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Contribution of geophysics to determine the sedimentary filling and aquifers levels position within Dradere Soueire coastal basin (North Western Morocco)

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Abstract

The Drader Souiere basin is a part of the hydrological basin of Sebou that is known by a high agricultural activity. The work aims to establish the relationship between sedimentary filling and aquifer facies distribution as well as to provide a new approach to interpretation, interpolation and identification. In this paper, a methodology that combines, a geological field and boreholes data with geophysical data (tomography, logging and seismic), is adopted and integrated, in a Geographic Information System (GIS), in order to establish isobaths map of Tortonian-Messinian marls bedrock, to determine the sequential position of Pliocene-Quaternary aquifers and to highlight the roles of deep structures in these aquifers arrangement. Tortonian-Messinian marls constitute the basin substrate; deposited on the Pre-Rif layers, from where he inherits his structuration, in the form of NW-SE ripples (an anticlinal-synclinal succession). The Pliocene-Quaternary sedimentary filling by paleo-channels, sea level oscillations and Miocene syn-sedimentary tectonics, give to the basin a «piano keys» geometry with various sedimentary environments. The most important aquifers of the basin match the regressive sea level periods of Zanclean and middle-upper Pleistocene. These new data provide other perspectives to quantitative research by hydrodynamic modeling of the water resources basin.

Keywords: boreholes geophysics; sedimentary sequence; Plio-Quaternary; paleochannels; deep structures; Moroccan aquifer

Resumen

Contribución de la geofísica a la determinación del relleno sedimentario y la posición de los niveles del acuífero de la cuenca costera Dradere Soueire (Noroeste de Marruecos)

La cuenca Dradere Soueire pertenece a la gran cuenca del río Sebou, conocida por una actividad agrícola muy importante. El objetivo del trabajo es establecer la relación entre el relleno de sedimentos y la distribución de facies sedimentarios de los acuíferos y también aportar un nuevo

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enfoque a la interpretación, interpolación e identificación. En el presente estudio, los métodos utilizados combinan datos geológicos de terreno y de sondeos, así como datos geofísicos (tomografía, diagrafía y sísmica), integrados en un Sistema de Información Geográfica (SIG),con un fin de establecer el mapa de isobaras del sustrato de margas Torto-Mesinienses, y determinar la posición secuencial de los acuíferos del Plio-Cuaternario además de poner en relieve el papel de las estructuras profundas en la disposición de estos acuíferos. El sustrato a nivel de la cuenca es de edad Torto-Mesiniense, depositado sobre los mantos pre-rifeños, de donde hereda su estructura, en forma de ondulaciónes NO-SE (una sucesión pliegues anticlinal-sinclinal). Se debe destacar que el relleno sedimentario pliocuaternario por paleocanales antiguos, las oscilaciones del nivel del mar y la presencia de movimientos tectónicos sinsedimentarios del Mioceno, confieren a la cuenca una geometría «en teclas de piano» con contextos sedimentarios que varían. Así mismo los acuíferos más importantes de la cuenca coinciden con los períodos regresivos de los niveles de Zancliense y Pleistoceno medio y superior.Estos nuevos datos abren nuevas perspectivas para estudios cuantitativos por modelización hidrodinámica.

Palabras clave: perforación geofísica; secuencia sedimentaria; Plio-Cuaternario; paleocanales; estructuras profundas; acuífero marroquí

Résumé

Apport de la géophysique à la détermination du remplissage sédimentaire et de la position des niveaux aquifères du Bassin côtier Dradere Soueire (Maroc Nord Occidental)

Le bassin Dradere Soueire fait partie du bassin hydrologique du Sebou qui est connu par une activité agricole très importante. Le travail vise à établir la relation entre le remplissage sédimentaire et la distribution des faciès aquifères ainsi que d'apporter une nouvelle approche d'interprétation, d'interpolation et d'identification. Dans la présente étude, une méthodologie où sont combinées, les données géologiques de terrain et de forages, ainsi que des données géophysiques (tomographie, diagraphie et sismique), est adoptée et intégrée dans un Système d'Information Géographique (SIG), afin d'établir la carte des isobathes du substratum marneux torto-messenien, de déterminer la position séquentielle des aquifères plio-quaternaires et de mettre en évidence le rôle des structures profondes dans l'agencement de ces aquifères. Le substratum au niveau du bassin est marneux d'âge torto-messenien, déposé sur des nappes pré rifaines, d'où il hérite sa structuration, sous forme d'ondulations NW-SE (une succession anticlinal-synclinal). Le remplissage sédimentaire plio-quaternaire par des anciens paléo-chenaux, les oscillations du niveau marin et la présence de mouvements tectoniques syn-sédimentaires miocènes, confèrent au bassin une géométrie « en touches de piano » avec des contextes sédimentaires variant. Les aquifères les plus importants du bassin coïncident avec les périodes régressives du niveau marin d'âge zancléen et pléistocène moyen et supérieur. Ces nouvelles données ouvrent de nouvelles perspectives aux études quantitatives par modélisation hydrodynamique.

Mots-clés: géophysique de forages; séquence sédimentaire; Plio-Quaternaire; paléochenaux; Structures profondes ; aquifère marocain

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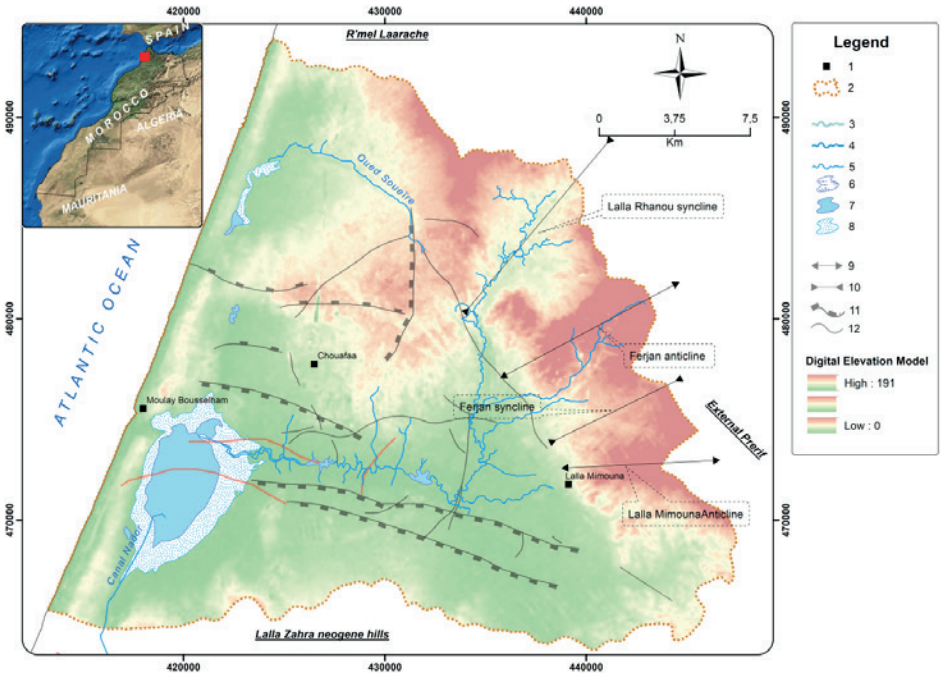
1. Introduction

Dradere Soueire basin is located along the Atlantic Ocean on an area of 600 km² approximately, between the Gharb-Maamora basin in Southern, south Rif ripple in the eastern and Loukkos basin in Northern. The natural borders of basin are marked by Lalla Zohra Hill in Southern that separates the Gharb-Maamora basin, by Lalla Mimouna hill to the southeast as transition area to the south Rif ripple, and by a succession of anticlines and synclines in the North East, that separates the Loukkos basin (Map 1). This area is a part of Sebou basin that is known by a highly large agricultural activity, supported by the availability of surface water, with an estimate of 1025 million m³ of mobilizable resources, about 25% of mobilizable resources in Morocco (ABHS, 2011).

The Dradere Soueire basin as a subsidize basin has accumulated a great amount of sediments carried by the old plots of Sebou and Ourgha river from the Rif (Benmohammadi et al., 2007). The stratigraphic model of the sedimentary filling, seems elementary with a Neogene-Quaternary succession (Chapond, 1955).

The challenge to bring a new approach for interpretation, interpolation and identification is required. In this work, it is question of; firstly, establish the isobaths map of Miocene marl bedrock, secondly, to determine the sequential position of Pliocene-Quaternary aquifers based on well log interpretations, thirdly, to highlight the roles of deep structures in the arrangement of these aquifers. These objectives are part of a reserves volume evaluation perspective and mathematical modeling of groundwater resources.

Map 1 : Drader Souiere basin location map, its post – sheet structure and the shape of actual hydrographic network with a DTM background (compiled from Flinch (1993) and Litto (2001) works).



1: Town; 2: Dradere Soueire basin boundary; 3: Water canal; 4: stream; 5: Tributary; 6: lough; 7: lagoon (main zone); 8: lagoon (sandy mud); 9: Anticline; 10: Syncline; 11: Overlapping fault (Pre-Rif ripple); 12: Normal listric fault. Source: self-made.

2. Geological and hydrogeological context

2.1. Lithostratigraphy

Drader-Souiere as a subsiding basin has accumulated a large amount of sediments carried by old plots of Sebou and Ourgha rivers from the Rif (Benmohammadi et al., 2007). The stratigraphic model of the sedimentary fill basin appears elementary with a Neogene-Quaternary succession (Chapond, 1955).

Pre-Rif layers constitute the basic bedrock in Dradere Soueïre basin, they outcrop amply around the edges and appear locally in the basin itself as a saliferous ground (Litto, 2001). Filling the basin is achieved by Tortonian-Messinian marls at the base of marine origin and Pliocene-Quaternary successions of the sand, clay and sandstones of continental and marginal-littoral origin (Le Coz, 1964; Cirac, 1987). From the fact that we present recent deposits attached to various domains, we use the datings published by Combe (1975) and Chapond (1955) that we have correlated with borehole data dating and identified on the international chronostratigraphic charter.

-Messenian: is characterized by establishment of the southern Rif Strait covering recent and thick fields (Chapond, 1955). A hundred meters thickness sedimentation formed by yellow, gray and blue marls (Combe, 1963). These marl amply outcrop in the South and the East.

-Pliocene: the opening of the Gibraltar Strait at the Zanclean, enables the Atlantic Ocean to flow into the Mediterranean Sea (Blanc et al., 2002), quick transgression is marked by the presence of reworked elements of Messenian, blue marl and sand with some pebbles at the base and sandy-sandstone formations at the top. This age outcrops, within the boundaries of basin, with an increase in thicknesses proceeding from the South to the North. (Chapond, 1955). The Piacenza progressive regression allows the deposition of continental formations as alternating red and yellow sand levels (The red sands are constant across the basin and exhibit a good stratigraphic landmark). In south areas, these deposits, past to red crushed stone, to mark the Pliocene-Quaternary transition (Chapond, 1955).

-Pleistocene: In Calabrian-Galesien, regarding Combe in 1963. The plastic clay deposits in depressions and red conglomerates at the higher areas of the basin, the latter often referred to as «conglomerates of Arbaoua». The Middle Pleistocene is well represented in the central part of the basin (bottom Dradere); current dunes and old dunes consolidated. The consolidated dunes form a cliff strip along the Atlantic margin, with a thickness of 30 m averaging consist of yellow sandstone, more or less concreted. This age appears as yellow and gray sand carried by the wind in depressions (sand lagoons) and current blackish soil of Holocene. These formations reflect a significant subsidence in the sector.

2.2. Tectonic

The subsiding has continued its droop during the Mio-Pliocene (Le Coz, 1964), it lies entirely within the southern Pre-Rif (Chalouan and Michard, 2004) this position is recognized by the interpretation of geophysical data at the south area (Flinch, 1993; Litto, 2001).

Several parts can be distinguished: In the southeast, the Lalla Mimouna anticline axis E-W and the Ferjane syncline which follows further north (Map 1), influence onto surface morphology (Combe, 1963). In the East, the presence of a Villafranchian meridional deflection (Benmoham-

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madi et al., 2007). In the north, the presence of cuvettes «El Mellah» which allows the outcrop of Pre-Rif layers and Triassic diapir following the rise of Miocene marl (Chapond, 1955). In the South, the East-West Lalla Zohra fault structure, enables a rise in Pre-Rif layers and base, according to gravimetric analysis, it also allows the isolation of the Moulay Bousselham gutter from the rest of subsidize basin (Benmohammadi et al., 2007). To the West the Messenian rises gradually towards an anticline summit parallel to the present coast and submerged at a short distance, the establishment of consolidated Pleistocene dunes that are present throughout the Gharb valley «Sahel» (Chapond, 1955) marks this coastal part.

The position of the current earthquake foci confirms the recent activity of some faults and parallel NNE-SSW ripples overlapping most probably to pre-existing undulations of the Pre-Rif layers (Combe, 1975).

2.3. Hydrogeologic context

The hydrogeology of the Dradere Soueire basin is a plurality of aquifer levels, recharged by rainfall infiltration with a piezometric equilibrium following a sufficiently large vertical permeability (Combe, 1975). Aquifers are unconfined, with impermeable bottom, made of Tortonian-Messinian marl.

The presence of tectonic ripples that spread throughout the basin allows the outcrop of impermeable soil, without permeable cover, at the NE and SE areas of the basin. Both areas are marked by a small quantity of water and emergence of coastal waters sources. Another feature area of the basin is at the Moulay Bousselhame town marked by brackish water a result of ocean exchanges with the lagoon.

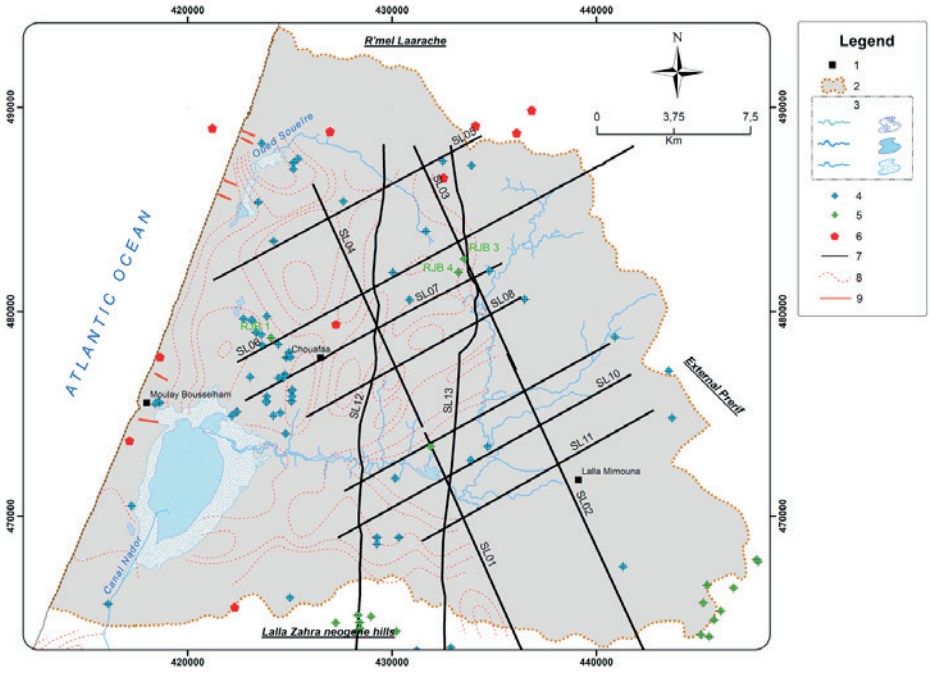
The synthesis of previous studies at the Dradere Soueire basin shows that the marl bedrock inherited a complex architecture, ripple of Rif tectonics (Flinch, 1993; Litto, 2001).The map of the top marl bedrock clearly shows the presence a series of moving depression following a hyperactive neotectonics (Benmohammadi et al., 2007), identified by the presence of foci current earthquake that synchronize the extensional structures identified by seismic (Litto, 2001).

3. Methodology

The Dradere Soueire basin was the subject of several investigations by geophysical methods and exploratory wells; particularly electrical tomography at the ocean boundary and well log records spread across the basin.

The adopted methodology is combined in a GIS, geological and geophysical data, including: firstly, 44 electrical imaging profiles, as graphic contour lines (pseudo 2D section). acquired by Wenner device, imposed because of the nature of the ground which is not too noisy; but also because, and as compared to other configurations, the device making them more easily recognizable structures on the pseudo-section. Processing is carried out by inverting the Res2Dinv software. Secondly, 72 hydrogeological drilling and 29 well logging that include electrical resistivity recordings, spontaneous potential, gamma ray and sonic recordings. The data used are of good to very good quality. Finally, 11 industrial seismic profiles calibrate by four deep oil drilling (Map 2).

Map 2 : Location map of the geophysical data.



1: Town; 2: Basin Limit; 3: Hydrographic network and lagoon; 4: hydrogeological drilling; 5: Oil drilling; 6: Seismic Foyer; 7: Seismic Profile; 8: transversal resistivity curve (RT); 9: Tomographic section. Source: self-made.

4. Results

4.1. New depth contours map of Tortonian-Messinian marls bedrock

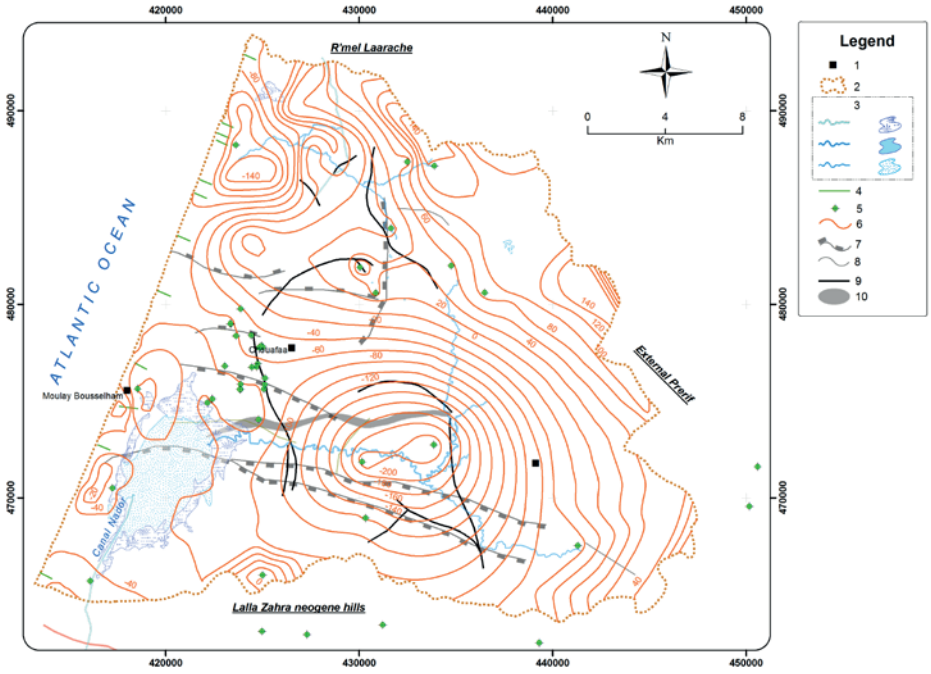
In order to establish a map of the bedrock (Map 3), the tomographic profiles conducted at the coastal margin of the basin are calibrated by logging data, electrical resistivity data and lithology cuts drilling. This indication has allowed us to determine the true resistivity layers of Tortonian-Messinian marls deposits. On the other hand the analysis of lithological drill cuttings and integration of geological mapping data that provide structural models has allowed us to positioned marls level in the rest of basin.

Generally, marls bedrock follows the NW-SE ripples of the Pre-Rif, characterized by thrust faults at the level of Lalla Zahra. The Tortonian-Messinian outcrops on marginal western hills and dips towards the Atlantic Ocean. Although a rise in the bedrock to a shallow depth is marked at the western area of Lalla Zahra, a view ascended of the Pre-Rif layers pre noteworthy on gravimetric data. At the Miocene, the basin totally emerged has had sedimentary contribution by paleochannels of Ourgha and Sebou (Cirac, 1987), this sediment body exerts a force on the Pre-Rif layers, the latter are allochtonous with limestone-sandy matrix which are packed elements of all sizes, creating a detachment level by listric faults. Brittle and active faults during the Messinian will individualize in the basin to create rift basins (grabens) which will fill of marl sediments. Synsedimentary tectonic movements, giving them as «piano keys» geometry.

The integration of seismic foci database saved in northern Morocco shows that the basin continuing structuring by sub-basin and individualization from the Gharb Basin by the presence of

a current earthquake activity, mainly in Lalla Zahra Neogene hills structure and Rhabet Jebila listric fault.

Map 3 : Depth map of Tortonian-Messinian bedrock in Drader Soueire basin relative to the general sea level.



1: Town; 2: Basin Limit; 3: Hydrographic network and lagoon; 4: Tomographic Section; 5: hydrogeological drilling; 6: bedrock depth curve; 7: thrust fault (Pre-Rif layers roof); 8: Normal fault (Pre-Rif layers roof); 9: listric fault (Messinian Roof); 10: major listric fault (Messinian Roof). Source: self-made.

4.2. Identification of homogeneous electrofacies areas

Lithofacies analysis and well log records comparison, allow establishing a first zoning in different sedimentary environments of Dradere Soueire basin, which highlights nine families, according to available data (Image 1).

The different areas deducted in the basin are:

- Zones 1 and 2: Lahbaber and Lahouaoura located in Southeast and North limits of Basin.
- Zone 3: El Mellah area is as a depression in the North East.
- Zone 4: El Ferjane forms a great synclinal axis East-West, which followed El Mellah anticline, is well marked surface.
- Zone 5: Bouhira presents a continuation to the center basin of Lahbaber Messinian layers.
- Zone 6: In the south, El Fahis area corresponds to the North Corridor from Lalla Zohra Neogene hills.
- Zone 7: Lannasba area corresponds to basin center depressions.
- Zone 8: Dhar El Hadchi is to the largest area of the basin with an important plio-quaternary filling
- Zones 9, 10 and 11: from North to South, there are North Coastal Basin, South Coastal Basin and Oulad Masbah area, that are the coastal basin margins differentiated because the swaying of marl level.

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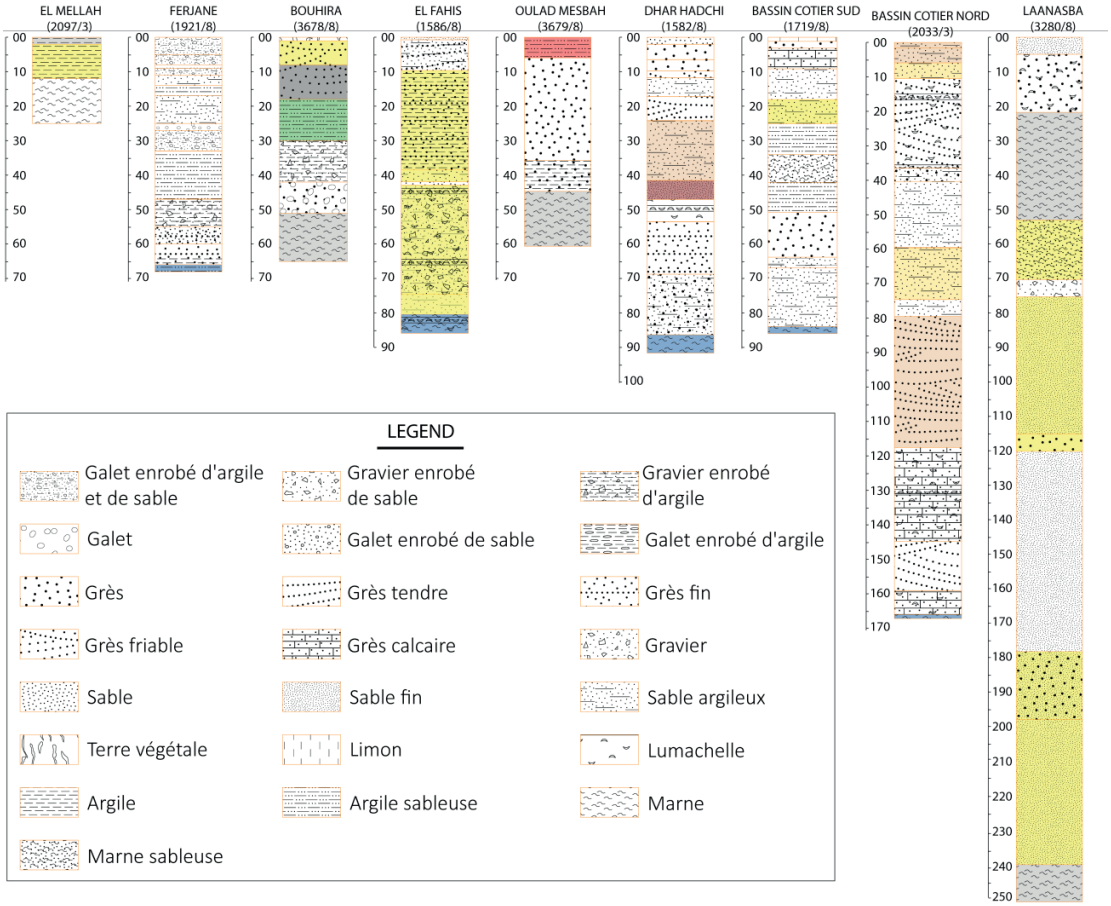
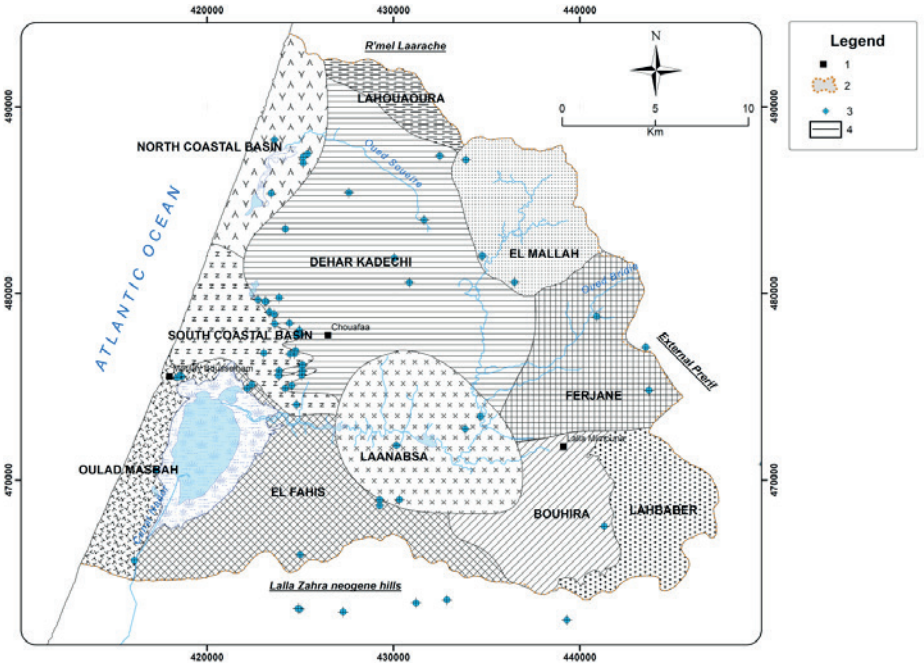
Image 1 : Lithostratigraphic type sections of different sedimentary basin contexts.



Source: modified and compiled. The spatial arrangement of all boreholes allows for a sedimentary fill reconstruction map of Dradere Soueire basin (Map 4).

Map 4: Different geological sectors with homogeneous lithofacies deducted at the basin.



1: Town; 2: Basin Limit; 3: hydrogeological drilling; 4: zone limit. Source: self-made.

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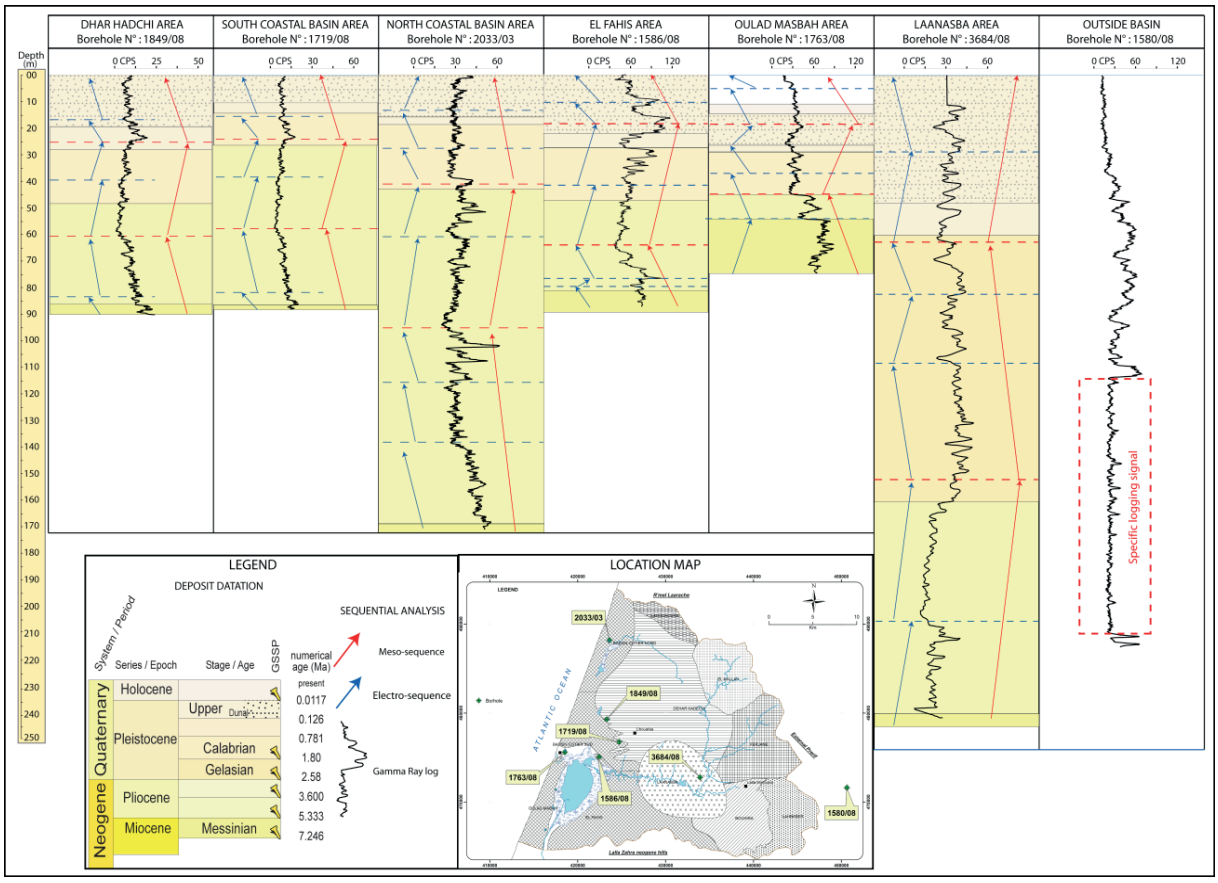
4.3. Identifying the basin evolutionary stages, Pliocene-Quaternary electro sequences and aquifers position in Dradere Soueire basin

The analysis of well log signatures (gamma rays logs) of boreholes in the various sectors of the Dradere Soueire Basin, allow carrying out a reconstruction of the basin filling evolution. Image 2, can show the sequential cutting in electrosequences and their mesosequences associations.

4.3.1. Mio-Pliocene stage

Lithofacies corresponding to the lower part of the well logs (in direct contact with the blue marls Messenian) show that they are highly variable; there is usually plastic clays and sandy clays deposits on all areas of the basin with the exception of the coastal area, where deposits brand of soft sandstone and limestone. On the logging records, the regressive evolution of radiation, corresponding to these period deposits, gradually drop to values lower than 30 c/s, thus forming a ramp ending in an electrofacies cleavage, marking the minimum radioactive radiation relatively to sandy sandstone.

Image 2: Gamma ray logging records showing the synchronous sequential progression between the different parts of Dradere Soueire basin.



Source: self-made. The sedimentation basin level is performed in three Mesosequences, which are from bottom to top: Mesosequence 1: Negative; Mesosequence 2: Positive and Mesosequence 3: Negative (image 2).

The arrangement mode of the electro elementary sequences shows that deposits of this stage are organized from the bottom up by three electrosequences:

- Electro Sequence 1: illustrates modalities of passage from marl bedrock to more clay marl.
- Electro Sequence 2: corresponds to stratum-increasing body illustrating the passage of plastic clays to sandy clays, sometimes with sandy passages.
- Electro Sequence 3: illustrates grano-decreasing structures showing the manner of passage of coarse sandstones in soft sandstone.

4.3.2. Pliocene-Villafranchien stage

According to drilling data, sedimentary facies corresponding to the middle portion of the borehole logs, from Pliocene age, are dominated by sandstone and sandy deposits (between 20 and 40 meters deep) due to a transgressive regime. In terms of logging facies the gamma rays gaits show that the first deposits radiation, gradually changing values less than 30 to 60 c/s, mark enrichment deposits of clays. Sea level oscillations follow these first deposits, allowing the presence of a succession of clay-sandstone benches, remarkable for clippings from well log records.

The exception is at the Laanabsa area, in Plaisancian-Galesien age, marl and plastic clays deposits covers the central basin area, these deposits due in early climatic oscillations who will give the typical Quaternary glaciations. These deposits are typically conserved in these depressions and eroded in the higher ground; thereby exerting pressure on Zanclean aquifers deposits, tend to give artesianism. The presence of coquina deposits to 20 meter deep is the stratigraphic regression witness the migration from a submerged environment to a dried environment.

4.3.3. Middle and upper Pleistocene stage

The upper part of the logging records present a Pleistocene mesosequence, which marks consolidated sandstone and sands deposits in a regressive regime. Generally, these deposits are split into two regressive electrosequences of the same aspect mark a sand enrichment. Except northern coastal basin boreholes where the top electrosequence look transgressive, marked a clayey sediment supply by Soueire stream.

4.4. Pliocene – Pleistocene aquifers geometry of Dradere Soueire basin

The interpretation of well log records has shown that the Pliocene-Pleistocene age levels include the low radiation levels, and thicker (Image 1 and 2) and, consequently, the main Dradere Soueire aquifers. To highlight aquifer geometry through the basin, cross section based on the correlation between well log and lithologic facies were performed (image 3 and 4).

4.4.1. Pliocene-Pleistocene monolayer Aquifer

The Pliocene-Pleistocene aquifer follows the bedrock undulations. The eastern limits of the basin present no aquifer levels, *(see the outcrop of Messinian formations)*. The Ferjane area between two summits anticlines is the first sector to lower aquifers at basin level. The aquifer dip towards the NW, allows the establishment of Dhar El Hadchi area, given the size and deposits nature, this sector is the biggest of the basin.

The hyperactive tectonics, at the Atlantic margin, has an individualization of areas; The NNW-SSE cross section at the margin (image 3) and the integration of seismic profile allows better illustrated this segmentation (image 3.B). The first area of Oulad Masbah to the south has medium

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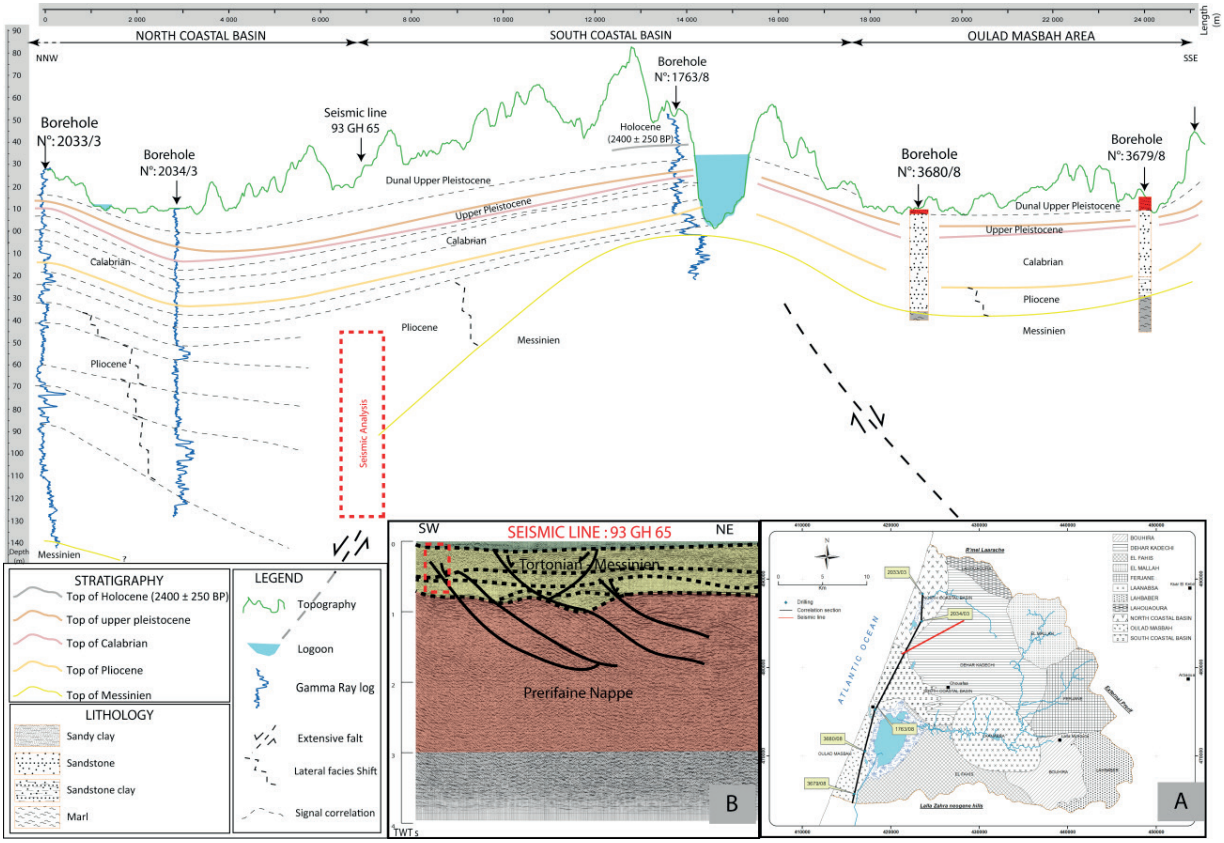
thickness levels (40 meters). Further north, the south coastal basin corresponds to the apex of an anticline and the establishment of the Moulay Bousselham lagoon. The extensive faults activity nowadays, allows the creation of a depression further north and thickening of aquifer levels (over 170 meters) in a fan shape at the North Coastal Basin.

Villafranchian Transgression allowed, at the central basin depressions the filing of lenticular clay formations (image 4). These Plaisancian-Gallissian deposits, allow the separation of aquifers in a multilayered system of two levels.

- Basal confined aquifer: At the Zanclean deposits with Messinian, marl substratum and villafranchien plastic clays rooftop. Recent drilling at the Laanabsa area tends to give artesianism (image 4).
- Unconfined upper aquifer: At the middle and upper Pleistocene deposits, flowing over Piacenzian – Galesian clay formations.

Image 3: Gamma-Ray logs and lithologic cuts Correlation on a NNW-SSE cross section at the Atlantic margin. Image 3.A: Cross section location map at Dradere Soueire basin. Image 3.B: Extract from NE-SW seismic profile GH 93 65.



Source: self-made. Multilayers Zanclean and Middle-Superior Pleistocene Aquifers

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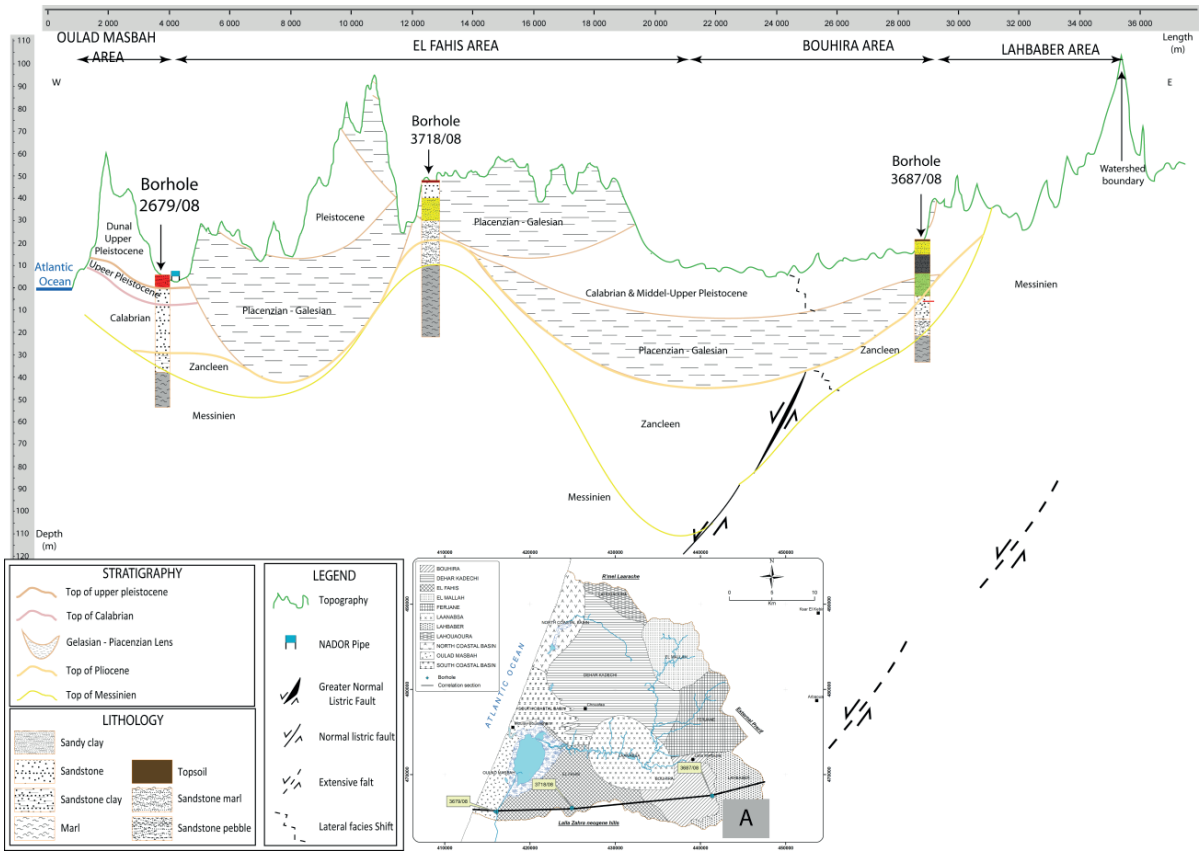
Image 4: lithologic cuts Correlation on a NNW-SSE cross section at the southern edge. Image 4.A: Cross section location map at Dradere Soueire basin.



Source: self-made.

In this paper, the use of a database having records logging, borehole data, seismic profiles and tomographic sections through the Dradere Soueire basin has shown that:

- The Pliocene-Quaternary basin inherited a complex Miocene substratum, marked by folds, faults and depression.
- The basin continues structuring and individualization to the present.
- Filling of the depressions was conducted through three Mesosequences regressive transgressive and regressive.
- The basin fill of dating is correlated to the chrono-stratigraphy international charter and Mesosequences evolution to glacial and interglacial stages recognized a global scale.
- The aquifer levels develop preferentially at major phase's regressive sea level. The thickness and the isolation of these aquifers is controlled by the deep structures of Messenian and Plaisancien – Galesian deposits in depressions.

5. Conclusions

Determination the sedimentary filling and aquifers levels position was made possible from the geophysical survey of the studied area (Dradere Soueire coastal basin). the results indicate that the Pliocene-Pleistocene filling the basin is organized in three mesosequences regressive-transgressive-regressive in depressions and provide series of sub-basin differentiated according to the

type and thickness of sedimentary deposits.The aquifers distribution in the basin is particularized one sector to another. The presence of a sufficiently large vertical permeability allows discussed a single aquifer level (Combe, 1975) of Pliocene-Pleistocene age. Nevertheless, separation of Plaisancian-Galesian clay formations, in the form lenses in depressions; separate this aquifer has a multilayer system, the first one of Zanclean age and the second one of Middle and Upper Pleistocene.

The synthesis of all the data in this study shows that the Pliocene-Quaternary basin is inherited a complex Miocene substratum and three Mesosequences regressive transgressive and regressive have filled the depressions. Aquifer's structure is controlled by Messenian and Plaisancien – Galesian deposits in depressions and the aquifer levels develop preferentially at major phase's regressive sea level.

So The hydrogeological potential evaluation of Dradere Souiere basin is intimately related to the identification of the geometry and power aquifers. The quantitative and qualitative modeling study should take account of this complex architecture.

6. References

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