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I-n-Atei palaeolake documents past environmental changes in central Sahara at the time of the "Green Sahara": Charcoal, carbon isotope and diatom records

Christophe Lécuyer [a,*,1], Anne-Marie Lézine [b], François Fourel [a], Françoise Gasse [c,2], Florence Sylvestre [c], Christine Pailles [c], Christophe Grenier [d], Yves Travi [e], Abel Barral [a]

[a] Laboratoire de Géologie de Lyon, LGL-TPE, UMR 5276 CNRS, Université Claude Bernard Lyon 1, France
[b] Sorbonne Universités, UPMC, University Paris 06, CNRS-IRD-MNHN, LOCEAN/IPSL Laboratory, 4 Place Jussieu, 75005 Paris, France
[c] Aix-Marseille Université, CNRS, IRD, UM 34 CEREGE, Technopôle de l'Environnement Arbois-Méditerranée, BP80, 13545 Aix-en-Provence, France
[d] Laboratoire des Sciences du Climat et de l'Environnement, UMR 1572 CNRS, CEA et Université de Versailles, Ormes des merisiers, Bât 701, Gif-sur-Yvette cedex 91191, France
[e] UMR EMMAH Environnement Méditerranéen et Modélisation des Agro-Hydrosystèmes, Université d'Avignon, France

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ABSTRACT

During the 'Green Sahara event', water bodies developed throughout the Sahara and Sahel, reflecting the enhanced influence of the Atlantic monsoon rainfall. Major lakes then dried out between 6.5 and 3.5 ka. This study investigates land cover change and lacustrine environment during the Holocene at I-n-Atei, Southern Algeria, a desert region lying in the hyperarid core of the Sahara. This site is remarkable by its extent (up to 80 km^2) and by the exceptional preservation and thickness of the lacustrine deposits (7.2 m). I-n-Atei was a lake from 11 to 7.4 ka, then it dried out and left place to a swampy environment. Charcoal concentrations show that the surroundings of the lake were vegetated throughout the wet period with two short phases of possible vegetation deterioration associated with a lowering of the lake level at 9.3 and 8.2 ka, coeval with well-known dry events in the tropics. The stable carbon isotope record reflects the penetration of C4 herbaceous populations in replacement of the original C3, typical of the regional vegetation at the time of the maximum lake expansion. The $\delta^{13}C$ of charcoals increase non-linearly with the ^{14}C-based ages from −24.5‰ to −13.0‰ (V-PDB). Assuming that these extreme values sample both C3 and C4 plant end-members, mass balance calculations suggest that C3 were replaced by C4 plants according to an exponential decay law with a half-life ($t_{1/2}$) of 850 ± 110 years. The replacement of C3 by C4 plants occurred in two main steps: a mixed C3–C4 vegetation of "wooded grassland" type was present from 10 ka to 8.4 ka while a C4 exclusive vegetation developed after 8.4 ka. After the end of the lacustrine phase a catastrophic event (flooding?) provoked the lifting of most of the lacustrine deposits and their re-deposition above the lacustrine sequence.

1. Introduction

One of the main limitations of palaeoenvironmental reconstructions in arid and semi-arid tropical regions is the desiccation of lacustrine sediments that prevents the preservation of biological remains and favours the removal by wind erosion of exposed sediments during dry periods. As a result, high resolution and continuous records covering the entire Holocene period are extremely rare and the following question remains unresolved: how the environmental change that led to the setting of the "Green Sahara" took place in response to increased rainfall during the African Humid Period (deMenocal et al., 2000a) in central Sahara? Lézine et al. (2011a) showed that the filling of lakes and wetlands north of 10°N started from ca 15 ka onward in central Sahara. This sector benefited from the presence of the Saharan mountains (mainly the Hoggar, Aïr and Tibesti Massifs) which acted as a "water tower" generating primary expansion of permanent water bodies: for example, at Adrar Bous in the Ténéré desert of NE Niger, the first flooding linked to surface runoff and wadi underflows from the nearby mountains was recorded at 15–15.3 ka (Gasse, 2002). Then water bodies widely developed throughout the Sahara and Sahel after 10.5 ka reflecting the enhanced influence of monsoon rains over North Africa and dried out between 6.5 and 3.5 ka according to the latitudes (Lézine et al., 2011a). Regarding the vegetation response to increased rainfall and availability of soil water, recent progress in palaeoenvironmental

* Corresponding author. Tel.: +33 472448376.
E-mail address: clecuyer@univ-lyon1.fr (C. Lécuyer).
[1] Also at Institut Universitaire de France.
[2] Deceased author.

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reconstructions (Watrin et al., 2009; Hély et al., 2014) point to two specific observations:

1) Tropical trees, which were restricted to the Gulf of Guinea during the last Glacial period, migrated northward (Watrin et al., 2009) during the deglaciation and reached at least 25°N as recorded by pollen analyses at, e.g., Uan Tabu in the Lybian desert (Mercuri et al., 2001). The modern flora of the Saharan mountains confirms the northward expansion of tropical biomes during the past since tropical plant communities mainly of Sahelo–Sudanian phytogeographical affinity and isolated species of even more humid (Sudano–Guinean) affinity, are present (Quézel, 1954; Bruneau de Miré and Gillet, 1956; Gillet, 1968; Wickens, 1976).
2) The co-occurrence of tropical and desert plants at the time of the “Green Sahara” suggests that the landscape was probably complex with gallery forests of tropical affinity along rivers and lakes and more xeric plant communities in the surroundings.

Here we use charcoal fragments and their carbon isotope compositions from the I-n-Atei lacustrine deposits of Southern Algeria with the aim of documenting the regional landscape evolution and particularly the penetration of C4 herbaceous plant communities being characteristics of tropical savannas into the present-day desert. Diatom assemblages are used in complement to characterize the lacustrine environment.

2. Environmental setting: I-n-Atei palaeolake

I-n-Atei palaeolake is located at 20.474086N and 6.323595E and 451 m in altitude, 250 km SW of the Hoggar Massif, close to the north-western limits of the Tin Seririne Synclinorium. In this area, the outcropping Paleozoic sediments are affected by deep N–S trending faults determining flexures and dissymmetric folds (syncline and anticline) when crossing the E-NE secondary fault system (Reboul et al., 1962; Guergour and Amri, 2009). The palaeolake lies in a depression roughly triangular, situated in the central part of such a small anticline, forming a topographic barrier on the southern side (Fig. 1).

The climate of the region is hyperarid. The mean annual precipitation can reach 100 mm/y in the Hoggar massif but is limited to roughly 20 mm/y in the lower regions as the one of I-n-Atei (Gribi et al., 1992). However, such precipitation can happen in the form of a high rainfall event related with the monsoon that leads to wadi floods (Gribi et al.,

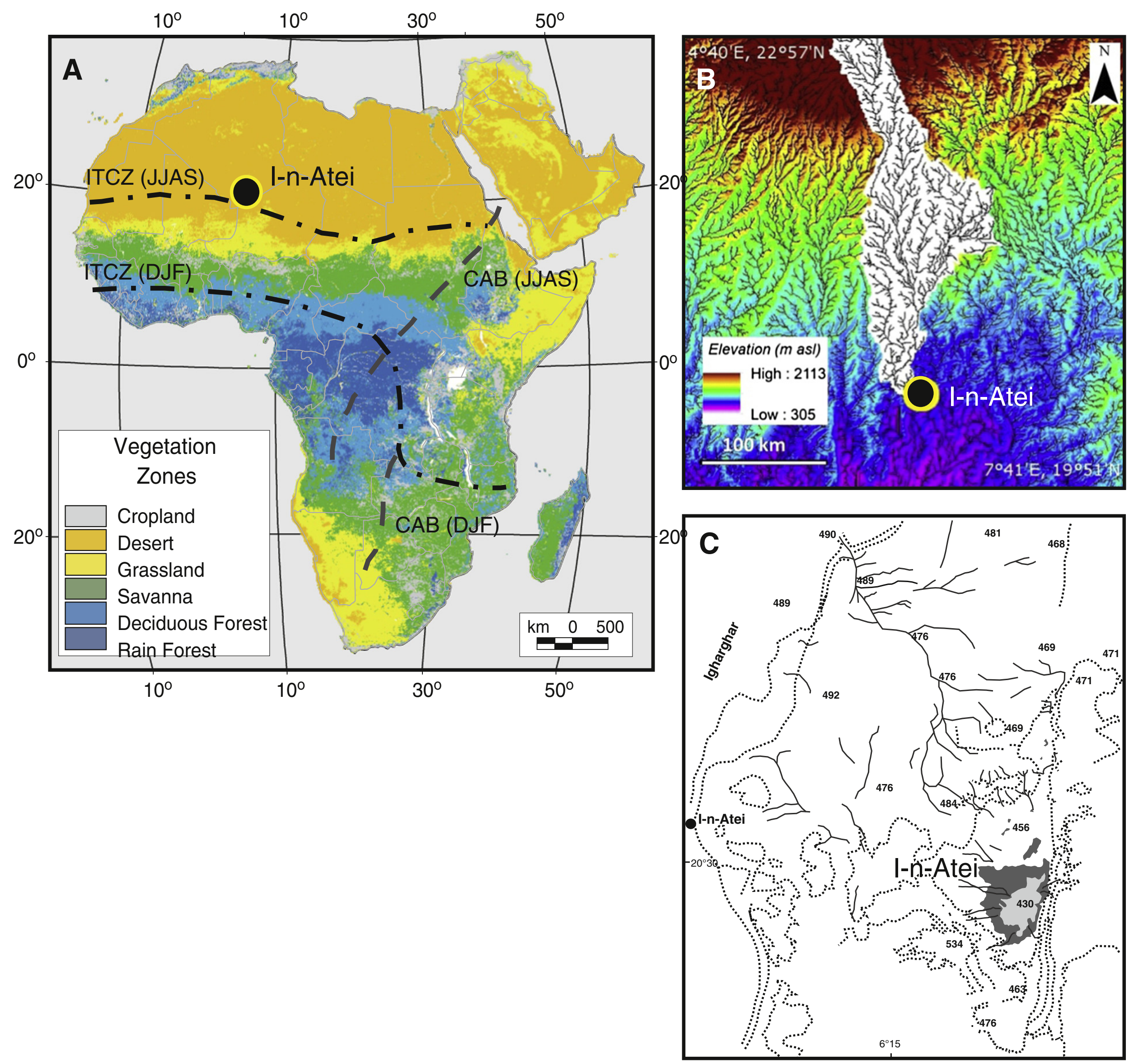

Fig. 1. Location of I-n-Atei in Africa. A: general patterns of vegetation and air masses (Nicholson et al., 1988): ITCZ: Intertropical Convergence zone, CAB: Congo Air Boundary, JJAS (June, July, August, September); DJF (December, January, February); B: the I-n-Atei watershed from the Hoggar massif; C: the detail of the location of the palaeolake: topographic map.

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