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Hydro-geophysical Investigation via 2D Seismic Reflection, Nefzaoua CI and CT Aquifers, Southwest Tunisia

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Abstract: ***Groundwater resources in the Nefzaoua region are represented by two large covered aquifer systems: Continental Intercalaire (CI) and Complexe Terminal (CT). Waters housed in these two aquifers are potential targets for drinking, manufacturing, and especially for irrigation. Sampling rates increase daily, resulting in a significant drop of piezometric levels. Continuation of the current exploitation regime will lead to irreversible effects on quantity and quality of water in the two aquifers. This work integrates geology, hydrogeology and geophysics data for understanding the CI and CT aquifer systems. Petroleum wells, water boreholes, and seismic profiles led to precise distribution of sedimentary series, geometric characterization of reservoir layers, and delimitation of the CI and CT aquifer intervals in the Nefzaoua area. 2D seismic reflection analysis highlights subsurface sedimentary evolution in relation with tectonic deformations that have affected the southern Tunisia during the Mesozoic and Cenozoic times. The proposed geo-seismic section accurately highlights structure and geometry the CI and CT aquifers. The inferred model reveals relationships and communications between the reservoir layers, and explains its variations. The obtained results led to refine and complete the previous geological and hydrogeological results, and highlight new favorable zones for exploitation of the CI and CT aquifers.***

Keywords: Seismic investigation, CI and CT, Basin structuring, Aquifer geometry, Nefzaoua

1. Introduction

South of Tunisia is well known by major agricultural interest where the oases are the only viable and productive in the desert environment. Nefzaoua, situated in the southwest of Tunisia, is limited to the north, the northeast, and the east by a hummocky relief formed by the Tébaga outcrop and the Matmata Mountains, which constitute an insulating barrier against maritime influence where the sea is 120 km away. The Nefzaoua region is limited by Chott Djérid to the west, and by northern Sahara (oriental Erg) to the south and south-east (Figures 1 and 2). It covers an area of around 22454 km^2, and it constitutes 14.43% of territory of the country and 24.9% of that of southern Tunisia.

Nefzaoua is a part of the Saharan platform domain in southern Tunisia. It is marked by a lower arid bioclimatic zone, with a tendency to a typically Saharan hyper-arid climate. Agriculture activity constitutes the main source for socio-economic development in the region. In Nefzaoua, the impressive volumes of groundwater are the only source of irrigation. Moreover, the exploitable water resources are basically non-renewable fossil groundwater. In fact, the rare rain waters are generally exploited on the surface. The surface waters slightly involved in recharging deep aquifers. The exploited water tables are housed, in north Sahara, in two major aquifer systems namely the Continental Intercalaire (CI) aquifer [1**]**, and the Complexe Terminal (CT) aquifer [2,3].

Hydrogeological works, which started in south Tunisia since the end of the 18th century, made it possible to highlight two very important aquifer systems whose reservoirs cover almost the entire Chotts region; these are the Complexe Terminal and Continental Intercalaire layers aquifer units. Between 1968 and 1972, UNESCO conducted a study on water resources of northern Sahara (ERESS) with the aim of developing a mathematical model for the evaluation of the resources of the CI and CT aquifer systems, and the proposal of an exploitation scheme. From 1981 to 1983, the RAB / 80/011 project was designed as a verification of the reliability of models adopted by the ERESS project, and to inject new hydrogeological knowledge acquired in the meantime, to extend exploratory simulations to the year 2020. The aim is to produce other more efficient and more precise models (UNDP, 1983). In 2003, the Sahara and Sahel Observatory (OSS) completed the SASS (Aquifer System of Northern Sahara) project. Compared to its predecessor projects [2,3], SASS [4] benefited of a significant asset represented by the integration of Libya and exploitation of data accumulated during the last thirty years. Several geological and hydrogeological studies carried out academic scientists and by DRE (Direction of Water Resources). These works have interested particularly the Chotts region and cover all south Tunisian [1,5,6,7,8,9,10,11].

This work aims to summarize the geological and hydrogeological data, integrate petroleum and water well data, and make an interpretation of seismic reflection lines. The main objective is to highlight basin structuring and geometry of reservoirs layers and aquifers of Continental Intercalaire (CI) and Complexe Terminal (CT) in Nefzaoua.

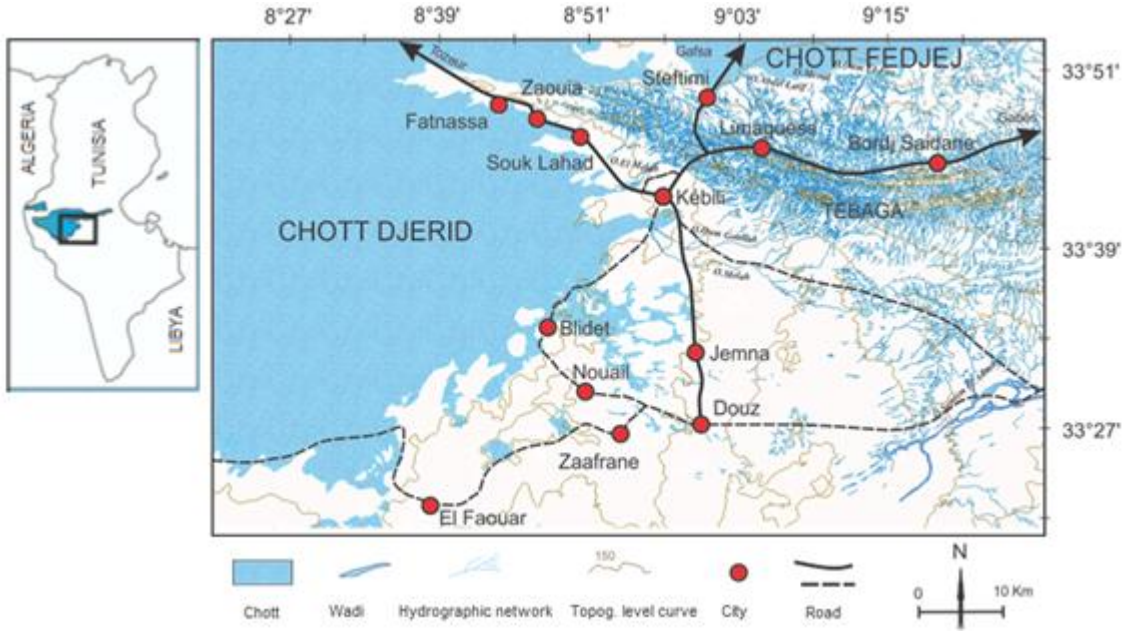

Figure 1: Geographic setting and distribution of the hydrographic network in the Nefzaoua region, southern Tunisia (Extract from the agricultural map of Kébili)

2. Geology

2.1. Structural setting

Nefzaoua occupies an intermediate position between two tectonic domains, distinct by their deformation style, the slightly deformed Saharan platform southward and the Atlassic folded domain northward [12,13, 14, 15, 16, 17, 18, 19, 20, 21, 22] (Figure 2). The Nefzaoua region is a part of the southern Atlas of Tunisia that forms the eastern extension of the Saharan Atlas of Algeria. From the north to the south the geological outcrops are subdivided into four morpho-structural groups; northern Chotts fold belts, Fédjej mega-structure, southern range of Chotts, and Dahar [11, 13, 14, 15, 21]. Genesis of these folds has been explained by varied proposed models [13, 15, 21, 22].

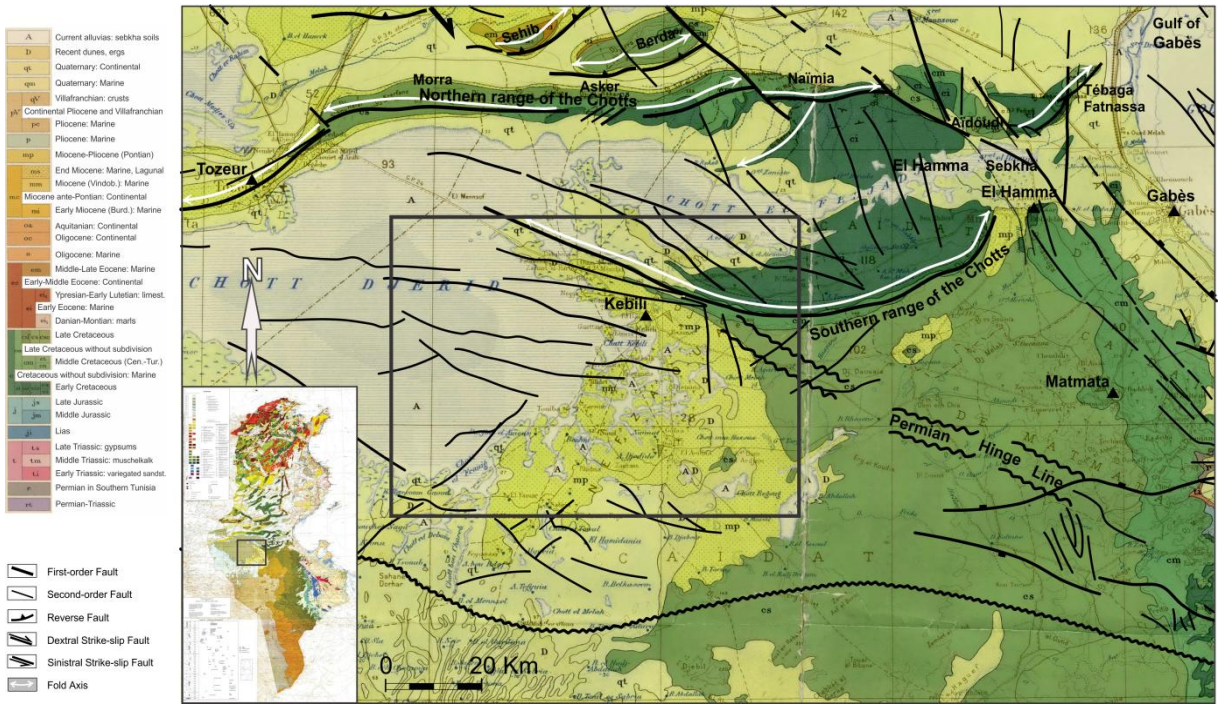

Figure 2: Structural map showing the location of major features and fold axes in southern Tunisia [17, 20, 21, 32].

2.2. Lithostratigraphy

Lithostratigraphic strata in the Nefzaoua study area were identified using surface and subsurface data (Figures 2, 3, 4 and 5). Barremian to Quaternary series are recognized in outcrop [8,12,13,14,15,23]. The rest of Mesozoic and Paleozoic deposits are known from oil and water drillings [5,6,7,8,9,10,11,18,19,20,21], and other works made by oil companies.

The Paleozoic, of about 1000 m thick [26], consists of sandstone, clay-sandstone and evaporite series, interspersed with carbonate levels. Triassic outcrops locally outcrop at Hadifa structure in the eastern end of the Chotts chain, and in some locations along the Gafsa master fault. Petroleum wells, that cross the whole of the Triassic series, reveal strata of about 400 m thick composed of detrital facies in its lower part and evaporite-carbonate in its upper part (Figure 4). The Jurassic is composed of the three members of Nara Carbonate Formation (Figure 4), with detrital and evaporite elements [27,28,29]. The early Cretaceous is dominated by a continental detrital sedimentation. The late Cretaceous is characterized by an alternation of dolomite and limestone layers with clay-marl deposits, sometimes containing gypsum and anhydrite (Figures 4 and 5).

During the Paleogene, the Saharan platform, including the Chotts area, is devoid of deposition (Figure 4). The Miocene-Pliocene sedimentation in the Chotts basin is typically lagoon/lacustrine with the two main detrital units. The Béglia Formation attributed to Upper Miocene [30], and the Ségui Formation containing sandy clays and conglomerate levels in its upper part (Figure 4). The end deposits of the Ségui Formation were attributed to Villafranchian [31], then to Pliocene [32]. Similar to Pliocene, ancient Quaternary is marked by persistence of fluvial deposits [30]. The Villafranchian age Formation is represented by a gypsum-limestone deposition [31].

3. Hydrogeology

3.1. Exploited aquifers

Groundwater exploited in the Nefzaoua region is stored in two major aquifer systems in northern Sahara, namely the Continental Intercalaire aquifer (CI, [1]), and the Complexe Terminal aquifer (CT, [2, 3]) (Figures 3 and 4).

The Continental Intercalaire proposed by Kilian [1] is defined as a continental sedimentary episode between the Paleozoic and Upper Cretaceous times. The aquifer series consist of clay-sandy and sand Formations of Neocomian-Barremian times. They are composed of “Kebeur el Hadj sandstones”, “Chott sandstones”, “wood sandstones”, and “upper sandstones”.

The Complexe Terminal adopted by the ERESS study [2,3], designate the most recent reservoir and aquifer series. The CT includes sedimentary Formations of Turonian, Senonian, Eocene, Miocene and Pliocene-Quaternary. Other semi permeable or little permeable layers separate the aquifer series, included in the Complexe Terminal aquifer system.

3.2. Hydrogeological parameters

Borehole data, exploiting the Continental Intercalaire and the Complexe Terminal aquifers in southern Tunisia (Figure 3), reveal continuous decrease of piezometric level. The Complexe Terminal reveals a regression, of about 23 to 35 m during 30 years in the Kébili quasi-peninsula, 7 to 20 m over 15 years in the rest of the Nefzaoua area, 1.2 to 10 m during 20 years in the Redjem Maatoug region. The piezometric drop in the Continental Intercalaire water table is more noticeable; it is around 15 m in 18 years for the Kébili region, 2.5 to 4 m by year in the Kébili quasi-peninsula, 5 m by year in the Chareb region.

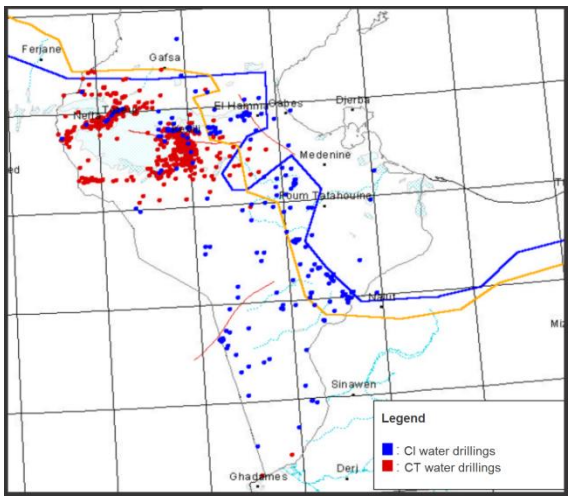

Figure 3: Location of the Continental Intercalaire (CI) and Complexe Terminal (CT) water drillings in southern Tunisia [4].

The Complexe Terminal aquifer in Nefzaoua shows a significant overexploitation. Compared to year 1900, this exploitation recorded an increase of 8214 l/s in 2009. Exploitation of the Continental Intercalaire aquifer has witnessed also a remarkable evolution. It increased from 253 l/s in 1985 to 2458 l/s in 2009. The increase should be related to implementation of new artesian boreholes.

Groundwater salinity of the Complexe Terminal has increased of about 2 to 4.5 g/l in the Kébili quasi-peninsula, 1.5 to 2.5 g/l in the Negga-Guettaya region, and 1.5 to 4 g/l in the Kébili region. Waters of the Continental Intercalaire have relatively high salinity (dry residue > 2 g/l), and exceeds 4 g/l in Nefzaoua.

4. Aquifer structures

4.1. Reservoir correlations

Lithological logs in drillings and outcrop sections allow us to make of a regional lithostratigraphic correlation around the Nefzaoua study area. The correlation summarizes, in space, the lateral and vertical evolution of sedimentary layers forming the Continental Intercalaire aquifer. The proposed section (Figure 5) includes from the north to the south; the water drilling of Chareb CI 24 north of Chott Fédjej, Limaguess CI 8 south of Chott Fédjej, Jemna CI 11, and Douz CI 12 south of Djébel Tébaga, and the petroleum well SAB N1 (Figure 5). It shows a noticeable thickening of lower Cretaceous series northward.

The major fault crossing the southern range of Chotts (Figure 5) induces a major collapse of the southern compartment. The correlation clearly highlights a shift, where the upper sandstone Formation is recognized at the start of drilling CI8, while it is reached at 1502 m at drilling Douz CI 12. The upper Cretaceous series exceed 1100 m thick south of the Tébaga chain, while they are completely eroded in the Chott

Fédjej anticline. Only part of the Cenomanian deposits remains on the northern flank of the anticline, in the Chareb plain (Figure 5).

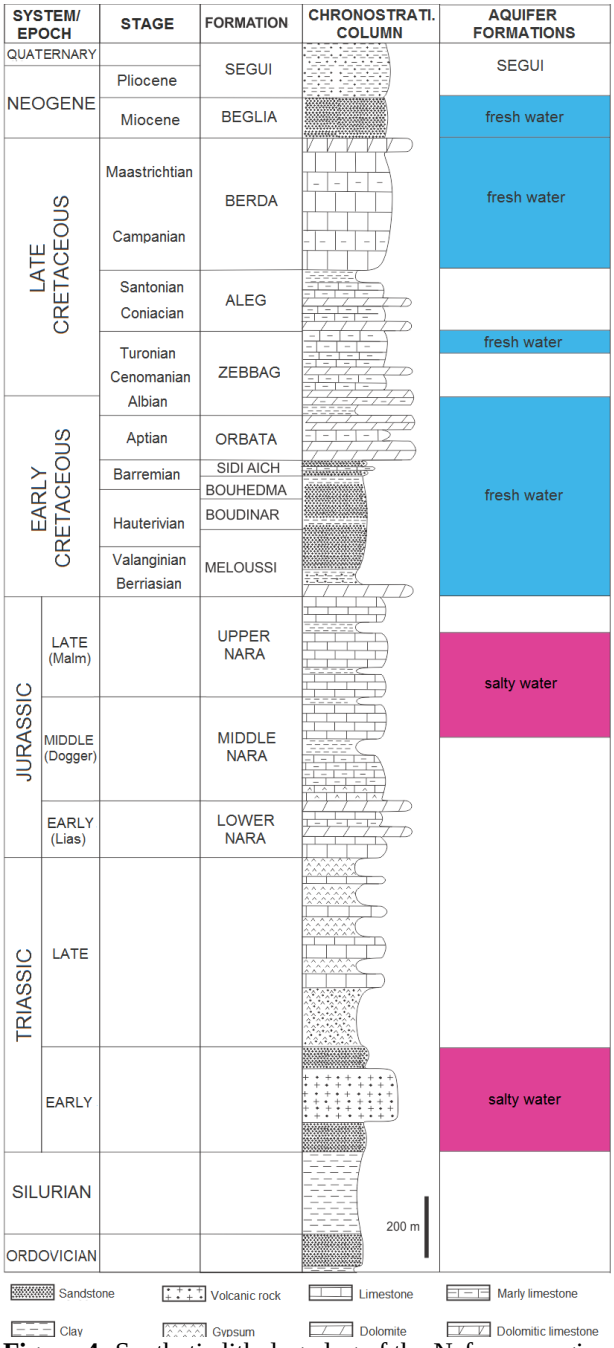

Figure 4: Synthetic lithology log of the Nefzaoua region (field and well data), and position of the CT and CT main aquifers

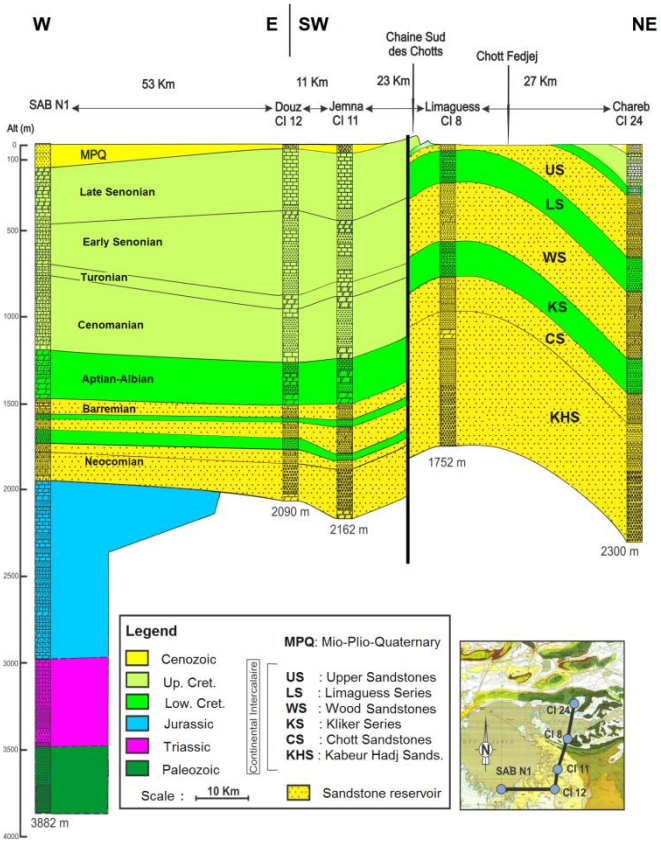

Figure 5: W-E and S–N lithostratigraphic correlation, from petroleum well (SAB N1) to Chareb water drilling (CI 24).

4.2. Basin structuring

Geophysical investigation of subsurface layers in northern Nefzaoua was made by analysis of five seismic reflection lines (L1, L2, L3, L4, and L5) (Figure 6). Calibration and interpretation of the profiles made it possible to point out and follow change of the most remarkable seismic horizons, represented by reflectors of high acoustic signals. The high continuous reflectors are highlighted at the top of the Nara Formation (top Jurassic) composed of dolomite limestones, and the top of the Orbata Formation (top Aptian) composed of dolomite strata.

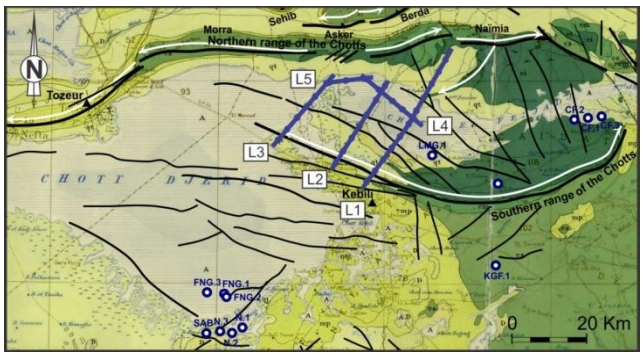

Figure 6: Location of seismic lines on the geological map.

The seismic profile L1 of NE - SW direction, connects the Kébili area southward to the Chareb plain northward, crossing Chott Fédjej (Figure 7). Interpretation of seismic reflections reveals highly deformed sedimentary layers affected by intense and deep fracturing.

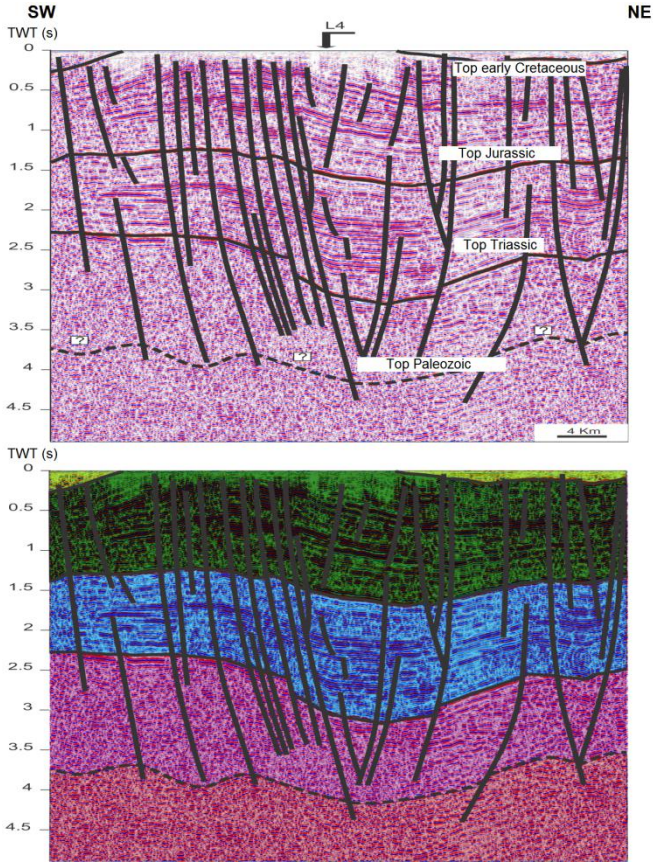

Figure 7: NE - SW oriented seismic profile L1 across the Kébili area southward and the Chareb plain northward.

Despite section L1 does not crosses the northern range of Chotts structures, its correlation with the adjacent outcrops, allows inference of the basin geometry into high and subsiding low zones. Several parallel deep network faults affect the Fédjej sealed uplift. Architecture in subsiding sub-basin associated with Triassic rising highlighted in articulated zones at the borders of two uplifts. Movements along network faults caused deformation and migration of Triassic series. Extensional to transtensional tectonic regime, during the Triassic-Lias times, induced regional dislocation of the Liassic platform.

The NW-SE oriented seismic profile L4 (Figure 8) crosses the northeastern part of the study area, and correlated to profile L1. Profile L4 shows non-deformed structure except two faults affecting the roof of lower Cretaceous series. It shows progressive thickening of Mesozoic deposits towards the southeast.

5. Reservoir geometries

Interpretation of the seismic data over the Nefzaoua region, provide knowledge on lateral and vertical distribution and structuring of deep reservoir layers of the Continental Intercalaire (CI) and the Complexe Terminal (CT) aquifers.

The established NE-SW synthetic geological model extends from northern range of Chotts to southern range of Chotts (Figure 9). The model integrates the interpreted seismic line L1, data from water and oil drillings, and closest geological outcrops.

The structural framework is marked by intense and deep normal and reverse faults affecting the sedimentary layers. Deep seated faults seem reach the Paleozoic strata, indicating an inherited tectonics (Figure 9). The highlighted dominant faulting mainly linked to lower Cretaceous extensional and transtensional tectonics.

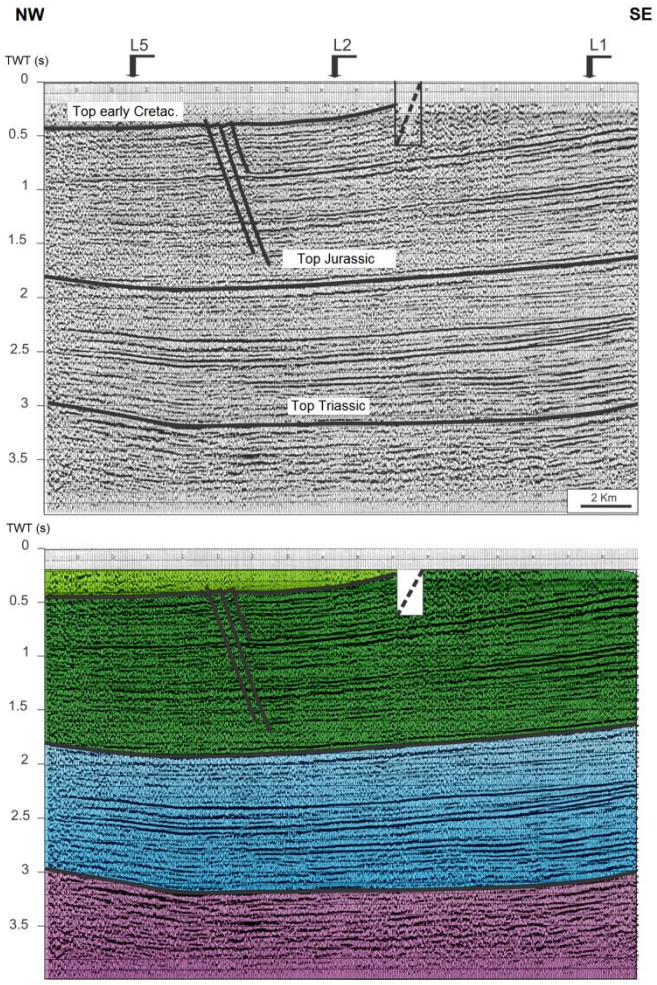

Figure 8: NW-SE oriented seismic profile L4, showing progressive thickening of Mesozoic series southeastward.

Towards the northeast, the Chareb plain is covered in outcrop by Quaternary deposits, while on the subsurface the seismic profile shows overlying of Miocene-Pliocene deposits, Cenomanian marly limestones, Aptian-Albian sandy limestones, and Barremian-Neocomian sandstones (Figure 9). The central part of the section, covered by the Chott Fédjej sebkha soils, is occupied in subsurface by an anticline structure corresponding to the Fédjej dome, where the Barremian-Neocomian sandstone series are overlaid. The southwest part is occupied by the southern ridge of Chotts marked by outcropping of dolomite limestones, clays, and sands of the Aptian, clays and limestones of the Albian, alternation of gypsum, marls, and limestone of the Cenomanian, and dolomite bar of the Turonian (Figure 9). The seismic profiles show a lateral continuity of the sedimentary series on surface and in subsurface (Figures 7 and 8).

The lower Cretaceous sedimentary series show lateral variations from the southwest to the northeast. They are formed essentially by the four aquifer layers of the

Continental Intercalaire named Kebeur el Hadj sandstones, Chott sandstones, wood sandstones, and upper sandstones (Figure 9). These Continental Intercalaire shows thickening of deposition series from 1750 m to the southwest to 2300 m to the northeast. However, upper Cretaceous and Miocene sedimentary series, forming the Complexe Terminal aquifers, show thinning from the southwest to the northeast. They are marked by reduction in their thickness from 750 m to less than 300 m where all series have been eroded in the center of the anticline (Figure 9). The Turonian deposits lack towards the northeast.

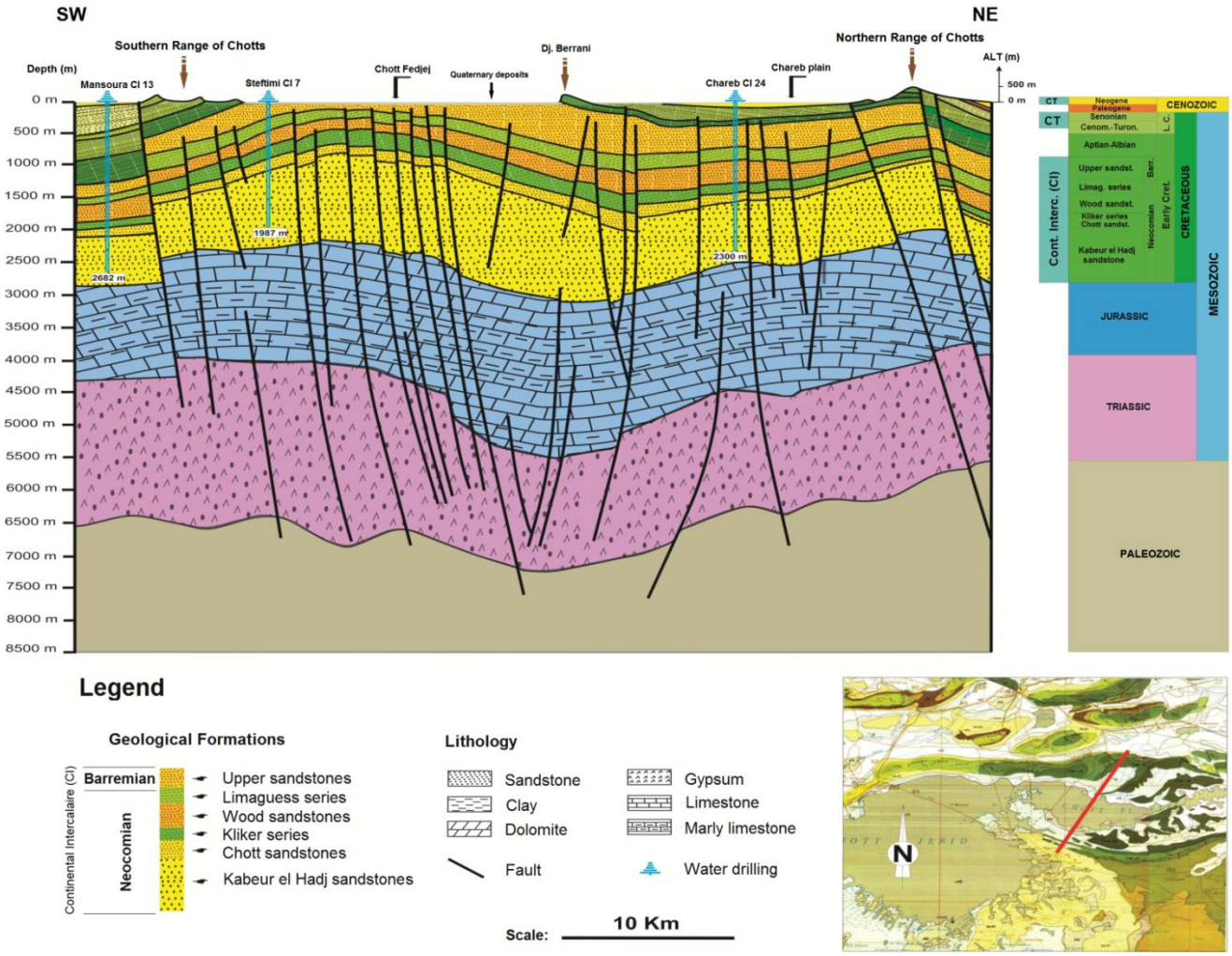

Figure 9: NE-SW oriented geological section deduced from the interpreted seismic lines, showing the geometry and structure of the Continental Intercalaire and Complexe Terminal reservoirs in the Chott Fédjej area.

6. Conclusions

Interpretation of seismic sections across the Nefzaoua region provides several scientific details on the geometry and structuring of the Mesozoic and Cenozoic series that contain the Continental Intercalaire (CI) and Complexe Terminal (CT) aquifers. The sedimentary series were recognized by lithology identified in water and oil drillings, and by field logs. Integration of drilling data and seismic reflections helps for a better characterization and of reservoir levels. It allows us to create a stratigraphic and structural model at substantial depths.

Continental Intercalaire aquifers were totally identified and characterized. They reveal, from the bottom to top; the Kebeur el Hadj sandstones, the Chott sandstones, the wood sandstones, and the upper sandstones. The Kebeur sandstones series enclose three members, the lower composed of coarse sandstone, the medium formed by fine sandstone with intercalation of clay, while the upper member consists of alternating clay, marl and gypsum.

Nevertheless, the Complexe Terminal aquifers were partially characterized. Unfortunately the acquired data only allow study of the Turonian dolomite and the early Senonian consists, at the base, of clays and gypsum, and at the top of dolomite limestone with clays intercalation.

Seismic sections crossing the Nefzaoua area highlight structuring in high and collapsed blocks and significant lateral variations, mainly but not alone, the Continental Intercalaire aquifers, which reveals very important hydrogeological implications in several regions. Consequently, the creation of new deep boreholes appears to be an urgent priority in some regions, such as the "Bled Faraoun", which suffers from the over-exploitation of water resources and the terrible proliferation of illegal wells.

This study, based on the integration of surface and subsurface data over the Nefzaoua area, would be necessary to be applied regionally all along the Saharan domain, in order to more understand the tectono-sedimentary events and, consequently, to highlight the main geometrical characteristics of CI and CT reservoirs and aquifers in depth.

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