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Charophytes as bio-indicators for lake level high stand at "Trou au Natron", Tibesti, Chad, during the Late Pleistocene

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ABSTRACT

The present paper deals with the charophytes collected by H. Faure and P. M. Vincent from outcrops of lacustrine deposits inside the caldera "Trou au Natron" at an altitude of 1875 m above sea level. Characeae represent up to 93% of these carbonates and characterise a new type of sediment, defined as "Characeite". The remains consist in vegetative (thallus) fragments and in gyrogonites (the calcified fructifications of the Characeae). The presence of both these types of materials and their high frequency indicate *in situ* fossilisation of the former fresh water vegetation, termed a "charophyte meadow". The topographical position of the deposits corresponds to a rocky plateau or bench on the slopes of the caldera, located c. 300 m above the present-day floor of the caldera. The development and preservation of the charophytes lead to conclude that the lake was at least 300 m deep at the time when the plants grew. Radiocarbon dating of the thallus fragments provided an age of 14,260 ± 300 yr B.P. This age is consistent with analyses obtained previously on gastropod shells from Trou au Natron and indicates high lake level in the Tibesti Mountains during the Late Pleistocene.

1. Introduction

Charophytes are a relatively new type of lacustrine biomarkers that complete the pluri-disciplinary reconstruction of Quaternary palaeolakes especially in North Africa (Gasse et al., 1987; Kröpelin and Soulié-Märsche, 1991; Soulié-Märsche, 1991, 1998).

Charophytes are benthic macrophytes that generally grow as dense vegetation, called "charophyte meadows". Their habitats encompass nearly all types of continental waters from brackish coastal ponds to mountain lakes at high altitudes. The complete ripening of the female fructification provides the calcified gyrogonites. One plant can easily produce more than one hundred gyrogonites in one growing season and thus the fossil gyrogonites are usually very abundant. As the remains of former aquatic vegetation, they represent autochthonous fossils and indicate the ecological conditions at the very time and place of their embedding. The charophytes provide complementary information to the study of other biomarkers such as diatoms, ostracodes and gastropods. Several ecotype species allow inferring precise conditions of temperature or salinity, and can be used as a "palaeobathymetre" (Soulié-Märsche, 2002; Soulié-Märsche et al., 2008).

The present paper deals with the fossil charophytes recovered from the lacustrine deposits of "Trou au Natron", central Sahara, Chad. The abundant and well-preserved gyrogonites were identified to species level. Ecological data of the corresponding living species provide a modern analogue to infer water depth of the palaeolake at the time indicated by radiocarbon dating of this material. The significance of the lake level fluctuations is discussed in terms of climate change in relationship with the late Pleistocene humid period identified in other Saharan regions.

2. Geographical and geological setting

The Tibesti Mountains extend from 19° to 24° N and from 15° to 20° E in the central part of the Sahara, where they occupy the north-western tip of Chad (Fig. 1). They originate from volcanic activity that extended from the Late Cenozoic to the Late Pleistocene and into the Holocene (Gèze et al., 1957; Vincent, 1963; Ergenzinger, 1968; Vincent et al., 1994). The basement mainly consists of basaltic lava flows with interstratified ignimbrite sheets. The lowest dated ignimbrite provided an Ar/Ar age of 17 Ma (Vincent in Maley, 2004, p. 203)

Pic Toussidé, one of the youngest volcanoes in the Tibesti, provided trachybasaltic lavas. Pic Toussidé is a stratovolcano with a height of

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[1] This paper is a last homage to Professor Hugues Faure who had initiated this study based on material collected by him during earlier fieldwork and to his untiring interest in research on the Tibesti palaeoenvironments.

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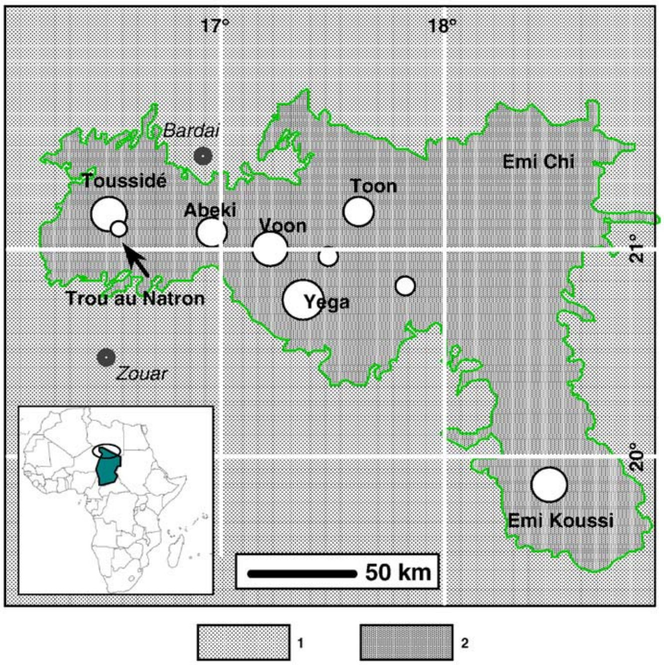

Fig. 1. Location and geological sketch map of the Tibesti Mountains (redrawn and simplified from Vincent (1963)). Inlet shows Chad; circle shows the Tibesti area. 1 — Substratum; 2 — Tertiary and Quaternary volcanic rocks; limit of the Tibesti Mountains above c. 1500 m altitude.

3265 m, and the second highest peak in Tibesti. The present study is devoted to Trou au Natron (20°58′ N; 16°33′ E), a caldera located at the south-eastern rim of Pic Toussidé (Fig. 1).

"Trou au Natron" represents an explosion-collapse crater of about 8 by 6 km atop in diameter and almost 1000 m deep. The name "Trou au Natron" refers to the white native soda deposits (sodium carbonate), which cover large parts of the floor due to still active trona-springs in the deepest part of the caldera. Four small volcanic cones composed of basaltic lava, in the centre of the caldera attest to very recent volcanic eruptions (Fig. 2a).

The existence of a former deep lake in "Trou au Natron" was documented through fossiliferous layers with aquatic gastropods and lacustrine deposits identified as diatomites (Vincent, 1963; Faure, 1969; Maley et al., 1970). Well-stratified, thinly laminated diatomites with a thickness of 3 to 8 m occur both on the slopes and near the floor of the caldera. The highest lake level was recognised from the position of lacustrine deposits found attached to the slopes of the caldera up to an altitude of 2040 m (Kaiser, 1972) (Fig. 2b). Böttcher et al. (1972, Photo 11) showed a remarkably thick, horizontally layered, undisturbed diatomite also in the very centre of the caldera. These authors concluded that Trou au Natron must have been filled by a lake of about 500 m depth during the Last Glacial Maximum (LGM), co-even to the end of the European Würm.

3. Lacustrine deposits and chronology

In 1969, H. Faure reported on two samples of "calcareous diatomite": one that was collected at 1580 m a.s.l. (Fig. 3), about 60 m above the bottom of Trou au Natron (sample 4545), and a second one collected at 1850 m a.s.l. (sample 4546).

Radiocarbon dating on tiny gastropods from these samples, performed at the Laboratory in Gif, provided two rather similar ages in the range of 14,500–15,000 ^{14}C yr B.P. Although these dates met other ^{14}C dates yielded by diatomites in Niger (Faure et al., 1963), Faure (1969) did not neglect the possibility that the ages could be contaminated by CO_2 of volcanic origin and thus would appear too old. Further dating performed on a sample of calcareous crust taken from a rhyolite block located 75 m father down, at 1775 m altitude, provided an age of 12,400 ± 400 yr B.P. (Delibrias et al., 1969; Faure, 1969) (Table 1).

The diatomite samples with shells were situated at the base of the upper third in each of the two lacustrine outcrops. They contained identical diatom flora composed of 35 taxa, mainly planctonic forms, indicative of oxygenated water. Some littoral and epiphytic diatom species were also present (Ehrlich and Manguin, 1966, 1970). This led to conclude that the diatoms had been deposited simultaneously on the margin and in the centre of the caldera, and that Trou au Natron was occupied at that time by a lake of at least 300–350 m depth (Faure, 1969).

Subsequently, palynological analyses were carried out on four samples from the lacustrine outcrop situated at 1850 m. The lowest sample (n°1) was collected near the base of the profile. The second sample originated from a brownish layer rich in organic material, located just below the diatomite level from which the gastropod shells had been dated. The third sample (n°3) was analysed from the dated shell layer. The last sample (n°4) was collected near the top of the profile. The samples n°1, 2 and 3 revealed the dominance of spores of ferns and mosses (94 to 81%), suggesting a humid environment associated with fog during a large part of the year. The sample n°4 from top of the series, in contrast, showed a large dominance (85.2 %) of pollen from phanerogams. The identified taxa belong to species still living in the area today, thus suggesting that the temperature progressively approached the recent conditions (Maley, 1981). The organic rich layer was interpreted as an indicator of lake level decrease below the bench at 1850 m (Maley, 1981, 2000).

The characeite described in the present paper (sample 4548, H. Faure) was radiocarbon dated later at the "Laboratoire de Géologie du Quaternaire". This sample, noted "tuffaceous layer located at 1875 m a. s.l." provided an ^{14}C age of 14,620 ± 300 yr B.P., and thus proved consistent with the previous dating (Soulié-Märsche et al., 1995) (Table 1).

4. Results

4.1. The charophyte material

The lacustrine deposits studied here were sampled by H. Faure on April 10, 1965, during a French volcanologic expedition. This outcrop was situated at the southernmost end of a flat level stretch on the south-west slope of the caldera, at 1875 m above sea level (Faure, 1969).

The position of sample n. 4548 was in the upper third of a 2 m thick series mainly composed of "calcareous diatomite". The nature of the sample containing the charophytes, however, corresponded to a slightly harder, tuffaceous and a little coarse limestone band of 10 cm thickness (Fig. 4).

Here we propose "Characeite" as a suitable term for calcareous rocks whose dominant components are Characeae-algae or any remains clearly identified as belonging to charophytes. According to this definition, the characeite can be composed of corticate thallus fragments (Fig. 5a) and/or contains also a number of calcified fructifications, mostly consisting in gyrogonites with a typical spiral structure (Fig. 5b). In Cretaceous and older rocks, an additional type of reproductive organ consisting in utricles, that are gyrogonites coated with a supplementary envelope, may occur. Sample 4548, analysed in the present paper, was composed of 93% of calcium carbonate, 98% of which was in the form of "figured carbonate matter", clearly belonging to different parts of Characeae.

Numerous modern examples of so-called *Chara*-lakes demonstrate the importance of these plants, in terms of volume and biomass. The process of intracellular assimilation of calcium carbonate combined with extra-cellular adsorption during their life cycle fixes an enormous amount of calcium from the water. Subrecent characeite deposits in Michigan, USA, were even considered as a possible source