Paleoclimate Evolution of the Kordofan Region (Sudan), During the Last 13 ka

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Abstract

The Kordofan region is located at the southern end of the present-day Sahara in Sudan. AMS ^{14}C dates and archeological findings allowed dating the latest Pleistocene–Holocene deposits in Kordofan. Several paleo-proxies (i.e., sedimentology, gastropod sub-fossil shells, pollens, stable isotopes, major element chemistry, and clay mineralogy) were used to reconstruct the climatic evolution for the past 13 ka. The region was subjected to an arid climate prior to 10 ka. Between 10 and 6 ka, the region experienced a wet climate marked by lacustrine/palustrine and fluviatile deposits. After ≈6 ka, the climate evolved to dry conditions, although the southern part remained more humid. Between 3 and 1 ka, a strong aeolian activity was recorded by a sedimentary hiatus and erosion features. From 1 ka to Present, the region became arid. This evolution can be correlated to the well-known evolution of Eastern Sahara during this time interval.

Keywords

Holocene • NE Africa • Stable isotopes
Climate • Kordofan region

1 Introduction

The period between 20 and 12 ka is well documented as a period of dune building in Northeast Africa [1]. This hyper-arid period was followed by a humid phase between ≈12 and 6 ka (African Humid Period, AHP) [2], marked by the occurrence of numerous lakes [2], locally exceptionally large [3]. The subsequent development of the Sahara Desert is recorded by the migration of prehistoric populations toward the present day Sahelian zone or the Nile valley in the last 10 ka [4].

The Kordofan region (Sudan) is located at the southern limit of the Eastern Sahara; however, its latest Quaternary climate evolution has never been studied. This paper is focused on the understanding of the climate evolution of central Kordofan during the latest Quaternary using several paleo-proxies of climate.

2 Methodology

Two field campaigns were carried out in Kordofan, complemented with short field works, which allowed us to perform a sedimentological study and a collection of 119 samples for further laboratory analyses. The latter includes AMS ^{14}C dating, paleo-biology of gastropods, palynology, stable isotopes of C and O, XRF of major elemental measurements and clay mineralogy.

3 Results

3.1 Sedimentology and Stratigraphy

The study of 24 sedimentological sections and 17 AMS ^{14}C dates from charcoal and organic-rich soils and limestone, allowed us to distinguish four main chronological units, corresponding to five main climatic periods (Fig. 1b).

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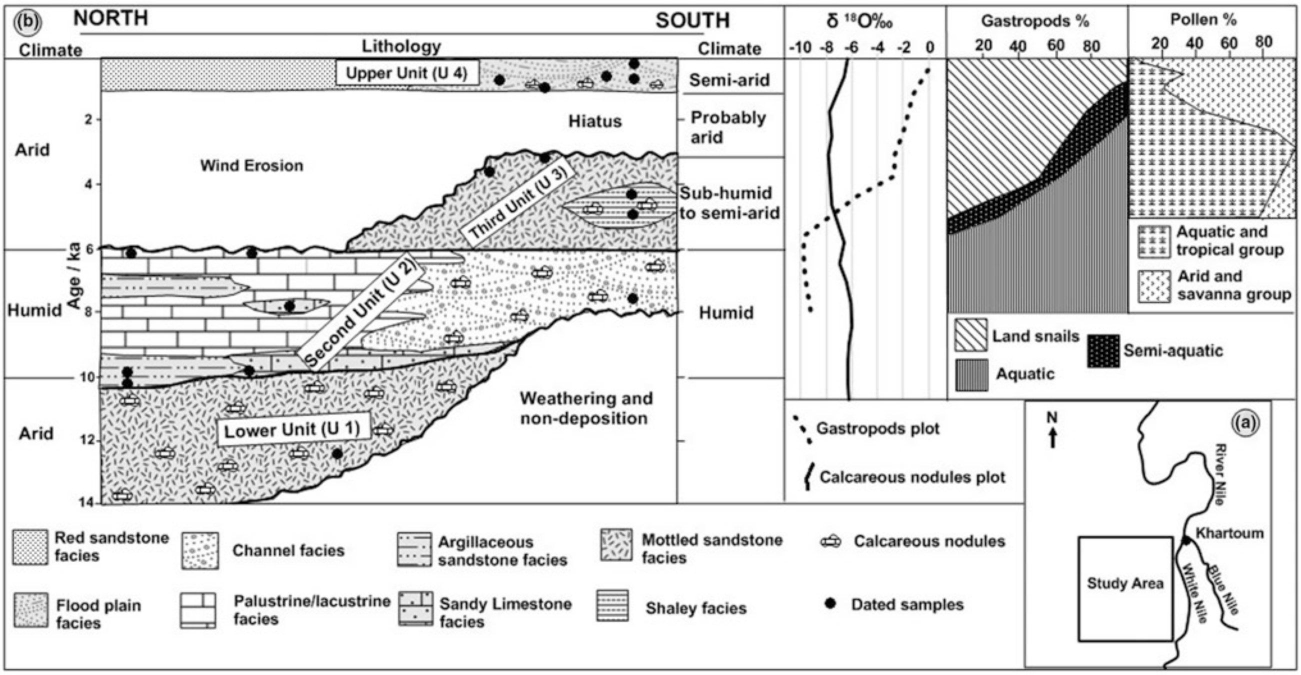

Fig. 1 **a** Location map, **b** summary of paleoclimate results

- The lowest unit (U1) is made of fine to coarse sands, subsequently pedogenetized (mottling, calcareous nodules), which yielded ages varying from ≈13 to 10 ka.
- The second unit (U2) consists of palustrine limestones in the northern and central part, and of fluviatile deposits in the southern part. ^{14}C ages vary from ≈10 to 6 ka in the North and from ≈8 to 6 ka in the South.
- The third unit (U3) is restricted to the southern part. It is formed of mottled sandstone and sandy shales. ^{14}C ages vary from ≈5 to 3 ka.
- A hiatus, detected between ≈6 and 1 ka in the North and between ≈3 and 1 ka in the South, and locally materialized by deflation surfaces, is interpreted as a period dominated by strong wind erosion, which occurred between ≈3 and 1 ka (Fig. 1b).
- The upper or fourth unit (U4) is formed of red sandstone in the North, replaced gradually by flood plain sediments to the South. Its maximum age is ≈1.1 ka.

In all units, grain size in sands decreases, and sorting increases, southward, suggesting deposition related to dominant southward blowing winds. Moreover, the South–North evolution of these units indicates that the southern area was more submitted to fluviatile influences than the northern ones during Holocene times.

3.2 Paleobiology

The vertical distribution of gastropod sub-fossil shells shows that aquatic and semi-aquatic gastropod species dominated in the palustrine limestone (U2), while land snails dominated in U4. This indicates that U2 was deposited under wetter conditions than U4.

22 samples from 3 sections from the southern area were analyzed for palynological investigation. 1213 counted pollens and spores were classified into 4 groups, representing aquatic, tropical, savanna and arid environments. Pollen assemblages from U3 are dominated by the aquatic, tropical and savanna groups indicating wet conditions, while those from the U4 are from the arid environments, reflecting dry conditions.

3.3 Stable Isotopes

49 samples of gastropod shells (3 sites) and calcareous nodules (2 sites) for oxygen and carbon isotopes. Gastropod shells of the U2 are depleted in ^{18}O, while those from the U4 show a rapid ^{18}O enrichment upward. Coeval depletion in $\delta^{18}O$ recorded in the Nile valley has been interpreted as due to high rainfall episodes [5]. The enrichment in ^{18}O in the

U4 can be interpreted as the result of a strong evaporation [6], reflecting drier conditions [5]. The calcareous nodules are generally depleted in ^{18}O, with little variability through time.

3.4 Geochemistry and Clay Mineralogy

23 samples from the U1 and U4 of two sections were analyzed for major elements. The calculated Chemical Index of Alteration (CIA) [7] is high for both the U1 and U4. High CIA values (76–100) in sedimentary rocks suggest intense chemical weathering in the source region [8].

8 samples from U1, U3 and U4 of one section show a remarkable predominance of smectite and kaolinite, while illite is less dominant. Smectite decreases upward, while kaolinite shows an opposite trend. These results suggest that the source areas were more submitted to chemical weathering than physical weathering, especially during the deposition of U4.

4 Discussion

The evolution of the Kordofan region can be summarized as follows. Aeolian deposition took place prior to ≈10 ka and covered most of the studied area. We correlate this arid period with the 20–12 ka interval, which is known as an arid period of dune building in northeastern Africa.

Palustrine–lacustrine limestone, pollens of humid vegetation, aquatic gastropods and depletion in $\delta^{18}O$ in the gastropods shells are recorded between 10 and 6 ka, and evidence a wet climate during the early to middle Holocene. This wet event is correlated with the AHP [2, 3], during which the present-day hyper-arid Sahara Desert was vegetated and covered by numerous lakes [9]. The exact start and termination dates of this wet phase could not be accurately determined, since part of the corresponding sediments were removed by subsequent aeolian erosion. According to previous works, this wet phase occurred between 11–9 and 6–4.5 ka in Northeast Africa [3, 10, 11].

The late Holocene period (≈6 ka to Present) recorded drier conditions in the northern part of the study area, while the southern part remained wetter. This aridification is well documented in Eastern Sahara [12]. As illustrations, we can mention northern Chad experienced a progressive drying out due to an abrupt hydrological change [13], palynological evidence from Lake Yoa (Chad) indicate a gradual shift from moist to arid condition during the last 6 ka [14], and desertification and aeolian deflation occurred during the Middle and Late Holocene in Egypt and northern Sudan [15].

5 Conclusion

The study of the sedimentary record of the Kordofan region allowed the reconstructions of the climate variability since 13 ka, based on the sedimentological, geochemical and paleontological analyses. The climate evolution can be summarized as follows: dry conditions prior to ≈10 ka, wet conditions between ≈10 and 6 ka, wet to dry conditions from ≈6 to 3 ka, dry from ≈3 to 1 ka associated with strong aeolian erosion, and dry after 1 ka, although wetter in the south. These climate changes can be correlated to the well-known climatic evolution of Eastern Sahara during this interval. These results highlight the climate changes along the still poorly known southern limit of Eastern Sahara.

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