Geology, Geomorphology and Hydrogeology of El Ga`ab Depression West of the Nile, North Sudan and their Implications to Early Population Settlements in the Area

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Abstract

El Ga`ab depression is an elongated NNE-SSW oriented basin located in the desert west of the Nile. Archaeological surveys have revealed the presence of several Mesolithic (5000-7000 BC), Neolithic (5000-3000 BC), Post-Meroitic, Christian and Islamic sites in the area and currently, the depression is a fertile plain used for agriculture. The objective of the study was to reveal the environmental conditions that made the area favourable for inhabitants to settle over time. Interpretation of remote sensing imagery, geological survey and laboratory analysis of rock and water samples were employed. Geologically, El Ga`ab depression is formed due to structural and erosional effects in the Cretaceous Nubian sandstone and was later, connected to the Nile River through a meandering channel making a fresh water lake. The paleo-lake was filled with over 2 meters thick lacustrine silt transported with water before dry up. Freshwater diatoms and gastropods and remains of fish bones and crocodiles were encountered in these sediments and within the depression. Near surface groundwater is now available that is continuously recharged from the Nile River maintaining good quantity and quality. Lithic tools were found to be made of local and transported geological material. In conclusion, the environmental conditions (fresh water, food and materials) at El Ga`ab depression were favourable to support early human settlements within the area.

KEYWORDS: El Ga`ab depression, Holocene Nile, geology, paleolake, lithic tools

INTRODUCTION

El Ga`ab depression is located west of the Nile River, Northern Sudan extending for more than 100 km in the NNE direction. The area is located within the North African Sahara zone that receives less than 0.1 mm of rainfall annually. It represents the only area in the western desert of northern Sudan that supports life where shallow groundwater and fertile soil exist. The recent inhabitants of the area are El Kababish. They practice both agriculture and animal husbandry. Never the less evidences of population activities could be traced back to prehistoric times. The survey conducted by the team of the Archaeological, Ethnographical and Ecological Project of El Ga`ab Basin in Western Dongola has revealed the presence of several Mesolithic (5000-7000 BC), Neolithic (5000-3000 BC), Post-Meroitic, Christian and Islamic sites in El-Ga`ab (Tahir 2012). The area is also a center of physical therapy as well is an important archeological and tourism site. Nevertheless, the area is known as a source of natural chemicals such as salt and alkali.

A geological survey was conducted in a El Ga`ab in the area bounded by latitudes 19° 17' 7.3'' and 19° 38' 12.54' N and longitudes 30° 7' 31.5'' and 30° 21' 56.94'' E (Fig. 1). It is the first detailed study of its kind in this area. The survey has covered; the main channel, Wadi Al hashsha and some Ga`ab Oasis such as Ga`ab El lagia, Abu Namil and Al mueilih. The main objective of this study was to reveal the geology, geomorphology and hydrogeology of El Ga`ab depression in order to characterize the environmental conditions that have encouraged human settlements in the area since prehistoric times. Other objectives include: the identification of rock types used as Paleolithic tools. It is believed that the physical environment of the depression has contributed to the population movement and human activity in the area over time.

MATERIALS AND METHODS

In the pre-field phase, processing and interpretation of Landsat 7 ETM+ imagery and SRTM generated Digital Elevation Model DEM (90m) were performed for the preliminary identification of geomorphology, lithology and lineaments. Geological survey was conducted in a El Ga`ab depression and the surroundings including landscape observation, description of outcrops and succession of rocks in hand dug borehole sections, rock and water sampling and dip and strike measurements. This was followed by the identification of rock samples and Paleolithic tools, chemical analysis of groundwater samples, preparation of topographic and subsurface sections and finalization of the lithological map of El Ga`ab area. Compilation and integration of spatial data was done using Geographical Information System (GIS).

RESULTS

Geomorphology of El Ga`ab Depression

In the digital elevation model (DEM), El Ga`ab forms a clear depression extending in the NNE-SSW direction for at least 60 km. The elevation ranges between 210 and 225m a.m.s.l increasing from south to north of the depression. The bottom of the depression is at least 10 meters below the Nile terrace west of the Nile. The width of the depression ranges from 6 km in the north close to the Nile to 18 km in the south far from the Nile (Fig. 2).

The gravel sheet covering the Nubian sandstone described by Whiteman (1971) occupies the area between the Nile terrace and El Ga`ab depression. Entrance of the paleo-channel some 50km north of Dongola, can be easily observed in the Landsat image and in the DEM of the study area (Fig. 2). It is formed of a narrow channel dissecting the gravel plain extending 6km west of the Nile terrace. Nevertheless, there is a possibility of at least one more less pronounced paleo-channel connecting the depression to the Nile terrace about 18 km to the south. The main channel meanders and diverges through the depression covering it with the fertile alluvial soil (Barbour, 1961). The channel can also be recognized and traced in the satellite image (Fig. 3).

Regional Geology of the study area

The geology of northern Sudan is poorly studied and only little information has been gathered over the years. Vail et al. (1973) studied the area around the Third Cataract, directly to the north of El Ga`ab area. They concluded that the rocks comprise late Precambrian greenschist facies, metasedimentary and metavolcanic rocks, para- gneisses with rare marbles and amphibolites cut by abundant microgranite dykes. These rocks

were intruded by minor gabbros and large masses of porphyritic and pink granites. Vail et al. (op.cit.) reported the presence of Nubian Sandstone and some Tertiary basalts, and defined at least three phases of deformation that have affected the area.

Sir W. Garstin, in April 1897 commented on the great depression of Dongola province: *it has been thought that this depression might be possibly utilized as a storage reservoir or as a means for escaping the surplus water in excessive flood.* According to Barbour (1961) El Ga`ab depression is covered by fertile alluvial soil and it has been connected with Nile in the past. Recently, Williams et al. (2010) indicated that in the now arid main Nile Valley in northern Sudan there was a significant overflow channel (such as the one run through El Ga`ab) from the early Holocene Nile between 9500 and 7500 BP based on radiocarbon dating evidences. Being part of north central Sudan, the area surrounding El Ga`ab is occupied by the following lithological units: Basement Complex, Younger granite, Nubian sandstone, Tertiary Basalts and Quaternary deposits.

Geology of El Ga`ab Depression

El Ga`ab depression is formed in the Nubian sandstone which underlain the alluvial/lacustrine sediments of the paleo-channel described by (Tahir, 2012) and outcrops bounding the depression at least from the east and west. The depression is most probably formed by down faulting or synclinal folding. The geological map of the Sudan (1981) 1:2,000,000 indicated an uncertain fault line bounding the gravel plateau to the west. Similar structural explanations were used by Whiteman (1971) to interpret the occurrence of Nubian sandstone outliers in the bend of the Nile near Kaibar Cataract. He provided an explanation that the basement rocks form part of an undulating topography and that their relation to the Nubian formation is strongly non-conformable. However, in this study no field evidence was found to support this assumption. Elevation data extracted from the digital elevation model (DEM) and from open hand-dug borehole sections were used to construct E-W and N-S sections of the Nubian sandstone surface of El Ga`ab depression (Fig. 4). The east-west section clearly portrays a typical depression profile having over 15 meters difference of surface elevation. The north-south section on the other hand indicates the undulation of Nubian sandstone surface with a general decrease in elevation from north to south. Following, is the description of the main lithological units observed in El Ga`ab depression and mapped based on the interpretation of satellite imagery and field survey (Fig. 3).

Cretaceous Nubian Sandstone

As mentioned above, Nubian sandstone covers the base of El Ga`ab depression underlying the fluvial sediments of the paleo-channel (Plate 1) as well as 1 to 6 feet thick skin of coarse, rounded, predominantly quartz gravel -the provenance of which is uncertain- according to Arkell (1949). In the upper part of the depression (wadi section at Al Hashsha), it is formed of medium to fine grained cross bedded sandstone ranges in colour from white to yellowish brown to buff or red depending on the cementing material (e.g. kaolinitic or ferruginous). In the exposed sections of hand dug wells, it is found below unconsolidated silts 1~2.5 meters thick. Moving southward, following the channel course, the thickness of the top silt cover decreases to less than 1m and finally the sandstone crops at the surface close to Ga`ab El lagia village (12 km south of the channel entrance) . The outcropping sandstone is white dark gray or buff course to medium

grained with dark reddish bands of ferricrete and some times well developed iron concretions. These iron rich sandstone forms the top surface of low lying as well as hilly outcrops around the depression. It is thought to be formed by the percolation of iron-rich solutions derived from the iron-rich Nubian formation which has been stripped off. They may belong to recent concentrations of iron in the Nubian formation itself when making hill tops or to lower parts of enrichment zones when topping low relief surfaces. No such layer of iron-rich sandstone was observed in the Nubian found below the alluvial sediments in borehole sections.

The Nubian sandstone is horizontally bedded to slightly dipping (~ 25°) affected by minor faulting in some places identified in the field by breciation, ferrugination and kaolinatization. Silicified wood (tree trunks) was found strewn on the surface extending for 1 km to the west interpreted as a fossilized forest. Plant cover during the Cretaceous was limited to Xerophilous plants while grasses have not yet established themselves. The climate must have been wet enough to flush soil and prevent formation of saline lakes (Whiteman, 1971).

Tertiary Basalts

In the study area, volcanic necks –mainly of basalt- were found cutting the Nubian sandstone in many locations forming hilly outcrops standing, sometimes, up to 70 m above the surrounding plain. In the infrared colour composite imagery it appears dark brown to black in colour surrounded by a dark gray hallow of basalt floats liberated by erosion. Whiteman (1971) reported Tertiary basalts north of Dongola dated as Turonian or earliest Senonian. The basalt forms dark gray to bluish black vesicular bouldary outcrops such in J. Koya -which is used to produce crushed aggregates for construction- , J. Akkad, J. El hashsha and J. El lagia.

Quaternary Deposits

The Gravel plain**:** covers the Cretaceous Nubian sandstone east of El Ga`ab depression appears in the infrared image buff in colour extending approximately in a north-south direction parallel to the Nile River. It is formed of well coarse, rounded predominantly quartz gravels with abundant agates consistent with volcanic sources probably from local basalts or more distal Ethiopian source from the Blue Nile according to Williams et al. (2010).

Lacustrine silt of paleolake: El Ga`ab depression is filled with lacustrine silt varying in thickness from 3 meters close to the mouth of the paleo-channel in the north, to less than 20 cm at the far southern edges of the basin (Plate 1). In the northern part the silt is inter-bedded with gravelly or pebbly silt which disappear southward of the basin. It could be washed out from the gravel plain by the paleo-channel connecting the depression with the Nile. The silt is rich in both diatom frustules and freshwater gastropod shells mainly (*Melanoides tuberculata*), according to Williams et al. (2010) (Plate 1). The gastropods have calibrated radiocarbon ages of 10.1 kyr near the base of the silt and 7.9 to 7.4 kyr near the top. The diatoms dominant species is *Aulacoseira granulata*, a taxon common in the upper Nile and one that especially favours turbid conditions (Williams et al. 2010). Nevertheless, during field survey Nile fish bone remains were also encountered (Plate 1). The remains of Nile crocodile were also discovered by Archeology team of the project. South of the depression, at Ga`ab Abu

Namil, the lacustrine silt is found as a thin (30 cm) light calcrete surface layer (caliche) white in colour showing mud cracks probably formed by the dissolution and concentration of diatom shells made of $CaCO_3$ and their ultimate mixing with fine silt material. All of the above mentioned evidences indicate that El Ga`ab depression was once connected to the Nile during Holocene through the paleo-channe that must be formed by faulting (straight and short course). On the Landsat imagery another paleo-channel less pronounced but more meandering can be seen about 18 km to the south of the main one.

Windblown sands and Nile silt: the whole area is affected by desert encroachment especially in the south and southwest of El Ga`ab (e.g west of Ga`ab Abu Namil where sand duns cover the undulating pediment interrupted by isolated hills. East of Ga`ab El lagia village one sand dune named locally as Qoz Alaafia is used for physical therapy.

Hydrogeology of El Ga`ab Depression

The fertile alluvial silt of El Ga`ab depression has been cultivated utilizing the near surface fresh groundwater. Conventional agriculture has made use of hand dug wells taping groundwater table few meters below the surface while large mechanized agriculture introduced pivot irrigation system by drilling deeper wells. The major groundwater aquifer is typically the Nubian sandstone. In the current study 21 water wells were visited, exposed sections were studied, depth to water table was measured or approximated and some water samples were collected for chemical analysis. In the northern part of the depression the water table is deeper than in the southern part for example at Ga`ab El lagia village and Ga`ab El muelih the water table is seen two meters below the surface the Nubian sandstone at that point exposes at the surface. The Nile River represents the main recharge zone since there is no appreciable recharge from rainwater and the water table therefore, forms a smooth sloping surface westward. Accordingly, considering the N-S elongated depression of El Ga`ab parallel to the Nile River the varying depth to water table from north to south must be topographically controlled. The hydrogeological map of the Sudan (1989) indicates El Ga`ab depression as a discharge zone and a groundwater flow from the southwest and southeast (Nile River base flow direction). The north-south section was constructed from the borehole sections and digital elevation data of El Ga`ab (Fig.5) is in good agreement with the hydrogeological map of Sudan (1989).

Thirteen groundwater samples, 12 from El Ga`ab depression and one from Mashsho village -close to the Nile River- (for comparison) were analyzed for physical properties, major constituents and some minor constituents in the laboratories of the General Directorate of Groundwater and Wadis. Three samples (G006, G013 and G053) showing high TDS, sulphate and sodium were considered unfit for drinking according to the Sudanese Standards. Elevated TDS values exceeding 1500 mg/l could be attributed to contamination from superficial deposits (Whiteman, 1971). Subsurface sections of borehole number G006 and G013 indicate the presence of alluvium silt over 2 m in thickness which may provide potential contamination source of groundwater by percolating irrigation water. Nevertheless, movement of water along flow direction from recharge zones implies addition of dissolved minerals due to rock-water interactions. Borehole number G053 is an open hand dug well at Ga`ab El muelih having a very shallow groundwater table (~2 m below the surface) therefore it is more prone to surface

contamination as well as being subject to more evaporation due to absence of silt cover. Table 1 displays a statistical summary of the chemical analysis of the 12 groundwater samples from El Ga`ab.

Description of Lithic Tools

The second objective of this study was to identify geological materials used to make lithic tools by ancients. Lithic tools (Plate 2) were made of rocks found within El Ga`ab area and others were transported from as far as the Third Cataract (Table 2). The property of the geological material dictated its usage as a lithic tool. Table 2 provide a brief description of the different rock types used for making lithic tools as indicated by the archeological team.

DISSCUSSION AND CONCLUSIONS

El Ga`ab depression is an interesting archeological and environmental site rich in evidences that could be used to elucidate paleo-environment and paleo-climate of the region. Physical as well as biological factors could be closely linked to each other and to human activities in the area during Quaternary.

The geology and geomorphology of the basin allowed the formation of El Ga`ab depression which obviously has been linked to the Nile River through some channels. According to Williams et al. (2010), the now arid main Nile valley in northern Sudan was characterized by a significant overflow from the Early Holocene Nile between 9500 and 7500 BP. Therefore, El Ga`ab depression must have formed a large lake full of freshwater dwellers (fish, crocodiles) and was fed by silt rich in diatoms and freshwater gastropods. These conditions were favourable to support human settlements within the area (fresh water and food). Early inhabitants have used local and transported geological material to make tools for different purposes. Currently, the area represents a fertile plain rich in near surface groundwater of good quality providing optimum conditions for successful agricultural activities. The groundwater is continuously recharged from the Nile River maintaining good quantity and quality. El Ga`ab has been already occupied by the -previously-nomadic tripe El Kababiesh practicing traditional agriculture (mataras). Large scale mechanized agriculture has been also introduced in the area where caution must be taken in consideration of un-controlled use of pesticides and fertilizers. Other resources include the use of basalt as a construction material. Recently, artisan gold mining activities are practiced west of El Ga`ab with many new comers invading the area brining about different kinds of chemicals that may endanger the rich soil and groundwater resources of the area.

Geophysical survey, mainly gravity, is needed in order to identify the subsurface basin configuration a thing which will shed lights on the formation history and development of the basin. Advanced remote sensing study utilizing RADAR data may provide clear insight of the groundwater basin and paleo-channels and their potential link to other hydrological systems in northern Sudan such as Wadi Hawar.

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Table 1. Results of groundwater chemical analysis results of 12 water samples from El Ga`ab.

Parameter	Minimum	Mean	Maximum	STD
EC µs/cm	377	1010.6	2720	839.9
pH	7.6	7.8	8.3	0.17
TDS (ppm)	263.9	704.1	1904	590
T Hardness(ppm)	152	207.5	434	86.5
HCO_3 (ppm)	146.4	181	207.4	20
CO_3 (ppm)	0	20.9	245	70.6
Cl (ppm)	0	54.7	245	81.1
SO_4 (ppm)	14	125.7	500	151.6
Ca (ppm)	32.8	49.7	125.6	26.9
Mg (ppm)	14.6	20.5	34	6.3
Na (ppm)	18.3	115.9	386	122.2
F (ppm)	0.2	0.7	1.1	0.27
NO_3 (ppm)	0	6.2	26	8.1
NO_2 (ppm)	0	0.06	0.15	0.043
NH_4 (ppm)	0	0.5	5.6	1.6

Table 2. Description of Lithic tools made of geological materials

Local geological materials			
Name	**Type**	**General properties**	**Tool type**
Ferruginated sandstone	Sedimentary rock	Dark red in colour, iron rich (hematite), high specific gravity, very resistant	Grinders
Siliceous sandstone	Sedimentary rock	Light colour, silica-rich, very hard, resistant, medium specific gravity	Grinders, millstones, Building stones
Silicified wood	Fossil wood	Light brown, smooth surface very resistant, gives sharp edges when broken	Cutting tools
Basalt	Volcanic rock	Dark colour, high specific gravity	Grinders
Quartz gravels	Silicate mineral	Light coloured, very hard	Accessories
Transported geological materials			
Name	**Type**	**General properties**	**Tool type**
Green schist (green stone)	Metamorphic rock	Pale green, high specific gravity, compact, hard and resistant	Grinders
Chert	Sedimentary rock	Light red, silica-rich, very hard (hardness 7), smooth, less splintery, low specific gravity, wax resinous luster, gives curved concoidal fractures	Cutting and puncturing tools
Quartz	Silicate mineral in	Light colour, very hard, glassy	Puncturing tools

	the form of veins	luster	

Figure and Plate Captions:

Fig. 1. Location map of El Ga`ab depression.

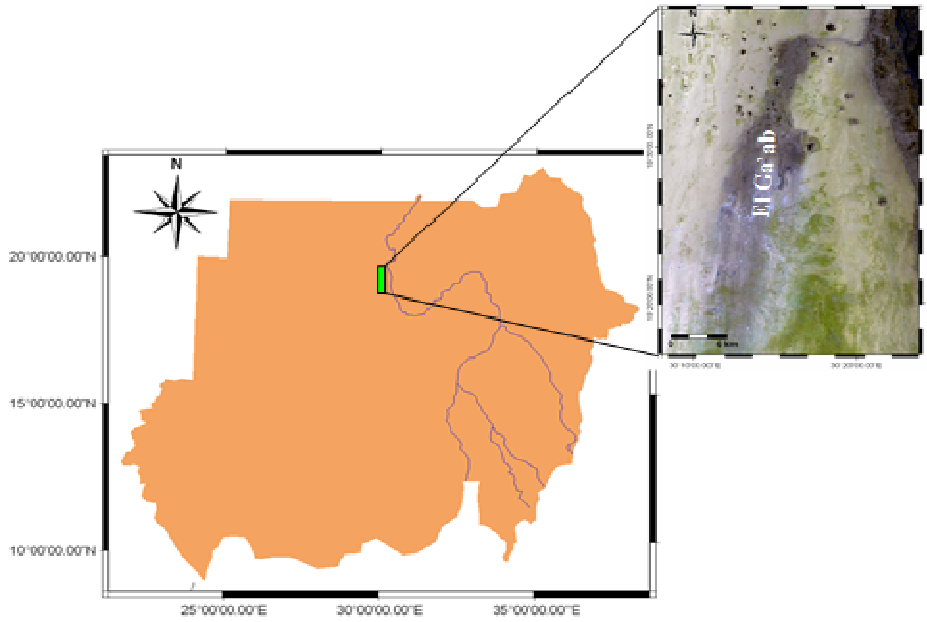

Fig. 2. On the left the digital elevation model of El Ga`ab depression. Diamonds indicate observation sites. On the right the topographic sections of El Ga`ab depression.

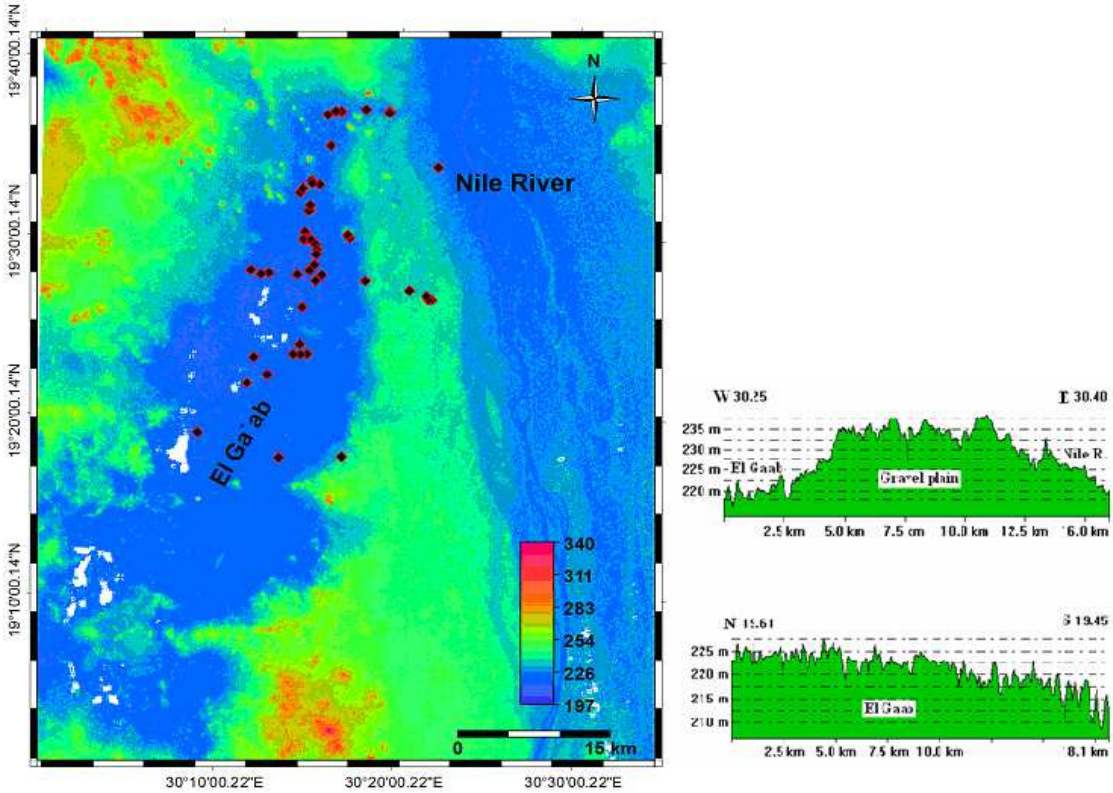

Fig. 3. On the left, infrared colour composite of (754, RGB) Landsat ETM+ image. On the right, the lithological map of El Ga`ab depression.

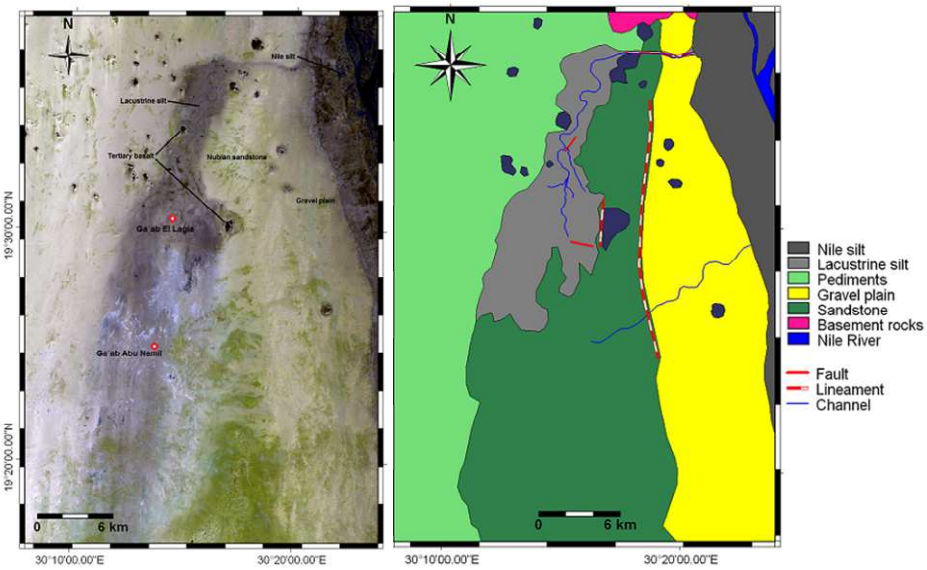

Fig. 4. East-west and north-south topographic sections of the Nubian sandstone surface of El Ga`ab depression.

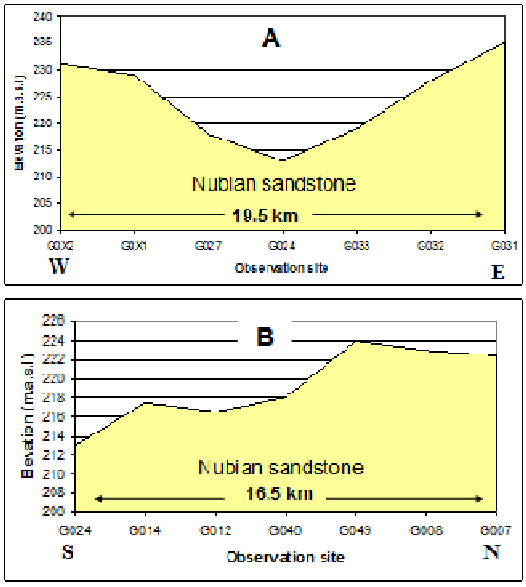

Fig. 5. A north-south section of the surface topography and water table level at El Ga`ab depression.

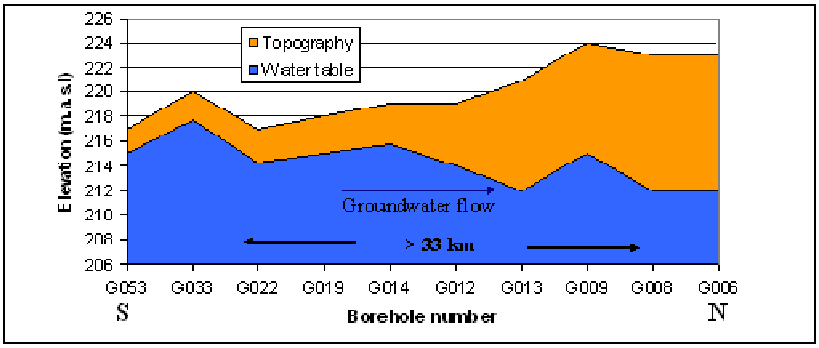

Plate 1. On the left a section of hand dug well at Al Hashsha area (the scale is 1m length). On the right the lacustrine silt rich in fresh water gastropods, diatoms and Nile fish bone remains.

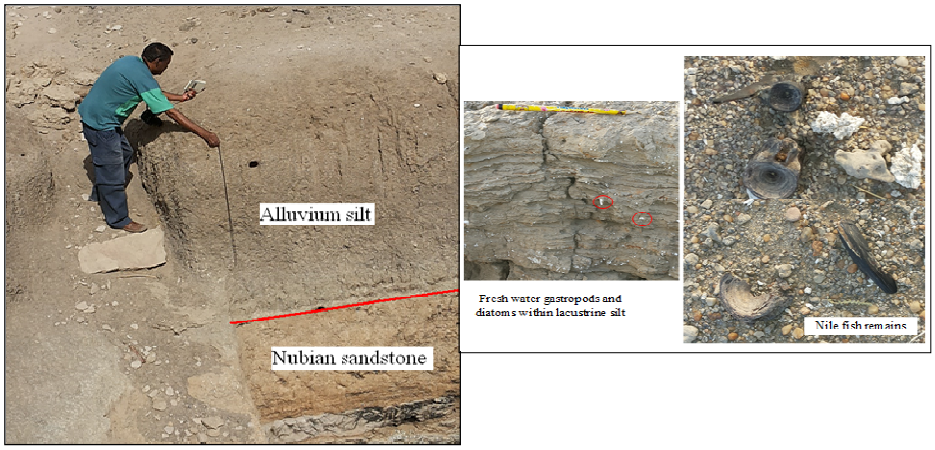

Plate 2. Geological material of lithic tools encountered at El Ga`ab area.