Original Research Article

Holocene Lacustrine Environment in the Western Eritrea-Evidence from Freshwater Shells

ABSTRACT

This study focused on Holocene paleoclimatic changes using evidence of freshwater shell in western Eritrea. Four species were distinguished from calcareous sediments at the bank of a tributary river named Shatera River, within the license of Bisha Mines. The ^{14}C age dating result of shell *Indoplanoribs exustus* and *Bulinus globous* showed (9326-9134 cal yr BP) and (9134-8999 cal yr BP) respectively, of which are in the mid-Holocene epoch (11,000–5000 yr BP). This epoch is best known for it was a time when the northern and eastern part of Africa experienced a warm and humid climate. Among the freshwater shells, the existence of *Melanonids tuberculate* makes it more significant, for its widespread occurrence in Quaternary deposits throughout Africa and Asia in both fresh and highly evaporated lakes. This is suggestive of the considerable development of the lacustrine environment in the western part of Eritrea, which at present has disappeared.

Keywords: Holocene, freshwater shell, lacustrine, sedimentary sequences, climate change

1. INTRODUCTION

Fossil evidence is important for the determination of age, sedimentary environment and understanding of paleoclimate. The occurrence of a fossil of fresh water shells (snails) is direct evidence of a lacustrine environment [1,2] and the development of such basin during geologic time. Exposure of bank sediments along some of the tributary rivers in western Eritrea is where fluvial and lacustrine sedimentary sequences developed. Along the banks of one of these rivers, calcareous muds yielded freshwater shells. Reports on the freshwater shells are rare in northeastern Africa and this discovery is useful for the reconstruction of paleoenvironmental changes [3]. Freshwater shells are considered highly sensitive to hydroclimate fluctuations and can record abiotic factors such as water chemistry, depth and turbulence [4,5,6,7].

2. MATERIAL AND METHODS

2.1 Study Area

2.1.1 Geography and Geology

Eritrea is situated in the northeastern part of Africa (Fig. 1). The topography of this country varies in altitude ranging from 60 to more than 3,000 meters above sea level. Eritrea has a variety of climate conditions that range from hot and arid near the Red Sea to sub-humid in isolated micro-catchments along the eastern escarpment, and the central highlands with a pleasant climate. the western lowlands have a comparable climate with the coastal area and December is the coldest month [8]. The mean annual rainfall in the coastal areas is less than 300 mm per year, while in the highlands and the western lowlands, it ranges between 500 and 1,000 mm [9]. The Barka River is one of the major rivers which runs from the highlands to the eastern coast of Sudan (Fig. 2). Several streams flow seasonally eastward from the plateau to reach the sea on the Eritrean coast [9].

Geology of Eritrea comprises of Precambrian basement rocks which cover about 60% of the surface and are unconformably overlain by predominantly Mesozoic sedimentary rocks, and Tertiary to Quaternary volcanic-sedimentary rocks [9]. The major part of the Precambrian rocks consists of Neoproterozoic (ca. 870-670 Ma) continental-marginal and juvenile intraoceanic magmatic-arc rocks. The Neoproterozoic basement rock has been divided into four terranes based on their distinct stratigraphic and structural characteristics [10], namely Barka Terrane, Hagar Terrane, Nakfa Terrane and Arag Terrane (Fig. 1). While the southeastern part of the country, the Danakil segment, and the northeastern part of the country, consists of Cenozoic volcanic and sedimentary rocks [10].

The western segment of the Barka Terrane developed in the north-western part of the country underlies the Barka lowlands (Fig. 1). It comprises amphibolite, amphibolite-facies pelitic schists containing kyanite and staurolite, quartzites and marble [10,11].
The central segment, the Hagar Terrane (Fig. 1), contains dominant mafic igneous rocks with various types of meta-igneous and meta-sedimentary rocks [12]. Occasionally, layered chloritic schists occur with epidotic and chloritic meta-basalts. The Hagar Terrane displays an east-verging thrust contact with the adjacent segment to the east. Chromite, platinum group elements, nickel, gold, and copper mineralization are the prospective minerals in this terrane [9].
The eastern segment, Nakfa Terrane (Fig. 1), is made up of granitoid-greenstone belts and syn- to post-tectonic granitoid rocks, varying from gabbro to syeno-diorite to granite [11]. The western Nakfa Terrane, near Bisha Mine (Fig. 1), comprises basin and range style topography with intrusive rocks and a flat valley floor underline by volcanic and sedimentary rocks [10]. Rock exposures in the valley floor are generally limited to the bases of the adjacent hills [10]. The Nakfa Terrane is the largest of the four Terranes, and it is considered to be a relict of island arc assemblage. Several volcanogenic massive sulfides (VMS), base-metal deposits and gold ores occur in this tectonic unit [10].
The Arag terrane (Fig 1) is bounded to the east by several Late Tertiary rocks, which consists of granitoid and metasedimentary rocks [12,13].
The southern segment, the Danakil Terrane (Fig. 1), is composed of metamorphic rocks, which may be grouped into three formations; hornblende biotite gneissic formation, a phyllitic formation consisting of schists, conglomeratic phyllites, crystalline limestones, and graphitic schists; and the third formation is Post-tectonic granitoids [9,10].

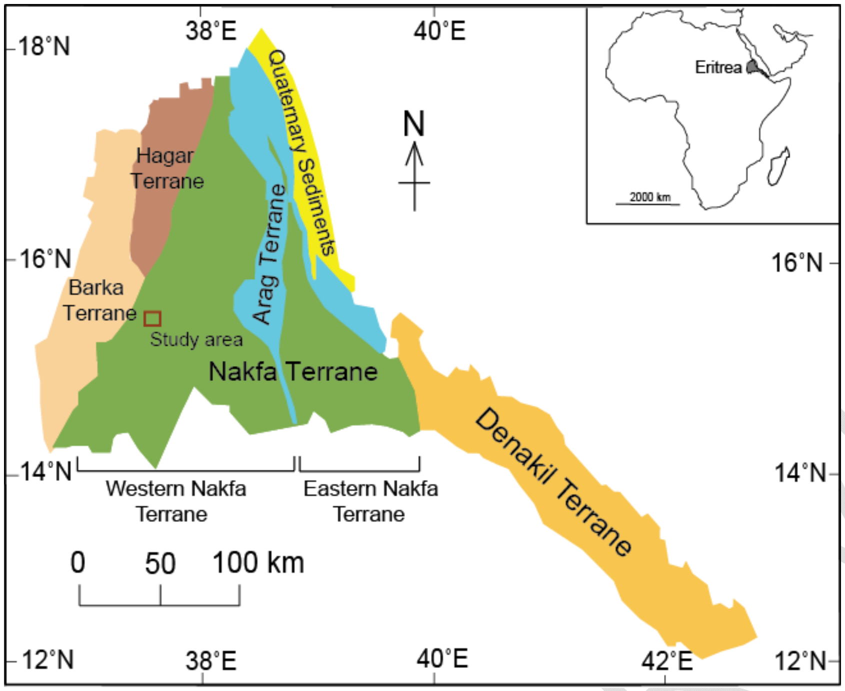

Fig. 1. Map of the study area with Index map of Eritrea showing geologic terrane division [10]

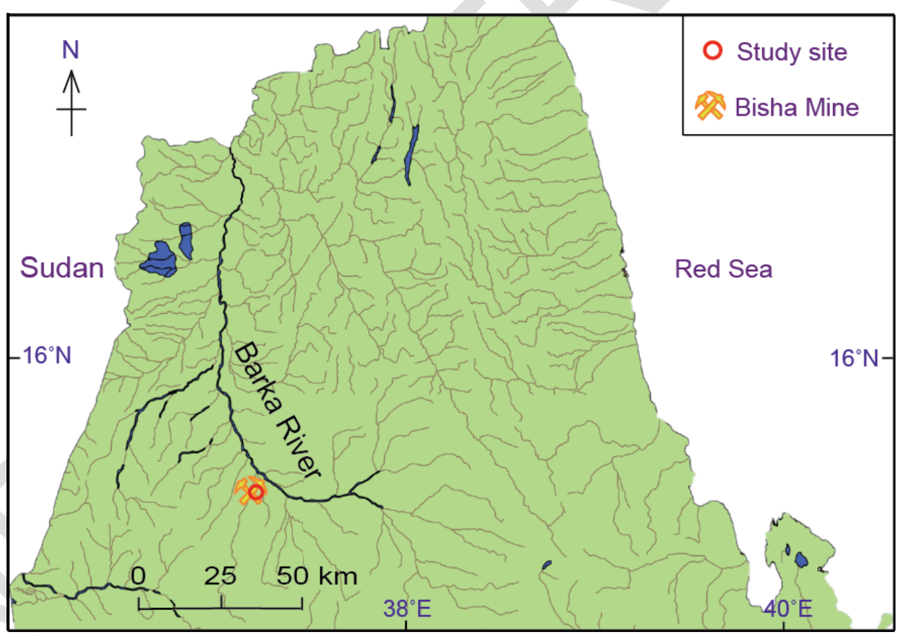

Fig. 2. Topographic map showing Barka River and the location of the study area. Generated using QGIS, 2018

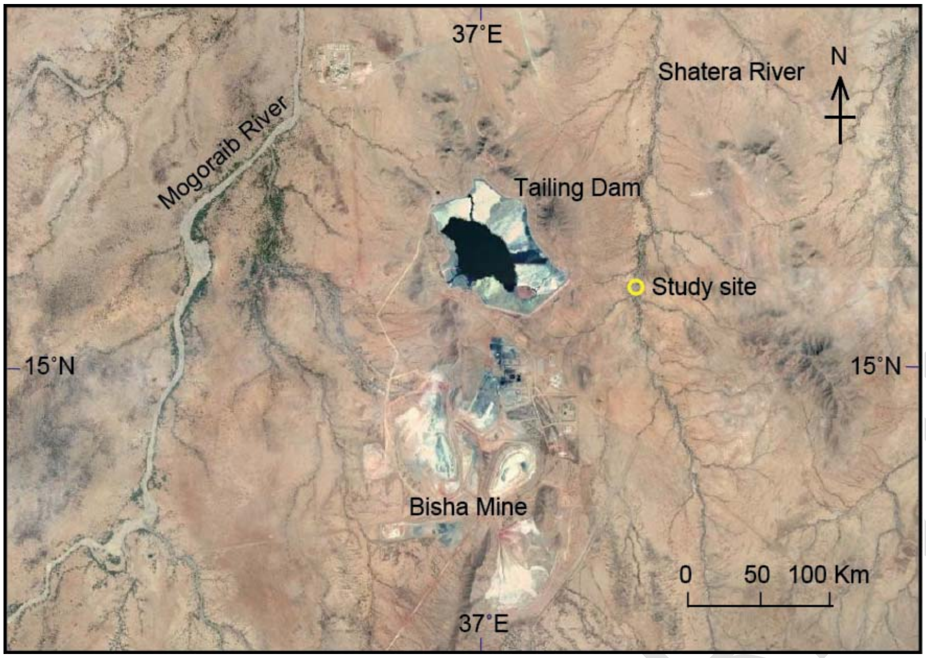

Fig. 3. Satellite image of the study area within Bisha Mine (Google Earth, 2018)

2.1.2 Stratigraphy

Freshwater shells occur in calcareous mud intercalating fine-grained sand in conglomerate (Fig. 4), at the riverbank of Shatera River (Fig. 3). This conglomerate consists of angular pebble and cobble within the poorly sorted coarse sandstone. Conglomerate clasts are mainly basic rocks and quartz grains. Shell-bearing bed show light color yellowish grey (10 YR 6/2 of Mansel soil color chart). The bed forms a lenticular body of which thickness decreased laterally rightward (from north to south) from 1 m to 20 cm (Fig. 4). This shell bearing bed changes to poorly sorted sandy silt laterally, which is overlain by massive sandy silt and further by alternating beds of fine-grained sand and mud. Fine-grained sand is characterized by parallel lamination. Shells can be mainly distinguished into two types, elongated conical shell and ovoidal shell which are described below. Elongated and ovoidal shells sporadically occur in the bed, and conical shells occur parallel to the stratigraphic plane (Fig. 5). Ovoidal shells are arranged in the bed of which some are with their apex obliquely upward (Fig. 5). Disk-shaped shells were not common among the observed shells on the mud surface as indicated by the arrow in Fig. 5.

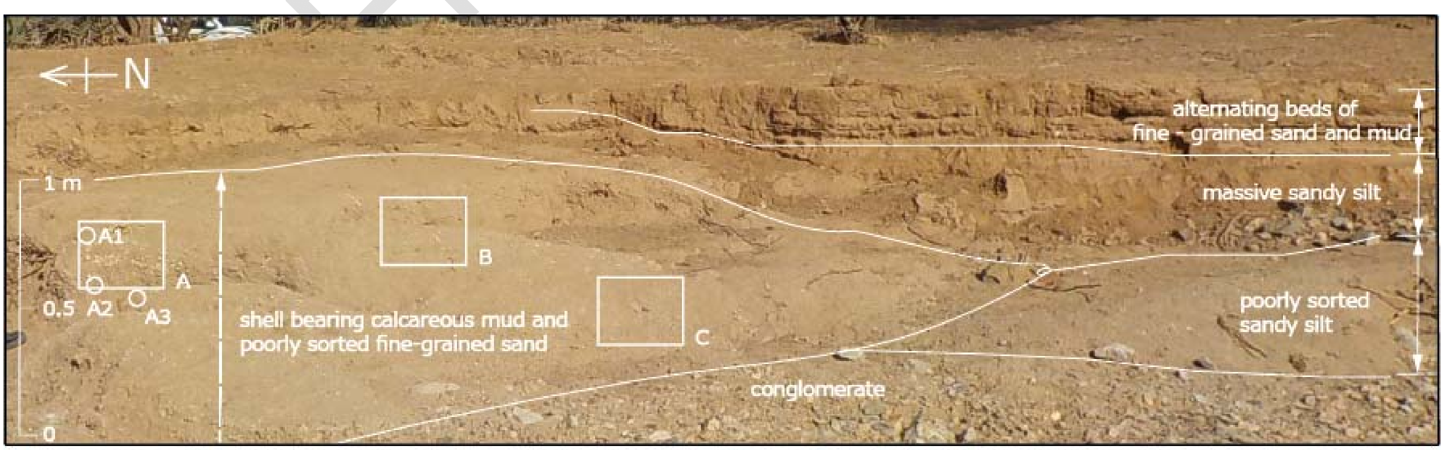

Fig. 4. Image showing outcrop of freshwater shell bearing bed (Loc. SW 6 in Figs. 2, 3) within Bisha mining area, Eritrea. A, B and C are indicating shell sample collections of which species and numbers are given in Table 1. A1

in A is for detail shell examination and A1, A2 and A3 are calcareous mud samples collected for geochemical analysis of which the results are indicated in Table 3.

Fig. 5. Closeup picture of locality SW6 showing the mode of occurrence of shells at A1 (Fig. 4).

2.2 Sample Collection and Preparation

2.2.1 Shell Collection

The freshwater shell samples were collected from three points; A, B and C (Fig. 4) from Shatera Riverbank (Fig 3), (N 15˚31'44.21" and 37˚31'24.16"). Besides this, mud of about 263 g was collected from sample point A. These samples were packed in a plastic bag and put in a plastic box, then imported to Shimane University, Japan for analysis. These samples were imported under the permit of the Ministry of Agriculture, Forestry, and Fisheries in accordance with the Plant Protection Law, Japan. Mud sample of about 200 g was softened by water to observe the abundance of the shells within the mud. Relatively larger shells were collected in the field while tiny shells in the laboratory after softening sediments by water. From the collected 3 samples, one-point sample (A1 at SW 6 in Fig. 3) was suitable for the determination of species because of better preservation. Species name and numbers are indicated in Table 1. Smaller shells dominated in A1 (Table 2).

2.2.2 Calcareous mud sample Collection and Procedure for Geochemical Analysis

Calcareous mud samples A1, A2, and A3 were collected from sample point A (Fig. 4), from Shatera Riverbank. About 200 g calcareous mud samples were packed in plastic bags and imported to Shimane University, Japan for analysis, under the permit of the Ministry of Agriculture, Forestry and Fisheries. Approximately 50 g of each mud sample was dried in an oven for 48 hrs at 160°C to remove weakly-bound volatiles. The dried samples were then grounded for 20 min using automatic agate pestle and mortar grinder. Then for XRF analyses about 5 g of the powdered samples were compressed into briquettes by a force of 200 kN for 60 sec in line with the method of [14]. Average errors for all elements are less than ±10% relatively. Analytical results for GSJ standard JSl-1 were acceptable compared to the proposed values of [15].

Table 1: List of freshwater shell species collected in the field from A, B, and C of Fig. 4 within the Bisha mining area, Eritrea.

Species name	Point A	Point B	Point C
Melanonids tuberculate	9	7	4
Bulinus globous	7	4	6
Indoplanoribs exustus	1	1	0
Total Number	17	12	10

Table 2: List of freshwater shell and their numbers distinguished from calcareous mud mud sample from A1 (Fig. 4) within the Bisha mining area, Eritrea.

Species name	A1
Melanonids tuberculate	40
Bulinus globous	26
Indoplanoribs exustus	56
Bivalve	2

2.3 ^{14}C Dating

The ^{14}C dating was carried out using *Indoplanoribs exustus* and *Bulinus globous* shells (Table 3). The analysis was done using AMS in GEOSCIENCE LABORATORY, Nagoya Japan.

2.4 Geochemical Analysis

Abundances of selected major elements (Fe_2O_3* (total iron expressed as Fe_2O_3), MnO, CaO and P_2O_5) and TS (total sulfur) of the calcareous mud samples (A1, A2, and A3 in Fig. 5) were determined by X-ray fluorescence analysis (XRF) in the Department of Earth Science, Shimane University, using a Rigaku Co. Ltd. RIX-2000 spectrometer. Analytical results are indicated in Table 4.

3. RESULTS AND DISCUSSION

3.1 Shell Description

The shell of *Melanoides tuberculate* has a dextral turreted and is 5-17 in mm long with a pointed apex and 2-5 in mm wide for specimen SW 6-A1 (Fig. 6). The aperture is almost oval and broadens as it goes down to the basal margin of the shell.

This species has five to six angular whorls. The inner lip is inconspicuous due to filling by sediments. The sculpture of the shell consists of a parallel row of tubercles of various sizes forming fine transverse lines. Generally, the *Melanoides tuberculate* shells are of various sizes but have the same shell morphology of the proportion. The occurrence of *Melanoides tuberculate* in the surface of the calcareous mud is higher compared to other species. Living *Melanoides tuberculate* is known to burrow through lake deposits during the day time and come out to feed in the night. They are carnivorous and avoid strong current by inhabiting near the banks of freshwater [16].

Shells of *Bulinus globous* are oval, whitish in color, has a large aperture with two whorls on their body. Shell length is 5-10 mm while the width is 3-7 mm. The sculpture of the shell consists of faintly growth lines. It has a short conic spire and its coiling direction is sinistral. The columella of the shells is a bit thin and the inner margin is somehow straight. In some of the shells, the apex is a pit and some are very obtuse.

The disc-shaped *Indoplanoribs exustus* shells have a length that ranges 2-10 mm while the width is 1.4 - 10 mm (Fig. 6). These shells have a dextral coiling direction and whitish in color. The upper side of the shell is evenly rounded, while the back side, the apex is deep but as more whorls grow, it widens up evenly. The number of *Indoplanoribs exustus* increases within the mud. This is because they have invasive nature and ecological tolerance [17] in which it can survive during dry season mingling in the mud.

The Bivalve shell is 5 mm in width, whitish in color, spherical in shape and consists of equal right and left valves. The shell sculpture has faint traces of the growth line. The Bivalves were only found buried within the mud. Freshwater bivalves can occur in all latitudes and depth as well as can withstand drought conditions [18].

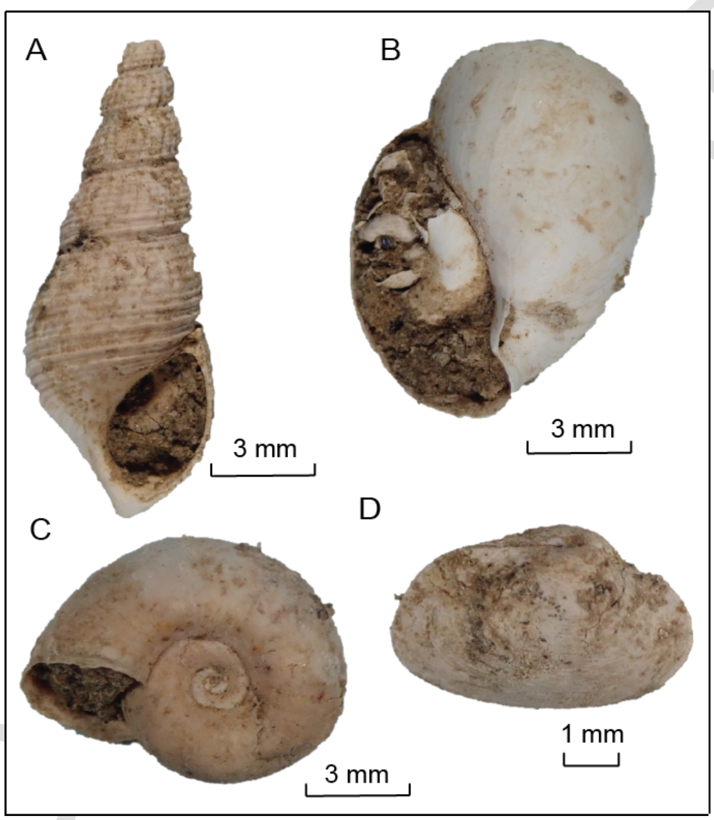

Fig. 6. Photos of four species of freshwater shell from A1 at SW 6 within Bisha mining area, Eritrea. A; *Melanoides tuberculate,* B; *Bulinus globous*, C; *Indoplanoribs exustus*, D; Bivalve.

3.2 Significance of Freshwater Shells

Well-preserved shells from western Eritrea clearly demonstrated taphonomy of freshwater mollusks. Shells are thin and fragile and are rarely preserved since they usually transport by the water current. Thus, shells reported in this paper could be considered as autochthonous (in situ burial). The abundance of *Melanonids tuberculate* at the surface of the calcareous mud was more compared to the other species. After washing with water, *Indoplanoribs exustus* were found to be more abundant (Table 2), and their sizes were less than 7 mm. The other species were found to have relatively lower concentrations in the mud samples. Bivalve shells were found to occur closed in the left and right valves. This strongly suggests that they were buried alive. Shell preservation is occasional, and shell bed in the fluvial coarse-grained sediments is very rare. The discovery of shell bed suggested the possibility of a wider distribution of lacustrine deposits in western Eritrea. The results of the ^{14}C dating of both *Indoplanoribs exustus* and *Bulinus globous*, show 9326-9134 cal yr BP and 9134-8999 cal yr BP, respectively (Table 3). These ages signify the mid-Holocene Epoch, and after 5000 yr BP drastic climatic change was inferred [6]. A number of studies have been carried out on the impact of climatic change after the mid-Holocene Epoch in the East and North African countries by examining Holocene freshwater shells. From the previous data compiled by [19], numerous paleoclimatic data show that in parts of tropical Africa precipitation increased in the early to mid-Holocene which produced the well-documented greening of the Sahara and Sahel, and large lakes of the Holocene have now disappeared in the northern Africa, where higher water levels throughout East Africa were estimated. The discovery of these shells and their ^{14}C age confirmed the existence of a lake in western Eritrea during the mid-Holocene epoch.

Fossilized freshwater shells were widespread in tropical and sub-tropical Quaternary deposits [20]. The presence of *Melanonids tuberculate* is important as they were reported to have occurred in the Quaternary deposits throughout Africa and Asia, in both fresh and highly evaporated lakes [21]

Table 3: Result of ^{14}C age dating for the two samples of freshwater shell from A1 (Fig. 3) within the Bisha mining area, Eritrea.

Sample ID	Shell species name	Type of material	$\delta^{13}C$ (‰)	Conventional age (yr BP)	Calibrated age (2σcal BP)	Probability
1a	*Indoplanoribs exustus*	Shell	-6.06	8270 ± 30	9326-9134	95.4%
1b	*Bulinus globous*	Shell	-4.27	8130 ± 30	9134-8999	95.4%

Lacustrine deposits are possibly the most powerful basis for integrated insight into the past ecosystems of the world [22]. In contrast to colluvial and alluvial deposits, many lake sediments are characterized by a more or less continuous sedimentary record of the past [23]. Lacustrine deposits are been studied by sedimentological, biological, geochemical and geophysical analyses for quantitative reconstructions of processes of the lakes [24]. The depositional history of lakes is highly sensitive to the interaction of humid and arid climate conditions [25]. Fossil-rich sedimentary deposits provide evidence of the geologic record that often hold chronostratigraphic significance [2]. Fossils of freshwater mollusk shells are among the most common macrofossils from Quaternary lacustrine sediments, which are abundant in calcareous sediments under non-acidic waters [26].

Geochemical composition of calcareous mud samples (A1, A2, A3) showed higher carbonate ($CaCO_3$) contents with Sr contents (Table 4) compared to PAAS and UCC composition [27], suggesting enrichment of carbonate matter in this bed. Significantly lower TS (total sulfur) contents showed non-marine depositional condition for the shell bed. Fe_2O_3 contents have slightly higher values than these standards (Table 4) indicating oxic sedimentary conditions. However, MnO and P_2O_5 contents are similar to those of the standard values suggesting a common composition of sediments.

Table 4. Geochemical analysis for the calcareous mud (A1, A2, and A3) from A and soil color in Fig. 3 within Bisha mining area, Eritrea. PAAS and UCC compositions [27].

3.3 Holocene Climatic Change and Palaeo-Geography

The mid-Holocene epoch is known as a time when the average temperatures reached the maximum level [5,7,28]. Proxies for rainfall suggest that there was a shift from a predominantly wet episode, known as the African Humid Period (AHP) to dry conditions of the post ca. 5.5 ka [5,7,29,30] in the parts of the northern, eastern and greater Horn of Africa. This African Humid Period came to an abrupt end around 5.5 kyr cal BP [31]. Although the AHP was variable in temporal and spatial distribution, plant and animal communities reorganized into new ecological niches [32,33,34]. The abrupt AHP termination yielded a non-linear, positive biogeophysical feedback between vegetation and precipitation in the Sahara region. The topography of the western part of Eritrea is characterized by landforms of less than 300m above sea level (Fig. 7). There are several small tributary rivers that flow towards the western and southwestern parts of the country, from the highland areas. Accumulated water could form a marsh, which might become a lacustrine environment on the topographic depressions [35]. The outlined depression in Fig. 7 is suggestive of past lake-basin margins estimated to be several tens of km wide. However, this superposition involves inflated assumption. The topographic representations in Fig. 7 could be suggestive of the reconstruction of the western Eritrean mid-Holocene geography.

	Remarks
sa	Soil Color
SV	
A	10YR 6/2
A	10YR 7/2
A	10YR 7/2
PA	
U	

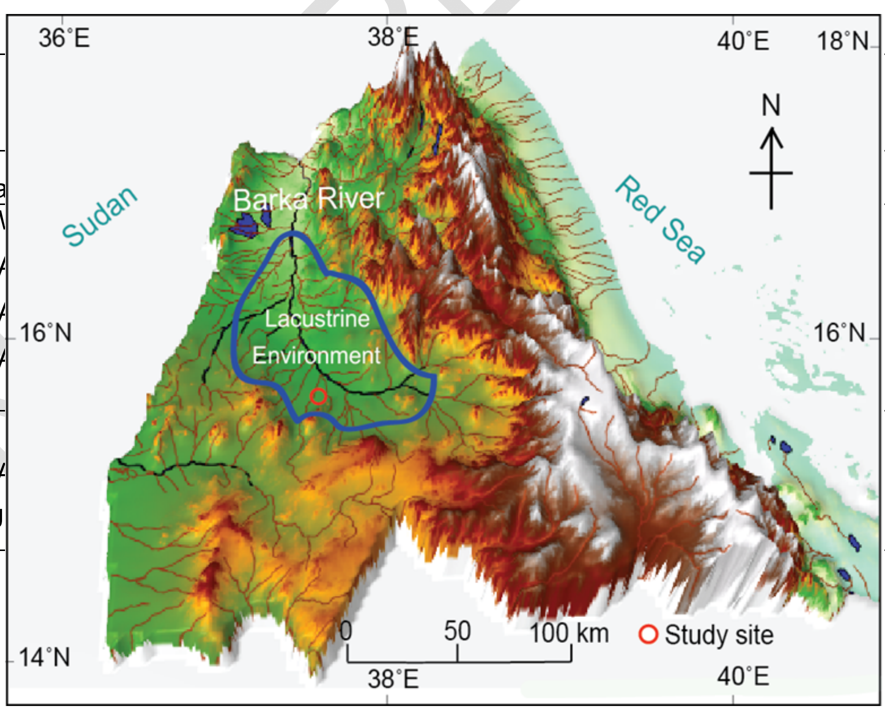

Fig. 7. 3D model geography indicating estimated lacustrine paleoenvironment in western Eritrea. Generated using QGIS, 2018.

4. CONCLUSION

Fossilized freshwater shells obtained from calcareous mud in western Eritrea were carbon dated using ^{14}C. The evidence thereof demonstrated the existence of a lacustrine environment in western Eritrea during the mid-Holocene. *Melanonids tuberculate*, a common freshwater shell in North Africa and Asia are suggestive of a widespread biota in the huge lake environment in northern Africa. The existence of such lakes, then, was related to the warm and humid climate mode called African Humid Period (AHP). However, from 5500 yr BP to the present such lakes disappeared due to the climatic changes resulting in northeastward expansion of the Sahara Desert.

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