Paleofire activity in North Africa during the last 21 ka inferred from a charcoal record from lake Ifrah (Middle atlas – Morocco): Climatic implications.

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Introduction :

Under natural conditions, fire, climate and biomass are inextricably linked (Turner, 2008; Pausas, 2004; Whelan, 1995). The duality of the climate (e.g. humid vs. arid) influences the structure and the composition of the vegetation and therefore fuel availability, which is limiting biomass burning activity (Turner, 2008; Bond et al., 2005).

Charcoal particles have been largely used to reconstruct fire events over multiple timescales in different parts of the world (Power et al., 2008). However, there is a lack of knowledge about the long-term fire dynamics in the Southwestern Mediterranean that hinders the understanding of the fire activity pattern associated with forcing factors for several Mediterranean subregions.

Since the Last Glacial Maximum (LGM, 21 ky BP), Significant changes in the regional climates of Western North Africa have been documented from multiproxy analysis of lake sediments, combining chemical, physical and biological markers. Although the few available studies indicate that arid conditions prevailed in Northern Africa during the LGM, there is a lack of climate reconstruction data from North Africa, and especially from Morocco for this period.

In this work, we present a sedimentary record of regional fire history since the LGM, inferred from Lake Ifrah basin located in Middle Atlas of Morocco. In order to better understand the influence of climate and biomass changes on fire activity, new micro-charcoal analyses have been integrated with documented data used to reconstruct past hydrolological and vegetation changes (Anja, 2010). Here, we present for the first time a record of wildfire activity in the Middle Atlas of Morocco covering the last 21 ky BP. The comparison between microcharcoal and paleoenvironmental tracers from the same sediment core makes possible to study how fire activity responded to abrupt climate changes in the Mediterranean region. Lake Ifrah is one of the first North African sedimentary record spanning the LGM and the Holocene age for which such a combined approach, is used to characterize climate-induced environmental changes. This study provides new perspectives for better understanding the impact of global climate changes on fire dynamics.

The study Site :

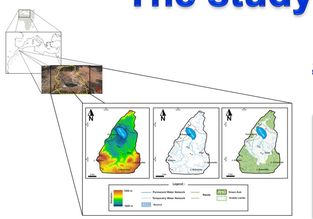

Figure 1. Topographical map of Lake Ifrah catchment showing the position of the lake, the drainage system and the main vegetation types.

- Lake Ifrah (33 ° 33'N, 04 ° 56'W, 1610 m) occupies an endoreïc basin.
- The catchment area of the lake is about 44,77 km2 with a perimeter of 32.9 km.
- The topography of the catchment varies between 1600 m and 1941 m above sea level (asl).
- The catchment is mostly composed of red mud-stones and doleritic basalt of Triassic age and is sealed by limestone and dolomite of liassic age (Arboleya et al, 2004).
- The basin does not have any significant surface inflows and the lake is solely fed by rainfall and temporary ground-waters.
- Lake Ifrah is located in a sub-humid bioclimatic zone, characterized by a mean annual precipitation of 900 mm and about 20 day of snow per year. Monthly Mean temperature is 5°C in January and 27°C in August.
- The vegetation cover surrounding Lake Ifrah is dominated by an evergreen oak forest. Scattered patches of cedar occur on the southern slopes of the landscape.

Sediment stratigraphy :

- A coring campaign was organized in 2004 in the Ifrane region (Moroccan Middle Atlas).
- A Segelm corer fixed on a coring platform was used and a 9 m core was obtained.
- Sediments samples were taken at different depth intervals along the core sequence (every 2 cm upcore and every 10 cm downcore).
- Sediment stratigraphy was established by visual observation of the sediment (Fig. 2). It mostly consists of silty to clayey sediments which contain plant remains and/or millimeter-size mollusk shells.
- Six AMS ^{14}C dates were obtained on total organic matter (TOM) and by Accelerator coupled to a mass spectrometer of Tandetron type (Fig. 3; Damnati et al., 2007; Rhoujjati et al., 2010).
- The ^{14}C have been calibrated using CALIB 6.1.1 program (Stuiver and Reimer, 1993) with the calibration curve Intcal09 (Reimer et al., 2009).

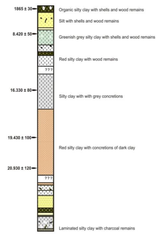

Figure 2. Stratigraphic log description.

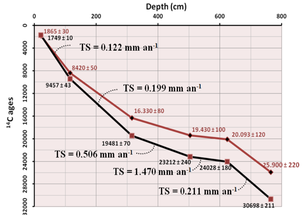

Figure 3. ^{14}C year BP ages vs depth of Ifrah core.

Methods :

Sediments samples have been subjected to Several sedimentological, geochemicals (mineralogy and trace elements) and micro-charcoal analyses :

-I-
Measures of calcium carbonates have also been done with a Bernard calcimeter.

-II-
The contents of organic carbon has been measured with a CHN analyser ⇨ ⇨ ⇨ This method permitted measurement of the quantity of CO2 freed by the organic matter and carbonates when the sample was heated to more than 1000°C.

-III-
Magnetic susceptibility was measured on the bulk sediment samples using a magnetometer. The specific susceptibility of the sediment c used in this study is expressed in 10^9 m^3.kg^{-1}

-IV-
Quantitative geochemical analysis of trace elements was performed by spectroscopic emission plasma torch (ICP-MS).

-V-
Mineralogical qualitative analyses of sediments took a place on a Siemens D5000 diffractometer with a Cu anode X-ray tube. The Semi-quantitative analysis was carried out using XPowder software.

-VI-
The microcharcoal counting is based on the optical counting of microcharcoal particles using the Clark (1982) point count method. The smear slide preparation follows the method developed in Thevenon (2003).

Results :

Microcharcoal distribution shows tree well-defined units :

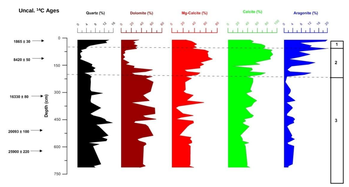

Figure 5. Diagram of minerals percentage from lake Ifrah.

Unit 3 (≥ 213 cm ; ≥ 10.7 kyr BP) :

In this unit, microcharcoal concentration is the lowest of the record, with a maximum of microcharcoal particles (9 x 10^6 Char. g^{-1}). The microcharcoal distribution shows weak fluctuations (Fig. 4). Multiproxy analysis also indicate a low variability (Fig. 4): the organic contents remain relatively low, C_{org} decrease, the mean grain size shows no significant fluctuation and follows the magnetic susceptibility, thus indicating low terrigenous input under a cold and arid climate.

The pollen data show that during this period, the arboreal pollen doesn't exceed 10% of the vegetation cover (Fig. 5). Furthermore, we note a very low pollen percentage for evergreen oak and taxa cedars which suggests that the arboreal cover is not largely expanded (Fig. 7), suggesting a relatively cold and dry climate.

Unit 2 (203 - 61 cm; 10.2 – 5.0 k yr BP) :

This unit is characterized by a sharp rise in the concentration of microcharcoal particles (Fig. 3). A peak of microcharcoal particles takes place at 107 cm (8.7 ky BP) (Fig. 3), associated with a decrease in quartz, dolomite, trace elements contents, grain size and in magnetic susceptibility. Conversely, calcite, Mg-calcite and the carbonate content ($CaCO_3$) show an opposite trend with highest values of the record. Such pattern indicates that evaporation attained its optimum (precipitation of calcite and Mg-Calcite) and that rainfall is relatively low (low concentrations of lithogenic and terrestrial input proxies), therefore suggesting a low lake level under a dry and warmer climate (Fig. 5). A short interval (around 185cm, 9.2 ky BP) of high lake level indicated by limnological data.

The arboreal pollen data during this period reach their highest percentages (Fig. 5), with the pollen percentage of evergreen aok taxa indicating that the landscape was dominated by evergreen oak forest. Additionally, the pollen percentage of cedars taxa decreases implying that cedrus forest declined.

Unit 1 (≤ 49 cm; ≤ 4.0 kyr BP) :

This unit is characterized by a moderate decrease in the microcharcoal particles concentration between around 49 and 1 cm (~ 4.0 – 0 kyr BP) (Fig. 3). The number of microcharcoal particles fluctuates from 11.8 to 15.3 x 10^6 Char. g^{-1}. (Fig. 3), associated with an increase in quartz, dolomite, trace elements contents, grain size and magnetic susceptibility. In opposition, calcite, Mg-calcite and the $CaCO_3$ content show a relative decrease.

The pollen data indicate that percentage of evergreen aok taxa decrease during this period. On the contrary, the pollen percentage of cedars taxa increase significantly, suggesting that cedrus forest took place (Fig. 5).

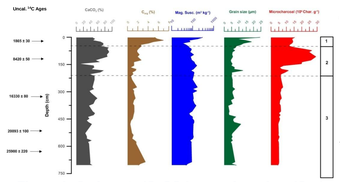

Figure 4. Carbonate ($CaCO_3$), organic carbon (C_{org}) contents, magnetic susceptibility, Grain size and microcharcoal distributions.

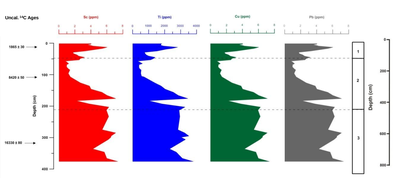

Figure 6. Distribution of traces elements.

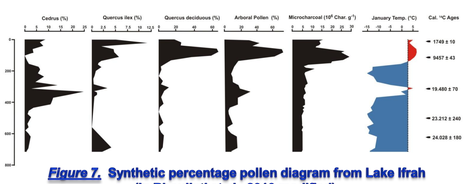

Figure 7. Synthetic percentage pollen diagram from Lake Ifrah (In Rhoujjati et al., 2010 modified).

Concluding remarks :

- Several records of climate over the past 21 ka in the north of Africa have been reconstructed using multivariate approaches. These reconstructions have contributed to broaden our understanding of past climatic variability, and are important in the comprehension of the nature of environmental changes associated to only natural (during the LGM/Early-mid Holocene) or mutual natural-anthropogenic (during the last two millennia) factors.
- Microcharcoal analyses combined to paleohydrological record of Ifrah core document the fire history of Morocco during the last 21 ky BP, the record provides evidence for a variable paleofire activity divided to tree relatively distinct intervals :
  - **A glacial interval**, when microcharcoal concentration was very low, this may be explain by a pattern of low fire activity; this is consistent with the fact that the global climate was generally colder and drier than present, leading to an overall reduction in terrestrial biomass and thus a decrease in fuel avaibility (Power et al, 2008). Pollen data from lake Ifrah suggest a restricted forest under a cooler climates during the LGM with January temperatures roughly 10 - 15°C less than present (Rhoujjati et al., 2010);
  - **An early-mid Holocene interval**, register highest microcharcoal concentration, lowest terrestrial input and highest pollen percentage, these suggest a high fire activity while the forests were more open and when climate was warmer and submitted to a prolonged arid period due to an interconnected forcing factors acting at globally, regionally and locally scale;
  - **A late Holocene interval**, with a moderate decrease of microcharcoal concentration accurately reflects a modest decrease in fire activity. Climate during this period approached that of present and human influences start acting.
- This study allows us to deduce that the fire occurrence seems therefore directly influenced by climatic forcing. The chronology of major events in our record and their paleoclimatic implications match relatively well those described by several authors in the study area, as well as with global climatic events.
- This work is a first attempt to synthesize charcoal records covering the LGM and to explore changes in North African fire regimes during a period characterized by millennial-scale climate variability and rapid warming events.