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Hydrology and Sedimentology Study of Badr Area- NW Libya and its Tectonic Implications

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Abstract

The Badr area is part of the Jifarah plain at the northern escarpment of Jabal-Nafusah, northwest of Libya. According to hydrological information, groundwater depths in the area under study range between 200 in the south and 130 m in the north. However, this information did not indicate the stratigraphic sequences and nature of the groundwater layers. Geological and hydrological information was collected from 33 wells in the area to investigate this. The wells information revealed the existence of two aquifers. The first shallow aquifer lies between 16-25m depth within silty sand sediments. The second aquifer lies between 60-90m depth. In some wells (located near the present valleys and have sandy clay lithology), this aquifer has low salinity & high rate of discharge. In other wells (located away from the present valleys and have evaporitic mud lithology), it has high salinity & low rate of discharge. These differences have been interpreted to be related to multiple stages of uplift and erosion that occurred in Jabal-Nafusah during its tectonic history and to the difference in sizes & lengths of valleys, which cause additional variations in the sediments & groundwater nature. Through this study, a subsurface fault along Jabal-Nafusah and ancient valley sites has been deduced.

Keywords: Jabal Nafusah, Badr area, Groundwater, Desert sedimentary, Basin environment, Alluvial fan.

دراسة هيدرولوجية ورسوبية لمنطقة بدر- شمال غرب ليبيا وتداعياتها التكتونية

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الخلاصة

تعتبر منطقة بدر جزءاً من سهل الجفارة بمحاذاة المنحدر الشمالي لجبل نفوسة شمال غرب ليبيا. تشير المعلومات الهيدرولوجية في هذه المنطقة إلى أن عمق المياه الجوفية يتراوح بين 200 متر في الجنوب و

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130 متر في الشمال، دون الإشارة إلى طبيعة التتابعات الطباقية التي تتواجد ضمنها المياه الجوفية. ولغرض التحقق من ذلك، تم جمع المعلومات الجيولوجية والهيدرولوجية من 33 بئراً موجودة في المنطقة. كشفت معلومات الآبار عن وجود طبقتين مائيتين. يقع الخزان الجوفي الأول الضحل على عمق يتراوح بين 16–25 متراً داخل رواسب رملية غرينية تغطي المنطقة بشكل عام وتمتاز بنفس الملوحة ومعدل التصريف. بينما يقع الخزان الجوفي الثاني على عمق يتراوح بين 60–90 متراً وتكون في بعض الآبارذات ملوحة قليلة ومعدل تصريف اكثر (تقع بالقرب من الوديان الحالية وترسباتها رملية طينية)، بينما في ابار اخرى يكون مرتفع الملوحة ومعدل تصريف منخفض(وهي الابار الواقعة بعيدا عن الوديان وترسباتها طينية – متبخراتية). وقد تم تفسير هذه الاختلافات على أنها مرتبطة بمراحل متتابعة من الرفع والتعرية مر بها جبل نفوسة خلال تاريخه التكتوني، مما ادى الى حصول تغيرات عمودية في السحنات الرسوبية. كما ان اختلاف أحجام وأطوال الوديان سبب تغيرات جانبية افقية في الترسبات وطبيعة المياه الجوفية. ومن خلال هذه الدراسة، تم استنتاج وجود صدع تحت السطح على طول جبل نفوسة ومواقع الوديان القديمة.

1. Introduction

Since ancient times, groundwater has been used worldwide for agricultural, industrial, and domestic purposes. Although many issues affect water resources globally, the most significant ones are caused by global conditions such as high temperatures and a lack of rainfall, which have increased the occurrence of drought and the spread of desertification [1]. So, it has become increasingly clear in recent years that groundwater is one of the most important natural resources [2]. As a natural resource, groundwater is an essential water source used in surrounding rural and urban environments. One of the natural water sources in residential and rural areas is groundwater [3], which is widely used in homes and agricultural lands. About 90% of the water extracted from the groundwater is mainly used for agriculture [4]. Around the world, groundwater is divided into many parts, with 15% going toward industrial and mining purposes, 20% going toward agriculture and animal feed, and 65% going toward drinking water [5].

The primary source of water in Libya is groundwater because there is no perennial surface water [6]. Studies that deal with groundwater resources in arid and semi-arid regions are among the most important studies due to the scarcity of rainwater and high evaporation rates [7]. Geological formations may or may not be water-bearing depending on their location above the groundwater level, structural position, climate changes, or lithological characteristics. The lithology of an aquifer depends on the mineralogy of the rock, parent rocks, and the transport history of those deposits. These factors and other environmental and climatic conditions affect the water quality [8]. The sedimentation history in the study area has evolved in three stages: pre-rift, syn-rift, and post-rift phases [9], The first stage involved uplifting and faulting during the Palaeozoic. In the syn-rift phase, the major faults and structural elements were either initiated or rejuvenated, and significant subsidence allowed major sedimentation of carbonate, siliciclastic, and evaporates. The Post-rift phase comprises the middle Jurassic–Recent marine depositional sequences that witnessed the uplifting of the Jifarah Plain, which acted as a source of the clastic influx, and thus, siliciclastic deposition was resumed toward the offshore area [10]. This study aims to evaluate the hydrology and sedimentology of Badr area - Northwest Libya to understand the geological situation of groundwater by collecting information from 33 wells drilled in the area.

2. The Study Area

The Badr area is located within the Jifarah Plain between longitudes 11° 26' 50" and 11° 35' 50' east, and latitudes 32° 00' 00" and 32°08' 40" north. The study area has a relatively flat topography, with elevations ranging from 150 meters in the north to 200 meters in the south above sea level. The region gradually rises towards the south, where Jabal Nafusah is situated to the south of the area. Numerous valleys traverse the region with orientations of NNW -SSE (in the same direction of the Red Sea), such as Wadi Bin-Khal and NNE-SSW (in the same direction of Aqaba Gulf) such as Wadi Al-Stael (Figure 1). Notably, the western side of the area exhibits denser valleys compared to the eastern side, and their lengths are shorter. Badr region is located at the foothills of the Northern cliff of Jabal Nafusah. Jifarah Plain is generally characterized by flat topography gradually descending towards the Mediterranean Sea.

The region is covered by recent Quaternary deposits, representing the desert environment sediments adjacent to a mountain slope. These deposits include seasonal wadi sediments, sand dunes, and sabkhas (Figure 3). Kiklah Formation rocks (Upper Jurassic-Lower Cretaceous) are exposed at the base of Jabal Nafusah to the south (Figure 4), while the Lower Jurassic rocks of the Abraghes Formation are exposed at the north (Figure 5). Structurally speaking, except for the presence of Jabal Nafusah, there are no folds or faults within the study area, as per published researches [11].

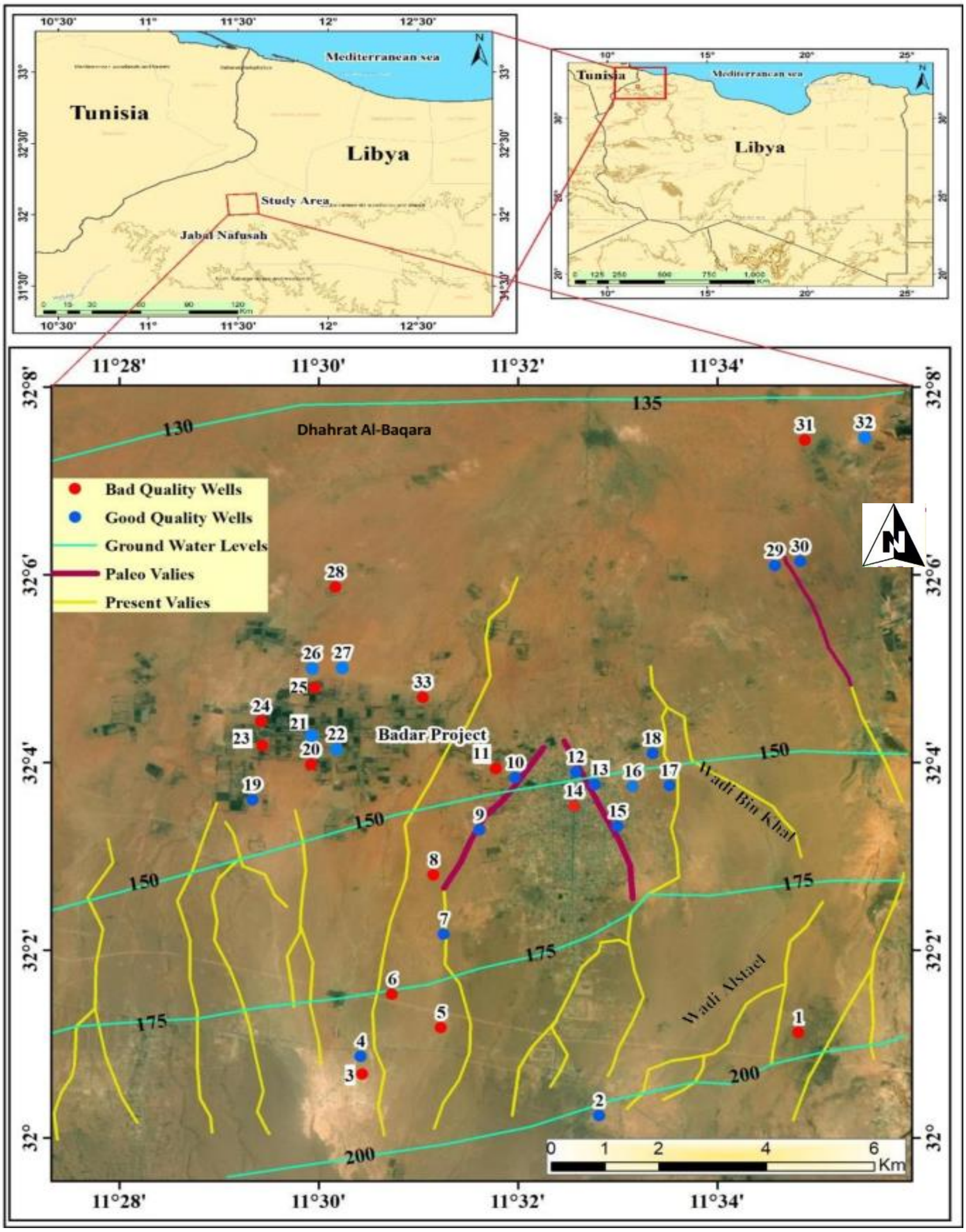

Figure 1: Location map of the study area and wells. Green contour lines represent groundwater level depths taken from [12] study, as shown in Figure 2.

2.1 Geologic Information obtained from previously studied wells

Geological information obtained from wells, including M1-23, I2-23, and H1-23, reveals stratigraphic sequences shown in Figure 5. The locations of these wells are illustrated in Figure 2 and were cited in the study by [12]. Additionally, details of the stratigraphic sequences for the Badr project well (T/1/0352/0/89) [13] and the Joosh well (T/1C /0037/0/78) [11] were compiled for comparative purposes and drawn in Figure 5.

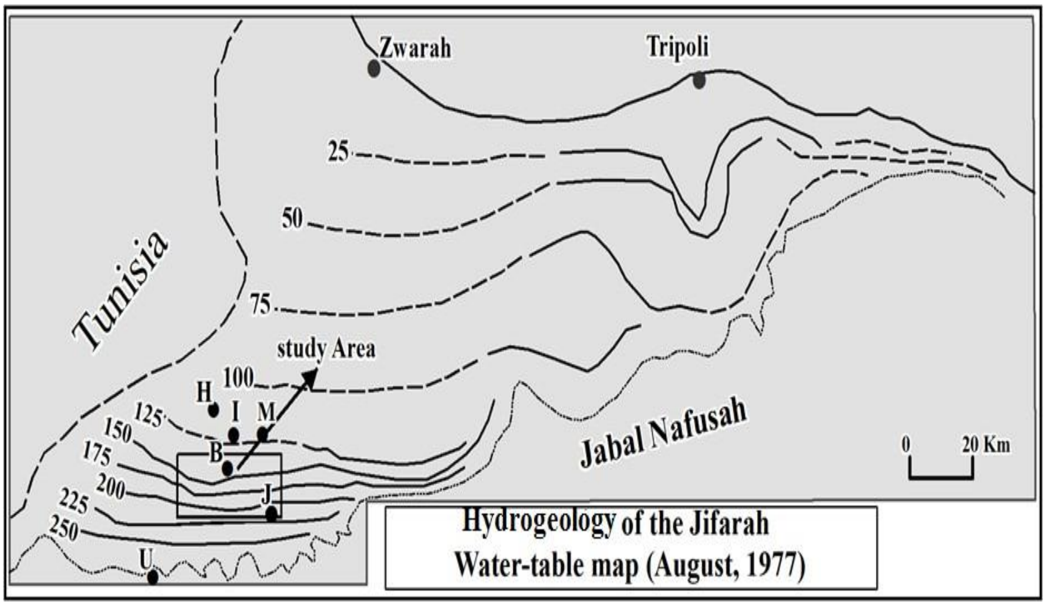

Figure 2: Showing the contour lines of groundwater level depths according to [12] in Jifarah plain area (●J = Al-Joosh Well, ●B = Badr Project Well, ●M = M1-23 Well, ●I = I2-23 Well,
●H = H1-23 Well, ●U = U1-23 Well)

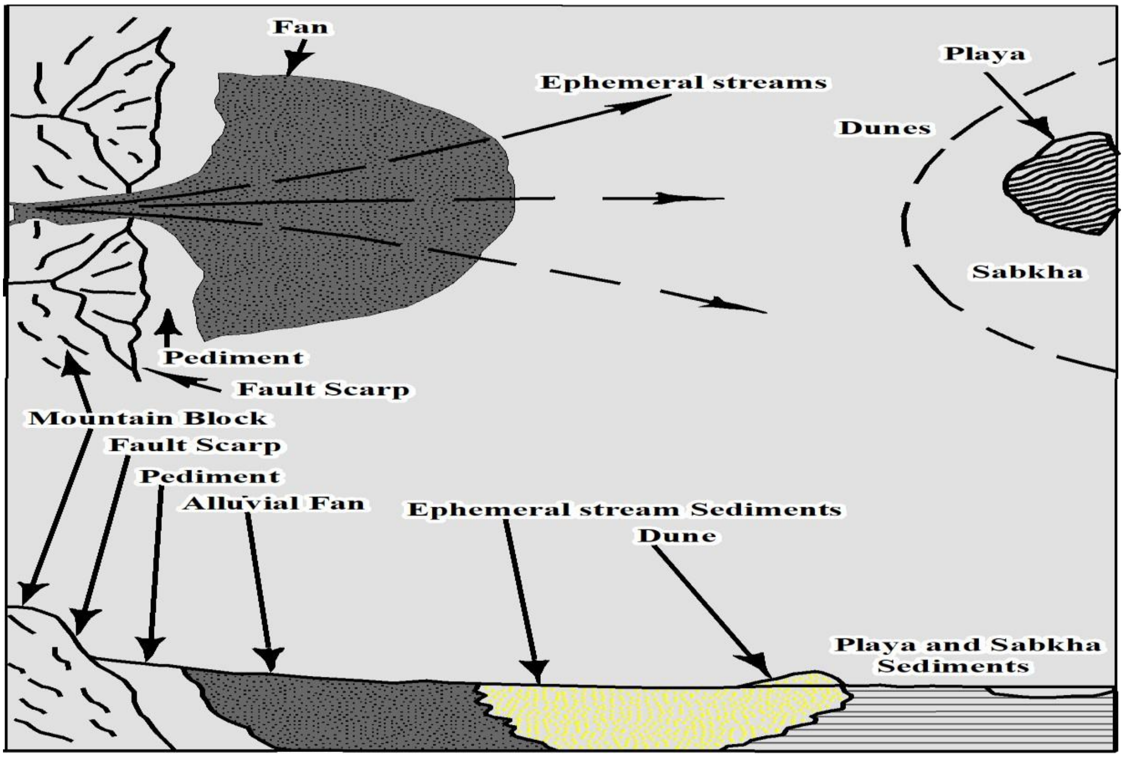

Figure 3: Distribution of sediments of typical desert depositional environment.

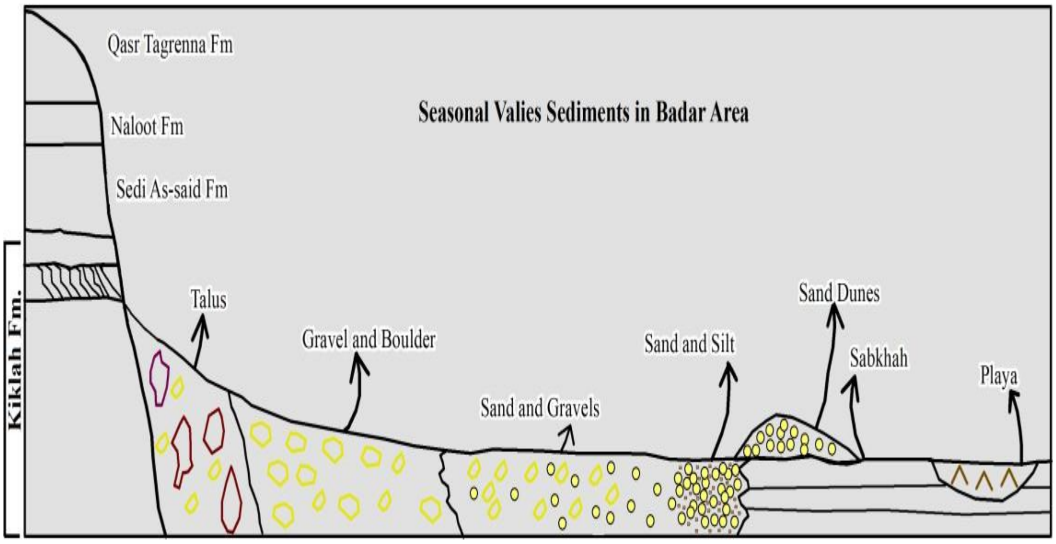

Figure 4: Nature of sediments present in the desert depositional environment adjacent to Jabal Nafusah.

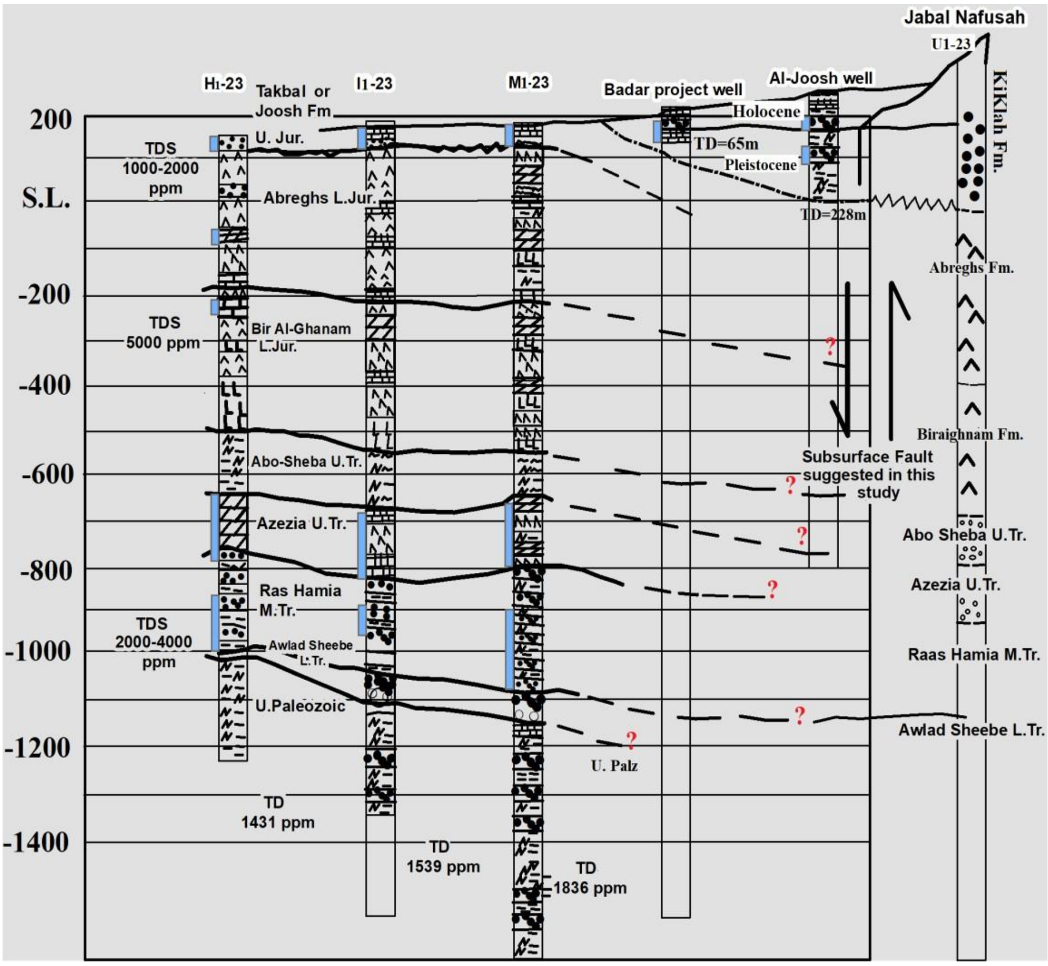

Figure 5: Stratigraphic sequences of previously studied wells (H1-23, I1-23, M1-23 taken from [12] and U1-23 taken from [15], Joosh Well taken from [14], and Badr Project Well taken from [13].

2.2 Tectonic History of the area

The tectonic history of the region indicates that Northern Libya, including the study area, was tectonically stable for most geological epochs. All tectonic activity in the region results from the epeirogenic movements [16]. The tectonic activity in the region occurred along faults, causing block movements involving uplifts and subsidence. For this reason, there is a clear absence of subsurface folds. Figure 5 reveals that most stratigraphic sequences during the Mesozoic were either evaporitic (lagoon) or shallow marine deposits. There are no deposits between the Upper Jurassic and Quaternary, suggesting the area was above sea level before the Quaternary, leading to the loss of deposits between the Upper Jurassic and Quaternary [17].

Due to the tectonic history of Jabal-Nafusah, which was influenced by the Alpine movements, the mountain underwent multiple stages of uplift and erosion, significantly affecting the nature of the deposits in the adjacent study area of Badr as it will be seen later.

3. Results

3.1 Preliminary information about groundwater depth in the region

Preliminary information about groundwater depth in the region was obtained from previously published hydrological studies of the Jifarah Plain (which includes the study area) [12], [18], [19]. A map representing the groundwater level depth in the region was prepared from [12] Figure 1), indicating depths ranging from 200 meters in the south to 130 meters in the north. The mentioned studies did not provide precise information on the stratigraphic sequences in the Badr area, groundwater depth, and economic aquifer layers within shallow depths.

Field observations of some wells in our visited area revealed that the general groundwater depth does not exceed 90 meters. Therefore, information was gathered from various regional project well to gain insights into these aspects.

3.2 Hydrological information available from wells

The information from some wells published in the mentioned studies previously, such as the Badr project well and Joosh well, was collected through their respective reports available in the General Water Authority of Libya (Figure 5). The Joosh well report did not specify the aquifer layers for groundwater but mentioned stable water levels (23 to 27 meters) and dynamic levels (42 meters). Similarly, the Badr project report mentioned a stable water depth of 20 meters and a dynamic one at 31 meters. Neither report indicated the presence of shallow groundwater (as we will refer to it as shallow groundwater in this study).

To understand the nature of groundwater in the study area, information was also collected from 33 wells drilled in the area (as mentioned earlier) to understand the hydrogeological nature of the groundwater. From this information, it was clear that the area studied has two groundwater zones (not suitable for drinking. [20]):

1. The upper zone contains shallow groundwater with depths generally between 16 and 25 meters, characterized by uniform salinity (TDS=3500 ppm). These waters coincide with silty sandy deposits, likely of recent (Holocene)- (Upper Pleistocene) origin.
2. The lower zone contains moderately deep groundwater with depths ranging from 60 to 90 meters. These waters vary in salinity, with some wells having low salinity (TDS =3500 ppm) and higher discharge rates (in blue color in Figure 1). In comparison, others have higher salinity (TDS=4500 ppm) and lower discharge rates (shown in red color in Figure 1). This suggests that these two types of wells are unconnected and have different geological characteristics.

From collected data, it was clear that the geological stratigraphy in the wells generally consists of layers from top to bottom as follows: Soil (2-5 meters), yellow clay and silt (5-10 meters), gravel and sand (10 meters), and green to brownish clay with varying thickness (30-120 meters depending on the well location).

Some wells exhibit significant clay thickness exceeding 100 meters (like well No. 6 and well No. 16), while others show sequences of clay, sand, and gypsum (like well No.9). Other wells have sequences of consolidated gravels, clay, and sand (as well No. 5). So there are considerable lateral variations among different wells.

The information from wells north of the study area indicates extremely high salinity in those wells, particularly near the Dhahrat Al-Baqara area (Figure 1). The aquifer layers at greater depths, which are currently challenging to exploit, can be referred to for details in [12] (Figure 5).

3.3 Interpretation of the hydrogeological situation of the area

By Interpreting the hydrogeological situation of the area based on the previous points and comparing the information with wells and wadies locations in Figure 1, the following general observations can be made:

1. Wells close to current wadi locations tend to have lower salinity (2000-3000 ppm) and higher discharge rates (e.g., wells 4, 2, 7, 19, 18, 17).
2. While wells distant from current wadi locations generally exhibit higher salinity (5000-9000 ppm) and lower discharge rates (e.g., wells 5, 3, 6, 8, 14, 23, 24, 28)
3. Moreover, some distant wells share the same characteristics as those Wells close to current wadi locations (e.g., wells 9, 10, 15, 13, 12,29, 30).

In accordance with Carroll's classification [21] of water quality by TDS content, these wells have water that is brackish. The above observations suggest that wells near current wadi locations (as mentioned in point 1 above) receive continuous recharge from rainfall runoff in the wadies, resulting in increasing water quantity, higher discharge rates, and lower salinity. The wells mentioned in point (2) appear unaffected by current wadies, indicating they are not recharged by water infiltration from active wadies during the rainy season. This reinforces the lack of connection between these wells and those mentioned in point (1).

Considering the nature of sedimentary environments in desert basins adjacent to mountain slopes (Figures 3 & 4), including alluvial fan and seasonal river valleys sediment environments in addition to the sabkhah environment (to the north of the Badr area), there are lateral variations due to the differences in wadi lengths and vertical variations in deposits due to the distance (near or far from the mountain). Numerous interactions occur between the sedimentary environments associated with adjacent desert basins and Jabal Nafusah. The wells near current wadi locations, receiving water from rainfall, suggest that these wadi locations also represent ancient wadi sites during the Pliocene and Pleistocene epochs, considering periods of water flow interruptions and changes in erosion and deposition. This explains the groundwater conditions in the wells mentioned in points (1) and (2) above.

While the wells mentioned in point (3), may represent sites of ancient wadies buried beneath recent Quaternary deposits. These ancient wadi locations are illustrated in pink color in Figure 1. Shallow groundwater is replenished and infiltrated by rainfall and wadies water, causing increasing in water quantity during rainy seasons. These waters lie in recent sediments covering the entire area, suggesting they don't originate from valley sediments. Instead, they may result from shallow marine deposits that covered the region during a recent marine transgression that happened after the Pleistocene epoch.

4. Discussion

Analyzing the horizontal and vertical interactions in the deposits of the Badr area and considering the distribution of mountain adjacent desert sedimentary basin environments (i.e.

seasonal wadi deposits, sand dunes, and sabkhas) it can be inferred that vertical interference in deposits results from successive elevation phases of Jabal Nafusah. These phases, influenced by the Alpine orogenic movement, caused the mountain to uplift and undergo erosion during the recent geological history (which was a sedimentary basin to Sedi Alsseid, Naloot, and Qasr Taghrinah Formations during Mesozoic times). A subsurface fault, presumed to exist (Figure 5), might have facilitated this movement.
The successive mountain uplifts (Figure 6) lead to vertical interference in sedimentary sequences, as observed by [22], [23].

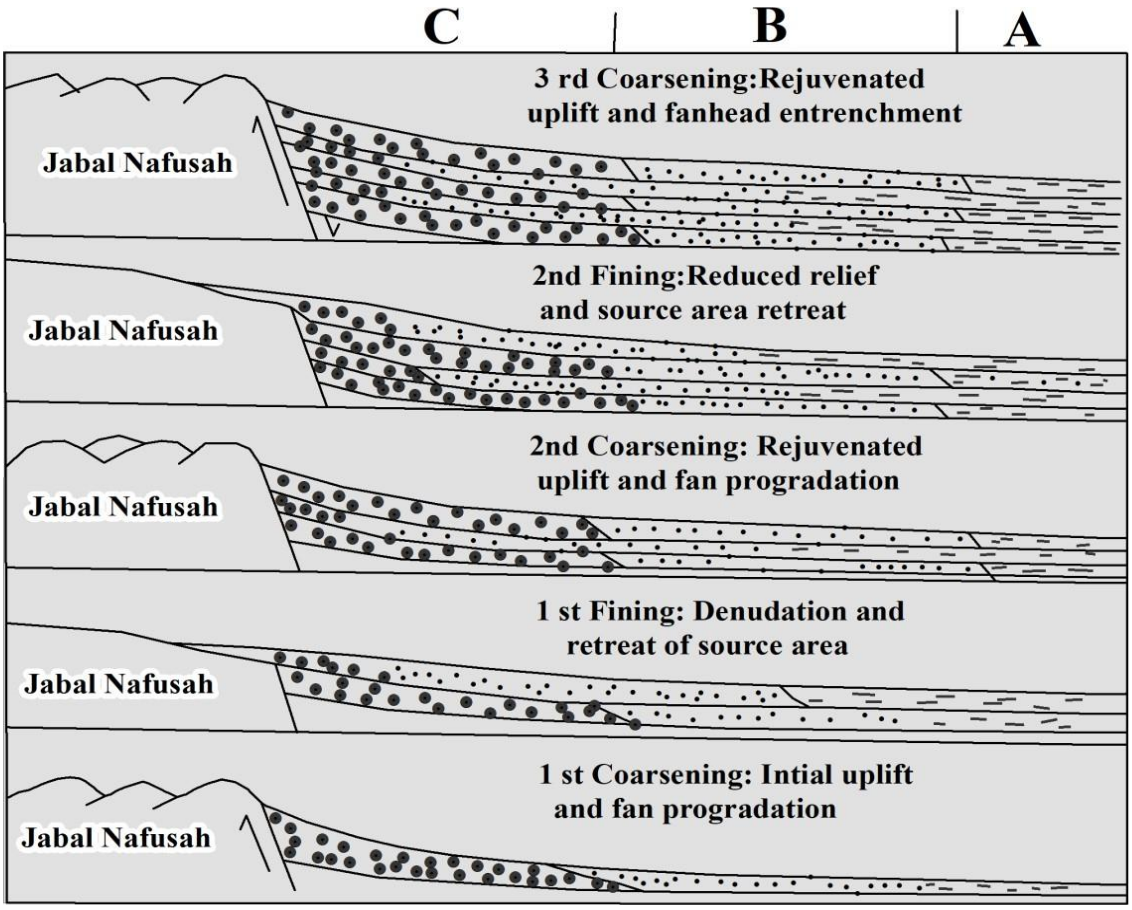

Figure 6: Clarify the lateral and vertical variations in sediment types according to the many stages of uplift and erosion that happened in Jabal Nafusah.

As shown in Figure 6, wells in Zone A exhibit significant thicknesses of mud and silt deposits (as in Wells 33 and 11), whereas Zone B has thinner mud deposits (like wells 16 and 17). Zone C shows varied sequences of gravel, sand, and silt (as in Well 5 mentioned earlier), As a result, the sediments sometimes become coarse upwards and sometimes downwards due to tectonic activity. While wells located far from the mountain behind Zone A contain sabkhah deposits of evaporites like gypsum, calcium carbonate and salt, as seen in wells at Dhahrat al-Baqara (Wells 31 and 32).

It is clear from what was mentioned above that Jabal Nafusah underwent successive tectonic stages of uplift and erosion, causing the observed vertical distribution changes in deposits. Also, the varying lengths of wadies in the region added another horizontal variation in deposits distribution. For this reason, we rarely find similarities in lithological sequences between wells in the Badr area.

3. Conclusion

The collected data from the present 33 drilled wells in the Badr area (NW Libya) revealed the existence of two aquifers. The first shallow aquifer lies between 16-25 m depth within silty sand sediments covering all parts of the Badr area (attributed to the marine transgression that happened after the Pleistocene epoch). It has the same salinity and discharge rate in all wells. The second aquifer lies between 60-90 m depth. In some wells (located near the present valleys and have sandy clay lithology) the second aquifer has low salinity & high rate of discharge. In other wells (which are located away from the present valleys and have evaporitic mud lithology), it has high salinity & low discharge rate.

These differences have been interpreted to be related to multiple stages of uplift and erosion that occurred in Jabal Nafusah during its tectonic history, and to the difference of sizes and lengths of valleys, which cause additional variations in the sediments and groundwater nature. Through this study, a subsurface fault along Jabal Nafusah and ancient sites of valleys have been deduced.

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