THE GEOLOGY AND HYDROGEOLOGY OF THE AAMMIQ WETLANDS REGION

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SUMMARY

The Aammiq Wetlands Region of the western Bekaa can be divided into three NE-SW aligned strips. The most westerly strip is that of the high Jurassic limestone mountain uplands of Jebel Barouk. This is broken up by a series of NE-SW aligned faults, movement along which has given rise to the uplift and locally, complex folding. This zone is the main area of water catchment for the wetlands although some major springs occur within it. A narrower central zone occurs of low lying and poorly exposed Lower Cretaceous sandstones, clays and limestones. These are downthrown against the Jurassic and appear to act as a barrier to the water flow. The third zone is the area of the wetlands proper in which only soft Quaternary sediments appear at the surface and probably occur in considerable thicknesses, reflecting a long history of episodes of lacustrine and wetland deposition over the last few million years. The Aammiq Wetlands are the last remains of the lakes and swamps that filled much of the southern Bekaa and as such act as a last refuge for many plants and animals that were once much more numerous in the region during moister climatic periods of the Pleistocene and Holocene.

The natural processes which have led to the drying out of these ancient lakes have been greatly exacerbated by recent reclamation of the land for agriculture and the diversion of water for irrigation. This decline in the area of permanent open water is plainly visible m a comparison of maps done in 1939 and 1963 with the present day. However the water losses appear to have resulted in only a partial draining of the swamp so that the present water table even at the driest time of the year appears to be only 3-5 metres below the surface. To restore the water table to a level which would allow standing bodies of water all year round is technically feasible.

Introduction

The geology of the Aammiq Wetlands Region is superficially simple with a limestone massif to the northwest passing rapidly into low lying wetlands to the southeast. In detail however it is highly complex, raising numerous issues to do with the tectonics and geological history of Lebanon. The geology is however important because of its close links with the water supply to the wetland.

There have been few geological studies done on the Aammiq area. The region is covered by the Rachaya North sheet of the 1:50,000 geological map (completed 1945) and, in passing in the accompanying memoir of Dubertret (1960). A detailed report was completed on the hydrogeology of the Ammiq Estate by Haas in 1954. Some useful hydrogeological data are to be found in UNDP (1970).

This technical summary represents a synthesis of available information data coupled with some new field data. It is however a provisional study and in the conclusions section some suggestions are made as to how the geology and hydrogeology of this area can be better understood.

A summary geological map is given in Figure 1 along with a schematic cross section in Figure 2.

Geological Divisions

The Aammiq region is plainly divisible into two.

The northwestern part is the southeastern flank of the Barouk-Niha Ridge. This region is made up of the steep, rocky and forested slopes of Jebel Barouk which rise to nearly 2000m and which are underlain by hard, pale Jurassic limestones. For the most part these seem to dip gently westwards. Although out of the area of the Aammiq wetlands proper this area is integral to it as its abundant springs are the chief source of the moisture for the Bekaa floor in this region. Furthermore these slopes form a relatively unspoiled sequence of hillside environments which act as a continuation between the Arz-el-Chouf and the Aammiq conservation areas. For these reasons the geology of this area is discussed here in some detail.

The southeastern part, the Bekaa valley floor region which includes the Aammiq Wetlands, is a virtually flat plain at 863-865m which is made up of thick soft Quaternary sediments with rich moist soils.

Structural Geology

Faults

A key feature of the area and the explanation for the striking differences between the southeastern and northwestern areas is that this region is here bisected by the NE-SW trending Yammouneh Fault System. This is one of the main fault zones in Lebanon, extending all the way through the country from the Hula Depression to the south until the Horns Basalts at the border with Syria, and along much of its length forming the western margin of the Bekaa. The Yammouneh Fault System is itself part of the Dead Sea Transform Fault which extends from the Red Sea to the Taurus Mountains through Lebanon and which marks the line along which the Arabian Plate slides past the Levant portion of the African Plate. The nature, amount and timing of the motion on the Yammouneh Fault System in Lebanon is still debated and a summary of the most probable situation is given below after a description of the faults.

In the Aammiq area it seems probable that there are at least three discrete parallel branches of the Yammouneh Fault System in this area (see Figures). These are presumably linked at depth.

The most westerly fault, associated with a widespread zone of fine breccia and powdery rock flour, can be seen cutting the hillside at an altitude of around 1200 m and appears to be linked with the widespread springs at this level (see the hydrogeology section below). This upper fault, here termed the Upper Aammiq Fault, appears to have been the site of major lateral motion.

At a lower level, another NE-SW fault zone runs from old Aammiq Village to the edge of the knoll of Qaalat el Mdiq. This structure is here termed the Middle Aammiq Fault. On neither of these two faults has a significant vertical throw been demonstrated as in both cases Jurassic limestones are juxtaposed against each other.

The third fault, and the one lowest in altitude, is to be found at the base of the slope, and runs from new Aammiq Village along the base of Qaalat el Mdiq. This Lower Aammiq Fault has a proven major vertical displacement as Lower Cretaceous rocks are here faulted against Jurassic limestones (see Figure 2). This suggests a vertical displacement of at least 500m and possibly well over a kilometer.

The precise vertical orientation of these three major faults is unclear but the best evidence is that they dip slightly westwards. Given the fact that the Yammouneh Fault System must cut the whole lithosphere here (presumably at 80-100m km depths) there is every likelihood that these parallel faults are linked at depth.

In addition to these major NE-SW features Haas (1954) identified a number of transverse faults which trend NW-SE and occur within the compartments of the main Yammouneh Faults. The existence of these have not been confirmed.

In terms of its overall character the Yammouneh Fault System is clearly largely strike slip or lateral in character with the eastern, Bekaa portion having moved many kilometers northwards with respect to the Barouk portion. Quantifying the motion is difficult. To the south of Lebanon the motion is widely held to be 105 km. By no means all of this is continued into the Yammouneh Fault System (Walley, 1988) but even so the amount of motion is probably here is at least 40 to 50 kilometres perhaps distributed across the three main faults.

An issue of considerable scientific and practical interest is that of the age of this fault system. There seems little doubt that the Dead Sea Transform Fault System started to move around 15 million years ago with the opening of the Red Sea so that the probable 40-50 km plus movement on this segment of the system must have taken place since then. Whether these faults are still moving is a key issue. This has a bearing on the issue of seismic risk in the area as the Dead Sea Fault System to the south is still active, with recurrent earthquake activity. There are however no signs of recent movement (fresh faults scarps, displaced streams etc.) along any of these Aammiq faults in this or the adjacent areas (although for the lower fault this is hard to determine) and it may well be that this portion of the Yammouneh Fault is inactive. Evidence from the area of the Horns Basalt suggests only a few kilometers of motion on the Yammouneh Fault over the last five million years. This fits with the evidence that, at present, the active faulting in western Lebanon occurs on other branches of the faults that spring off from the Dead Sea Fault.

In addition to the lateral motion these faults have probably, by virtue of a westward dip, given rise to the uplift of the Jebel Barouk. It is relatively easy under such circumstances for tens of kilometres of lateral motion to be converted through a wedge like action to a few kilometers of vertical motion.

Other structures

The Jurassic strata in the slopes of Jebel Barouk appear generally to dip westwards. However between the Middle Aammiq and Lower Aammiq Faults the Jurassic limestones of the Kesrouane Formation have been thrown into a number of tight and complex folds. This is well seen at Qaalat el Mdiq and, to a lesser extent, in the valley immediately above old Aammiq Village. Similar such features occur also to the north and south of the area and appear to be due to compressional effects occurring as result of the shearing between the differing fault segments of the Yammouneh Fault System.

The structure east of the lower fault is poorly known due to the poor nature of the exposures. There is no doubt that Lower Cretaceous strata have been thrown against the Jurassic immediately along the margin of the lower fault but the geometry is plainly complex and other subsidiary faults may exist. The overall dip, most plainly seen immediately below Qaalat el Mdiq, appears to be one of an eastwards dip. This is shown in Figure 2. The true picture may however be more complex and there is some suggestion in the area of Haouch Aammiq of an NE-SW aligned anticline occurring parallel to the main road.

East of the main road the structures underlying the Bekaa Valley are almost entirely unknown. There is good evidence that the bedrock below the Aammiq Wetlands area is at some depth. The shape of the wetlands from old maps and from satellite imagery suggests the existence of a deep broadly east-west channel in the area. Certainly there is no evidence of any rock near the surface in the area of the wetlands and it may be that what exists here is a deep gorge which has been infilled with at least one or more kilometers of soft sediment during the 2 million years of the Quaternary. It is notable that in the comparable Hula Depression, some 90 km to the south, some 1.6 km of Quaternary sediments have been drilled (Horowitz, 1989). There is some limited geophysical support for the idea that several kilometres of unconsolidated soft sediments occur in the central Bekaa and UNDP (1970, page 68) shows a deep pre- Quaternary gulf on the basis of simple geophysical methods. This is adopted in the cross section of Figure 2. Without deep boring or modem geophysics all that can be said is that the Cretaceous strata appear to plunge deep under the Bekaa in this area.

Stratigraphy

Jurassic

The oldest strata in the area are the massive and monotonous pale limestones exposed in the Jebel Barouk area. This is the massive Kesrouane Formation of Lower to Middle Jurassic age (see discussion in Walley, 1996). Because the area is so badly fractured it is very hard to determine the dip and whether or not any fault repetition has taken place; this makes any estimate of the overall thickness speculative. However it seems probable that the sequence is at least a kilometer (and probably) more thick, comparable to the c. 1.5 km known in the type Nahr Ibrahim gorge. Haas (1954) identified a marl unit within the Jurassic limestone whose occurrence he considered caused the prominent line of springs in the hillside above Aammiq. This marl unit has not been seen elsewhere and its occurrence along the line of the upper fault zone is curious. It is more probable that the 'marl' is in fact the ground-up limestone rock flour generated by extensive faulting.

These Jurassic limestones have a good deal of porosity. This is largely due to the extensive fracturing and jointing in these rocks which has been enhanced by subsequent karstic activity. At the foot of Qaalat el Mdiq two large caverns occur in these rocks. These features, which are rather unusual in this area, may have may have formed at the edge of lake that formerly covered the Aammiq area (see below).

Cretaceous

A discontinuous line of Cretaceous sediments occur along the West Bekaa between the foot of the Jurassic Jebels of Nina and Barouk and the Bekaa floor. These have never been studied in detail and the studies of Dubertret (1960) and Haas (1954) are contradictory but the beds are plainly Lower Cretaceous in age. Small occurrences of deformed basal Cretaceous Chouf Sandstone can be found along the road to Haouch Aammiq. Lying just east of them (and possibly also to the west) are ferruginous limestone units of the Abeih Formation. Just in front of Qaalat El-Mdiq can be seen beds of the Mdairej Limestone. Although the geometry and arrangement of these beds is far from clear there seems no doubt that the clays within the Lower Cretaceous make it into an aquiclude and encourage a spring line at this point.

Paleogene

Eocene limestones are found all along the eastern part of the Bekaa and also to the south of the Aammiq area near Mansoura and to north in the Zahle area. It is probable, but unprovable without drilling, that some Eocene carbonates underlie the western Bekaa.

Miocene-Pliocene.

What are probably Late Miocene to Pliocene sediments are known to the south of the Aammiq area (near Kefraya) and to the north (near Zahle). These exist in two types, a coarse limestone conglomerate unit, apparently the product of alluvial fan deposition associated with active faulting, and a finer grained sequence which seems to represent quieter, humid lake conditions. These sediments may also occur here at depth. These represent deposition in a basinal setting after the first phase of regional tectonic activity in the Late Eocene to Oligocene time.

Immediately below Qaalat el Mdiq a small area of lithified alluvial fan fades occurs dipping gently eastwards and unconformably overlying an eroded Mdairej Limestone sequence. The age of this feature is unknown but it appears to be older than the Pleistocene-Holocene alluvial fans on the hillside (see below). It is tentatively ascribed to the Miocene.

Quaternary-Holocene

The final sequence in the Aammiq area is the thick succession of unlithified alluvial and lacustrine clays of Quaternary age that infill the valley floor. There is little firm evidence of either the thickness or the nature of these sediments but, as noted above, a thickness of in excess of one kilometer in parts of the wetland area is probable.

Examination of map data and of some satellite imagery strongly suggests that the extremely flat part of the southern Bekaa was relatively recently a large lake body. This is best seen in the sharp break of slope at the base of the Barouk-Niha and southern Anti-Lebanon Ranges which corresponds to the maximum extent of the alluvium. This is at the 890-900m level along both the eastern and western flanks of the southern Bekaa. The current level of almost all the southern Bekaa in the Qabb Elias-Mansoura area is at 860-870 m altitude, probably reflecting some compaction of sediments in these deeper parts of the basin.

The existence of such a major lake feature in this area has not to my knowledge been previously proposed although there are allusions in Rosenthal et al. (1989) and Besancon (1993). However in a tectonically active intermontane basin such as the Bekaa such a feature is not improbable. All it would require would be some sort of faulting or volcanism to block off the drainage outlet to the south and create a natural dam. The resultant lake would only have been drained when the Litani cut a new channel down through the blockage. Dating this lake feature is speculative as its probably expanded and contracted depending on the climatic fluctuations. It is probable that three main episodes can be identified.

Rosenthal et al. (1989) have suggested that the Litani originally flowed southwards through the Bekaa into the Hula/Galilee area before being dammed by lava flows around 2 million years ago in the Hasbaya area and diverted eastwards through the Litani Gorge towards the Mediterranean. This may have been the main flooding episode coinciding with the start of the Pleistocene glaciations.

A further flooding phase probably occurred during the last or Wurm glaciation which lasted from around 100,000 years until 10,000 years before the present. It is now felt that glacial events like this corresponded in the Middle East to a moist, low evaporation rate climate in which rains occurred all year around (Horowitz, 1989). A final series of wetter episodes have also been identified at later dates in the post glacial Holocene period. Besancon (1993, Table) considers that the Middle and Late Neolithic archaeological periods coincide with a lacustrine episode in the Central Bekaa and this he dates as c. 4500 to 3800 years B.C. This corresponds to a widely known wet period, the so-called Holocene Optimum (Antoun, 1984; Le Metour et al. 1995). Besancon also identifies briefer wet periods between 350 and 50 BC and in the period from 630-1100 AD associated with what he terms the Bahariyet al Biqa'a or the Bekaa Lakes. The well marked, but currently inactive alluvial fans on the mountain slopes (Figure 1) probably date to this time. The Aammiq wetland area seems therefore plainly to represent the last remains of these Bekaa Lakes.

Although without coring the nature of these sediments is uncertain they can be predicted to be a thick sequence of lake sediments with days and peats. Near the Bekaa margin where the old alluvial fans existed the sediments will contain abundant coarse limestone clasts brought in by the alluvial fans. Towards the east, near the basin centre, it is probable that clays and peats will predominate. The almost total absence of quartz bearing sediments in the hinterland (apart from patchy Chouf Sandstone units) suggests that few, if any, quartz bearing sands will occur.

The detailed stratigraphy of the uppermost sediments would be of interest in that it may provide an indication of how widespread any impermeable clays are. Such units may be widespread and homogenous or localised and varied. If these units are discontinuous then it may be easier to preserve as wetlands those areas underlain with clay. On balance the eastern part of the Aammiq wetlands is more likely to be clay rich and to be therefore better at retaining water.

Hydrogeology

The water in the Aammiq Wetlands comes from two main sources.

The average rainfall over the wetland area itself is between 880 and 700 mm a year (Plassard, 1972; Chapond, 1976) and is quite insufficient to support a wetland given the high levels of evaporation over the summer months.

A far greater input of water is from the numerous springs in the area (Haas, 1954; UNDP, 1967; 1970, Besancon 1993). These drain the Barouk slopes where, along the summit, the rainfall is very much higher, c. 1500-1600m a year (Plassard, 1972; Chapond, 1976; Haas, 1954). These springs are derived from the rainfall and snow melt recharge of the fractured and karstified Jurassic aquifers along the mountain hillside. These have an infiltration rate of between 30-50. The area of the aquifer exposed to recharge is difficult to assess but plainly considerable. Haas and others have suggested between 20 and 30 km2. It is notable that Haas in his 1954 report attributed the high water input into the Aammiq area as being due to the dense forest cover. The lost of this density over the last forty years will doubtless have had a major effect on groundwater recharge. Reforestation and slope management (such as subtle terracing) might greatly reduce runoff and enhance aquifer recharge.

A third and probably minor source of water is the Nahr el Hafir which apparently used to drain into the northeastern part of the Aammiq wetlands. This has now been diverted and flows into the Litani without passing through the swamp. The relationship between this and the swamp is unclear. Its polluted state makes it an improbable source for artificial recharge of the wetlands in the future.

The total amount of water output into the wetlands area has not been estimated with any accuracy. UNDP (1970) gives a total average figure of 22 million m3.

Modifying the figures in Haas (1954) to match this suggests a crude breakdown as follows for the four major water outputs into the area .

Ain es Salhouk	1.1 million m^3
Ain el Abed	1.7 million m^3
Ain el Tine	0.9 million m^3
Qaalat el Mdiq	18.5 million m^3
Overall total	22 million m^3

With respect to the water table within the Aammiq Wetlands the level of the water table in late October-early November 1996 appeared to be widely to be at 855-860m, i.e. within a few meters of the Bekaa surface. There may be a gentle slope of the water table downwards eastwards to the Litani River, a phenomena suggested in the maps of UNDP (1967; also used in Besancon 1993). This is confirmed by the development of an all-year-round pool some 2 km to the southeast of Haouch Aammiq at an altitude of c.860m (see Figure 1) which is unmarked on the older topographic maps and which was formed by water infilling a large scale excavation by the Israeli Army in the 1980s. The level of the Litani River in this area appears to be within a few meters of 860m. Within the wetlands it is unclear whether the water table is at a uniform level across the area or is compartmentalised with local highs and lows due to differences in sedimentologv. One interesting feature is the strong evidence that the Lower Aammiq Fault marks the edge of major compartment as it juxtaposes the Jurassic aquifer against the Lower Cretaceous aquiclude. The area immediately north. of Qaalat el Mdiq was flooded in November 1996 although lying several meters higher than the main wetlands area. This suggests that some local compartments may exist.

It should be noted that the drying out of the lake systems of this area reflects —to some extent—natural processes. Lakes are temporary phenomena which are always vulnerable to silting up or drainage as a river cuts down. This is particularly the case with lakes in areas of active tectonism. where there is a regular sediment supply. However it is undeniable that human activity has played a major part in the dramatic recent decline of water levels within the Aammiq area.

The evidence suggests that over the last twenty years the water table has dropped by some 3-4 metres resulting in a substantial water shortfall. Some rough calculations may be useful. The area of the wetlands are around 8 million square meters or a 800 hectares, the water table seems on average 3 meters below the surface in late summer and the porosity of the upper subsurface peats and soils can be estimated to be around 30. On this basis an extra 8-9 million cubic meters of water would restore the wetlands to a waterlogged condition throughout the year. In addition to this enough water would need to be supplied to ensure a continuous balance between water input and water loss. This however is simplistic and neglects losses by evaporation and transpiration.

Other comments

Some interesting and relevant studies have been carried out in the Hula Depression of northern Israel. This area, only some 90km south of Aammiq but at an altitude of near sea level some 800 meters lower was a major lake and wetland complex which drained by early Jewish settlers in the 1950s. That this was misguided from the environmental point of view has long been recognised (see Gabbay, 1992, p. 13). Undesirable effects produced appear to have included soil subsidence, subsurface combustion and leaching of soluble nitrates due to the rapid decomposition of dry peat (Markel et al, 19)7). Recently attempts have been made to restore part of the old Lake Hula to wetlands. This however is a far from simple matter as the drying out of soils produces irreversible changes with the oxidation of organic material and the formation of calcium carbonate and calcium sulphate cements. Fortunately Aammiq has not been so drastically drained and much of the area has not undergone such major changes.

CONCLUSIONS

1. In terms of geology the Aammiq Wetlands area can be divided into three NE-SW strips. The most westerly zone is that of the high Jurassic limestone uplands of Jebel Barouk. This is broken up by a series of at least three NE-SW aligned faults, movement along some of which has given rise to complex folds. This zone is the main area of water catchment for the aquifer although springs occur within it. A narrower central zone occurs of low lying and poorly exposed Lower Cretaceous rocks. These are downthrown against the Jurassic and appear to act as an aquiclude, i.e. a barrier to the water flow. The third area is the area of the wetlands proper in

which only soft Quaternary sediments appear at the surface and are probably at least 1 km. thick. This reflects a series of episodes of lacustrine deposits over the last two minion years.

2. The Aammiq Wetlands reflect the last remnants of a series of bodies of water that once filled much of the southern Bekaa and which have successively shrunk due to natural changes in climate and drainage as well as the progressive infill of the lake area by sediment influx. These natural changes have however been greatly exacerbated by reclamation of the land for agriculture and the diversion of water for irrigation. This decline in the area of permanent open water is plainly visible in a comparison of maps done in 1935 and 1963 with the present day.
3. The Aammiq Wetlands that remain today represent probably a last refuge for many organisms that were once much more numerous in the region, particularly during moister climatic periods of the Holocene and Pleistocene.
4. The present water table, even at the driest time of the year, appears to be only 3-5 metres below the surface. There is little evidence so far of lasting and irreversible loss within the soils of the main part of the Wetlands although without remediation the oxidation of soils will become major issue.

Future work

1. It would be useful to work out a water budget for the wetlands. This would involve calculating the balance of water input for the wetland from various sources and comparing it with losses due to drainage, evaporation, transpiration and pumping. This modeling would allow the definition of exactly how much water needs to be replaced.
2. It is important to test where the water table is precisely across the area and whether there are substantial seasonal fluctuations.
3. The nature of the boundary between the Jurassic and the Cretaceous strata is interesting and further careful mapping work may show the exact nature of the boundary. Geophysical studies across the area might also help to determine the geometry of the fault system. This might help issues of groundwater flow.
4. Ultimately it would be a very valid scientific exercise to try to drill the deepest part of the wetland and to recover continuous cores from this area. These would almost certainly give a detailed record of environmental change over the last two million

years or more. Although an expensive venture (the drilling depths could easily be up to 1.5 km or more) such a project would have significance beyond the region and could probably draw international funding as it would provide climatic data for an area that is very badly known.

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