic and metamorphic rocks (Lachassagne et al., 2014). These rocks are characterized by a very low matrix permeability (less than 10^{-8} m/s).

Bedrock is the subsoil of continents and outcrops over 20% of unfrozen land, mainly in tectonically stable areas such as old chalk: 40% of the entire African continent, especially in West Africa (nearly 50%), respectively 24% and 21% for South and North America, 45% for India, a large part of Australia and nearly 20% in Europe. (Lachassagne et al., 2014).

Contrary to the base of Central Africa where hydrogeological studies are little developed (Djeuda et al., 1999; Gombert, 1999), the West African basement has been the subject of numerous research works (Courtois et al., 2009; Kouadio et al., 2010; Kouakou Kouassi et al., 2012).

The hydrogeological characterization of the cracked basement will contribute to the knowledge of the structure and hydrodynamic functioning of the basement aquifers. It shows structural links with other aquifers described worldwide and regional specificities that influence the hydrodynamics of weathered and cracked bases (Bon et al., 2016).

The Beni-Abbes region is part of the Saoura Valley and belongs to the Hamada of Guir. Geologically and on a regional scale, the study region is linked to the chain of the Ougarta Mountains, made up of a range of very varied terrains, ranging from the Precambrian to the present.

Groundwater is the only water supply resource for the Béni-Abbes region. The subsoil of the latter is well provided with groundwater resources, knowing well that all the aquifers

do not represent the capacity for interesting exploitations. We summarize these resources as follows: The Mio-Pliocene aquifer (Occidental Grand Erg) is fed mainly by the Namous Wadi, as for that of the hamada of Guir, it is renewed by rainwater. The water tables of the Paleozoic formations at the level of the villages of Zéghamra and Ougarta are partially fed by meteoric waters and those of the Saoura wadi.

The Saoura region has been the subject of several fragmentary hydrogeological studies by different authors: Schoeller (1945), Cornet (1952), Conrad (1965), Roche (1973), from the Igli region to its outlet from the Saoura valley at Foum Lakhneg.

In the Northwest of the Algerian Sahara, the Chain of Ougarta constitutes an imposing geological entity. The sedimentological characteristics of the Cambro-Ordovician have been analyzed by: Arbey (1962, 1966, 1968, 1971, 1979, and 1985), Gomez et al. (1982), and Aït Kaci (1990). The region of Beni-Abbes is attached to the chain of Ougarta, which stands out clearly in the Algerian Sahara, and forms a relief elongated over 400 km in length and 200 km in width. The Ougarta chain is made up of volcano-sedimentary and magmatic formations forming a substratum or basement of Upper Precambrian age and Paleozoic lands reported to a cover, sealed by Cretaceous or more recent, Tertiary and Quaternary sediments.

At the level of the Ougarta range, the aquifers are poorly defined; however, the various catchments that are made at the level of the Zéghamra and Ougarta villages (springs, wells, boreholes) favor of the existence of several Paleozoic basement aquifers. It is probably a superposition of fossil aquifers fed during the humid Quaternary periods. Paleozoic basement aquifers, are probably a multilayer system, the details of which are poorly understood.

In the rest of the text, the Algerian word “Wilaya” is used to design a province. Each wilaya constitutes a decentralized administrative area composed of a certain number of towns.

The issue addressed in this article is limited to the space of the Béni-Abbès region, and can therefore be summarized in four points. The first aspect concerns the question of the

geometry and structure of the Cambo-Ordovician aquifer. The second aspect is hydrodynamic (discharge) and hydrochemical characteristics. The third point is limited to the possibility of making a transfer to strengthen the drinking water supply for the new wilaya of Beni Abbes.

To this end, the objective is to understand the geological, hydrogeological and geochemical characteristics of the hydrogeological system of the Cambro-Ordovician basement aquifer. It, therefore, seems necessary to identify the aquifer and determine its hydrogeological mode of operation and its mode of recharge. To do this, we first synthesized the knowledge gained from previous data and work. Subsequently, we used and interpreted our data collected during the various field measurement campaigns. A series of sampling and measurement campaigns were carried out (20 water points) with approximately ten water points scattered in the great western erg between 2014 and 2017.

GEOGRAPHIC LOCATION

In the northwestern part of the Algerian Sahara, between the coordinates 0° 30 '- 5° 00' of the longitudes west and 28° 30'- 31° 00' of the latitudes north, the Mounts of Ougarta are locared. It is a vast zone of elongated reliefs NW-SE, over an area of 400 x 200 km². The Mounts of Ougarta are limited to the north by the Hamada of Guir and the Kemkem plateau, to the south by Hamada of Chammar and Touat, to the east by a spectacular system of dunes of the great western erg and to the west by the Hamada of Draâ, the ergs Iguidi and Chech (Fig. 1). The Mounts of Ougarta are subdivided into two substantially parallel bundles: the Saoura and Daoura beams, separated by erg Er Raoui (Fig. 2).

The reliefs are carved by different phases of erosion from the Permian to the Upper Jurassic (Conrad, 1969), and they do not exceed 250 m above the surrounding plains. The average altitude is 550 m, with two culminations of 890 m at Jebel Bet Touaris and 865 m at Jebel Ghannouma.

The hydrographic network, which is dry most of the time, is well taken in the landscape. Inside the chain, the Wadis make a net with tight and entangled meshes. By cons, two main borders of the chain, the Wadi de la Saoura to the east and that of the Daoura to the northwest, are highlighted.

Rainfall is very low, from 10mm to 30mm/year (Dubief, 1960). High aridity of the atmosphere is characterized by a hot summer (temperature > 42°C) and a harsh winter with temperatures that drop below 0°C. The winds are frequent, especially in March and April. A temperature has large amplitude variations, both daily and seasonal.

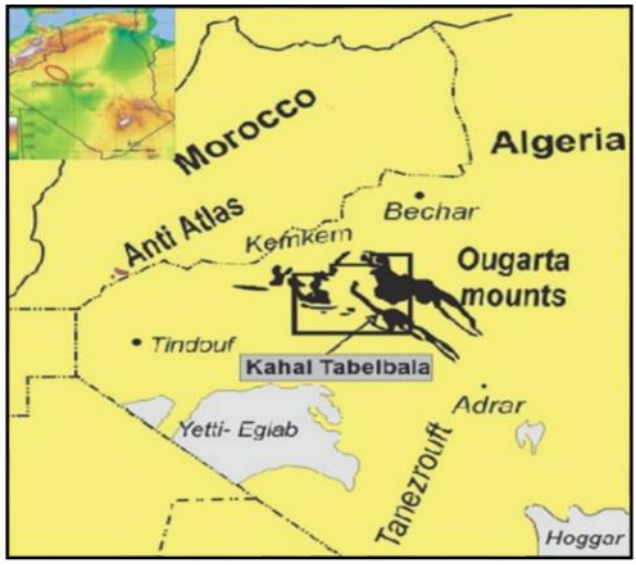

Figure 1: Location of the Ougarta Mounts

The vegetation cover, almost zero, is limited to Wadi beds, where Acacias radian (Talha), Zizyphus lotus (Sedra), and some dune flanks, grasses, especially the drain (aristida, pyngens) are the most spectacular. In circular bowls in Hamada, we encounter curious salsolaceae, known as the Bouamama mushroom (Anabasis aretioides). Most of the water points focus on the borders of erg Er Raoui, which is known as a drinking water reservoir. The most famous are Hassi El Hariga, Hassi Aouissia and Hassi El Kheil.

GEOLOGY

The Ougarta Mounts consist of volcano-sedimentary and magmatic rocks forming an Upper Precambrian bedrock or bedrock and Paleozoic soils referred to as cover, sealed by Cretaceous or later, Tertiary and Quaternary sediments.

The Ougarta range consists of a set of volcanic and volcanic-detrital formations, upon which a powerful sedimentary cover of mainly Cambro-Ordovician Paleozoic age is unconformably connected with a polygenic conglomerate at its base with a known element. The name of the "conglomerate of Ben Tadjine" (Chikhaoui and Donzeau, 1972).

The Paleozoic basement-cover relationship of the Ugarta region is re-examined and an ante-cover alteration profile affecting the volcanic bedrock at Bou Kbeïssat is highlighted. The major geological events show instabilities at various times linked to the particularly sensitive position of this region of Western Sahara. The tectonic stability is quite relative; the Caledonian and Hercynian phases are well recorded (Nedjari, 2007)

Lithostratigraphy

The Ougarta Mounts consist of volcano-sedimentary and magmatic rocks forming Upper Precambrian Substratum and Paleozoic soils (Fig. 2).

The latter are sealed by Cretaceous sediments or more recent deposits, namely, the Cretaceous plateau of Kemkem in the northwest and the Hamada of the Guir Mio-Pliocene in the east. The Paleozoic is impressive by its power; it reaches more than 5 km northwest of this vast territory. The Cambrian includes arkoses and quartzites of 1200 m.

The Ordovician is known on almost the entire surface of the chain and is the backbone of the chain. It remains detrital, and it is a siliciclastic deposit with carbonate occurrences (900 m). The Silurian (1000 to 1250 m) is known as the Wadi Ali Formation, and is a thick series of black shales, a major source rock in North Africa (MacGregor, 1996; Boote et al., 1998). The Devonian is very powerful; at the base, it is argilo-silty and carbonate, and then it becomes sandstone.

The Cretaceous (20 to 30 m) are clayey sandstones, sandy limestones and dolomitic limestones. The Neogene (40 m) is either the immense Hamada du Guir or the buttes witnesses (Gour) present here and there. It is tabular and discordant on all terrains. It

consists of fluvio-lacustrine deposits crowned with a silico-carbonated shell. Quaternary erosion-sedimentation cycles governed by arid rainy climatic variations, developed during the Quaternary period. This cycle gave, below the Hamada du Guir, Quaternary formations accumulated by the course of the Saoura where the Quaternary specialists (Alimen, 1952; Chavaillon, 1964), distinguished:

- Ancient terraces (Pliocene - Villafranchien) formed of a detrital series surmounted by conglomerates and sands,
- Middle terraces (Pleistocene) (Saourian) formed of a series of encrustations surmounted by fluvio-aeolian sands with marl pasts that correspond to lacustrine sedimentation,
- Upper Terraces (Holocene), composed of an alternation of sand and gravel intersecting with the presence of alluvial sand.

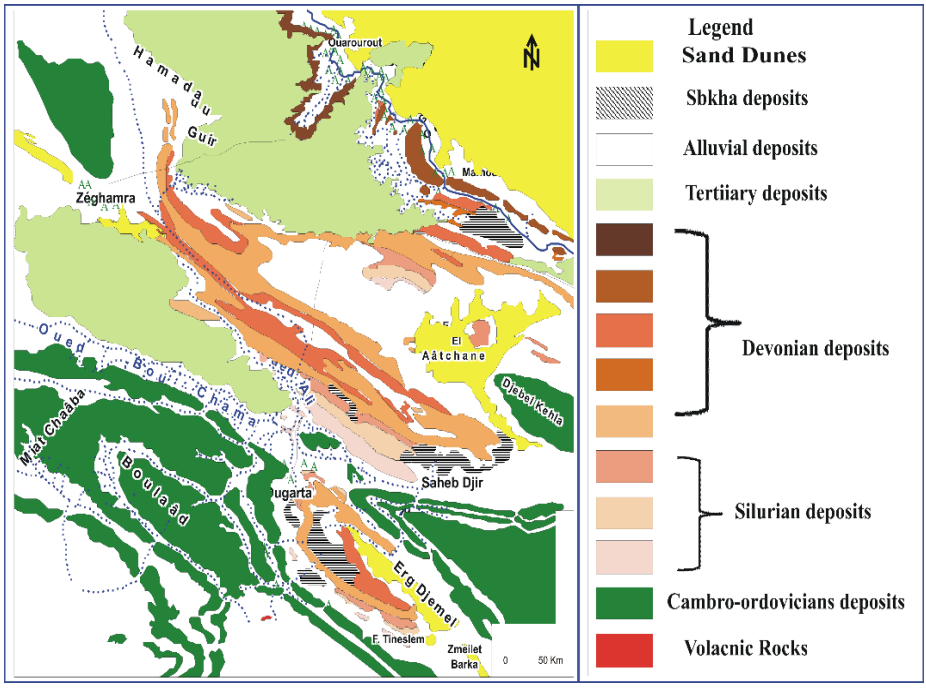

Figure 2: Simplified geological map of the Ougarta Mounts and synthetic cut of the Ougarta Mounts (Mekkaoui and Merzougui, 2015)

Tectonics

The Ougarta Mounts form a succession of narrow anticlines and wide synclines, NW-SE and sometimes intersected by accidents in the same direction, as well as accidents NE-SW and E-W directions (Fig.3).

The Plicative tectonics

The Ougarta Mounts present a general structure NW-SE, in which we classically distinguish three megastructures:

- The anticlinorium of the Kahal Tabelbala consists of the Ben Zohra anticline, the Ben Tadjine syncline, the Wadi Damrane-Erg Atimin anticline, the Kahal Tabelbala syncline, the anticline and the syncline of Oglat Mohammed.
- The Ougartian or Central anticlinorium, structurally, is characterized by wider bands with steep flanks (dips of 30 to 35°). Aeromagnetic data show that this anticlinorium corresponds to a basement bulge. This system is complicated by more transverse faults E-W to ENE-WSW. The result is a system of anticlines and synclines (Menchikkoff, 1952). The synclines of Bou M'haoud and Koudiat M'daga are good examples. The NW-SE fold axes dip 5° to the NW. Most transverse axes are horizontal (Donzeau, 1971).
- The Kerzaz anticlinorium includes the anticlines of Sebkha El Melah, Djebel Kahla and Djebel Zeghamra. The NW-SE folds are tight and limited to the NE by the large border fault, separating the chain from the platform.

In brittle tectonics three fault systems can be distinguished namely:

- The N140° (ougartiennes) faults correspond to the rejuvenated faults of the Hercynian basement with the formation of breccias, ferruginization and silicification.
- Faults N E (Ksiksou) also reflect fractures of the socle; they are sometimes in the form of parallel fracture zones. Their replay is Hercynian, and they are accompanied by intense ferruginization and manganese mineralization (Mn).
- The E-W faults are late and represent the geometric result of the large fractures of the NW and NE basement. Finally, smaller fracture bundles, parallel to large faults, have a quartz filling with polymetallic mineralization (Cu, Pb, Zn, Ba, etc.).

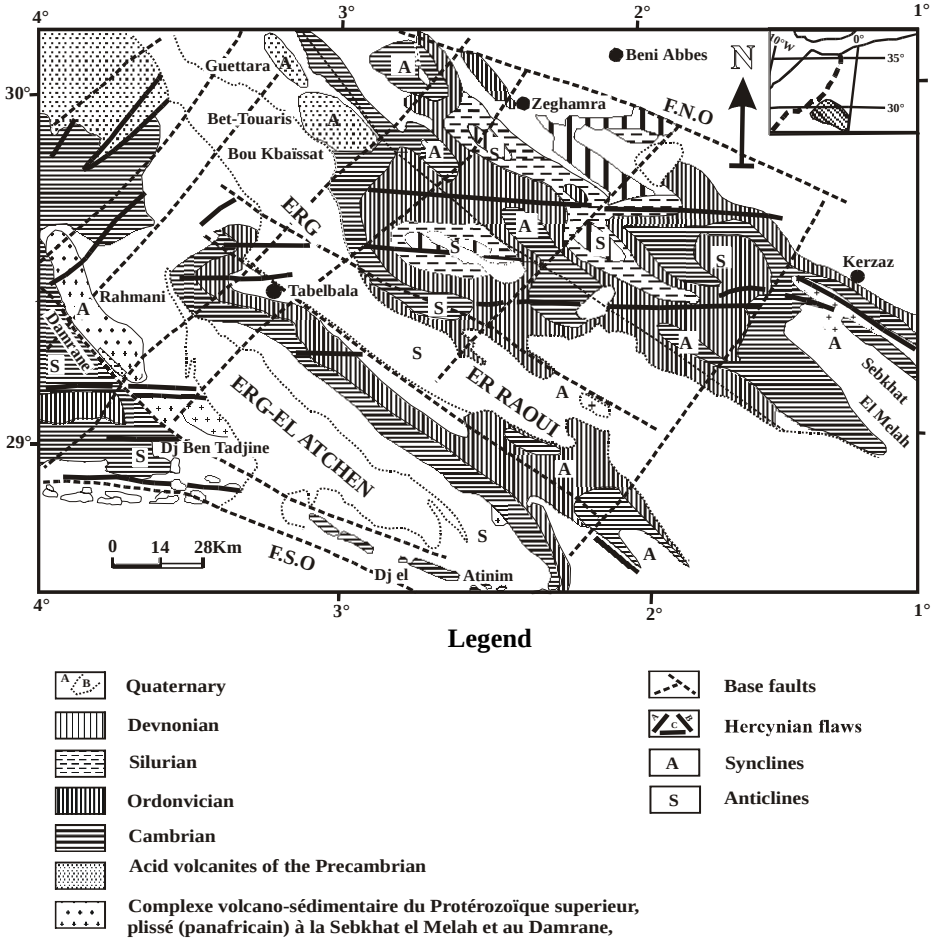

Figure 3: Schematic diagram of the flexural axes of the synclines and anticlines of the Ougarta Mounts (In Bouima 1986, modified)

CONTRIBUTION OF GEOPHYSICS

The results of the electric geophysical prospecting carried out in 1999 by A.N.R.H. in the area of Zeghamra and Ougarta cover a surface of approximately 546 Km^2, including 18 profiles with 112 soundings in the line of emission AB = 4000 m. This geophysical study allowed us to detect formations likely to be aquiferous in the investigation area (Fig. 4):

Quaternary formations, calcareous-sandstone formations of the Lower Devonian, Silurian formations and sandstone and quartzite formations of the Cambro-Ordovician.

From a hydrogeological point of view, the first three formations are not of great hydrogeological interest because of their low thickness and the low rainfall in the region. However, the Cambro-Ordovician aquifer is of great hydrogeological interest, for the following reasons:

They contain resistant sandstone and quartzite levels with fissures, clayey-sandstone or limestone that constitute good aquifer horizons.

They are very thick, especially in the depressions of the synclines, which are more than 800 m thick for the Ordovician. This shows that the formations can form large groundwater reservoirs with favorable water accumulation conditions (Fig. 4).

The two boreholes drilled in the Zeghmara region through the Si-Lurian and Ordovician yielded flow rates exceeding 50 l/s.

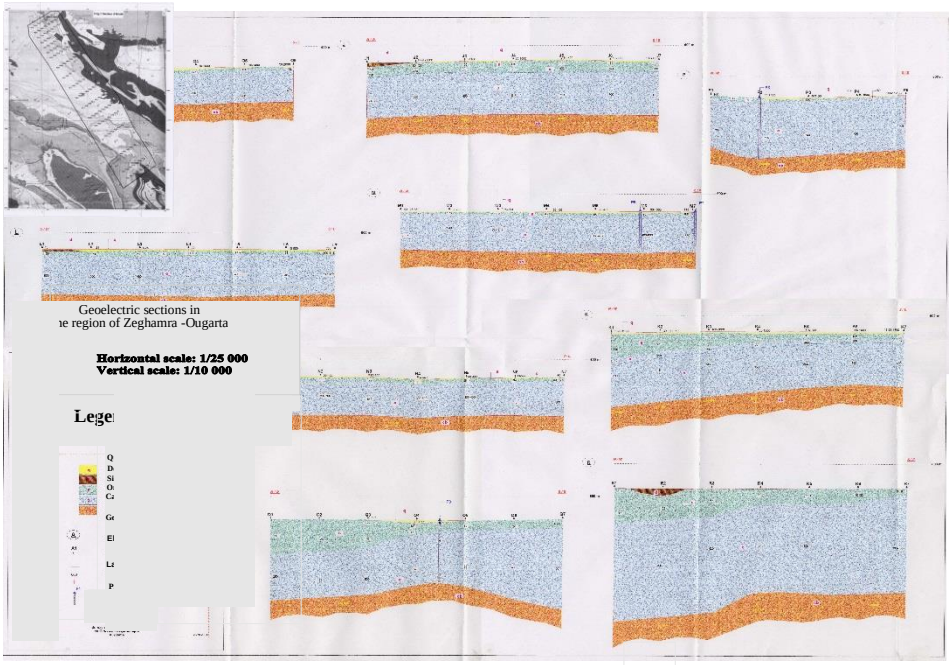

Figure 4: Geoelectrical section through the Paleozoic formations in the Zeghamra Ougarta region

HYDROGEOLOGICAL CONTEXT

The subsoil of the Saoura region contains significant groundwater resources and closes an interconnected system whose Saoura Valley is considered to be an umbilical cord (Merzougui 2007). This system comprises the following (Fig. 5):

- The groundwater of the great western erg is hydrogeologically well defined; its recharge is ensured mainly by the Namous Wadi of the Saharan Atlas. The large source, usually referred to as the "source of Sidi Othmane", represents an outlet par excellence that captures the groundwater of this aquifer, with a flow of 33 l/s (Merzougui, 2005). It plays a dual role: the drinking water supply of the city and the irrigation of the palm grove.
- The groundwater of Hamada du Guir, fed by the rare rainwater and wadis Aicha and Abiod, is contained in the limestone lakes of the Tertiary.
- Paleozoic aquifers are known only locally in the villages of Zéghamra and Ougarta, whose aquifer is Cambrian and Ordovician. The groundwater is partially fed by rainwater and probably by the Saoura River.
- The layers of alluvial terraces and underflow constitute a particular type of groundwater formed by the large spreads of sand and gravel of Saoura.

The Saoura Valley divides this system into two compartments: west and east. The West is passive and includes the Groundwater of the Hamada of Guir, which communicates in places with the Groundwater of the Upper Paleozoic.

On the other hand, the eastern compartment is active: it is a natural drain ensuring the flow of water from the great western erg to the tables of terraces and underflow. The latter will be able to communicate in places with Paleozoic aquifers.

One may observe a succession of monoclinal layers of shale, sandstone and quartzite; the whole rests on infracambrian substratum. The aquifer is composed of sandstones and quartzites with thicknesses of 300 to 500 m. The groundwater in the Ougarta Mounts is divided into three sandstone and quartzite formations isolated by shale layers (Roches, 1973). The Groundwater is thus partly free and partly captive under the three impermeable schists. From the point of view of the hydrogeological are those of the Combro-Ordovician and called the basement aquifer. It is fed by the infiltration of runoff water on the reliefs at the edge of the Ougarta Mounts, paleorecharge by the direct infiltration of precipitation water and by the waters of the water table of Hamada de Guir, which drain the Cambro-Ordovician aquifer.

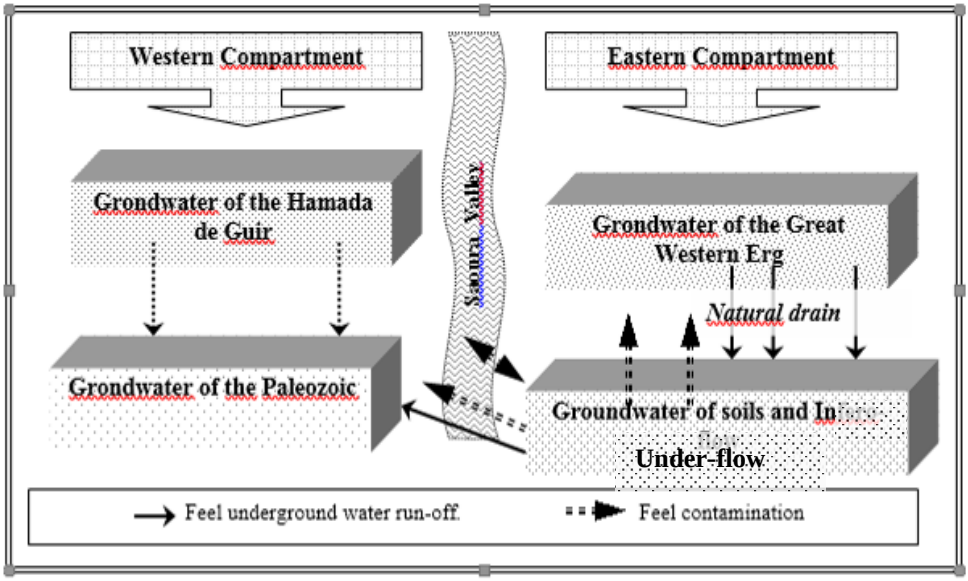

Figure 5: Simplistic sketch of the water-bearing system of Beni Abbes). Conditions and deposits of the Paleozoic aquifer (Merzougui, 2021)

Hydrodynamic behavior of reservoirs

Given the heterogeneity, the hydrodynamic parameters vary from one area to another depending on the types of geological formations (fissured terrain) that predominate. The permeability of aquifers is either interstice (sandstone) or fissures (sandstone and quartzite + the transmissivity and storage coefficient values calculated from which the behavior of the layers of the aquifer emerges. They are respectively of the order from T = 10^{-4} to 10^{-5} m^2/s and S = 10^{-1} for the alterite aquifer and T = 10^{-2} to 10^{-3} m^2/s and S = 10^{-2} for the aquifer of cracks and fractures.

The two hydrogeological units of the Mounts of Ougarta, present different characteristics: the first unit offers good quality water with very good flow rates at the village of Zeghamra and Ougarta (10-40 l/s), and the second unit has low to very low flow rates with mediocre quality (0.1-1.5 l/s).

Water flow and piezometry

The March and April 2016 piezometric campaigns enabled us to draw a piezometric map of the western Great Erg aquifer, and the inventory of water points is shown in Table 1. The waterways of the aquifer of the Cambro-Ordovician aquifer are generally: North.East/Southwest (Fig. 6). The static level of the Paleozoic aquifer oscillates between

06 and 31 m from the groundwater. The water masses are distributed in two sandstones and quartzitic beds. Two hydrogeological units are isolated by the shaly layers. The Groundwater is thus partly free and partly captive under impervious schistosity. In synclines, such as the syncline covered in part by Erg el Djemal, the reservoirs must be large. The water points currently exploiting these aquifers are generally in contact with sandstones and shales.

Table 1: Inventory of water points (Merzougui, 2016)

Water points	Type	Depth (m)	Piezometric level (m)	Flow rate (l/s)
Ougarta P1	Well	14	407	05
Ougarta S	Source	00	411	0.5
Ougarta F1 AEP	Drilling	150	400	10
Ougarta F2	Drilling	120	409	06
piezometer 1 Zeghamra	piezometer	150	515	-
Zeghmara chinoi	Forage	600	505	0
piezometer 2 Zeghamra	piezometer	150	507	-
Zeghamra F1	Drilling	200	513	10
Zeghamra F3	Drilling	150	502	12
Zeghamra F2	Drilling	250	503	60
Hi Bo M'hawad	Well	10	500	2
hi Sidi Madani	Well	9	418	-
Hi Ouchtat	Well	12.5	470	-
Hi zemlat barka	Well	11	480	-
El ksaib	Source	0	400	0.005
Ain Dhob	Source	0	340	0.001
Hi Ain Dhob	Well	10	300	2
Hassi Alaouissa	Well	8	452	-
Kheng Alaten	Source	12	477	-
Ain Nechea	Source	0	335	0

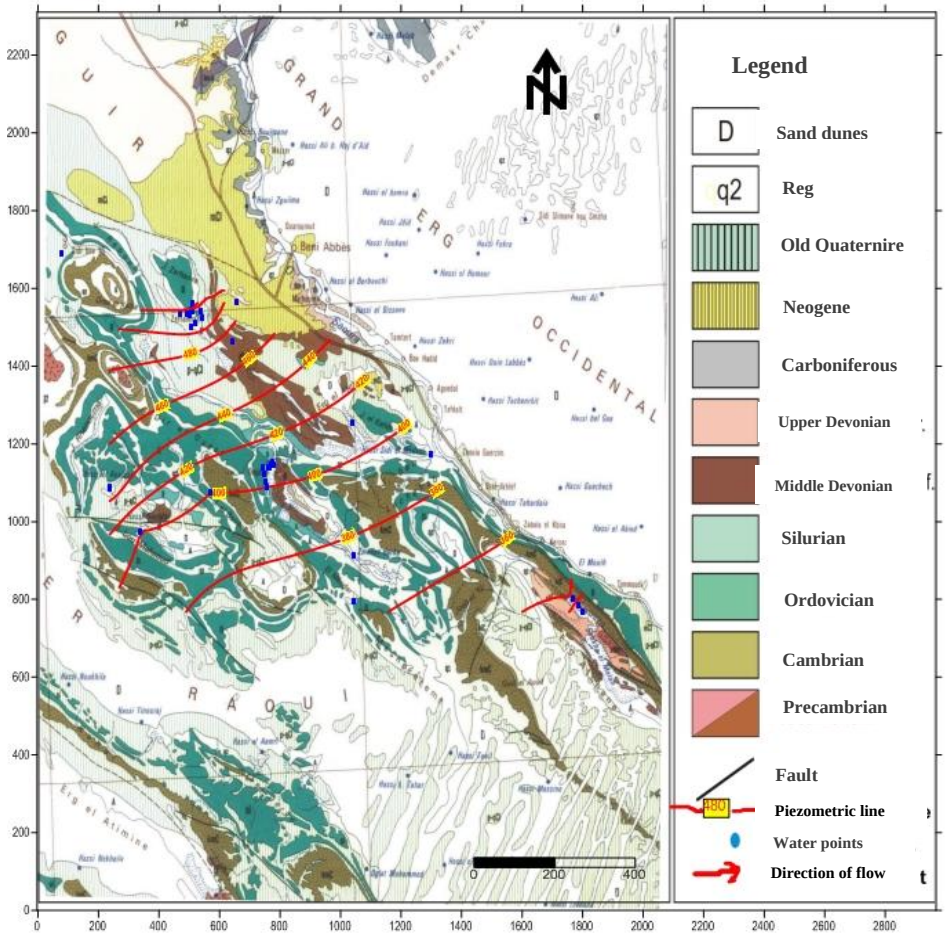

Figure 6: Piezometry of the Cambro-Ordovician nappe of the Ougarta Mounts, (Merzougui, 2016)

According to the investigation data of the Paleozoic hydrogeology of the Ougarta mounts, we have found two units:

The first unit gives more or less important flows oscillating between 10-60 l/s (Fig. 7), Drilling was carried out in 1995 in the direction of the water resources, giving a flow rate of 60 l/s. Exsurgences are also localized to the exit of the Ordovician Silurian contact. This unit is located in the northern part of the Mounts of Uganda (Zeghamra + Ougarta + Bou M'haWadi).

A second unit offers low flows to kheneg el Aatene (Hassi Aluoine) and to the edge of Sebkhat el Melah, providing very low flows than those of the previous unit. Two water points are located at the foot of the ridges: Ain ed Dhob and Ain Néchea (Fig. 7).

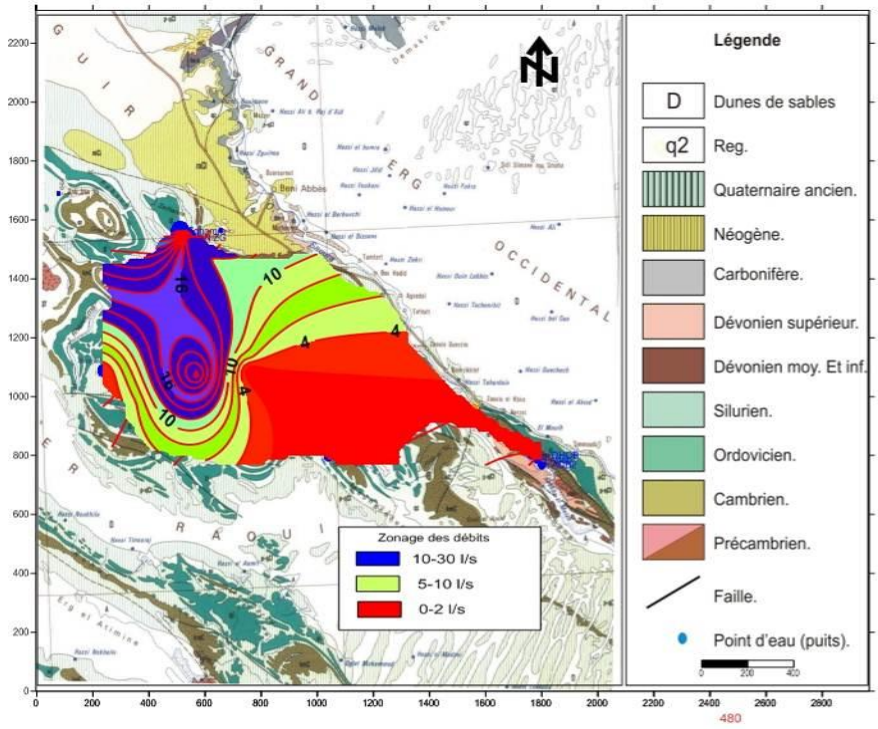

Figure 7: Zoning of the flow rates of the Cambro-Ordovician groundwater

HYDROCHEMISTRY

The study of groundwater quality in the region of Ougarta was carried out on water points in the different zones (Fig. 8).

The sampling campaigns we carried out during the period, March-April 2016 gave high temperatures (35°) and temperatures higher than the air temperature; these waters can be classified as thermal waters. These are waters that come from quite deep areas, with a TDS concentration varying between 700 and 2050 mg/l, and the majority of the water is soft in the Zeghamra and Ougarta areas.

The Cambro-Ordovician aquifer system comprises more or less important horizons. To characterise the water in each aquifer in a hydrochemical manner, we compiled data over

a 60-year period, as several analyses in our possession date back to 1963 and 2016 (Table 2).

Water quality analyses from Roche 1973 showed variable characteristics for the three regions Zeghamra, Ougarta and Kheneg El Aatène

Groundwater quality in the Ougarta region is generally poorly mineralized, with the predominant chemical facies being sulphate-sodium and sometimes chloride-calcium for both the early (1963) and recent (2016) periods (Table 3). The spatiotemporal evolution of the physicochemical quality of the waters of the different areas studied has identical hydrochemical characteristics, as shown in Tables 2 and 3.

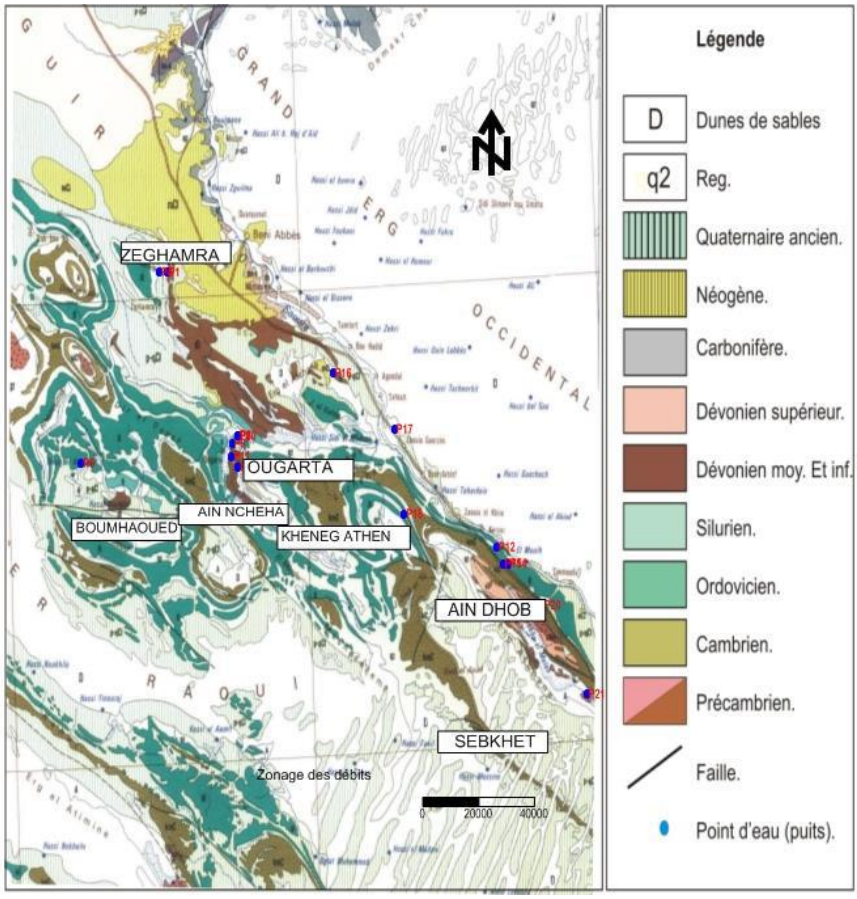

Figure 8: Map of point locations and hydrogeological potential area.

Table 2: Hydrochemical characteristics and evolution of the waters of the Ougarta Mounts

Region	Date	pH	TDS mg/l	Ca^{++} mg/l	Mg^{++} mg/l	Na^{+} mg/l	Cl^{-} mg/l	SO_4^{---} mg/l	NO^{3-} mg/l	HCO_3^{-} mg/l
Zeghamra	1963	7.47	970	97	58	133.6	185	380	21	119
	2016	7.47	1000	100	60	132	191	401	27	124
Hi Bou M'hawed	1963	7.87	960	82	62	140	220	298	49	168
	2016	7.17	1010	132	55	120	200	289	27.5	183
Ougrata	1963	7.65	980	105	37	170	260	268	14	159
	2016	7.49	1050	122	26	171.8	295	230	15	128
El Kseib	1963	7.17	1010	132	55	120	200	289	27.5	183
	2016	7.49	1050	122	26	171.8	295	230	15	128
Sebkat el Mellah	1963	6.2	32152	604	202.	11000	17800	1250	-	72
	2016	7	41300	774	269	14160	23700	1728	-	72.2

Table 3: The characteristic formulas for the different intervention zones

Zone	Period	Characteristic formula	
Zeghamra	2016	r SO4- - >r Cl-> r HCO3-	r(Na++ K+)+> r Ca++> r Mg++
	1963	rCl > r SO4 > r CO3	r Ca> r Na > r Mg
Ougarta	2016	r SO4- - >r Cl-> r HCO3-	r(Na++ K+)+> r Ca++> r Mg++
	1963	r SO4 > r Cl > r CO3	r Ca> r Na > r Mg
Kheneg alatene	2016	r SO4- - >r Cl-> r HCO3-	r(Na++ K+)+> r Ca++> r Mg++
El kseib	2016	r SO4- - >r Cl-> r HCO3-	r(Na++ K+)+> r Ca++> r Mg++
	1963	r Cl >SO4 > r CO3	r Na > r Ca > r Mg
Sebkhet el Mellah	1963	r Cl >rSO4 > r CO3	r Na > r Ca > r Mg

To assess the potability of the groundwater in the Paleozoic aquifer system of the Ugarta region, we refer to the Scholler diagram, (Fig. 9). The use of this diagram shows that the groundwater in all the studied areas of the Ugarta chain has good and average potability characteristics, except for the water in the Sebkhat EL Mellah area, which is suspected to be nonpotable.

The Piper diagram shows the similarity of the chemical facies of these waters for all the Paleozoic hydrogeological units of the Ougarta Range (Fig. 10).

The groundwater quality of the Ougarta region is, in general, low mineralized, a feeding zone of the aquifer system, and they are predominantly chlorinated; they are quickly loaded with sulfates on the boundaries of the free surface area.

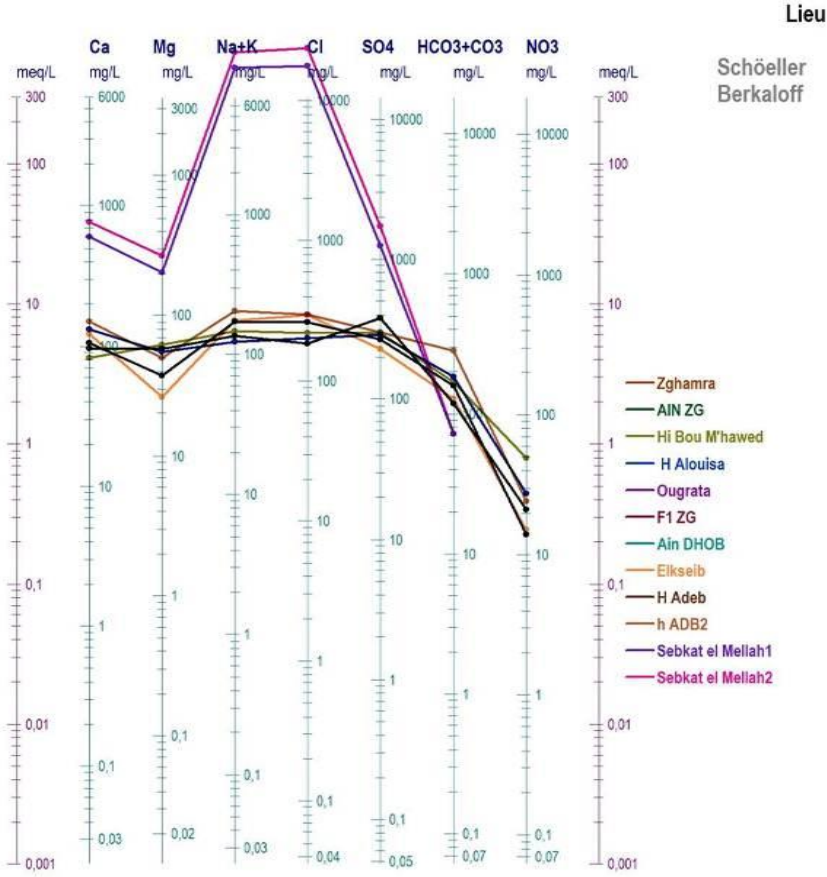

Figure 9: Scholler diagram of the potability of groundwater in the Ougarta Mountains

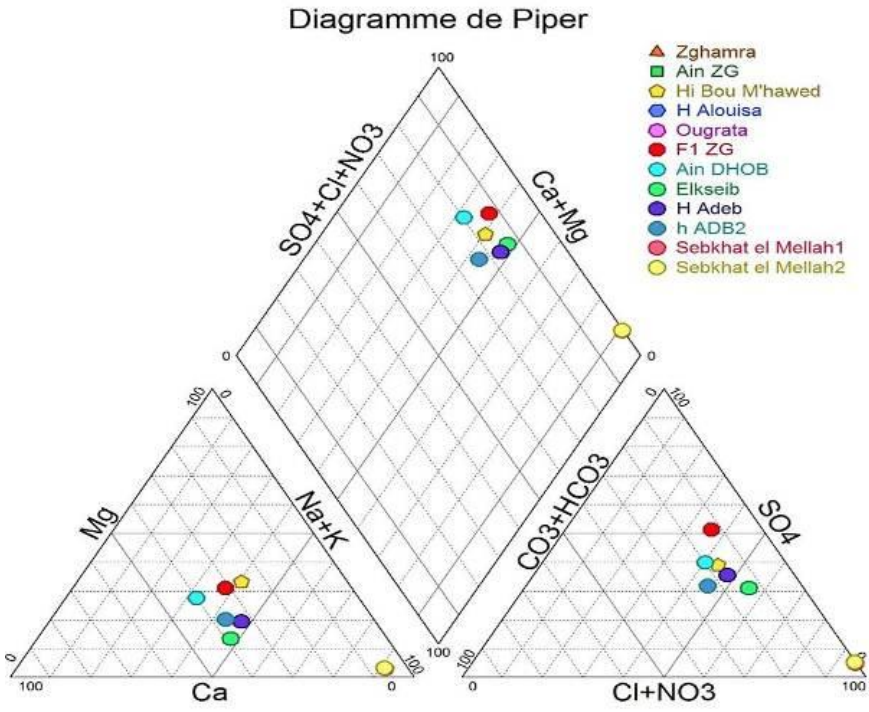

Figure 10: Graphic representation according to Piper of the waters of the Paleozoic aquifer of the Ougarta Mountains (Merzougui, 2021).

Relation of the aquifer of the socle and the buttonhole of Sebkha el Melah

Sebkha el Melah, a vast button hole in the beam of the Saoura, occupies an approximate surface of 350 km². It is located near Kerzaz. Its heart is a real depression. It receives the waters of Wadi Souirek, which is a deviation from Saoura Valley. Taking into account the climatic conditions that prevail in the region within this broad depression, salt and gypsum deposits have developed. Moreover, artisanal exploitation is largely exercised by natives.

Sebkha el Melah's group is considered equivalent to the Targui shield green series (Caby, 1971; 1983; Black et al., 1979), and the flyschoide series of Bled El Mass and Adrar (Caby. 1983. Fabre et al. 1983). The descriptions given by our predecessors agree on the volcano-sedimentary character of this group (Dostal et al., 2002; Cherfouh, 2002; Hamdidouche, 2009; Caby, 2010).

The hydrochemical study has made it possible to highlight the offset of the phenomenon of dilution of the deep waters following a smaller rainfall contribution. This shift is due

to slow infiltration at the upper aquifer of alterite and feeding by the formations of the Hamada aquifer.

A chemical stratification of the waters has been highlighted: the upper aquifer of alterite has a less mineralized bicarbonate-sodium facies than the waters of the deep aquifer of fissures and fractures which presents a sodium-chloride facies.

Regarding the distribution of ions, the maps developed show the influence of the Wadi Tensift water, used for irrigation, on the chemistry of the waters of this aquifer and the contamination of the water by the mineralization of this socle (example mine of Kettara). All of these studies helped to develop the basics of a methodology for water research and exploration in the Jebilet region.

Whereas the sebkhet el Melah remained fed by the important floods of 2008 and 2014 by waters of Wadi Saoura relatively charged (2.5 g/l), the concentration of the waters of Salt Lake at the level of Sebkhat, 32 g/l according to Merzougui (2021), was noticeably that of seawater. The floodwaters that flood the sebkha dissolve the evaporites that cover the surface of the ground, which very strongly increases the salinity of the lake as soon as it is filled. The lake of sebkhat and Melah has a very large area of approximately 200 km² and a shallow depth of 1 to 4 m.

On October 8, 2008, and November 11, 2014, the flow rates of the Saoura were 5 m^3/s and 3 m^3/s respectively as observed by Merzougui (2021). A significant difference in mineralization was noticed between both periods of winter and low water since it ranges from the value of 32 g/l in January to the value of 400 g/l during July.

On the other hand, analyses show the growing importance of magnesium, which has supplanted first calcium and sodium, the latter being removed from the brine by the precipitation of halite.

CONCLUSION

The work carried out in this study has provided a picture of the hydrogeological characteristics of the Paleozoic basement formations of the chain of Ougarta.

At the end of this work, it appears that the future security of the drinking water supply of the city of Beni Abbès can be achieved by a transfer from the Cambro-Ordovician groundwater.

- The faults of directions N 140 ° E and N 50 ° and N 70 ° E. play a role in the drain or supply of the Cambro-Ordovician tank, depending on the formations that put in abnormal contact. At the level of the palm groves of the upper Saoura Valley, at the level of the slab of the Neogene, Foggaras and springs emerge through these fissures and fractures cause a local change in the direction of flow.

- According to the thickness of the formations, the Paleozoic is potentially important from a hydrogeological point of view. On the other hand, the Tertiary and Quaternary rocks present thin thicknesses, and consequently, their water potentialities remain limited.

- The water reserves in Mounts of Ougarta that are entrusted to the synclines of the aquifers of the Ordovician Cambron may have older origins (Roche. 1965). These little-explored aquifers presumably constitute a multilayer system. The current characteristics of the Paleozoic aquifer confirm that its waters are inherited from the Quaternary wet phases as well as a current diet through rain infiltration.

- The underground resources are organized in an interconnected aquifer system whose main features of its dynamics and functioning are known. It comprises three different hydrogeological units in the northwest and south of the chain governed by geological factors.

- The piezometric maps show a general direction of flow from north to south of the Erg chain. Pludges by water generally have chloric-calcic and sodium facies, and sometimes sulfated calcium. One may classify the waters of the Mount of Ougarta as thermal waters.

- At the moment, the Paleozoic foundations are probably fed by the waters of the hamada of Guir groundwater.

- Exploitation of the Paleozoic aquifers by the realization of other boreholes and piezometers and highly recommended with the objective of improving the hydrogeological knowledge of the Cambro-Ordovician sits.

These results will enrich the database on the characteristics of the aquifer and help decision-makers to better decide on the management of water resources for better sustainable development of the region.

In addition, in the future work and research perspectives to be envisaged, we propose the following:

- Climatological study of daily rainfall to estimate the potential recharge on the Paleozoic aquifer.

- Geophysical study using geophysical imaging with the multifrequency EM method.

- We plan to improve the knowledge and understanding of the hydrogeological functioning of the aquifer, especially in the basement pay, through the use of other approaches, namely the operational applications of the conceptual hydrogeological model of the basement aquifers from a quantitative point of view.

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