REPUBLIC OF LEBANON

MINISTRY OF ENERGY AND WATER

GEOLOGICAL AND HYDROGEOLOGICAL STUDY WITHIN GHABOUN REGION

Final Report

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1 GEOLOGY OF GHABOUN REGION

The geological investigation of the study area is originally based on the previous work done on Mount Lebanon region. The bulk of information has been analyzed from stratigraphical work done by L. Dubertret, several techniques were utilized to modify the geological map and, hence, better understand the geology. These are particularly the remote sensing methods of MAPS photo satellite, aerial stereographic photographs with a scale 1/25000 (1963). Fieldwork also took an important share of the investigation. The final result is an up to date geological map with a 1/20000 scale (**Figure 1**) covering the study area and the proper understanding of the different geological aspects of this area such as: geomorphology, lithostratigraphy, structural geology and hydrogeology.

1.1 GEOMORFOLOGY

The study area lays in Ghaboun village, in Mount Lebanon. It is bounded by the following grids:

$$-331 \Rightarrow -328 \text{ N},$$
$$-42 \Rightarrow -39 \text{ E}.$$

This area is located on the western flank of Lebanon's western mountain chain. It stretches over 20 km^2.

The study area is characterized by a moderately steep topography, and consists of the Jurassic and Cretaceous System with an altitude between 500 and 1000m above the sea level.

1.2 LITHO-STRATIGRAPHY

The outcropping rock formations in the study area extend from Middle Jurassic (J4) to the Sannine Formation (C4), through the Chouf Sandstone Formation (C1), Abeih Formation (C2a), Mdairej limestone Formation (C2b) and Hammana Marl Formation (C3). Furthermore, recent Quaternary alluviums and slope deposits especially in the plains, valleys, and along toes of the slopes.

1.2.1 The Jurassic System

<u>The Kesrouane Formation (J_4)</u>

The Middle Jurassic Formation consists of dolomitic rocks at its lower part (J4a) and limestones at its upper part (J4b).

- The stratigraphic thickness of the (J4a) is 600 m and consists of pure hard dolomite as well as disturbed dolomites that appear in the form of Dolomitic sands along the Faults that are present in the region.
- The (J4b) consists of limestones and sometimes of dolomitic-limestone rocks with an average thickness of about 200 m.

The Bhannes Formation (J_5)

This formation makes relatively narrow belts surrounding the (J4) formation. These deposits (J5) consist of alternation of yellowish to grayish shales, marls and tuffs, which are semi pervious. They are overlain by highly fissured pervious columnar basalts and then by poorly fossiliferous chocolate shales. In the area of study, this formation is however essentially volcanic with an average stratigraphic thickness in the order of 70m.

The Bikfaya Formation (J_6)

The Bikfaya Formation (J6) consists of massive limestone (light gray to beige) rocks containing quartzitic veins and siliceous concretious. They are highly porous, permeable, and deeply carstified. The thickness of the Bikfaya Formation in the study area is about 60m.

The Salima Formation (J_7)

This Formation consists of yellow to light brown detretic limestones, and makes a very narrow belt surrounding the (J_5) Formation. The average thickness of the Salima Formation in the study area is around 20m

1.2.2 The Cretaceous System

The Neocomian Formation (C_1)

The Chouf sandstone averages a stratigraphic thickness of 300 m in the study area. It has a Neocomian – Barremian geologic age, and marks the beginning of the Cretaceous system. The Chouf sandstones outcrop in relatively wide surface area at the middle and south eastern part of the of the study area especially in Ghaboun and Kfar Aammay villages. This formation is dominated by poorly sorted sandstone often cross-bedded, weakly siliceously cemented making it highly friable. It is generally seen as having a brown to orange color due to a long atmospheric exposure, which enhances further oxidation in iron oxide rich sand. Dark purple iron oxide 0.5 cm thick bands sub-parallel to bedding could be seen within the sand probably indicating higher iron concentrations. Recently exposed sandstone sections in quarries for example reveal lighter colors such as yellow or light brown due to lower oxidation levels. The quartz grains vary greatly in size some reaching 0.5 mm and they are mostly sub-rounded. Green and light blue clay inter-layers are found within the Chouf Sandstone Formation with one layer reaching 0.5 m in thickness. The sandstone is highly porous and moderately permeable allowing a good filtration of groundwater.

The Lower Aptian Formation (C_{2a})

The Abeih Formation (C_{2a}) has a Lower Aptian geologic age and outcrops in small patches on the middle and northern part of the study area. Its stratigraphic thickness within the study area is in the order of 100 m. A zone few meters thick of alternating sandstone and limestone thin layers marks a transitional boundary with the underlying Chouf Sandstone Formation (C_1). Starting with the top of the Chouf Sandstone and going up the sequence an increasing calcite percentage is observed providing better cementation, whereas the sand percentage in the bedrock decreases until disappearing completely giving way to the classic sequence of limestones and clays of the Abeih Formation (C_{2a}). This formation is characterized by medium to thick bedding reaching at most 1 m. It presents an alternation of medium grey, light pink and yellow limestone beds mainly grainstones, with yellow and green marl and clay layers, as well as volcanic materials. The exposures are observed as ochre yellow only due to surface weathering. The clay and marl layers are thinner than the limestone except at the bottom and top of the formation where they equal the limestone beds in thickness. These soft layers are

friable and sheetlike. The grainstones, on the other hand, possess a high strength, they are highly oolitic, crystalline, and can easily bear clasts such as broken shells, quartz grains etc. Cross-bedding within the Abeih can also be found, another evidence for the high energy depositional environment. Relatively wide fractures and joints make the bulk of the enhanced secondary porosity and subsequent permeability. On the other hand, the impervious marl and clay layers may isolate the water bearing limestone beds, constituting perched water bearing zones.

The Upper Aptian Formation (C_{2b})

This formation in the study area it outcrops in wide surface area surrounding the c_{2a} formation at the middle, southern, and the eastern part of the study area. The total thickness of this formation does not exceed 100m in the study area. The boundary between the Abeih and Mdairej formations is marked by a friable marly limestone layer about 2m thick, which is the extreme top of the Abeih Formation (C_{2a}) below the massive micritic limestone of the Mdairej Formation (C_{2b1}). This boundary is very clear due differential weathering of the incompetent marly limestone underlying the highly competent Mdairej cliff. This forms a rock shelter few meters wide at the foot of the cliff. Oyster shells are observed in the marly limestone layer. The limestone of the Mdairej has a light grey fresh color and is micritic. It has a very high strength and presents fairly high secondary fracture porosity and permeability.

The Albian Formation (C_3)

This formation has an Albian geologic age. It is exposed in a small surface area at the western part of the study area. The total thickness of the Hammana Formation approximates 100m in the study area. The Hammana Formation (C_3) presents an alternation of marl, limestone, and marly limestone beds. The marl beds have a creamish white color and fine silt sized grains. The marly limestone beds have moderate strength and are more fractured and jointed than the limestone beds having a higher strength, which makes them easily friable into silt sized material. The top of the Hammana ends with marly limestone beds which give way to the more massive and homogenous very fine grained chalky limestone of the Sannine Formation. Bedding thickness varies between medium and thick. On the whole this formation has a low permeability due to its marly nature in addition to the middle volcanic unit which has even lower porosity and permeability.

The Sannine Formation (C_4)

This formation can be subdivided into 3 lithological units from bottom to top these are:

1) The lower Cenomanian rocks (C4a) which includes bioclastic limestones, yellowish marls and cherty limestones, thick bedded limestones, dolomites, and dolomitic limestones. The lower Cenomaian rocks outcrop in a very small surface area at the northern part of the study area. The average thickness of C4a is about 150m.
2) The middle Cenomanian rocks (C4b) that consists of interbedded between limestones and marly layers with an average thickness of 150m.
3) The Upper Cenomanian rocks (C4c) that consists of a considerable limestone and dolomitic limestone block forming a cliff. This formation outcrops in small surface area in the study area and has an average thickness more than 100m

1.2.3 Quaternary Deposits (Q)

These deposits are recent in age and consists of loose sandy clay in the plains, and gravel sin the valleys and along the toes of the slope. These deposits originated from older formations by gravity and running water.

1.3 STRUCTURAL GEOLOGY

The general structural configuration describing the study area is related to the western flexure of Mount-Lebanon and the presence of the regional major faults with east - west trend, as well as Ghaboun Bhouara syncline. One of these faults passes beside the proposed well location with major throw about 100m that made the layers of the lower Aptian formation (C2a) drop to face the sandy layers of the lower cretaceous formation (C1).

The axis of Ghaboun Bhouara syncline is oriented SW-NE and it is located along Nahr Ghaboun to the north west of Ghaboun village.

The beds of the SE flank of this syncline are dipping by 15° towards the NW, while the NW flank of this syncline are dipping by 25° to the SE

1.4 HYDROGEOLOGY

The study area consists of different hydrogeological units. The limestone formations are the major aquifers and form very important ground water reservoirs. The thickness is suitable (n x 100 meters), fracturing is intensive and enhanced by karstification process. The two main aquifers in the study area are the Aptian and Jurassic units. These are karstic aquifers and characterized by very high secondary porosity and permeability as well as a large stratigraphic thickness. The Neocomian sands are a semi aquifer, and the Bhannes and Hammana units are impervious.

The Aquifers

The Jurassic Aquifer

This is a karstic aquifer and is characterized by very high secondary porosity and permeability as well as an important thickness.

The limestones and the dolomitic limestones within the Middle Jurassic Aquifer form the biggest reservoir in the study area. This formation is tapped by high yielding wells (more than 1000 m3/day) for an example of these we can mention the Jisr el Qadi wells.

Aptian aquifer

It is the second in range important water-bearing unit in the area as evidenced by the highest yielding springs Naba Remhala, and the large numbers of public and private wells that taps this aquifer.

Semi-Aquifers

The Neocomian Semi-Aquifer

Sandstone is well known for its water bearing qualities. This unit is however relatively thick in the study area and is limited in exposure and superimposed by low permeability units which makes its recharge insufficient. In addition the sandstone is characterized by poor sorting, which decreases pore spaces and consequently permeability. Hence, this unit does not yield sufficiently large quantities of water.

Aquicludes

The Bhannes Aquiclude

This unit consisting of highly impermeable basalts except for secondary fracture porosity that might increase permeability and storativity. The potential however for basalt to be weathered into silt sized material has lead most fractures to be infilled with this fine material, which decreases permeability. Thus, this unit is considered to be an aquiclude.

Albian Aquiclude

The Albian unit as discussed previously consists lithologically of three sub-units. Going up the sequence the first and the third sub-units consist of marly limestone beds alternating with marl layers whereas the middle unit is essentially basalt. The hammana unit is therefore a remarkable aquiclude incapable of yielding water but often held in esteem for being the perfect seal below the aquiferous Sannine unit, thus forcing water to emerge as springs at the boundary between these two units.

1.5 DESIGN OF THE WATER WELL

1.5.1 Ghaboun well

1.5.1.1 Borehole location

The well is located on the right side of the road leading to Nahr Ghaboun to the north of Ghaboun village at the following coordinates (**Fig. 2**):

X = -329.618 km
Y = -40.374 km
Z = 510 m
(Aaley map, 1/20.000)

1.5.1.2 Access to Borehole

Access to the site is easy on a main road. Some clearing and excavation for the well site is necessary.

1.5.1.3 Depth

650 m

1.5.1.4 Expected discharge

864-1037 m^3/day (or 10-12 l/s).

1.5.1.5 Static water level

300 m below ground level.

1.5.1.6 Geology

- The well is located beside a major fault, and will penetrates the sands and sandstones of the Chouf sandstone Formation C1 (100m) to reach the limestones and dolomitic limestones of the Middle Jurassic Formation J4.

1.5.1.7 Schedule of drilling, casing and grouting

The Contractor shall present the schedule for drilling in order to have a final casing and screen diameter of 10". The well is to be drilled with a rotary rig and provide for all additional equipment such as water and fuel, as well as treating collapsing rocks at his own expense.

Nevertheless, the schedule of the proposed works could be as follows (**Fig. 3**):

- Drilling by rotary methods with a 22" bit from 0 to 30m, with samples collection from this depth and onwards.

- Installing 18" I.D. casing (black steel, thickness 5mm)

- Grouting the annular space from the bottom to the surface, than waiting between 36 to 48 hours for the cement to set, and then continue the works.

- Drilling with a 17.5" bit from 30 to the depth of 200 m.

- Installing 15.5" ID casing (black steel, thickness 5mm).

- Drilling with 14.75" bit from 200 to the depth 0f 450m.

- Installing 12.5" ID casing (black steel, thickness 6mm).

- Drilling with 12.25" bit from 450 to the total depth 0f 650m.

- Installing 10" casing and screens as shown below:
  a) Casing:
  Diameter: 10" ID
  Type: Carbon steel
  Thickness: 6 mm
  Total length: 550m

  b) Screens:
  Diameter: 10" OD
  Type: Carbon steel, torch-cut slotted 12.2% void.
  Thickness: 6 mm
  Total length: 100 m.

  The installation of the casing and screens will be in accordance with the general specifications and in particular, the welding and closure of all openings such that the water only enters the well through the screen openings, in order to minimize the pollution from zones above the SWL.

FIG. 3 : VERTICAL CROSS SECTION OF GHABOUN BOREHOLE

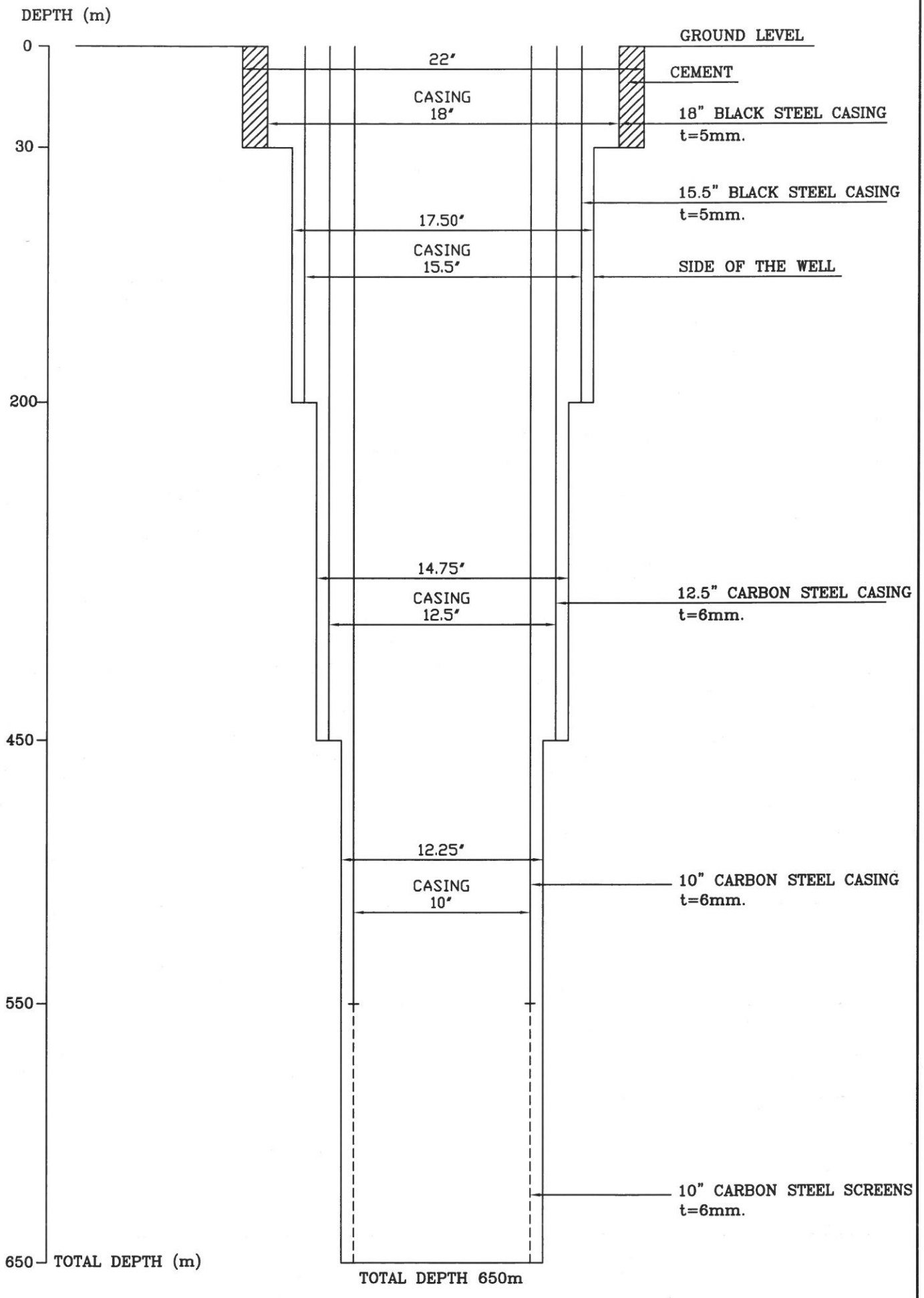

FIG.1 : LOCATION MAP OF GHABOUN BOREHOLE
SCALE:1:20000