Geology

Stratigraphically, there are mainly nine formations outcropping in the study area. Out of these eight formations, six belong to the Cretaceous Period, two belong to the Neogene Period, and one belongs to the Quaternary Period. The outcropping formations are described in detail in the sections below and summarized in (table no 1). From oldest to youngest, the following sequence is encountered in the study area. (Ref. General Geological map).

1. Cretaceous Period:

The Neocomian Epoch (C_1): This epoch is found outcropping south west of the proposed study area. It is characterized by reddish sand and sandstone rich with iron and is intercalated with shaley clay and lignite. The layers in this epoch are dipping toward the north east at an angle approximately 20°. The thickness of this epoch is about 125m.

The Lower Aptian Epoch (C_{2a}): the lower Aptien epoch is found outcropping south west of the proposed study area. They are a succession of shales, green sandy marl intercalated with sandy limestone and with pizolite. The thickness of this epoch is about 50 m.

The Upper Aptian Epoch (C_{2b}): This epoch is found outcropping south west of the proposed study area. This is a succession from bottom to top of marl, marly limestone and hard dolomitic limestone.With an overall thickness of about 25 m.

The Upper Aptian volcanic Epoch (BC_2): the Upper Aptian volcanic epoch is composed of basalt and volcanic ash. It is found outcropping south west of the proposed study area, they rely on the cliff of limestone and the basalt is covered by the limestone of the middle cretaceous at a big area. The thickness of the volcanic is approximately 150m. (Ref. Geological Cross- Sections).

The Albian Epoch (C_3): in the study area, the albian epoch has marly dolomitic facies and is not recognize and to separate from the Cenomanian epoch which overlays. It is mainly constituted by successive layers of green marls and dolomitic limestone. The layers of Albian are dipping at all directions at varying angles.

The Cenomanian epoch (C_4): The Sannine formation belongs to the Cenomanian epoch and is divided into three zones:

The Lower part (C_{4a}) is composed of whitish gray dolomitic limestone with some intercalations of limestone and marly limestone with geodes.

The middle part (C_{4b}) is composed of marls, marly limestone and crystalline limestone with geodes.

The upper part (C_{4c}) is mostly composed of gray dolomitic limestone with geodes of quartz or calcite; it is thick bedded and highly fractured.

Limestone beds of middle cretaceous (C_4)

The overall thickness of the Cenomanian epoch reaches up to 800m. This epoch is found outcropping in large patches within the study area. The proposed wind farm is present in this formation.

The Cenomanian layers are dipping at all directions at varying angles because there are several faults and folds. (Ref. Geological Cross- Sections).

2. Neogene Period:

The Miocene Formation (mcg): This formation is composed of lacustrine marl and conglomerates of breccia and pudding interbedded with red clay. This formation is found outcropping both west and east of the proposed study area. The layers in this formation are dipping at varying angles. The thickness of this formation is between 50-80m. This formation covers the limestone of middle cretaceous on the depressions.

The Pliocene Volcanic Complex (BP): The basalt flow outcrops in large patches on the north west of the proposed study area. The basalt flow covers the limestone of middle cretaceous in some places and the conglomerates of Miocene in other places. The basalt is black vesicular in an approximately horizontal setting and has a rounded surface and columnar structures. The basalt is intensely weathered and is interbedded with pockets and bands of stiff brown clay. In certain areas the basalt is bluish gray in color (may be andesite). (Ref. General Geological map).

3. Quaternary Period:

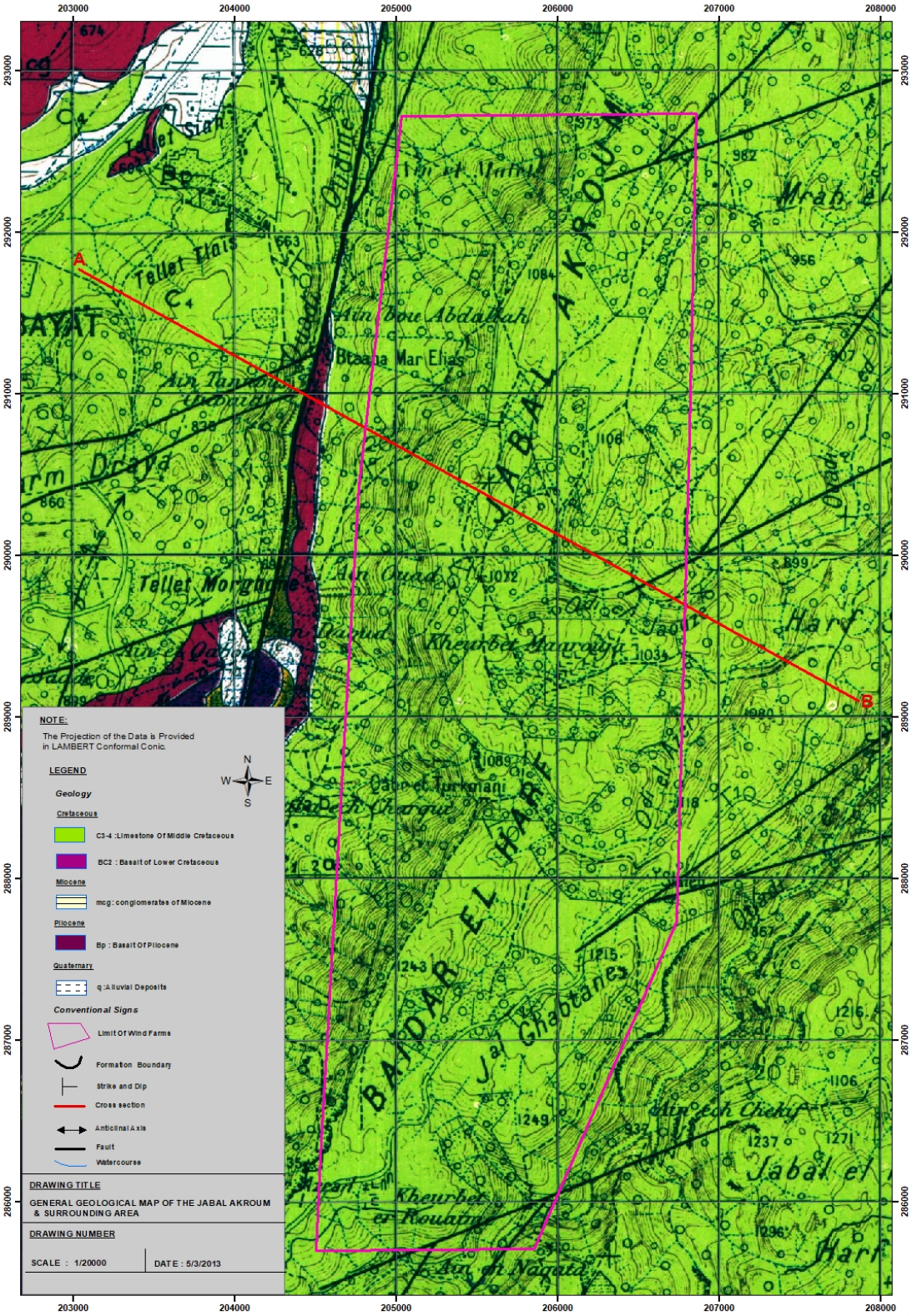
The quaternary deposits consist mainly of new alluvium deposits composed of limestone mixed with sands, shales and volcanic in the depression. The sediments are present on the valleys and slopes on the western and northern sides of the study area near the village of Andquet and the thickness of these deposits varies. (Ref. General Geological map).

Table No 1: Stratigraphy of the region

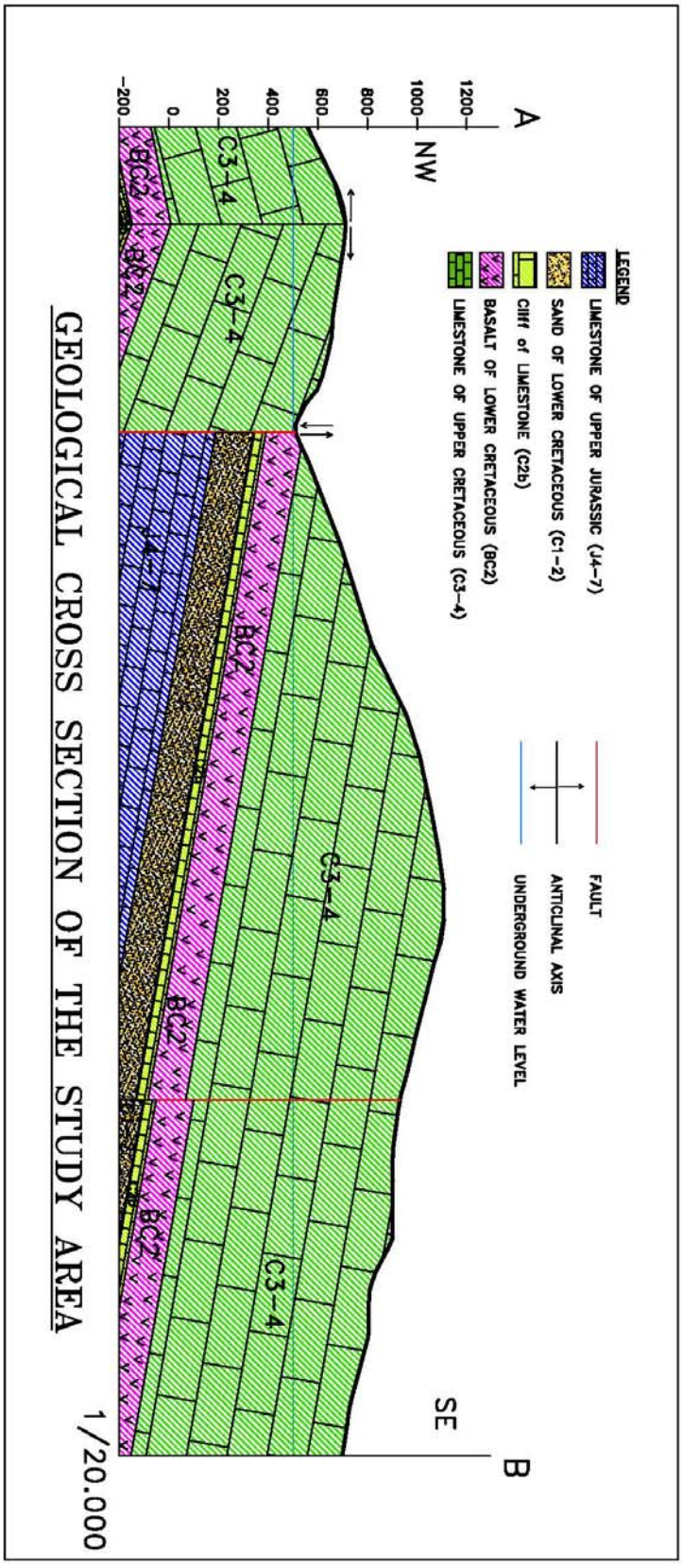
Period	*Epoch*	*Description*
CRETACEOUS	Neocomian epoch (C_1)	• This epoch is found outcropping southwest of the proposed study area. • It is characterized by reddish sand and sandstone and is intercalated with shaley clay and lignite. • The layers in this epoch are dipping toward the north east at an angle approximately 20° . • The thickness of this epoch is about 125m.
	Lower Aptien epoch (C_{2a})	• This epoch is found outcropping southwest of the proposed study area. • It is characterized by shales, and green sandy marl intercalated with sandy limestone. • The thickness of this epoch is about 50m.
	Upper Aptien epoch (C_{2b})	• This epoch is found outcropping southwest of the proposed study area. • It is characterized by marl, marly limestone and hard dolomitic limestone. • The thicknesses of this epoch vary between 20-30m.
	Upper Aptien volcanic epoch (BC_2)	• This epoch is found outcropping south west of the proposed study area. • It is composed of basalt and volcanic ash • The thickness of this basalt is approximately 150m.
	Albian epoch (C_3)	• This epoch is not easy to recognize and to separate from the cenomanian epoch. • It is composed of green marls and dolomitic limestone. • The layers in this epoch are dipping at all directions at varying angles.
	Cenomanian epoch (C_4)	• This formation is divided into three part: 1. The lower part (C_{4a}) is composed of whitish gray dolomitic limestone intercalations with marly limestone and geodes. 2. The middle part (C_{4b}) is composed of marls, marly limestone and crystalline limestone with geodes. 3. The upper part (C_{4c}) is composed of gray dolomitic limestone with geodes, it is thick bedded, highly fractured. • The proposed wind farm is present in this epoch. • The Cenomanian layers are dipping at all directions at varying angles. • Thickness of this formation reaches up to approximately 800m.
NEOGENE	Miocene formation (mcg)	• It is composed of marl and conglomerates interbedded with red clay. • It is found outcropping both west and east of the proposed study area. • Thickness of this formation is between 50-80m. • The layers in this formation are dipping at varying angles.
	Pliocene volcanic complex (Bp)	• The basalt flow outcrops on the northwest of the proposed study area. • The basalt is back vesicular and has a rounded surface. • The basalt is intensely weathered and interbedded with pockets and bands of brown clay.
QUATERNARY	Quaternary deposits	• The sediments are present on the valleys and slopes on the western and northern sides of the proposed study area. • These deposits are characterized by debris of limestone mixed with sands, shales and volcanic in the depression. • Thickness of these deposits varies.

Faults and Folds

The study area characterize as the complex tectonic, there is one major fault (N-S) that is located west of the proposed study area passes along the Wadi Oudine (east of the Andquet village). It bifurcates into several branches (NE- SW). This fault has both normal and strike slip types of movements both of which being in the order of hundreds of meters. Other smaller scale faults, trending approximately (NE- SW) crosscut the area of study (Ref. General Geological map). Normal displacement along these faults is variable and reaches up to 50 m in some cases. There is also anticlinal fold, the axis of anticlinal which is located west of the major fault (east of Qobayat village).



General Geologic Map of the Study Area


LEGEND
LIMESTONE OF UPPER JURASSIC (J4-7)
SAND OF LOWER CRETACEOUS (C1-2)
CLIFF of LIMESTONE (C2b)
BASALT OF LOWER CRETACEOUS (BC2)
LIMESTONE OF UPPER CRETACEOUS (C3-4)
FAULT
ANTICLINAL AXIS
UNDERGROUND WATER LEVEL
A
B
NW
SE
1200
1000
800
600
400
200
0
-200
C3-4
BC2
J4-7
GEOLOGICAL CROSS SECTION OF THE STUDY AREA
1/20.000

Hydrogeology

The area in the Jabal Akroum is underlain with two aquifers (C_4 Cenomanian Limestone epoch and C2b cliff of limestone) and three aquicludes that include the Aptian Marls and Shales epoch (C_2), the Aptian Volcanic epoch (BC_{2b}) and the Pliocene volcanic complex (Bp). The Neocomian epoch (C_1) and the Quaternary deposits and the Miocene formation (mcg) are classified semi-aquifers.

1. Aquifers

The Cenomanian Limestone epoch (C_4) constitutes the most important aquifer in the study area. The formation beds are clearly intensely fractured and karstified which indicates high permeability and transmissivity.

Voids within Limestone Formation

It is a karstic aquifer characterized by a significant amount of groundwater flowing in channels, faults and fractures. The amount of infiltration in this aquifer is approximately 40%. The underground water is movement at all directions because there are several

fractures and voids trend at all directions. The pizometric surface is at level about 500m above sea level. (Ref. Geological Cross- Sections).

The most of springs emerge from this aquifer are located at the Oudine valley (west of the study area) and at the Sabea valley (east of the study area). The very large yield of the springs reveals of the Jabal Akroum catchment, this aquifer supplies many springs such as Nabaa Charqi, Ain El Tine, Ain Sabea, Ain Qasab, Ain Chakif and Ain Naqata.

The upper Aptien epoch (C2b):

The Mdeirej Limestone formation (C_{2b}) constitutes cliff of limestone which are generally fractured and karstified. This formation is classified aquifer but is very limited in the study area.

2. Semi-Aquifers

The Neocomian epoch (C_1):

The permeability of sand and sandstone contributed to have a good aquifer but the presence of clay and marls lenses contributed to have a semi aquifer. Hence, only middle and low discharge springs arise from the Cenomanian epoch (C_1) such as Ain El Derzi and Nabaa el Gharbi.

The Miocene Formation (mcg) and The Quaternary deposits (Q):

The permeability and porosity of conglomerates and debris of limestone is high but the permeability of silt and clay is very low which therefore classifies these deposits as a semi-aquifer. However, small and medium seepage springs may occur within these formations such as Nabaa El Qabo.

3. Aquicludes

The Aptian Marls and Shales epoch (C_2), the Aptian Volcanic epoch (BC_{2b}) and the Pliocene volcanic complex (Bp) constitute aquicludes because of the low conductivity of marls and basalts present. However medium and small seepage springs may occur as a result of these formations such as Ain Ayoub.

In the case, the Cenomanian aquifer is overlay the aquiclude, this aquiclude constitutes a barrier to prevent water leakage into ground water depths, leading to raising the water table and the springs fed in some places such as Nabaa El Charqi and Ain El Tine.

4. Springs survey

A spring survey was conducted in the Jabal Akroum area. This survey revealed the presence of several springs (Ref. table No.2).

Most of the springs are small almost dry out during the summer season. The springs are used for irrigation and domestics purposes.

Outlet of Ain Sabea

The flow of the springs varies depending the seasons and the lithology and the structural geology.

The El Charqi spring and Ain El Tine issue close to the boundary between the Cenomanian epoch (C_4) and the basalt (BC_2) and close to the fault.

Table No.2 Results of surveyed springs

Spring name	X coordinate	Y coordinate	Z(m)	Aquifer	Discharge
Ain El Derzi	204093.6	288727	700	C_1	Low
Nabaa El Qabo	204009	289226	690	Q	Low
Nabaa El Gharbi	203913	288990	720	C_1	Low
Ain Ayoub	204053.9	287392	810	BC_2	Low
Nabaa El Charqi	204663.5	288594.1	820	C_4	High
Ain El Tine	204469.9	288850.3	750	C_4	High
Ain Sebea	207197.6	287699.6	870	C_4	High
Ain Qasab	206972.4	287165.5	900	C_4	High
Ain Chakif	206546	286492	950	C_4	High
Ain El Naqata	205472.2	285504.9	1080	C_4	High

5. Well Survey

A well survey was conducted along with the spring survey. This survey revealed the presence of 2 public wells in the study area.

- Well 1:

X=207849.8 m

Y=292598.5 m

Z=805m

This well is following to water authority, located North of Bsatine village; it is also exploiting the Sannine Formation (C4), and has a reported depth of 300m ,depth of water about 170m . Discharge of this well about 2″.

Well of the Bsatine Village

- Well 2:

X=208582.8 m

Y=292308.5 m

Z=684m

This well is following to water authority, located in Mrah El Kawekh village; it is also exploiting the Sannine Formation (C4), and has a reported depth of 200 m, depth of water about 100 m. Discharge of this well about 4″.

Well of the Mrah El Khawkh Village

Hydrogeology of the proposed wind farms

The proposed study area is located on the tops of Akroum Mountains on the Cenomanian epoch. This epoch constitutes a highly permeable karstic aquifer in the area and is characterized by its high porosity whereby ground water tends to flow mainly through fractures, joints and channels (Ref. General Geological map and Geological cross sections).

The ground water flow below the site is oriented towards at all directions and the water level is about 500m above the sea level. Impact of the effluent leak resulting from wind farms is very little on the underground water.

Surface water

Jabal Akroum area has an annual average precipitation of 1000 mm/year with a significant number of springs arising from the Cenomanian formation in the region. In the surrounding area of the wind farms, there are several permanent and seasonal springs as listed below:

- Nabaa Charqi, Nabaa Gharbi and Nabaa Kabo are located west of the proposed area.
- Ain Abou Abdallah, AinDerzi, Ain Ayoub and Ain El Tine are located west of the proposed area.
- Ain El Sabea, Ain El Qasab, Ain Chakif and Ain El Nokafat are located east of the proposed area.

Drainage waterways are abundant in the study area. Two valleys, Wadi El Manchara and Wadi Oudine, cross the western side of the proposed area .

Watercourse passes on the Wadi Oudine

While the valleys, Ouadi El Sabea and Wadi Chakif, cross the eastern side of the proposed area .

Watercourse passes on the Wadi Sabea

Seasonal watercourses are also crossing the study area and it's a branch of the main temporary rivers.

The study area is divided in to catchment basins:

The basin is located west of the mountain tops the runoff toward the Wadi Oudine and Wadi Manchara, and the basin is located east of the mountain tops the runoff toward the Wadi Sabea and Wadi El Chakif.

In the winter season, the snow covers the mountain tops and the runoff water increase during the snowmelt.