

Application of Electrical Tomography to Put in Evidence the Thickness and Structure of the Filling of Dayet Iffer (Middle Atlas, Morocco)

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Abstract

The Dayet Iffer belongs to the Dayets of tectono-karst origin of the Northern Middle Atlas. After its watershed genesis of middle altitude during the Quaternary, two lacustrine formations were deposited on the surface while other thick formations exist in depth. The detailed sedimentological study of the soltanian and holocene lithological sections on the surface and the 14C datings helped recognize part of the history of the watershed. The geophysical study allowed to detect the thickness of the superficial geological formations as well as the various geological phenomena (tectonic and/or karst) that affected them from the genesis to the present. The current shape of the watershed where the Davet Iffer exists is only the result of an evolution where sedimentary, tectonic and karst phenomena interfere. The tomography obtained with Res2DInv software, performed for the first time at the Dayet Iffer, reveals the presence of three ranges which can be interpreted as three resistive, intermediate and conductive zones with a large set of faults. These results helped determine the thickness (over 160 m) of the sedimentary filling. This shows that the hydrological behavior of the Dayet Iffer takes into account both horizontal flows at the stratification and/or karstic joints and the movement of sub-vertical fractures.

Keywords

Electrical Tomography, Resistivity, Lacustrine Sediments, Dayet, Quaternary, Middle Atlas

1. Introduction

The Arabic term Dayet or "Daya" in this region means a permanent or non-

permanent continental lake. The Dayet Iffer, which is the subject of this article, belongs to the Dayets of tectono-karst origin of the Middle Atlas. The latter have developed preferably in the northern and southern extremities of the wettest zone above 1200 m which receives the main precipitation coming from the Atlantic Ocean. Recent pluridisciplinary studies in sedimentology, morphology, structural geology, hydrology and karstification, carried out on sedimentary complexes trapped in some Middle Atlas Dayets, have allowed to recognize the structural and karstic frameworks, since the Pliocene [1] and allowed to establish an explanatory model of the genesis and evolution of Dayets in the Middle Atlas) [2] [3]. The studies undertaken on the lake basin of the Dayet Iffer, proceed from a qualitative approach of the contributions; this one concerns the filling whose sedimentation is continuous during the end of the Upper Pleistocene (Soltanian) and the Holocene. On this site, the work allowed to recognize the lithostratigraphy and the morphology of the watershed, to identify the nature and the geometry of the sedimentary filling, to specify the age and to establish correlations with the climatic [4] [5] [6] [7] [8]. The present study aims to specify the thickness, the shape and the structure of the sedimentary filling and the relations between the different bodies of the filling by a recent geophysical method, namely the electric tomography performed for the first time at the Dayet Iffer (high resolution imagery and better detection of lateral and vertical variations in electrical resistivity).

2. Geological and Geomorphological Framework

The Dayet Iffer is a permanent lake located in its catchment area at the edge of the "Causses" of Imouzzère and Amekla, in the tabular Middle Atlas. It is part of the lacustrine system of the Middle Atlas and forms with the Dayets Agoulmam, Afourgagh, North, and Ifrah, South, a group of aligned dayets following the Tizin'Tretten accident (N 40°) [9] (**Figure 1**). This small water body, which represents the residual part of the lake, occupies the western part of the bottom of the watershed depression, nested in lacustrine sediments of Upper Pleistocene (Soltanian) and Holocene age.

2.1. Liasic Substrate and Alteration Complex

The Dayet Iffer is in the form of a cauldron (chasm) filled with water [10] [11]. Its area is of the order of 1.5 ha and its depth does not exceed 14 m. The withdrawal of its water body during the last two decades following the drought, allows to emerge on the shores, except for the north shore, Holocene and sub-current lacustrine deposits. The substrate on which the Dayet was formed is totally dolomitic, with some shreds of Lias limestones. This dolomite, along the fault of Tizin'Tretten, presents several facies: massive, false breccia, sandy and crushed. The facies most affected by the fault are mainly to the west and south of the body of water, between it and the main fault of Tizin'Tretten. Massive dolomites, lying in the East and North, exhibit intense fracturing. On the dolomites,



Figure 1. Geographical location and lithologic map of the Dayet Iffer watershed.

there are remnants of old red soils (terra rossa). They sometimes present in stages whose thickness exceeds 3 to 4 m which can be the residual witnesses of a paleogeography of the depression. The contour of the watershed of the Dayet Iffer follows a geometric form (subrectangular) with rectilinear alignment of relief which explains the influence of the tectonics on its origin. It is a bottom (~1540 m of altitude) surrounded by slopes generally steep with a slope higher than 50% and which can reach 80% on average. The alluvial fan at the outlets of the "Thalwegs" formed on relatively flat surfaces.

On both sides of the Dayet, the soltanian lacustrine filling forms two terraces. One in the East, very clear in the landscape (1540 m of altitude), whereas the Western terrace is demarcated and eroded (1534 m of altitude).

2.2. Quaternary Filling

The nature of the sedimentary bodies of the Dayet Iffer basin infill shows that two main lacustrine phases have been clearly recorded by the deposits. The former lacustrine formation occupies the East and the West of the Dayet, while the most recent one is around the Dayet with which alluvial fan are connected to the West, and a delta under lacustrine to the East (**Figure 1**). To the east, the former lacustrine formation forms a terrace which is connected to the Dayet by an embankment where different of its horizontal dip layers are exposed, considering that the two lacustrine formations are superimposed under the Dayet.

3. Means Used

A prospecting team has been set up to carry out this study, which consists of:

3.1. Staff

-) 01 study engineer and a study chief;
-) 01 technician;
-) 02 team leaders;
-) 04 maneuvers.

3.2. Material

01 very powerful ARES II resistivity meter (850 W, 5 A, 200 Vp-p) with accessories;

- 02 48-channel switch box for connections;
-) 01 cascade connections for the 02 switch box (6×80 m);
-] 01 converter 12 V (electronic power supply) of 1500 W;

) 06 multi-electrode coils model MCC10 (10 m pitch) of 120 m length for each coil;

- 96 stainless steel electrodes;
- 96 connections between the electrodes and the multi-electrode cables;
- 01 12 V battery.

Two software with licenses; RES2DINV for 2D and 3DINV for 3D.

4. Principle of the Method

The sub-surface electrical tomography makes it possible to obtain an "electrical image" of the subsoil (*i.e.* a pseudo-section of apparent resistivity as a function of depth). It has been highlighted to obtain a model of the basement where the distribution of the resistivity varies vertically and horizontally along the profile. The electrical resistivity of the subsoil depends mainly on the physical and chemical characteristics of the soil, the interstitial water and the presence of an underground vacuum. The principle of the method is based on the measurement of electrical potential differences associated with the injection of an electric current. Ohm's law makes it possible to calculate the apparent electrical resistivity. This value results from the contribution of all the portions of the medium that are crossed by the current emitted on the surface. Thus, the measurement represents a value that integrates the resistivity of a certain volume of the subsoil simultaneously [12].

Four steps are required to use this method:

1) 1st step: create a sequence of measurements with the software Electro II-III. This sequence makes it possible to set parameters such as the type of device, the number of electrodes, the level of depth of investigation, as well as other acquisition parameters (number of measurements, spacing between electrodes) (Figure 2).

2) 2nd step: make field measurements (data acquisition): The acquisition technique consists of creating profiles by regularly increasing the space between the electrodes. By using a large number of fixed-spaced electrodes (24, 48, 72 or 96) (the distance between electrodes can be 1; 1.5; 2; 3; 5 or 10 m...) connected to a multicore cable and placed according to a profile, a laptop, in which is programmed the measurement sequence, is connected to a communication box and automatically selects the electrodes used for the injection of the current and the measurement of the potential. The current is injected via a very powerful type ARES II resistivity meter (850 W, 5 A, 2000 Vp-p). 02 Switch box of 48 channels makes it possible to execute a previously programmed measurement sequence (**Figure 3**).

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Figure 2. Image representing the number of measurements in a sequence.



Figure 3. Acquisition and multi-electrode system.

The commonly used devices are:

- dipole-dipole;
- Wenner-Schlumberger;
- Wenner, it is recommended to have a better resolution of the horizontal structures.
 - 3) 3rd step: data transfer and processing.

4) 4th **step:** interpretation of the data: the results obtained represent the variation of the resistivity as a function of the depth. Their conventional representation is a pseudo-section of the variation as a function of the depth of apparent resistivity or charge ability. Inversion of the data using Res2dinv allows to obtain a section of true resistivity. These are correlated and the ranges of values represent electro-layers. On the pseudo-sections, all information concerning the geology, (*i.e.* a geological identification of the different geoelectric horizons highlighted by the electric tomography) will be reported.

Figure 4 shows us that electric tomography (resistivity) allows to know the geological formations for example the resistivity of red colors can correspond to conglomerates, the resistivity of green and yellow colors can be assimilated to sands and the resistivity of blue color to clays. So, the tomography gives us an image of the basement according to the resistivity.





Figure 4. Explanatory diagram of the electric tomography process.

5. Tomography of Electric Resistivity

The method of electrical tomography (called electrical resistivity tomography or ERT) has been developed in order to obtain, after inversion of the 2D or 3D model of the subsoil [13], where the distribution of the true resistivity of the basement varies vertically and horizontally along the measurement profile, this has been possible by advances in computer science and mathematical processing of geoelectric data [14].

We recall that electrical tomography (resistivity) is used for a detailed mapping of deep geological formations (Figure 4).

For the two tomography profiles performed in our work on 04/27/2015, the depth of investigation is 132 m and 66 m with lengths of 710 m and 355 m respectively, and distance between 10 m and 5 m electrodes.

For both profiles, the device used is Wenner-Schlumberger, and the two profiles have directions SE-NW and SW-NE respectively.

6. Main Results Obtained

The preliminary interpretation of the electrical tomography profiles is done as the acquisition progresses in order to ensure a better quality of the measurements and to orient the acquisition in the field.

7. Methods of Processing of Data

Electrical tomography profiles were performed in the study area using ARESII resistivity equipment by a Wenner-Schlumberger configuration with a = 5 and 10 m; the total lengths of the profiles are 355 m and 720 m respectively. The values measured directly in the field are apparent resistivity. In fact, each measure represents a value that incorporates the resistivity of a certain portion of the earth. To obtain an image representing the quantitative changes in electrical resistivity, a basement modeling along two profiles (**Figure 5**) across lake Iffer where there is an intersection of the two profiles between the station 24 for profile 2 and station 32 for profile 1. The modeling was carried out by an inversion method based on a recursive method that attempts to minimize the difference between the pseudo-section measured and a pseudo-section recalculated from a model of the electrical resistivity theory that is modified at each repetition until the calculated value and the measured data reach an acceptable agreement or



Figure 5. Position of electrical tomography profiles in the watershed of the Dayet Iffer.

until no further improvement is possible [15] [16] [17]. The measure of the difference between the theoretical model and this model is expressed as measured by the Root Mean Square root (RMS). In general, the most reliable model is located just after the repetition where the RMS error does not change significantly (<3.3% improvement), which usually occurs between five repetitions.

8. Field Results

The electrical tomography profiles are considered representative since they cross all the recognized surface geological formations and the substrate. The first profile was carried out south of the lake in a SE-NW direction and crosses, from west to east, the Liasic dolomites of the substrate and the Soltanian superficial formations on both sides of the alluvial fan and lacustrine Holocene. The second one, east of the dayet, has a direction SW-NE and passes on the surface through the liasic dolomites of the substrate on both sides of the superficial soltanian geological formations which are surmounted in the middle by deposits of the alluvial fan of Holocene.

The surface presence of faults that affect both the substrate and the superficial formations is to be noted, but it remains to determine their presence in depth and the type of movement. It should also be noted that the nature and thickness of the superficial formations at depth have not been determined. Another factor, with the tectonics, to take into account is the genesis of the karstification depression [9]. Knowing that the bedrock substrate of the Dayet Iffer is located in a carbonate context dominated by faulted and fractured dolomites and that the geological formations have synsedimentary faults, a morpho-structural map was made based on the shape of the relief (alignment) and fracture directions [18] [19] (Figure 6). The data provided by the deep morpho-structural study can be



Figure 6. Morpho-structural map of the Dayet Iffer watershed.

confirmed by electrical tomography.

The analysis of the two electrical profiles revealed relatively more ancient, pre-Soltanian, superficial geological formations than those recognized and determined (Figure 1). The thickness of all these formations which has a large variation, exceeds 130 m in the middle of the bowl, while it is estimated to 30 m on the surface. The general pattern of the first survey shows continuous sedimentation with distension and/or compressive synsedimentary tectonics in some places. In the West, normal faults are numerous, including metric faults that affect the surface geological formations and appear on the surface as stepped shapes. In the East, in addition to the inclination of some formations, their thickness presents abrupt variations which are the results of sets of compressive faults in detachment. At the extreme west of the sounding, the substrate, normally under the superficial geological formations, appears above these, a phenomenon explained by a lateral sliding following a subsidence of the bottom. The second electrical survey shows a profile as complicated as the first one. The diagram is marked by the presence of faults in distension and compression (recess). Sliding movements are manifested by overlapping dolomite flaps of the substrate on the surface formations. The thickness changes of the superficial formations can only be the results of the replay in recoil of certain faults. The results obtained by the Wenner-Schlumberger profiles on the study area are made up of three panels (Figure 7). The first panel located above represents the pseudo-section of the measured apparent resistivity. The middle pseudo-section is the model calculated by the inversion program. The last panel is the inversion model of the section. The image clearly maps the structure that has affected the study area on this site.

In the light of previous geological data, the Middle Atlas geological map, the Tizin'Tretten accident (40°N) and the results of the geophysical data, we were able to establish an interpretation of the pseudo-sections of profiles 1 and 2 (**Figure 8, Figure 9**).

After processing the study results in the area, the preliminary interpretation of the two resistivity pseudo-sections shows that the values obtained oscillate between 20 and 3500 ohm.m. There are four resistivity ranges. A range denoted A which corresponds to an alternation of sands and silts with a resistivity of 20 to 140 ohm.m, A range B which corresponds to dolomites less resistant and fractured with resistivities which oscillate between 250 and 500 ohm.m, a range C with resistivity higher than 2500 ohm.m and which would correspond to compact very strong dolomites, and finally a range D which means a dislocated dolomite block. On these profiles have been reported the electrical discontinuities, corresponding to faults that participated in the genesis and evolution of the Dayet Iffer. It has been shown for the first time that the thickness of the superficial geological formations of the Dayet Iffer watershed can reach more than 160 m.

9. Geophysical Interpretation

The results presented in this paper show that electrical tomography (performed

for the first time at the Dayet Iffer) is a geophysical tool well suited to the detection of fills and the mapping of lake basins in karst areas. The technique is able to identify the thicknesses of the geological formations and to highlight electrical



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Figure 7. Profiles 1 and 2 Model of Apparent, Calculated and Inverted Resistivities in the study area.



Figure 8. SE-NW directional electrical tomography profile 1.



Figure 9. SW-NE directional electrical tomography profile 2.

discontinuities that could correspond to faults. The 2D perpendicular and parallel to the lake resistivity tomographies conducted here led to the mapping of the complex geometry of the sedimentary filling. The tomographic images calculated with the Res2DInv software reveal the presence of three ranges that can be seen as three; resistive, intermediate and conductive zones with a large fault gap. These results lead to propose a hydrological behavior of the Dayet Iffer associating, at the same time the horizontal flows at the level of the layering, and/or karstic joints along the sub-vertical fractures.

10. Conclusions

The geophysical study by application of tomography with two profiles of electrical tomography with almost perpendicular directions (SE-NW and SW-NE) in the catchment area of the Dayet Iffer, revealed for the first time several geological phenomena that accompanied the genesis and evolution of the watershed. The sedimentary filling of this watershed reaches a considerable thickness exceeding 160 m. The sedimentary filling is affected by post and synsedimentary brittle faults which testify to a permanent tectonic activity, linked to the replay of the Tizin'tretten accident. Variations in the thickness of some geological formations of the infill are linked to fault offset. In the middle, the sedimentary filling which presents in some levels a flexible structure on both sides of the recent filling is the sign of a karstic withdrawal and consequently its intervention with the tectonics in the genesis and the evolution of the watershed.

From these data, it is clear that the genesis of the Dayet Iffer watershed occurred in the Quaternary before its sedimentary filling. The geophysical study by tomographic profiles in the Dayet Iffer watershed is part of the conceptual model that will be used later to carry out hydrodynamic modeling of the flows of the other Dayets in the Middle Atlas region.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

- Baali, A. (1998) Genèse et évolution au Plio-Quaternaire de deux bassins intramontagneux en domaine carbonaté méditerranéen. Les bassins versants des dayets (lacs) Afourgagh et Agoulmam (Moyen Atlas, Maroc). Thèse d'État, Université Sidi Mohamed Ben Abdellah, Fès, 326 p.
- [2] Baali, A. and Lemdeghri Alaoui, B. (1999) Étude du remplissage fluvio-lacustre plio-quaternaire de Dayet Iffer (Moyen Atlas, Maroc). 15*th Colloque des Bassins*

Sédimentaires Marocains, Oujda, 27-29 avril 1999, 157-158.

- [3] Baali, A., Cheddadi, R. and Chairi, R. (2007) Evolution sédimentologique, pédologique et paléoclimatique du bassin lacustre de la dayet Agoulmam (Moyen Atlas, Maroc) depuis le Pléistocène (Soltanien) à l'Holocène. *Revue Méditerranéenne de l'Environnement*, 267-280.
- [4] Lemdeghri Alaoui, B. and Baali, A. (2005) Analyses polliniques des sédiments lacustres holocènes de la dayet Iffer (Moyen Atlas, Maroc). 18th Colloque des Bassins Sédimentaires Marocains, Fès, 102-103.
- [5] Lemdeghri Alaoui, B. and Baali, A. (2014) Mise en évidence d'une alternance d'épisodes climatiques pendant la fin du Pléistocène supérieur: Enregistrements dans les dépôts lacustres de dayet Iffer (Moyen Atlas, Maroc). 82nd Congrès de *l Acfas*, Montréal, 12-16 mai 2014. https://www.ecfas.co/orgrammats/congress/programma/82/200/202/d2encre=7026

https://www.acfas.ca/evenements/congres/programme/82/200/202/d?ancre=7026

- [6] Lemdeghri Alaoui, B., Baali, A. and Renault Miskovsky, J. (2014) Action anthropique depuis 3000 ans dans le Moyen Atlas marocain: Analyses polliniques des sédiments de dayet Iffer. 82*nd Congrès de l'Acfas*, Montréal, 12-16 mai 2014. https://www.acfas.ca/evenements/congres/programme/82/200/202/d?ancre=7026
- [7] Lemdeghri Alaoui, B., Baali, A., Chibout, M., Benslimane, A. and Faqihi, F.Z. (2015) Application de la tomographie électrique pour mettre en évidence l'épaisseur et la structure du remplissage sédimentaire de dayet Iffer (Moyen Atlas, Maroc). 22 nd Colloque International des Bassins Sédimentaires Marocains, Protection de l'environnement et gestion durable des ressources naturelles, Fès, 18-19 décembre 2015, 230-231.
- [8] Lemdeghri Alaoui, B. and Baali, A. (2017) Mise en évidence d'une alternance d'épisodes climatiques pendant la fin du Pleistocène supérieur: Enregistrements dans les dépôts lacustres de dayet Iffer (Moyen Atlas, Maroc). *European Scientific Journal*, 13, 362-377. <u>https://doi.org/10.19044/esj.2017.v13n2p362</u>
- [9] Baali, A., El Fellah, B. and Feddan, B. (1999) Modèle explicatif de la genèse et de l'évolution des dayets (Agoulmams) du Moyen Atlas (Maroc). Le 1st Colloque national sur le Jurassique marocain, Association Marocaine des Géologues Pétroliers, Rabat, 21-22.
- [10] Martin, J. (1981) Le Moyen Atlas central. Etude géomorphologique. Notes et Mémoires du Service géologique, No. 258, 445 p.
- [11] Rhoujjati, A., Nourelbait, M., Benkaddour, A., Damnati, B., Baali, A., Taieb, M., Decobert, M., Farid Malek, F. and Cheddadi, R. (2012) Significations paléoenvironnementales des dépôts du remplissage holocène du lac Iffer (Moyen Atlas, Maroc). *Quaternaire*, 23, 241-252. <u>https://doi.org/10.4000/quaternaire.6300</u>
- Benslimane, A. (2005) Apport de la géoélectrique à la reconnaissance des potentialités hydriques dans les formations basaltiques subaffleurantes. Thèse de Doctorat, Meknès, 216 p.
- [13] Dahlin, T. (1996) 2D Resistivity Surveying for Environmental and Engineering Applications. *First Break*, 14, 275-284. <u>https://doi.org/10.3997/1365-2397.1996014</u>
- [14] Fehdi, C., Baali, F., Boubaya, D. and Rouabhia, A. (2011) Detection of Sinkholes Using 2D Electrical Resistivity Imaging in the Cheria Basin (North-East of Algeria). *Arabian Journal of Geosciences*, 4, 181-187. https://doi.org/10.1007/s12517-009-0117-2
- [15] Loke, M.H. and Barker, R.D. (1996) Rapid Least-Squares Inversion of Apparent Resistivity Pseudosections by a Quasi-Newton Method. *Geophysical Prospecting*, 44, 131-152. <u>https://doi.org/10.1111/j.1365-2478.1996.tb00142.x</u>

- [16] Dahlin, T. and Loke, M.H. (1998) Resolution of 2-D Wenner Resistivity Imaging as Assessed by Numerical Modelling. *Journal of Applied Geophysics*, 38, 237-249. <u>https://doi.org/10.1016/S0926-9851(97)00030-X</u>
- [17] Qarqori, Kh., Rouai, M., Moreau, F., Saracco, G., Dauteuil, O., Hermitte, D., Boualoul, M. and LE Carlier de Veslud, C. (2012) Geoelectrical Tomography Investigating and Modeling of Fractures Network around Bittit Spring (Middle Atlas, Morocco). *International Journal of Geophysics*, 2012, Article ID: 489634. https://doi.org/10.1155/2012/489634
- Baali, A. and Lemdeghri Alaoui, B. (2005) Mise en évidence de plusieurs séismes majeurs d'âge fin Pléistocène supérieur (Soltanien) dans le moyen Atlas (Maroc): Enregistrement dans des sédiments lacustres. 18*th Colloque des Bassins Sédimentaires Marocains*, Fès, 103.
- Benabbou, M., Lemdeghri Alaoui, B. and Baali, A. (2018) Structures de déformation hydroplastique d'origine sismique dans les dépôts lacustres du Pléistocène supérieur de dayet Iffer (Moyen Atlas, Maroc). *Quaternaire*, 29, 15-25. https://doi.org/10.4000/quaternaire.10495