# Hydrogeology of the N'kob-Tazarine basin (Anti-Atlas, Morocco): Setup of geo-electrical prospection for potential deep aquifers characterization

## *Hydrogéologie du bassin de N'kob-Tazarine (Anti-Atlas, Maroc) : Apport de la prospection géo-électrique à la caractérisation des aquifères profonds potentiels*

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**Abstract.** The N'kob-Tazarine basin, located in Southeastern Morocco (Eastern Anti-Atlas), is characterized by a semi-arid to arid climate, accentuated by its geographical position in border of steep reliefs, where the groundwater resources are limited. The Tazarine wadi is the main stream and usually shows intermittent flow with frequent floods following brief rainfalls that occur in the basin. The aim of this study is to identify deep Paleozoic aquifers that may contain interesting groundwaters. The used approach is the electrical prospection application (soundings and trails). Two geo-electrical cross sections (GECS1 and GECS2), oriented Northeast-Southeast, have been established and have made it possible to define both resistant and conductive levels and to highlight facies and thickness changes of the geological formations. They show also a dipping of the geological structures in the basin, with a direction from North-west to South-east, an increase in the ordovician formations thickness towards the South-east, and an electrical discontinuity, located at geoelectrical cross section GECS2, which would probably correspond to a flexure affecting all the formations. Similarly, three electrical profiles TE1, TE2 and TE3, using the Wenner configuration, have highlighted the different zones of heterogeneities attributed probably to either the passage of flexures or the change of lithology. Geo-electrical prospection has also used in order to follow the depth variation in the geological formations of the Cambrian (depth ranging from 90 m to 800 m), to identify fracture zones that can store significant amounts of groundwater. The successful results of this study help direct hydrogeological research to the most favorable areas for the release of groundwater resources in the N'kob-Tazarine basin.

**Keywords**: N'kob-Tazarine, Anti-Atlas, electrical prospection, structures, hydrogeology.

**Résumé.** Le bassin de N'kob-Tazarine, situé dans le Sud-Est marocain (Anti-Atlas oriental), est caractérisé par un climat semi-aride à aride, accentué par sa position géographique en bordure des reliefs escarpés où les ressources en eau sont limitées sur les plans quantitatif et qualitatif. L'oued Tazarine est le principal cours d'eau et montre généralement un écoulement intermittent avec des crues fréquentes suite à des averses qui surviennent dans le bassin. L'objectif de la présente étude est d'identifier les réservoirs aquifères profonds du Paléozoïque qui pourront renfermer des nappes d'eau intéressantes. La méthode utilisée est celle de la prospection électrique (sondages et trainés électriques). Deux coupes géo-électriques (GECS1 et GECS2) d'orientation NW-SE ont été établies et ont permis de définir les niveaux résistants et conducteurs et de mettre en évidence les changements de faciès et d'épaisseurs des différentes formations traversées. Elles montrent un plongement des structures géologiques du bassin du NW vers le SE, une augmentation de l'épaisseur des formations de l'Ordovicien vers le SE, et une discontinuité électrique localisée au niveau de la coupe GECS2 qui correspondrait probablement à une flexure affectant l'ensemble des formations. De même, trois profils de traînés électriques (TE1, TE2 et TE3) ont été réalisés en utilisant le dispositif Wenner. Ces trainés ont mis en évidence les différentes zones d'hétérogénéités attribuées vraisemblablement soit au passage des flexures soit au changement de la lithologie. La prospection géo-électrique a permis également de suivre la variation de la profondeur des grès quartzitiques du Cambrien (allant de 90 m jusqu'à 800 m), de détecter les zones de fracture pouvant constituer des écoulements préférentiels des eaux souterraines. Les résultats pertinents de la présente étude ont permis d'orienter les travaux de recherches hydrogéologiques vers les zones les plus favorables au dégagement des ressources en eau souterraine dans le bassin de N'kob-Tazarine.

**Mots-clés :** N'kob-Tazarine, Anti-Atlas, prospection électrique, structures, hydrogéologie.

## INTRODUCTION

The Tazarine sub-watershed occupies the western part of the large Maïder basin (Fig. 1). This basin is bounded north by the Saghro-Ougnate complex, east by the plain of Tafilalet, west by the Jbel Bani, and south and southeast by the cretaceous Hamada of Kem-Kem. In this work, the geo-electrical prospection is carried out in the plain of the N'kob-Tazarine corridor, administratively belonging to in the province of Zagora. Studied area corresponds to an alluvial

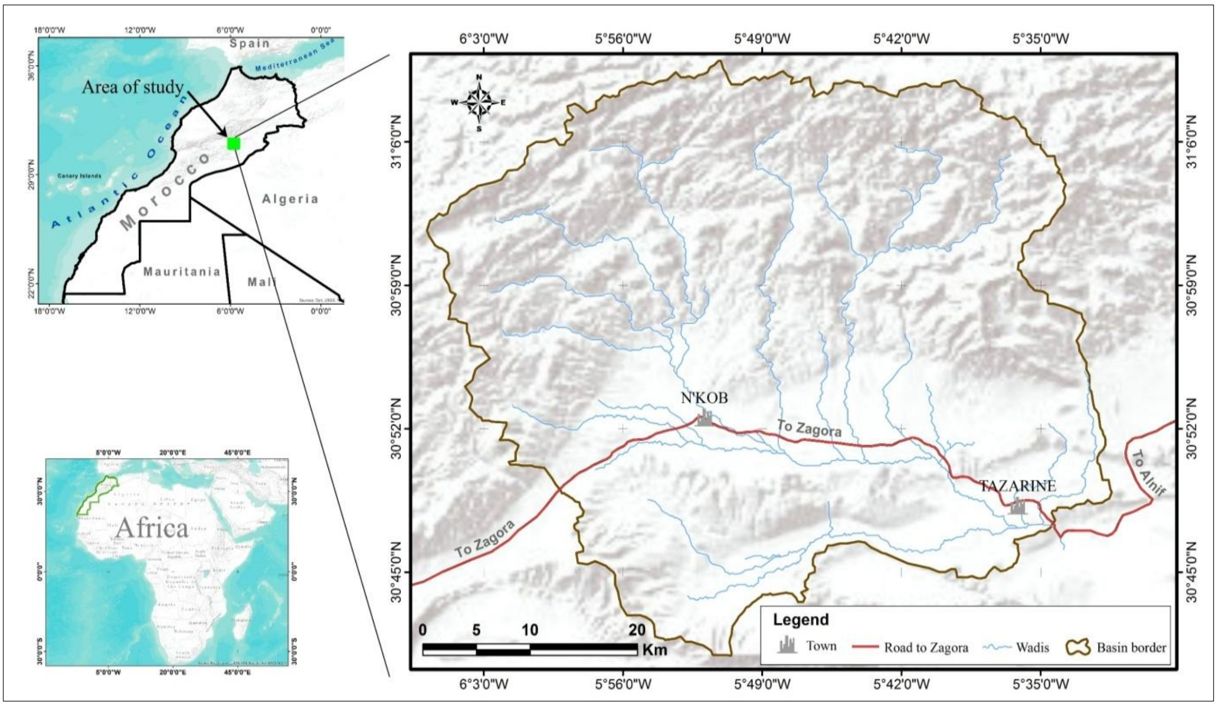



Figure 1. Geographical situation of the study area.

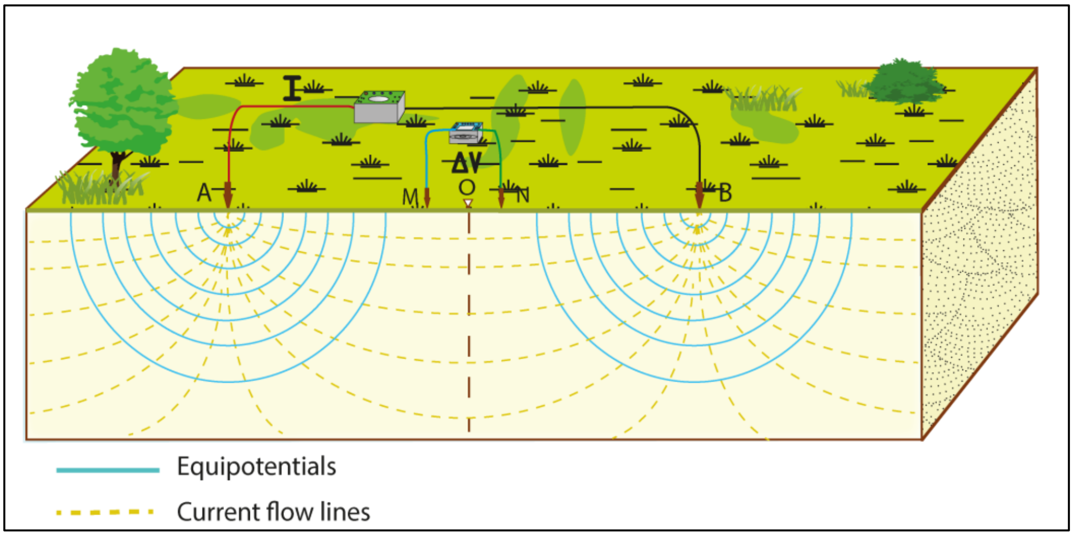



Figure 2. Principle of the electric prospecting method, the spread of electrical current through homogeneous ground. Dashed lines show the current flow, Solid lines the resulting equipotential lines.

plain limited north by the outcrops of the Cambrian and south by the Ordovician sandstone crests. The main exploited aquifers in the studied area are generally located in the palm groves, the deep aquifers remain poorly explored and exploited. These later are contained in Paleozoic sandstone, shale and limestone (Bahaj *et al.* 2013). Thus the necessity to study and exploit the deep aquifers in order to fill the water deficit in the N'kob-Tazarine basin is a primordial solution to remove or reduce the impact of water shortage constraints. The interest of the electrical prospection in the hydrogeological study is indispensable and essential, because of the quality of the information and the results that it provides to the hydro-geologist in order to see and understand the structure of the subsoil and the aquifers system, also to ameliorate the knowledge of the geometry of the structures and to optimize the implantation of the mechanical boreholes which allow, in their turn, to perfect and to precise the geophysical interpretation. We proceeded to a geophysical prospection by electrical sounding and profiles in order to develop a structural scheme, to guide the hydrogeological research and to better study the deep aquifer reservoirs. The geophysical prospection study using the geo-electrical method consists in the realization of 09 Schlumberger electrical soundings with a distance ranging from 1000 to 10000 meters; and 03 electric trail profiles with a total length of 14220 linear meters.

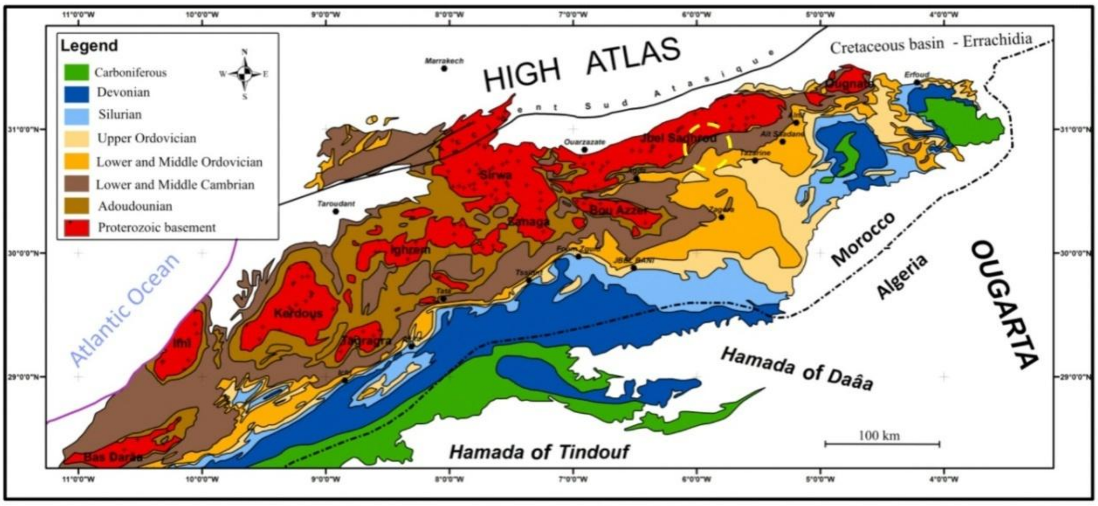



Figure 3. Simplified geological map of the Anti-Atlas made from the geological map of Morocco at 1,000000th; the study area is located in dashed lines, from Hollard & Choubert (1985) modified.

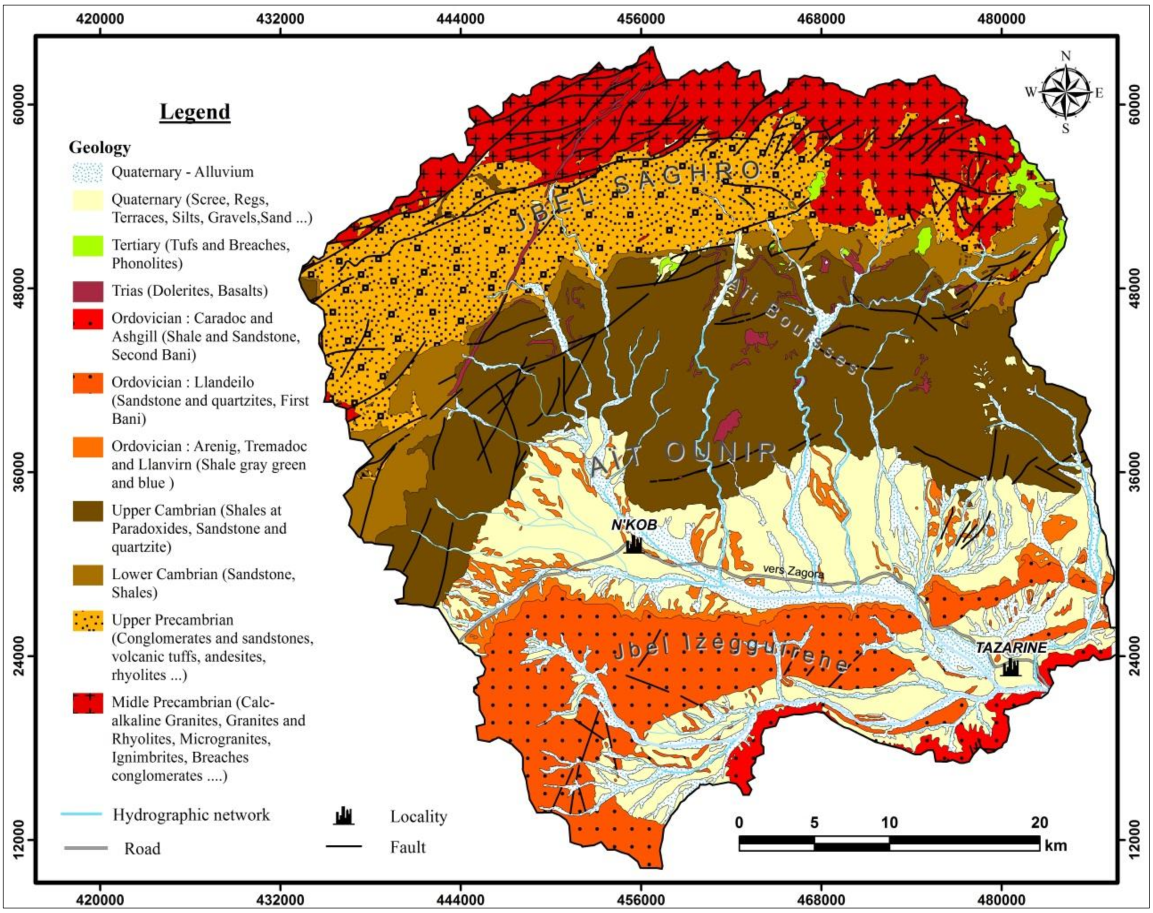
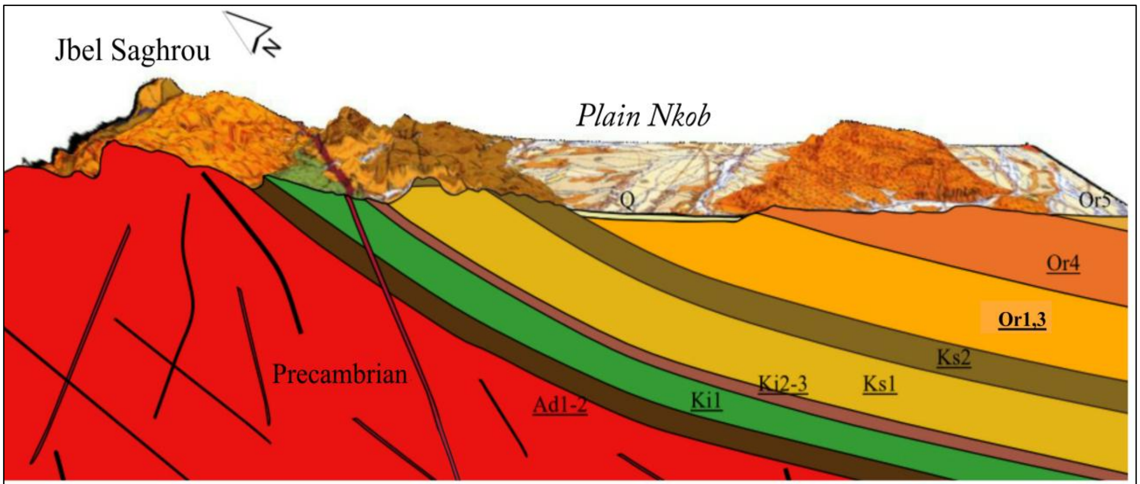



Figure 4. Geological map of the Tazarine basin (from the geological map of Morocco 1/200000, Jbel Saghro-Dades (Hindermeyer *et al.*1977).

## MATERIAL AND METHODS

The methods of electrical prospection is invented and developed by the brothers Conrad and Marcel Schlumberger in 1912 (Coulomb & Georges 1976, Telford *et al.* 1990). The principle of the method is based on the measurement of electrical potential differences $\Delta V$ associated with the injection of an electric current I (Fig. 2). Current is injected into the ground by means of a battery or a generator connected to 2 electrodes A and B. The intensity of the injected current is read on an ammeter. Ground potential differences between two M and N points are measured using a sensitive and powerful voltmeter. The apparent resistivity $\rho$ is deduced from the value of the potential difference, this resistivity will be interpreted to have the true resistivity and the thickness of the prospected layers.




**Or5** : Ktaoua formation (shales) [Mid. & Low. Caradoc]; **Or4** : 1st Bani sandstones & quartzites [Mid. Ordovician]; **Or1,3** : Feijas external (shales & sandstones ), [Low. Ordovicien]; **Ks2** : Tabanite sandstones [Mid. Cambrien]; **Ks1** : Internal Feijas (shales & sandstones) [Mid. Cambrien ]; **Ki2-3** : sandstones terminals [Cambrien inf.] ; **Ki1** : dolomitic shales [Low. Cambrian ]; **Ad1-2** : Basic conglomerates & sandstones [Precambrian terminal, Adoudounian]; **Precambrian** : Proterozoic basement

Figure 5. Schematic geological section of the upstream basin.

In this study we used the following material:

- Two resistivimeters with signal summation and reversal polarity, - one resistivi-meter (GRM), - one potentiometer, - graphic recorder (GRR) for small d.d.p values;
- Generating set and current converter;
- Coils of electric wire totaling a cable length of 10000 m;
- Steel electrodes for the electrical current injection;
- Copper electrodes for the measurement of the potential difference;
- Equipment for maintenance;
- Walkie-talkie: allowing the communication between team members in the field.

## GEOLOGICAL SETTING

The Anti-Atlas is located in the southern part of Morocco (Fig. 3). It extends from the southern edge of the High Atlas in the north to the northern flank of the carboniferous Tindouf, situated on the Saharan platform. It is limited eastward by the Guir Hamada and westward by the Atlantic Ocean. The geology of the Anti-Atlas is largely controlled by its position along the northern margin of the West African Craton (WAC). The area is considered as a very subsident zone (Baidder *et al.* 2008). The successive orogenic cycles Pan-African, Caledonian, Hercynian, and Alpine always take place around the margins of this stable shield. The Anti-Atlas shows an anticlinal structure with a Precambrian core and Paleozoic cover. The Precambrian lands are flush with inliers which follow each other throughout the length of the domain; the most important from west to east are Bas Drâa, Ifni, Kerdous, Ighrem, Zenaga, Bou-Azzer, Saghro and Ougnat (Essalhi *et al.* 2017, Boudzoumou *et al.* 2012, Piqué & Bouabdelli 2000). Their surface decreases towards the east, reflecting the submergence in this direction of the Anti-Atlas anticlinal structure. The Paleozoic formations are exposed on both sides of this anticlinorium ; they are not very developed in the north, but well spread on the southern flank where they constitute the northern flank of the platform of Tindouf (Essalhi *et al.* 2018).

### Geology of the Tazarine basin

The Tazarine basin is located in the Anti-Atlas whose cover is formed of sedimentary, volcanic and volcano-detrital formations dated from the Upper Neoproterozoic to the Paleozoic (Fig. 4).

The geological formations show a monocline series located on the southern flank of the Jbel Saghro. From north to south, the geological formations are successively (Fig. 4):

#### *Precambrian*

The axial part of the Saghro massive consists essentially of shales and granites of the Neoproterozoïc surrounded by a powerful rhyolitic carapace ; it rises to the north of the basin and extends over almost 30% of the basin area.

#### *Cambrian*

The Cambrian of this zone is predominated by sands (Baidder *et al.* 2008): It overlies directly the Late Neoproterozoic Ouarzazate serie. It begins with thick conglomerates, followed by the "Lie-de- vin" formation and ends with sandstone (Tabanite sandstone) (Landing *et al.* 2006).

#### *Ordovician*

The Ordovician is classified into four lithological groups defined in the Central Anti-Atlas. They consist of two clay assemblages (shales of external Feijas to the base and shales of Ktaoua at the summit) separated by a first sandy crest : the "Premier Bani". The whole is capped by a second crusty crest: the "Deuxième Bani" (Choubert & Termier 1947).

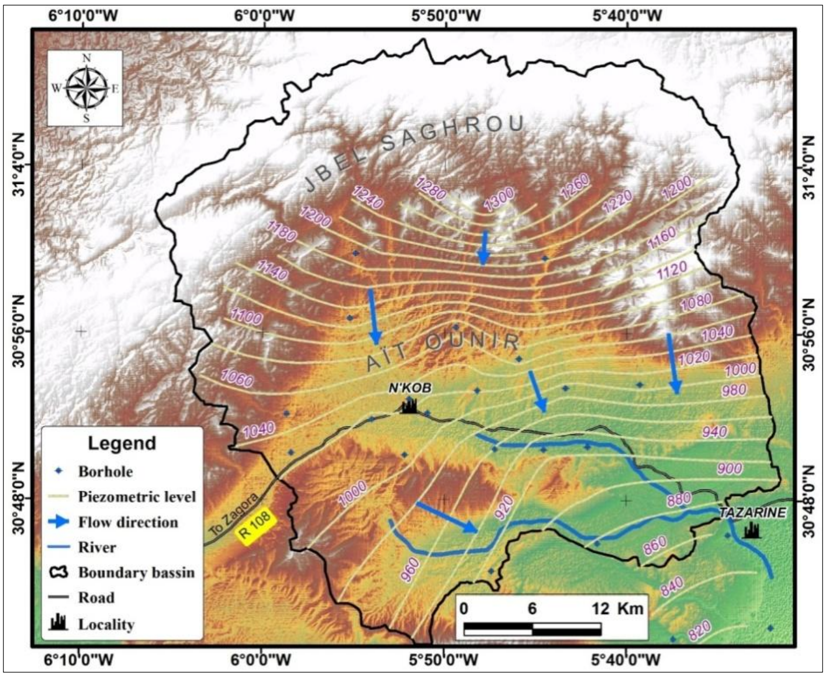



Figure 6. Piezometric map of the Paleozoic aquifer.

***Mio-Pliocene-Quaternary***

Its thickness is reduced and does not exceed 30 m compared to that of other flush facies. It is formed mainly of Miocene conglomerates and marls and Plio-Quaternary lacustrine limestone.

## RESULTS AND DISCUSSION

### Hydrogeological synthesis of the Tazarine basin

Most of the groundwater in the region is exploited in basin area where Plio-Quaternary formations have deposited. On the reliefs, the pre-Pliocene formations, with low permeability, contribute little to underground flows. The recharge is ensured mainly by the flood waters of the corresponding wadis. In this way, the direct infiltration of precipitations contributes to the recharge but in a small proportion due to the scarcity of rainfall in the region.

The geological section illustrated in the Figure 5 shows monocline behavior of geological cover formations on the southern edge of the Jbel Saghro. The dip of these geological series influences the depth of the potential aquifer reservoirs of the basin.

The aim of the electrical prospection is to deduce and characterize deep aquifers. The Lower Cambrian (terminal sandstone) and Middle (Tabanite sandstone) formations, and the Middle Ordovician series (sandstones and quartzites of the 1st Bani), may constitute potential groundwater reservoirs in their alteration fringes or in particularly fractured areas. These levels crossed by a network of fissures and large joints, and the fissure permeability can therefore exist in these sandstones and quartzitic banks.

The Lower Cambrian formations, made of sandstone, crop out at the base of Jbel Saghro. Affected by a large network of fractures, these formations become permeable and could absorb the water infiltration from the rain and perennial wadis draining the Precambrian.

The sandstone and quartzitic levels of the Upper Cambrian possess fracture permeability. These formations are covered by the shale of the Lower Ordovician External Feijas.

The Ordovician sandstone formations of the first Bani are largely crop out in the basin; these formations at least 100 m thick have shown a particular hydrogeological interest in the Tazarine-Taghbalt syncline (Kassou *et al.* 2016, Mahboub *et al.* 2014). It is a closed basin where the Ordovician water table could be fed by rainwater at the borders of the basin on the Bani flanks to the North, South and West; and by losses of the underflow of the Wad Taghbalt between Mellal and Tazarine.

A database of more than two hundred water points has been collected to attempt to identify the characteristics of the Paleozoic aquifers of the Nkob-Tazarine region. This database is based mainly on the IRE files of the Hydraulic Basin Agency of Guir Ziz Gheris.

The above piezometric map (Fig. 6) gives an idea of the groundwater basin plan conceptualized by the piezometric curves. The map is made by a 20-point piezometric level database distributed over the entire basin to better represent piezometric information and groundwater flow. The piezometry of the basin exceeds 1300 m in the North and goes down to 860 m in the South downstream of the city Tazarine which concludes that the direction of flow is generally North towards the South and it follows the topography of the basin.

The transmissivities of the Paleozoic aquifer vary from 0.007 to 3.65 .10-3 m²/s. That is an average of 0.86 .10-3 m²/s. The depth of the boreholes at the basin scale does not exceed 250 m (Fig. 7).

Ordovician formations whose outcrop covers 16% of the surface of the Tazarine basin (about 380 km²) are mainly

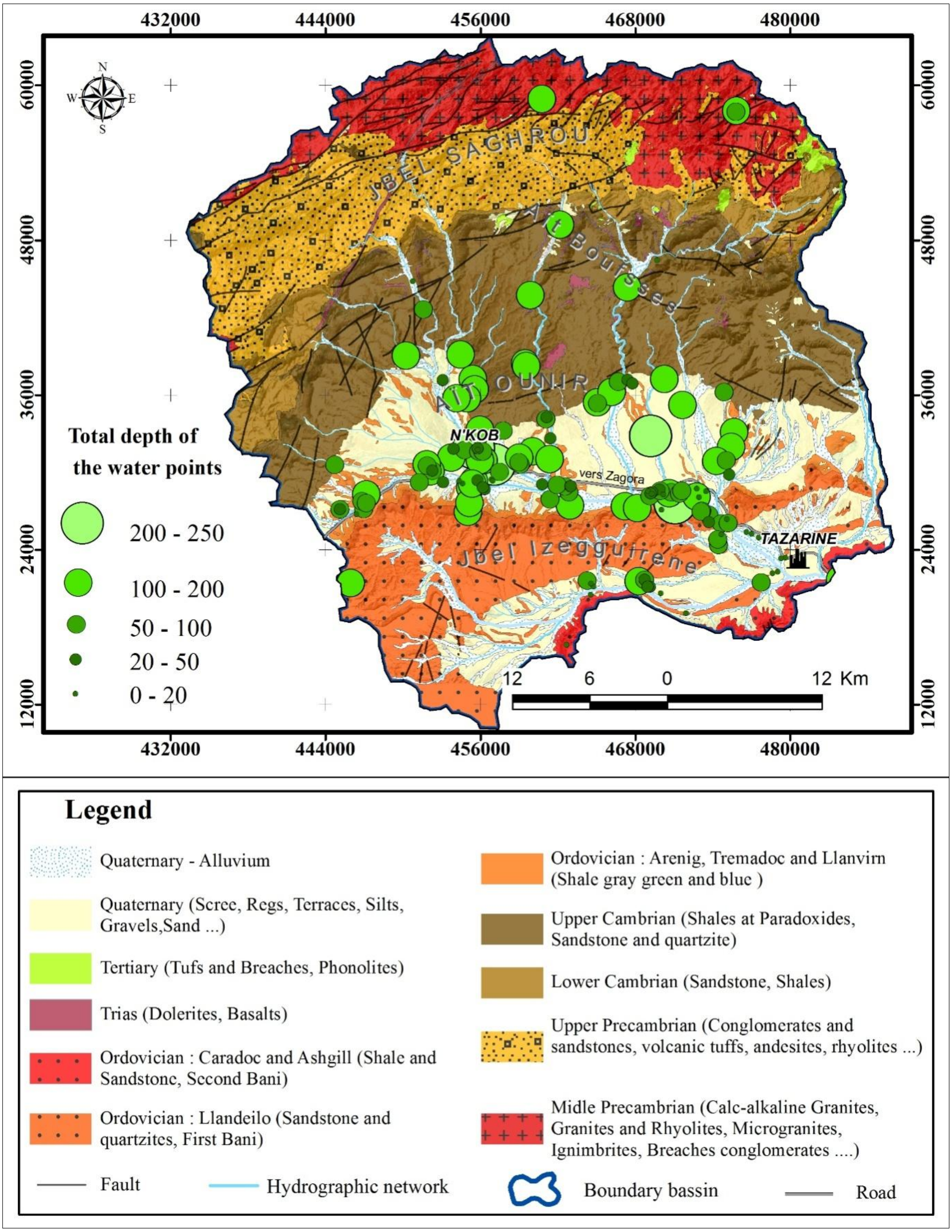



Figure 7. Distribution of water points on a geological background according to the total depth.

represented by sandstones and sometimes low-permeable shales. The outcrops of the Cambrian formations represent nearly 30% of the total surface area of the basin with nearly 610 $km^2$ formed by massive sandstones that are carved and fractured. Precambrian occupies a very large planimetric surface area of 512 km2 in the north of the basin, with an altitude of 2600 m, containing a variety of igneous and metamorphic rocks that are very strongly deformed and fragmented by faults.

The water resources are relatively not very important and limited to very discontinuous fractured zones with low storage coefficients and permeabilities spread in the range of 10 -4 to 10 -6 m / s. Flow rates for structures in Paleozoic geological formations capturing these aquifers are limited to

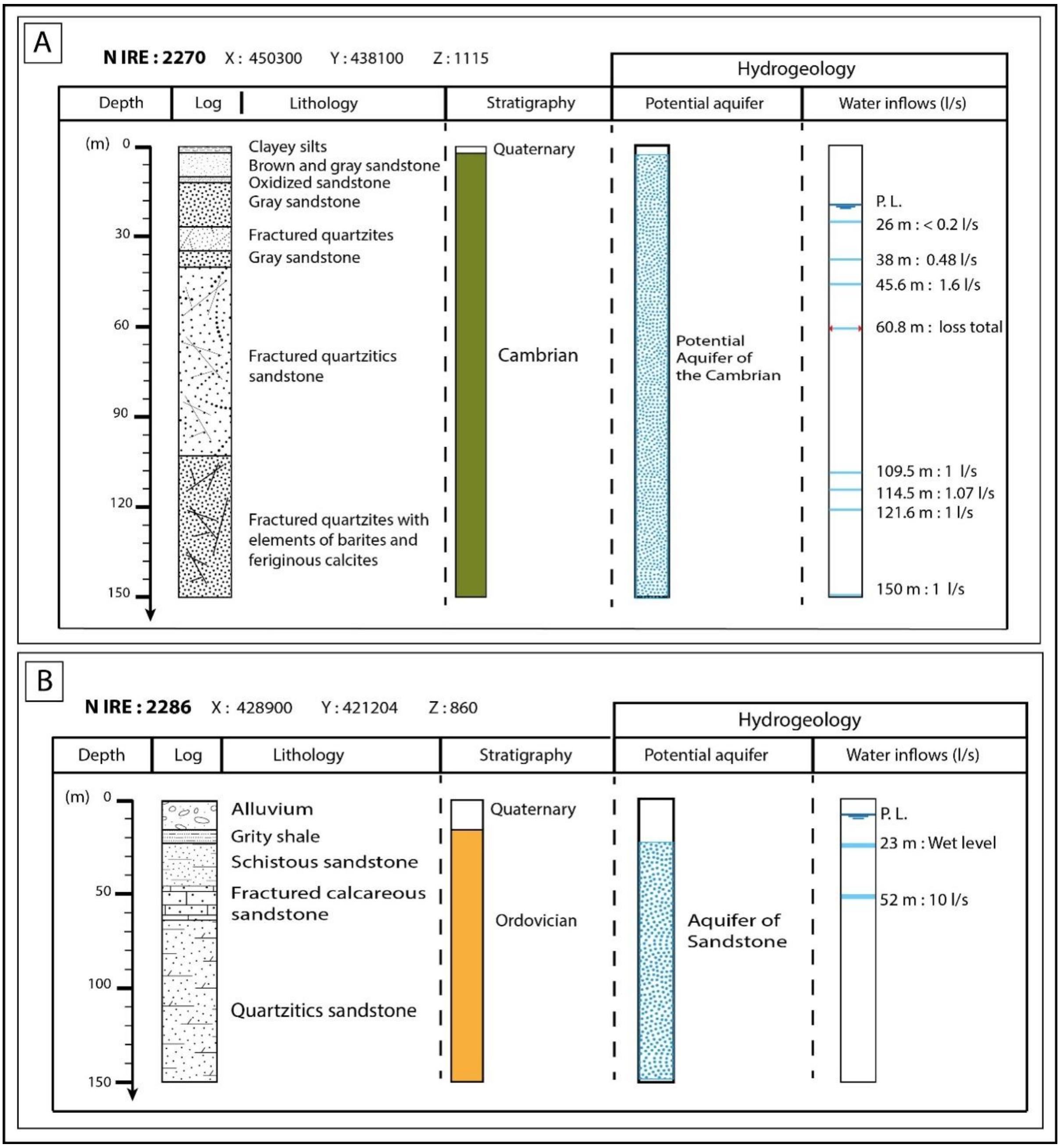



Figure 8. Drilling logs in the basin - A) to the north in the Cambrian - B) to the center in the Ordovician.

1.5 l/s at the time of excavation. On the other hand, the inflows of water at the time of excavation works in the Cambrian massif are relatively high and can reach 10 l/s (Fig. 8A and B).

In the Tazarine basin, surface water supplies are insufficient and subject to strong fluctuations, however the use of perennial groundwater (Paleozoic aquifer) remains the most appropriate solution to satisfy the water needs of the local population.

## Geophysical prospection results

### *Interpretation of electrialc soundings*

The geophysical measurements realized in the Tazarine basin include nine Schlumberger electric soundings, with an AB line ranging from 1000 m to 10000 m, and three profiles of electric trails totaling a length of 14220 meters (Fig. 9).

The interpretation of the diagrams shows generally an alternation of resistant levels and moderately conductive levels. The result of these electrical sounding diagrams shows the existence of two electrical sounding groups (Fig. 10). The difference between the two families being distinguished at the depth of the main resistant noted "MP".

- Group A: characterized by the electric soundings 1P1, 2P1, 1P2, 1P2bis and 2P2 (Fig. 10-A).
- Group B: characterized by the 4P1, 3P1, 3P2 and 4P2 soundings (Fig. 10-B).

The difference between the two groups is distinguished at the level of the depth of the main resistant.

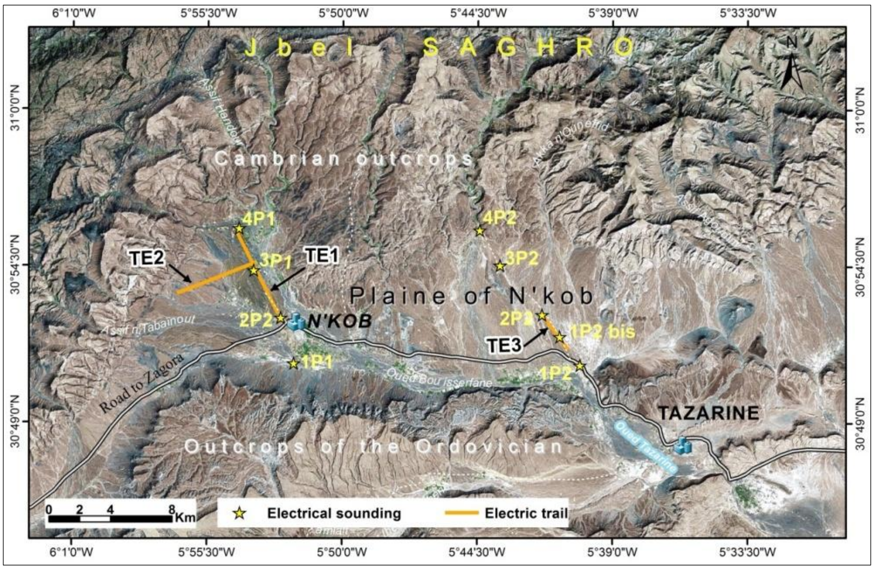



Figure 9. Situation of the soundings and electric trails carried out at the N'kob plain.

### *3D resistivity model*

The Figure 11 presents all electric sections in a 3D resistivity model of the prospected zone. This model is realized from the data of our electric soundings, it shows considerable variations of the resistivity due to the heterogeneity of the materials and the subsoil structure.

The surface and subsurface formations are characterized by low resistivity due to the nature of schistosity ground and quaternary glacis. Generally, in the north and north-east of the study area, strong resistivity values at shallow depth correspond to the resistant geological formations of the Cambrian which is exposed to the north of the study area. In the southern zone, the depth of the resistant formations is greater and corresponds to the geological layers of the sandstone-quartzitic of the Cambrian and shale-sandstone of the Ordovician.

### *Geo-electrical sections*

Two cross sections oriented NW-SE, have been established in order to clearly visualize the thickness variation as well as the structure of the deep horizons determined by the electrical soundings.

- The geo-electrical section n° 1 oriented NW-SE. This section includes the electrical soundings: 1P1, 2P1, 3P1, 4P1 (see Fig. 12) ;
- The geo-electrical section n°2 oriented NW-SE. This section includes the electrical soundings: 1P2, 1P2 bis, 2P2, 3P2, 4P2 (see Fig. 13).

Interpretation of the geo-electrical section GECS1

The interpretation of the geo-electrical section GECS1 let us say that (Fig. 13):

- All geological structures of the studied area are dipping toward the SE;
- There is an increase of the Ordovician formations thickness to the SE;
- That the main resistant level attributed to the quartzite and sandstones of the Cambrian dips from the NW to the SE to reach a depth of about 480m at the level of 1P1.

Interpretation of the geo-electrical cross section GECS2

The interpretation of the GECS2 section shows (Fig. 9) a similarity with the GECS1 section at the level of the dipping of the formations, excluding an electrical discontinuity detected between the electrical soundings 1P2 bis and 2P2 ; this discontinuity would most likely correspond to a flexure which affects the whole of the formations. As a result, the main resistant level (MR) reaches a depth of approximately 750 m at the right of the electrical sounding 1P2.

Result of the horizontal prospection profiling

In order to highlight eventual fractures within the Ordovician formations, three electric profiles trainers (TE1, TE2 and TE3) have been made using the Wenner array, with a length of injection line of current AB = 800 m. The formations prospected are composed mainly of shale and sandstone and may be rooted in deeper Cambrian quartzitic sandstones.

The TE1 profile, located in the north-western part of N'kob, in NNW-SSE direction, has a total length of 6000 meters (Fig. 14; for localization, see Fig. 9). It shows an electrical anomaly A1 (X=452030, Y=435694) due to the presence of a schistose sandstone hill, and a change in electrical resistivity from NNW to SSE that is due to the presence of a flexure (X=453105; Y=433533).

The TE2 profile, carried out to the north west of N'kob locality, in ENE-WSW direction, has a total length of 5420 linear meters and is perpendicular to the TE1 profile (Fig. 15; for localization, see Fig. 9). It shows an electrical anomaly A1 (X=452642; Y=434087) due to the presence of quaternary pebbles.

The TE3 profile, executed in the eastern part of N'kob, in NNW-SSE direction, has a total length of 2800 linear meters

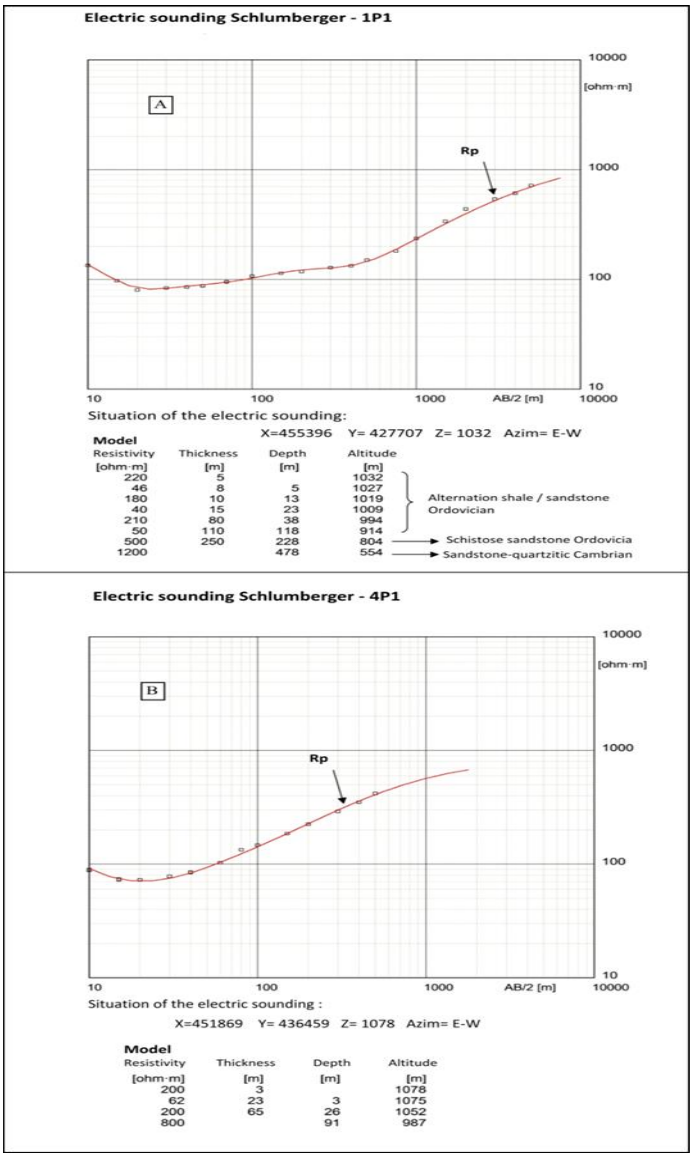



Figure 10. Diagrams of electrical soundings 1P1 (A : Group A) and 4P1 (B : Group) B).

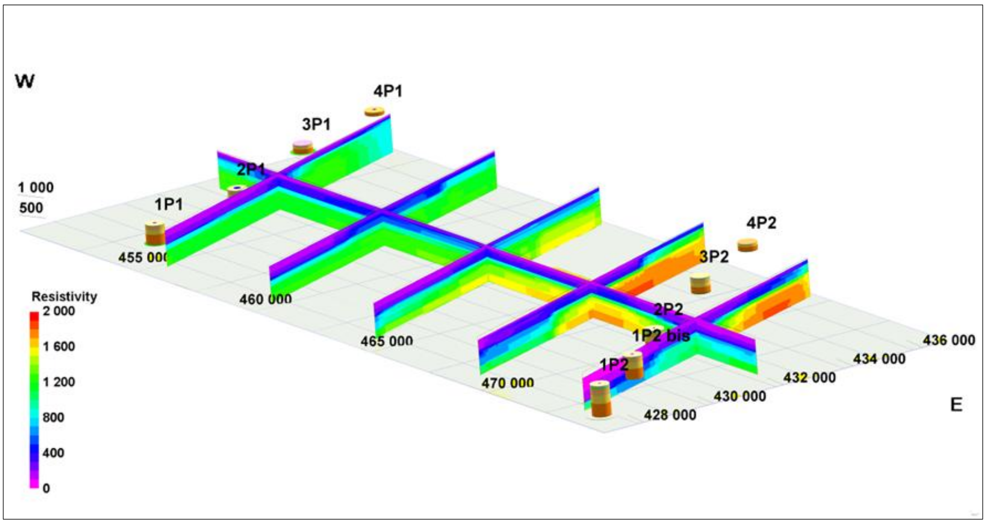



Figure 11. 3D resistivity model of the prospected zone.

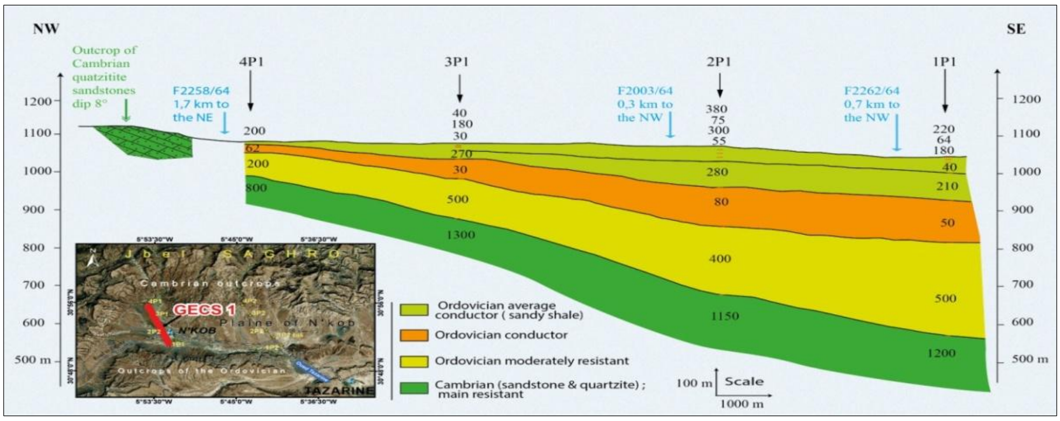



Figure 12. Geo-electrical cross section GECS1.

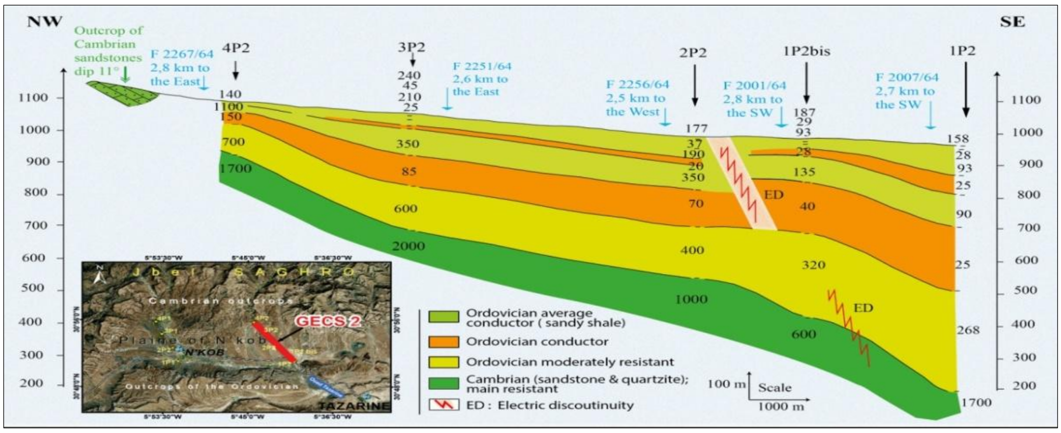



Figure 13. Geo-electrical cross section GECS2.

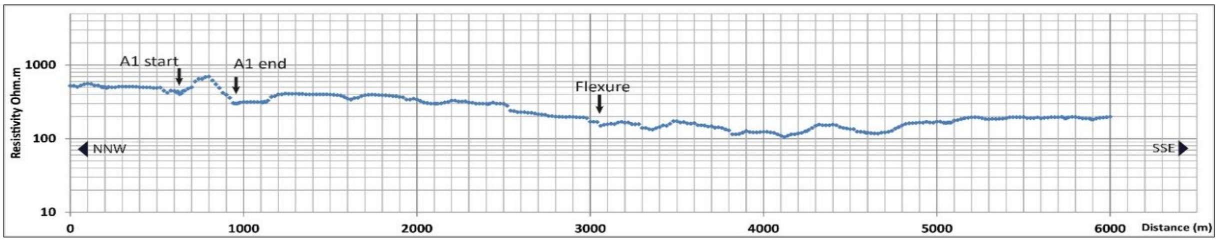



Figure 14. Profile of the TE1 electrical trail.

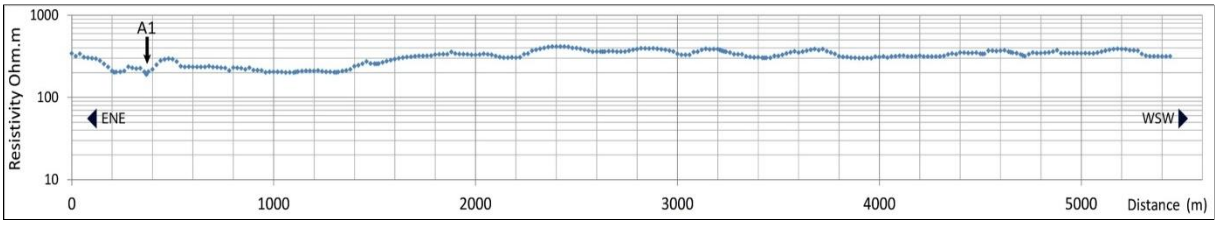



Figure 15. Profile of the TE2 electrical trail.

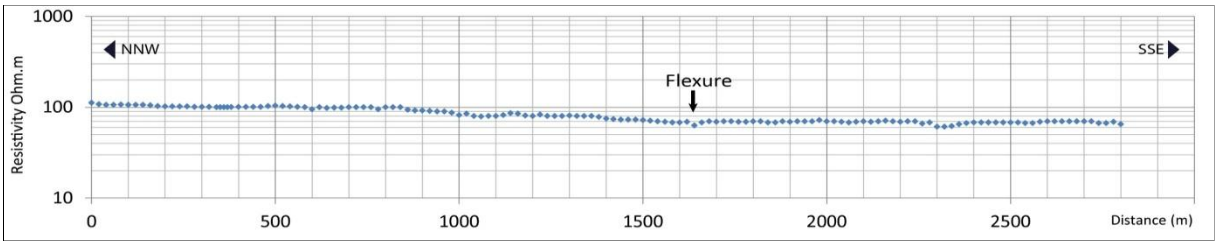



Figure 16. Profile of the TE3 electrical trail.

(Fig. 16; for localization, see Fig. 9). It shows a slight variation in the resistivity which could be interpreted as a change in lithology due to the presence of a flexure (X=472129; Y=430016) already detected in the TE1 profile.

## CONCLUSION

The electrical prospection study has enabled to differentiate the resistant levels of the potential zones from the hydrogeological view point, and to characterize the aquifer formations for the implantation of productive boreholes. The main results are presented as following:

- Paleozoic formations show two potential aquifer levels:
  - A shallow aquifer represented by shale and sandstone formations of the Ordovician;
  - A deep aquifer represented by quartzitic sandstone formations of the Cambrian.
- The thickness of the Ordovician cover increases from north to south where it reaches more than 800 m;
- The geo-electrical cross sections show a dip of the structures from north to south;
- The resistant substratum, probably corresponding to the quartzitic sandstones of the Cambrian, is exposed to the north, plunges under a thick series of shale and sandstone of the Ordovician. This resistant formation has been spotted by all the electrical soundings;
- The horizontal prospection, TE1, TE2 and TE3 electrical trails, were able to reveal different zones of heterogeneity imputed either to the passage of the flexures or to the changes of lithology.

## ACKNOWLEDGEMENTS

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