An overview of the geology and evolution of Wadi Mujib

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ABSTRACT

The rock units exposed in Wadi Mujib range in age from the Late Cambrian Umm Ishrin Formation (~ 500 million year (Ma)) ago, to Recent (Holocene). They represent a good percentage of the geological history of the country. The lower part of the geological column consists of about 600 m of sandstones (Umm Ishrin Formation and the Kurnub Group), while its upper part is dominated by about 700 m of carbonates, bedded chert and phosphorite.Volcanic rocks, 6 Ma old, are present on the southern side of the wadi. Tectonically, the Mujib is bordered from the west by the Dead Sea Transform fault (DST), a plate boundary separating the Arabian Plate, representing here by Jordan, from the small Sinai-Palestine Plate. Jordan moves to the NNE relative to Palestine along this DST 4-5 mm/y, with a total displacement of Jordan the middle Miocene, of 107 km. The DST system caused the formation of the Dead Sea basin and its subsequent subsidence as well as the continuous uplift of the mountains on both sides of it. Both subsidence and uplift are still ongoing. Other major fault is the Sewaga faults, an E-W fault with a small dextral strike-slip movement along them, where the Shihan volcanics are associated with it. Wadi Mujib had started initiation by running water at 5-4 Ma ago along the fractured, E-W axial plane of Mujib anticline. Rate of erosion of the wadi ranges between 0.1-0.23 mm/y. The Mujib deepening is still ongoing because of the ongoing lowering of the Dead Sea basin and uplift of its area.

Keywords: Wadi Mujib, Stratigraphy, Evolution history, Formation age

INTRODUCTION

Wadi Mujib is possibly the most magnificent canyon in Jordan. It can be compared with the Grand Canyon of Colorado in the United States albeit being smaller with much less water flowing through it. It cuts and exposes various types of strata from Recent to the Late Cambrian at its western reaches at the Dead Sea shores. Differences in elevation between its top and base can exceed 1000 m.

For the above reason, Wadi Mujib preserves and exposes most of the geological history of Jordan. It deserves being conserved as a Jordanian geopark suitable for geotourism, adventure, education, and research. The geology of Wadi Mujib and its surroundings has been discussed, as part of the geology of Jordan, by many authors since the early 20th century (e.g. Blake and Ionides 1939; Wetzel and Morton, 1959, Bender, 1974; Powell, 1989). More detailed works on certain geological aspects of the Mujib have been also carried out (e.g. Abed and Schneider, 1982; Karaishan, 1988; Abed and Kraishan, 1993; Masri, 2003; De Jaeger, 2003). This overview will discuss, in brief, the geology and evolution of Wadi Mujib.

LOCATION

Wadi Mujib crosses west central Jordan from east to west, some 60 km south of the capital Amman (Fig. 1). It separates two governorates; Madaba in the north and Karak in the south. Three major highways cross Wadi Mujib: The Desert Highway in the east, the King's Highway in the middle, and the Dead Sea -Aqaba Highway in the west, along the eastern Dead Sea coast.

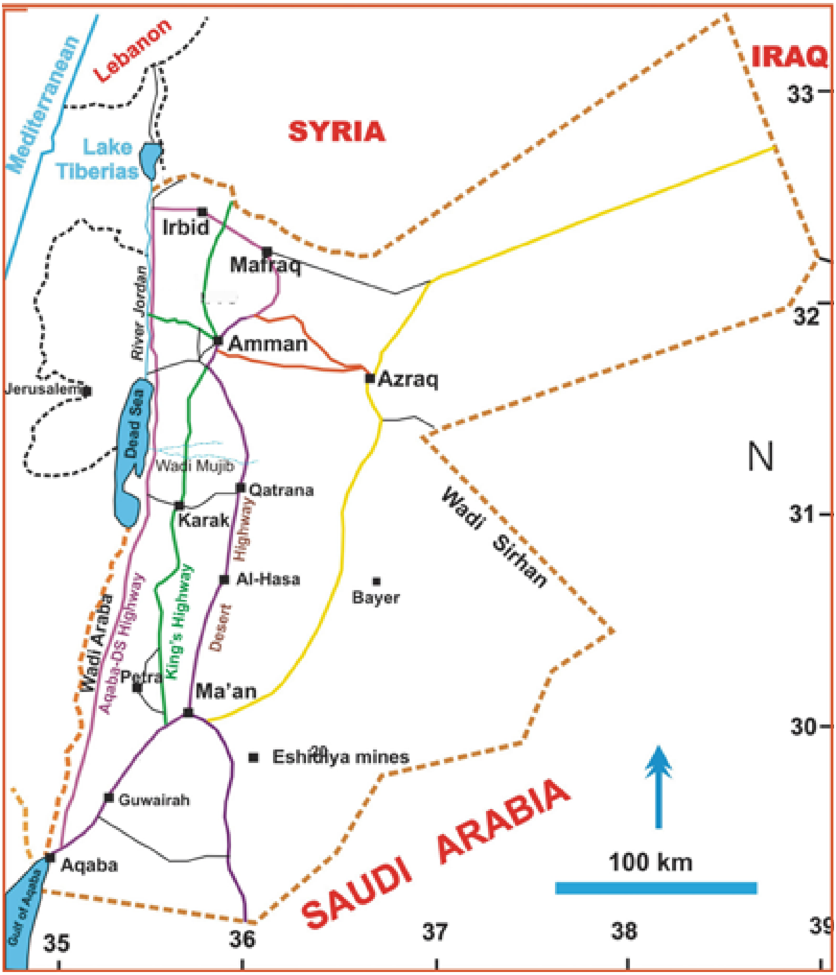
GEOLOGICAL SETTING

The geological framework of the Mujib area will be discussed in brief under two main subjects: stratigraphy and structural geology.

Straigraphy

Stratigraphy deals with the rock units (groups and formations) exposed in the study area. It thus gives an insight into the geological history of Wadi Mujib which extends for more than 500 Million years (Ma), from the Late Cambrian (~ 500 Ma) to the Recent (Holocene) time. The rock units are discussed from older to younger:

Umm Ishrin Formation (Late Cambrian)
Umm Ishrin Formation is the oldest rock unit exposed in Wadi Mujib. It belongs the Late Cambrian (~ 500 Ma) of the Early Paleozoic. It consists of around 300 m thick, brick red, fluvial, quartz sandstone. Excellent outcrops are present at the Mujib mouth in the west, into the wadi eastwards, and along the Dead Sea coasts from both side of its mouth, north and south (Fig. 2). Umm Ishrin Formation is characterized by its long vertical joints sets, at least in two orthogonal directions, cutting the whole length of the formation, very much the same as in Wadi Ram and Petra.

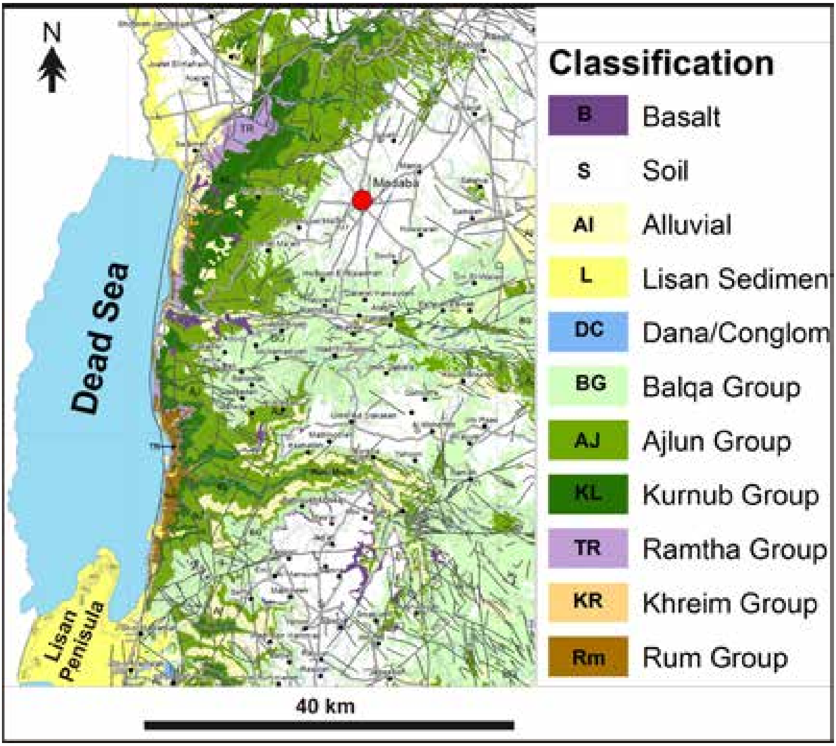


Figuer 1: Location map of Wadi Mujib area and its surroundings.

Figuer 2: Photo of the Umm Ishrin Formation south of the Mujib at the highway. Note the vertical joints and the brick red colour of the formation.

These joints are responsible for the formation of the narrow siqs (gorges) in the western reaches of Wadi Mujib (Fig. 3).The outcrops of the formation, are seen in the geological map (Fig. 4).

Figuer 3: Narrow gorges or siqs in the lower Mujib just east of the Dead Sea. The siq is formed through the erosion and widening of original wide open vertical joints in the Late Cambrian Umm Ishrin Sandstone Formation.



Figuer 4: Generalized geological map of the Mujib area

Long Time Unconformity

The upper surface of Umm Ishrin Formation is erosional. This surface represents a huge gap in the geological timescale of the Mujib extending from the late Cambrian (~ 500 Ma) to the base of the Kurnub Group of the Early Cretaceous (~ 135 Ma); i.e. around 365 million years of sediments were eroded/not deposited in the Mujib area. This huge gap and the lost sediments took place due to the erosion of the Paleozoic sediment associated with the Hercynian Orogeny at around the Middle Carboniferous (Andrews, 1991), non-deposition of the Permian Triassic and Jurassic Periods at this area because it was positive area relative to sea level, and the erosion associated with base of the Kurnub Group. Most of the lost sediments can be seen or drilled elsewhere in Jordan.

Umm Irna Formation

The Umm Irna Formation is 60 m in thickness, made of fluvial sandstone alternating with paleosoil containing iron pisolites. It is of late Permian age, uppermost Paleozoic and represents, with the overlying lower Triassic marine sediments, the first incursion of the Neo-Tethys Ocean into the area (Bandel and Khory, 1981;Stephenson and Powell, 2013).

Kurnub Group

The Kurnub Group is Early Cretaceous in age which consists of around 300 m offriable quartz sandstones of essentially fluvial origin. The Kurnub sandstones are massive white at the lower half of the group becoming varicoloured, dominantly violet, further up section. The Kurnub sandstones overly the Umm Ishrine Formation with a huge unconformity discussed above. See Fig. 4 for location of the Kurnub Group in Wadi Mujib.

Ajlun Group: A carbonate regime

The Ajlun Group represent the period when Jordan became submerged by the Neo-Tethys Ocean Between 100 – 88 Ma ago; that is during the Cenomanian- Turonian of the Late Cretaceous (Table 1). Jordan was part of the inner platform of that ocean (Powell and Moh'd, 2011; Abed, 2017), consequently a dominantly carbonate regime was deposited. The carbonate regime consists of limestone/ dolomite alternating with marl throughout the duration of the Ajlun Group. Total thickness of the Ajlun Group is ~ 450 m (Fig. 5). The exposures of the Ajlun Group are shown in the geological map (Fig. 4).

The Ajlun Group is subdivided into five formations (rock units) in north Jordan. They are from older to younger: Na'ur, Fuheis, Hummar, Shueib and Wadi Es Sir formation (Masri, 1963). In central and south Jordan, the middle three units are combined into one unit because of the difficulties of mapping the three units separately. The new unit has the name of the three original units combined; i.e. Fuheis/Hummar/Shueib (FHS) Formation. See Table 1 (El-Hiari, 1986; Powell, 1989) Thus, in the area in central Jordan, the formations from older to younger are Na'ur Formation, Fuheis/Hummar/Shueib (FHS) Formation, and Wadi ES Sir Formation.

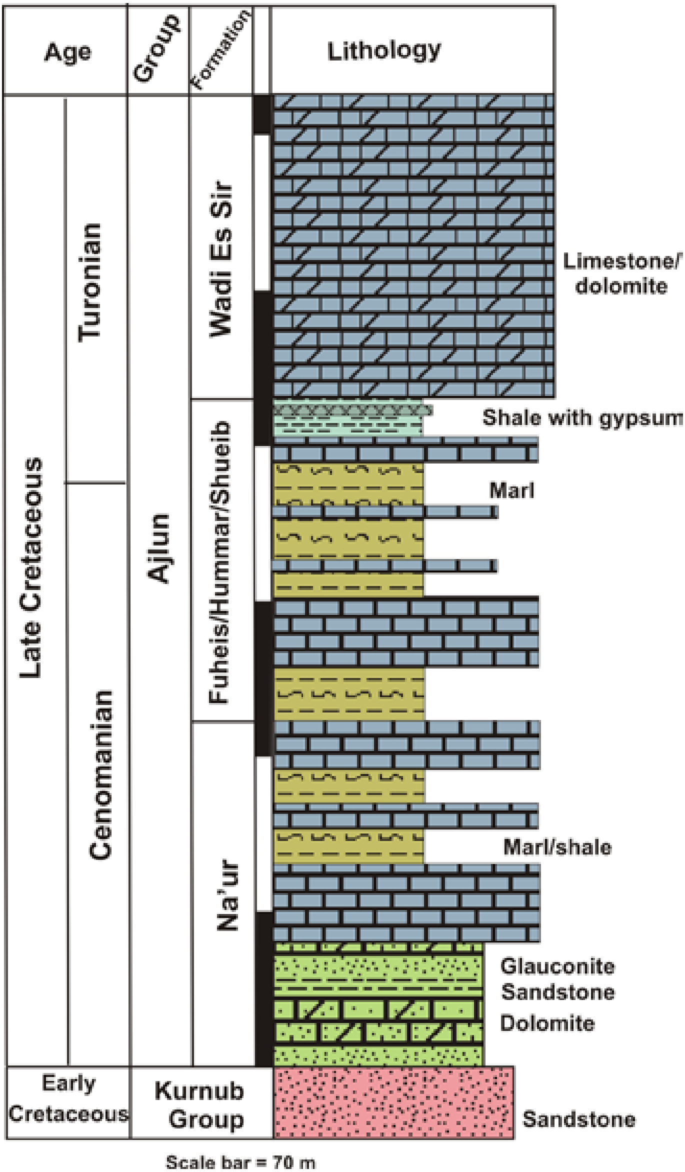
The **Na'ur Formation (A1-2)** forms the base of the Ajlun Group, is early Cenomanian in age, 150 m thick, and consists of hard limestone and/ or dolomite horizons alternating with similarly thick, soft marl to marly limestone horizons (Fig. 5). It is exposed at the base of the Mujib Dam and further west along the wadi course. The limestone beds are typically nodular due to burrowing (Abed and Schneider, 1982), while the soft marl horizons are the loci for landslides. There are evidences that the Mujib area formed a paleohigh (an island) during the lower Cenomanian (Abed, 1984).

Table 1: Nomenclature of the Ajlun and Belqa Groups (Powell, 1989).

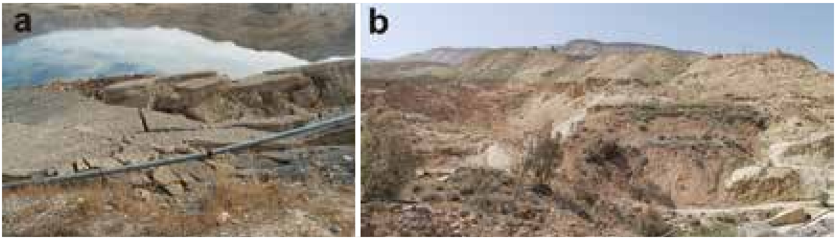
Age		Group	Formation	Member
Tertiary	Eocene	Belqa	Shallaleh	
			Umm Rijam Chert Limestone	
	Paleocene		Muwaggar Chalk Marl (MCM)	
Late Cretaceous	Masstrichtian		Al Hisa Phosphorite (AHP)	Qatrana Phosphorite
				Bahiyya Coquina
				Sultani Phosphorite
	Campanian		Amman Silicified Limestone	
	Santonian			
	Coniacian		Gudran	Dhiban Chalk
				Tafila
				Mujib Chalk
	Turonian	Ajlun	Wadi Es Sir	
	Cenomanian		Shueib	
			Hummar	
			Fuheis	
			Na'ur	
Early Createaceous	Aptian-Albian		Kurnub (Hathira) Sandstone Group	

The **Fuheis/Hummar/Shueib (FHS) Formation (A3-6)** overlies the Na'ur Formation. It is Cenomanian-Turonian in age, 140 m thick, consisting of soft marl/ marly limestone and shale with much less thick, hard limestone interbedded with them (Masri, 2003). Some minable, primary gypsum beds are also present towards the top of the formation especially in Wadi Mujib.

In Wadi Mujib, the FHS succession is exposed from the Mujib bridge eastwards along the wadi course, thus the Mujib dam lake is within the outcrops of this formation. Westwards of the Mujib bridge, the formation becomes part of the lower slope. The fact that the FHS consists dominantly of soft marl, makes it the loci for continuous landslides, easily seen east and west of the Mujib bridge (Fig. 6).



Figuer 5: A generalized columnar section of the Ajlun Group in Wadi Mujib showing the lithology of the formations.



Figuer 6: Landslides in the lower FHS: a) 2013 when a major collapse took place, immediately east of the dam, b) just west of the Mujib Dam when it started during 2011.

The **Wadi ES Sir Formation (A7)** is the uppermost formation of the Ajlun Group (A7). However, Masri (2003) described 25 m of clayey limestone rock unit belonging to the Khurayj Formation overlying the Wadi Sir Formation and belong to the Ajlun Group. The age of the Wadi Sir Formation is Turonian (Upper Cretaceous).

Within the study area the Wadi Es Sir Formation is 125-150 m thick. It is dominantly a limestone formation. Micrite (microcrystalline limestone) dominates the rock type in the formation with relatively minor various types of limestone such as shelly packstone-grainstone, oolitic grainstone. Chert nodules and sometimes thin bedded chert are present. Dolomite and dolomitic limestone are also present especially towards the bottom of the formation. The formation has abundant fossil content especially the Molluscs and Echinoderms. Bed thickness is variable from massive, cliffy strata as seen towards the top of the formation and its bottom.

However, thinly bedded limestone, sometimes marly, are also present especially in the middle of the formation (Fig. 5). From a hydrogeological view point, the Wadi Es Sir Formation is an excellent aquifer throughout Jordan. Due to the predominance of limestone and the near lack of marls and clayey material within the formation, the whole formation can be considered as a continuous aquifer.

The **Khurayj Formation** is a 25 m thick rock unit, overlying the Wadi Sir Formation, newly described, by Masri (2003) in this area of central Jordan. Previously it was described as part of the Wadi sir Formation. That is why the previous authors gave the Wadi sir Formation a thickness of 150 m in the Wala-Mujib area. The Khurayj Formation is essentially a limestone formation, very much like the underlying Wadi sir Formation. However, there are some marly limestone horizons in the middle part of the formation. In my opinion, these minor marly horizons do not affect the continuality and connection of the Wadi Sir aquifer. The age of the formation is possibly Coniacian-Santonian.

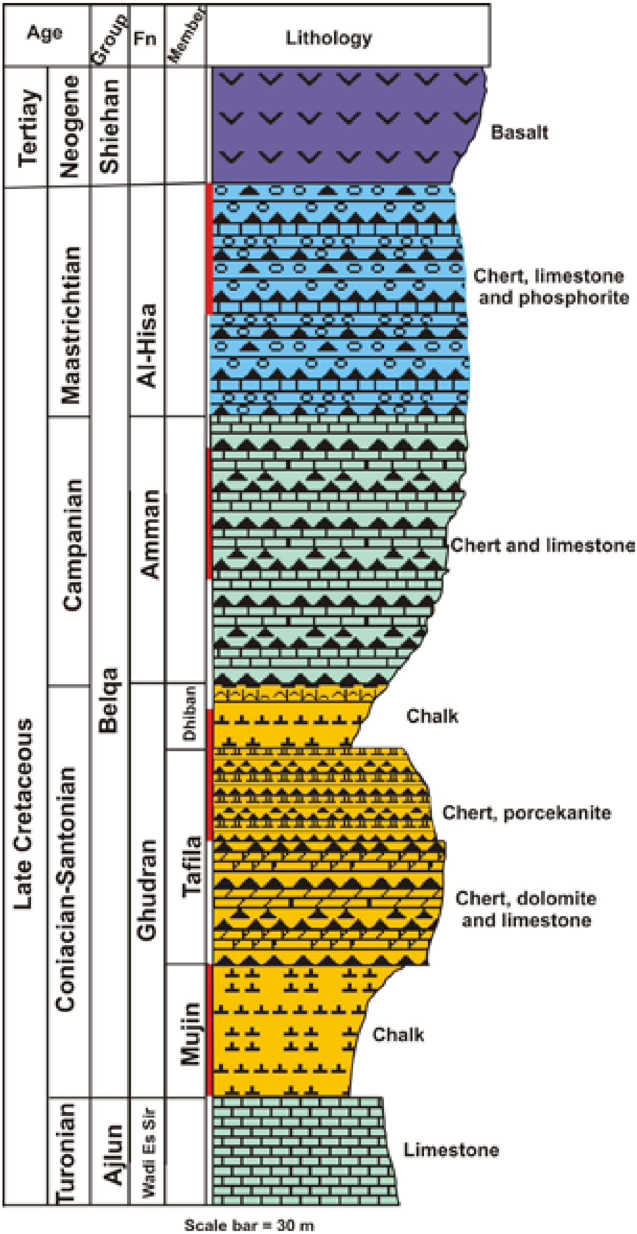
Belqa Group:
A chert-dominated regime

The predominantly carbonate regime of the Ajlun Group changed into an exotic sedimentation regime during the Belqa Group. This exotic regime consists of bedded chert, chalk, limestone, phosphorite, dolomite and porcelanite. The back bone of this regime is the bedded chert, a rock type present in almost all the formations representing the Belqa Group. The reason for the dramatic changes in sedimentation and sediment types is, most probably, related to the tectonics associated with the closure of the Neo-Tethys, circum global oceanic currents and upwelling, and the associated biodiversity. These conditions were the cause for the deposition of the bedded chert and phosphorite in particular (Abed (2013). The Belqa Group overlies disconformably the Ajlun Group. It involves all the marine sediments deposited from the Neo-Tethys Ocean from the end of the Ajlun Group till the closure of this ocean in the late Eocene some 35 Ma ago. Figure 4 shows the outcrops of the Belqa Group in the Mujib area and its surroundings. Due to uplift and erosion of the upper part of the Belqa Group, three formations of this group crop out in the study area (Fig. 7).

The complete rock units making the Belqa Group are shown in Table 1. These formations are from bottom to top: **Ghudran (B1), Amman (B2a) and Al-Hisa (B2b)**. The other, younger, formations of the Belqa Group such as the **Muwaqqar (B3), the Rijam (B4) and Shallaleh (B5) formations** are eroded from the study area and can be seen much to the east.

Ghudran Formation (B1)

The Ghudran Formation is well developed in central Jordan and especially in the Wala-Mujib canyon complex. It is in excess of 100 m in the latter area compared with only 20 m in the Amman region and about 35 m in north Jordan. In the Amman area and north of it, the Ghudran Formation consists essentially of chalk. While in the Mujib area it consists of three formal members: a lower whit, homogenous chalk horizon called the Mujib Chalk, a middle heterogeneous horizonmade essentially of bedded chert called the Tafila Member, and an upperchalk horizon called the Dhiban Chalk (Fig. 7). The Ghudran Formation is exposed above mid slope of the Mujib canyon and can be easily seen in the northern flanks of the Mujib with its conspicuous white chalk horizons. It is thus higher up in the succession and is not involved in the wadi course unless one travels much to the east.



Figuer 7: A generalized columnar section showing the lithology of the Belqa Group exposed in the study area.

Amman Formation (B2a)

Amman Formation in the Mujib is a very conspicuous formation characterized by its abundant bedded chert. The bedded chert comprises about 50% of the formation. In other words, the chert: limestone ratio is roughly 1:1 (Fig. 8). This is the highest chert ratio in any chert-bearing rock unit in Jordan including the Tafila Member. Its thickness is about 60 m (Fig. 7). The bedded chert is either massive or brecciated. Chert nodules are also present. The chert beds are in many instances fragmented.

There is much evidence that the chert is early diagenetic as a replacement of other rock types like limestone. Bedded chert alternates with limestone of various types such as coquinoidal limestone, chalk, micrite, etc. Further up in the formation, some minor phosphorite beds are present. In Wadi Mujib, the Amman Formation is exposed along the upper parts of the canyon; e.g. the rest area at the beginning of the descend in the northern flank of the Mujib and similarly in the southern side.

Figuer 8: A field photo from the upper slope of Wadi Mujib showing the interbedded chert and limestone.

Al-Hisa Phosphorite Formation (B2b)

Al-Hisa Formation consists of phosphorite, bedded chert, limestone and oyster coquinoidal limestone. Intermediate lithologies of these rocks are also present. The lower part of Al-Hisa Formation makes the higher most topographic parts of the Wala-Mujib canyon system. The thickness of the formation in the study area is in excess of 60 m, but certainly parts of it are eroded from the plateau (Fig. 7).

From a hydrogeological view point, Al-Hisa and Amman Formations behave similarly. Both were one formation called the Amman Formation in the Masri (1963) nomenclature in the early 1960s.

Volcanic rocks

In Wadi Mujib itself and its immediate vicinity, volcanic rocks are present on both sides of the wadi, especially the southern side. Abundant basaltic rocks are present further north of the Wadi Mujib which are not included in this overview. The volcanic activities associated with Mujib proper had started around 6 Ma ago and stopped before the initiation of the formation of Wadi Mujib; i.e. they are older than the Wadi Mujib. Two separate volcanic basalt events took place in the Mujib – Heedan canyon complex and its surroundings. These volcanic rocks are extensively exposed south of the Mujib with minor occurrences north of it.

The older basalt or the **Shihan Group basalt** which is up to 6 Ma in age (uppermost Miocene/Pliocene) (Bareberi et al., 1979). This basalt is cropping out at the higher slopes of the Heedan west and southwest of Al-Shgaig. It is the northern continuation of the Mujib basalt originated from the flows of Jabal Shihan further south (Fig. 9). The Shihan Group consists of 4 formation with more than 20 flows, at least 6 of these flows can be seen along the Kings Highway at the southern flanks of Wadi Mujib. The Shihan Group basalt is in excess of 100 m in thickness south of the Mujib. This basalt predates the incision of both Wadi Mujib and Wadi Heedan; i.e. older than both canyons (De Jaeger, 2003). In other words, both Wadi Mujib and Heedan had cut and eroded these basalt flows. That is why the basalt can be seen on both sides of the Mujib. However, this basalt does occupy a wide area especially south of the Mujib canyon.

Figuer 9: Shihan basalt in the form of a paleo wadi predating the Mujib Formation some 6 Ma ago.

The younger basalt is present along the western course of Wadi Heedan. (Fig. 10). It is much younger than the plateau basalt with an age of around 1 Ma, most probably, at a fault running partially along Wadi Heedan. Due to its high resistance to water erosion, this basalt has formed high, nice waterfalls within Wadi Heedan.

Figuer 10: The Heedan basalt along the course of the wadi. Its age is around 1 Ma; i.e. younger than the Shihan basalt and post date the incision of the Heedan.

Recent and subrecent deposits

These deposits are of minor importance to the geology of the area. They include limestone, chert, dolomite, phosphorite and basalt rock fragments. They occupy the course of Wadi Wala-Heedan to a certain depth varying from one place to the other. They can reach several metres in the wider parts of the wadi course, and are reduced to a very thin veneer in the narrow gorges and the cliffy parts of the wadi course.

These deposits include wadi terraces and slope debris. They are gravelly or conglomeratic in nature. Their composition varies with position and age. However, their framework consists of limestone and chert rock fragments of various sizes. They are bound together, in several places, by soil material. The true terraces have smaller amounts of the binding soil and they are much indurated becoming a true conglomerate. De Jaeger (2003) had studied the Pleistocene terraces in Wadi Mujib and their implications in the evolution of the wadi and paleoclimate of the area.

Geological structures

Several major faults are present within the larger study area. However, the structures adjacent to the Mujib are discussed here.

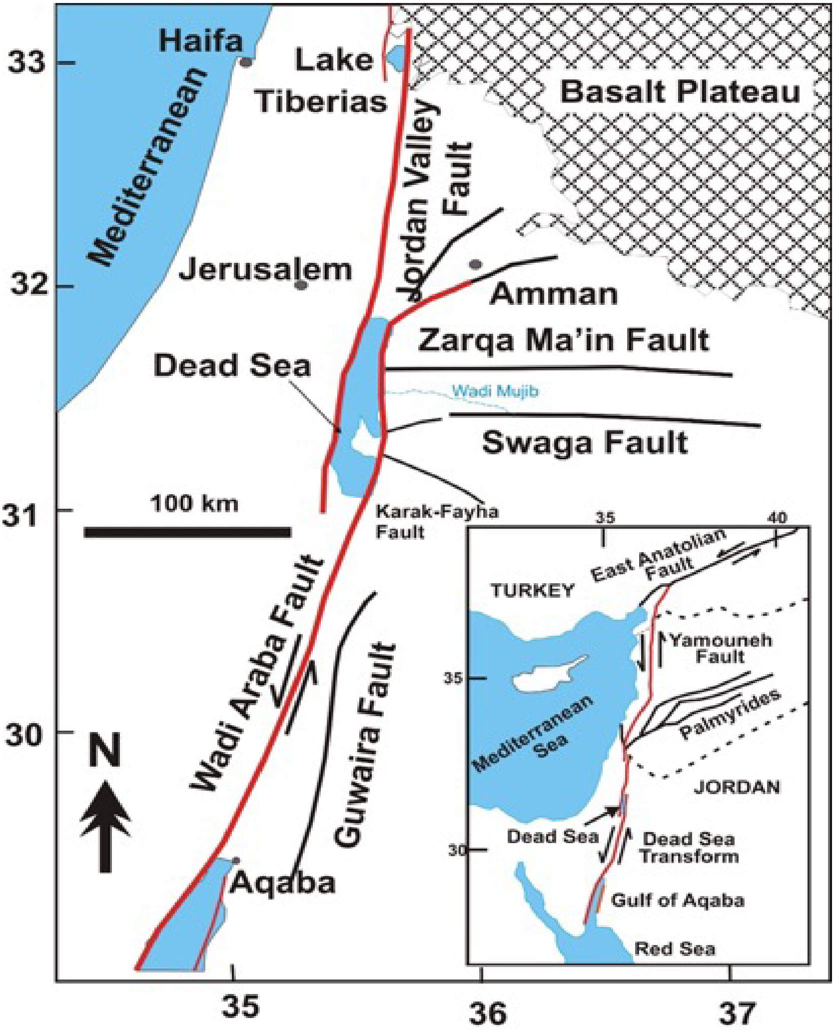
The **Dead Sea Transform fault (DST)** which bounds the area from the west along the Dead Sea shores and ends at the NE tip of the Dead Sea with the Amman-Hallabat structure (Fig. 11). The DST is a plate boundary separating the Arabian Plate, representing here by Jordan, from the small Sinai-Palestine Plate. Jordan moves to the NNE relative to Palestine along the DST with a rate of 5-4 mm/year. The total displacement of Jordan since the start of the activity of the DST in the middle Miocene some 17 Ma ago, is 107km. The DST system caused the formation of the Dead Sea basin and its subsequent subsidence as well as the continuous uplift of the mountains on both sides of it. Both subsidence and uplift are still ongoing. It is worth mentioning that the continuous deepening of the Dead Sea basin forced Wadi Mujib to dig deep to keep in equilibrium with the Dead Sea surface, its base level.

The **Sewaga and Zarqa Ma'in faults,** both are E-W faults with a small dextral strike-slip movement along them. The Sewaga fault starts slightly NE of the Lisan Peninsula, then passes by the Shihan volcano area and continues in an east direction to cross the borders with Saudi Arabia. The Zarqa Ma'in fault starts from the western parts of the wadi and continues eastwards until it joins the Sewaga fault nearby the Saudi borders (Fig. 11).

The Mujib anticline is a very broad anticline running along the canyon from the Dead Sea eastwards. Beds in the two flanks of the Mujib are very gently (several degrees) dipping away from each other, thus creating this broad anticline. Wadi Mujib seems to have created its course along the maximum curvature of this anticline. At the maximum curvature of the anticline, the strata are normally fractured, thus facilitating the movement of surface water to erode and form the Mujib canyon. The formation of the anticline seems to be due to the compression associated with the northward movement of Jordan, as part of the Arabian Plate, along the Dead Sea transform by a rate of around 5 – 4 mm/year (Galli , 1999). No one major fault has been identified running along the Wadi Mujib course or parallel to it in an E – W direction in the study area. However, E – W local faults are present within the flanks of the Mujib canyon.

EVOLUTION

The following discussion describes the evolution of Jordan and adjacent countries from the deep past up till the initiation of Wadi Mujib some 5 Ma ago, then the evolution of the Mujib will be discussed. For more details, see Abed (2005, 2017).



Figuer 11: Shows the DST in Jordan and the other major faults north and south of the Wadi Mujib.

Precambrian time

Pre 540 Ma ago, Jordan formed part of the Arabian-Nubian Shield (ANS) which now occupies western Arabia (Arabian Shield) and the area west of the Red Sea (Nubian shield). The ANS took about 700 Ma to form and stabilized from 1200-540 Ma, through island arcs subduction, collision, obducion and deformation. The resultant ANS consisted of plutonic and volcanic rocks of varying affinities, metamorphic and metasedimentary rocks, and sedimentary conglomerates, sandstones and carbonates. The Najd Fault system, 640 Ma onwards, had created highs and lows in the whole ANS where the highs were later eroded to create a thick sequence of conglomerates and sandstones in many parts of the Shield, such as the Saramouj Conglomerates in Jordan (595-605 Ma) (Fig. 12).

Figuer 12: A photo showing the Saramuj conglomerates near the SE tip of the Dead Sea (595-605 Ma).

This long period of erosion led to the peniplanation of the preexisting reliefs, which is nicely displayed in southern Jordan. The ANS is represented in Jordan by the igneous and metamorphic rocks around Aqaba and in Wadi Araba (800-540 Ma) (Abed, 2017, Al-Shanti, 1993).

The Paleozoic siliciclastics

By the end of the ANS, northern Arabia, including Jordan, subsided and became the scene of braided rivers running from south to north and depositing around 1000 m of sandstone rocks which are now forming Ram, Petra, parts of Wadi Araba and the coasts of the Dead Sea; e.g. Umm Ishrin Formation. This terrestrial period end by the Lower Ordovician (~465 Ma), after which the Paleotethys Ocean invaded Jordan, and the whole eastern Mediterranean, depositing marine shale and sandstone. By around 430 Ma (Late Ordovician), Jordan was within the arctic circle of the south pole and glacial deposits in south Jordan testify this location and environment (Abed et al., 1993). Permian, Triassic and Jurassic periods were deposited from the marine water of the Neo-Tethys Ocean in northern Jordan only, north of Wadi Mujib. It seems that Jordan became a positive relief during the Early Cretaceous (135-100 Ma ago), and rivers again had deposited a relatively thick sequence of Quartz sandstone throughout the country called the Kurnub Group.

Marine submergence (100 Ma-35 Ma)

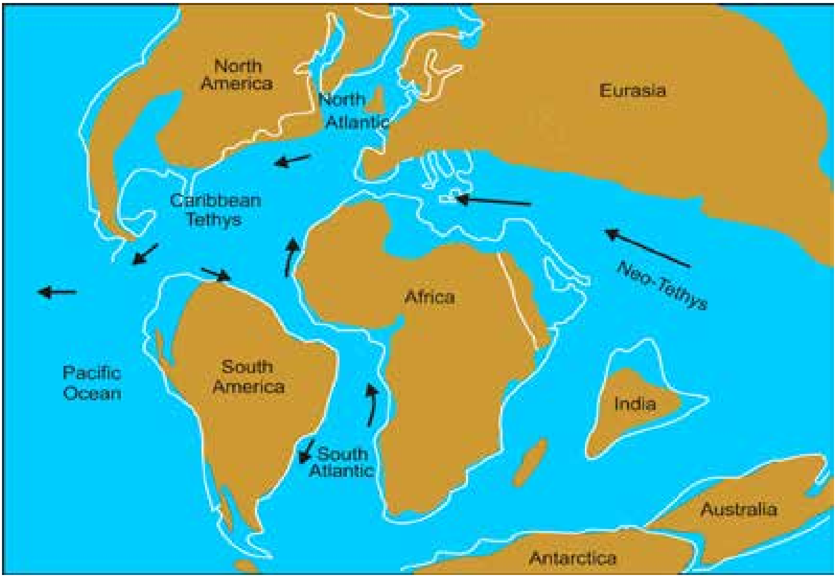
The onset of the Late Cretaceous, some 100 Ma ago, witnessed a major global sea level rise in excess of 100 m. This major global sea level rise was caused by the warm mid Cretaceous (Cenomanian – Turonian) green house climate event where all the ice sheets on the Earth poles and mountains were melted and returned to the oceans. Atmospheric temperature was several folds higher than present-day temperatures.

This green house event and the subsequent rise in sea level, led to the flooding of almost all the eastern Mediterranean including all Jordan except its extreme south. Jordan, thus, was submerged with shallow marine water of the southern continental shelf of the Neo-Tethys Ocean, and formed part of its inner shelf (Fig. 13). The shore line was far to the south, thus ensuring the deposition of a pure carbonate regime, several hundred metres thick in north and central Jordan including the Mujib canyon area, represented by the **Ajlun Group** described above.

By the beginning of the **Belqa Group**, base Ghudran formation of the Coniacian some 80 Ma ago, the ocean water transgressed due to a new sea level rise. The shoreline became several hundred kilometers to the south of the shorelines of the Ajlun Group, thus even southern Jordan was submerged. The Neo-Tethys Ocean became well connected to the global ocean currents which helped deep, cold, nutrient-rich upwelling currents to prevail all over Jordan. This regime is the one responsible for the deposition of several hundred metres of bedded chert, phosphorite, oil shale, chalk, porcelanite and limestone throughout the Belqa Group.

Neo-Tethys migration and Jordan exposure (35 Ma-present)

The above depositional conditions which led to the deposition of the Belqa Group continued up till the end of the Eocene of the Tertiary some 35 Ma ago. At around this date, late Eocene, the Neo-Tethys migrated from eastern Mediterranean including all Jordan, except for a small passage in northern Syria and into Iraq. The migration of the Neo-Tethys lead to the termination of marine deposition and to an end of the Belqa Group. The migration of the Neo-Tethys was due to the uplift of the eastern Mediterranean which in turn is due to the collision of the Afro-Arabian Plate, due to its northward movement, with the Eurasian Plate which took place at around the same time; i.e. late Eocene.



Figuer 13: Paleogeographic map of the world during the Late Cretaceous (Campanian Ma). Brown = land mass, white line = present day land mass, arrows = circumglobal currents. Note that Jordan was completely submerged.

Post Eocene, Jordan became emerged and terrestrial processes such as erosion of the previously deposited Belqa Group sediments commenced especially in western Jordan where uplift was, and still higher. At around 20 Ma ago, early Miocene, full-fledged collision and suturing of the Afro-Arabian Plate with the Eurasian Plate in Turkey and Iran, due to the continuous northward movement, took place and completely closed the remnants of the Neo-Tethys in northern Syria and Iraq. To release the stress mounting in the Afro-Arabian Plate because of that, at around 20 Ma ago during the Early Miocene, the Syrian–East African Rift formed, separating the Arabian Plate from the African Plate. This major structural event led to the formation of the Gulf of Aden, the Red Sea and the Dead Sea Transform system. A whole system of faulting formed associated with this Furthermore, the forevent, and some of these faulted areas were the scene of extensive basaltic fields throughout Arabia and the greater Syria; e.g. Harrat Esh Sham in NE Jordan.

Furthermore, the area along the DST started subsidence and became relatively lower than adjacent areas to the east and west; e.g. Dead Sea basin and the Jordan Valley. Several lakes, varying in size and salinity, formed and demised throughout this period (20 Ma) such as the Usdum Lake (Paleocene), Samra, Lisan and Damya Lakes (Pleistocene), and the Dead Sea, Lake Tiberias, and Lake huleh (Holocene).

Mujib formation

By around 6 Ma ago, the upper half of the Belqa Group was removed from the Mujib area by surface water erosion through smaller wadis draining the area. At this date 6 Ma ago, **Shihan volcano** became active sending its basaltic lava flows in all directions. One of these directions was towards the not-yet formed Wadi Mujib, sending the lava via a broad, shallow paleowadi where it crossed the Mujib area and reached to the Heedan NW of Shgaig. At least 6 basalt flows can be counted in this area separated by soil and calcrete; meaning 6 separate eruptions of Sihan volcano separated by a long period of time allowing the formation of soil between the flows. After the formation of the basalt flows across the Mujib, and sometimes about 4-5 Ma ago, Wadi Mujib started to form in its present day-course. This is possibly due to the deepening of the Dead Sea towards the mouth of the Mujib as well the formation of the E-W Mujib anticline. Running water selected the week E-W direction in the area, the axial plane of the Mujib anticline (Fig 14), and started the initiation of Wadi Mujib at around 5-4 Ma ago. It has to cut across the basalt flows first then to deepen its course with time, with an estimated rate of erosion of 0.23-0.1 mm/y. The presence of the basalt flows on both sides of the Mujib testifies for that (Fig. 9). Wadi Mujib is still deepening its course because uplift of its area and subsidence of the Dead Sea basin are still ongoing.

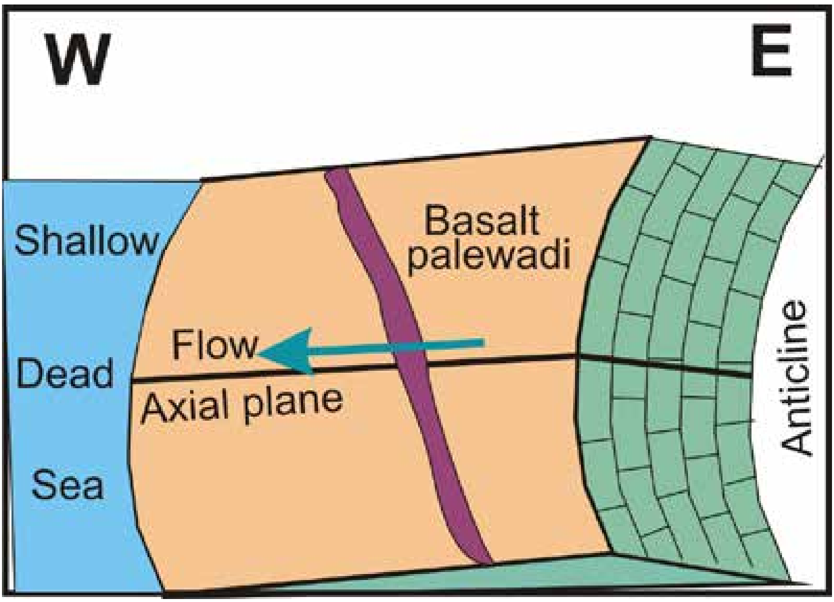


Figure 14: Thematic drawing of the Mujib anticline

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