STABLE ISOTOPE RECORDS OF HOLOCENE ENVIRONMENTAL CHANGE FROM MOROCCAN LAKES: AN EMERGING SYNTHESIS

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Background, research questions

Lacustrine sediment is one of the most interesting and reliable non-marine palaeo-archives that Morocco can provide for studying climate variability and change in North Africa

Holocene records of paleohydrologic and palaeoclimatic changes in Moroccan Atlas have been inferred from changing sedimentary facies, mineralogy, ostracods Mg/Ca and Sr/Ca ratios, and carbonate $\delta^{13}C$ and $\delta^{18}O$ in cores from several lakes. Here, we highlight data obtained on modern hydrology and isotopic analysis of three cores to address the questions:

How did the hydrologic behavior of each lake respond to climatic changes?

How important are local effects ?

What is the effect of detrital input on the isotopic and chemical signals in sediments?

Does the record of $\delta^{13}C$ and $\delta^{18}O$ support the lake-level record?

Hydrology and hydrochemistry

Based on salinity, natural Moroccan lakes fall into three categories:

- Very low salinity: Ifni (~50 mgl^{-1}).
- Low to medium salinity: Tigalmamine, Azigza, Sidi-Ali, and Tislit (~300 to ~1200 mgl^{-1}).
- High salinity: Isli (~2000 mgl^{-1}).

- Water chemistry is affected mainly by
  - Catchment lithology and morphology
  - Residence time
  - Human impact

- Lake Ifni, located in crystalline rocks (granite, rhyolite) is fed mainly by surface water during snow melt. Water is under-saturated with respect to carbonate minerals.
- Except for Tigalmamine and Azigza, where the bedrock is mainly dolomite, groundwaters are less concentrated than lake water. Calcite precipitation removes Ca and HCO_3 from water.
- In Sidi-Ali main lake, Tislit and Isli, when carbonates begin to precipitate, the relative proportions of calcium and magnesium decrease and increase respectively until Mg replaces Ca as the dominant cation.
- In all cases, water is under-saturated with respect to gypsum, halite and amorphous silica.
- Most of the lakes are fed by the local aquifers and seeps via small springs.

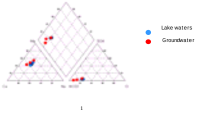


Fig. 2: Piper diagram , Tigalmamine basin

At Tigalmamine, groundwater enters the lakes from the upstream area via bedrock fractures and porosity. Lake water is over-saturated for calcite and loses part of its Ca and HCO_3 by carbonate precipitation. Springs below the lakes reflect different degrees of groundwater and lake water mixing

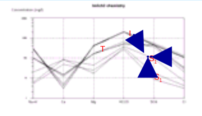


Fig. 3: Fingerprint diagram of the data of Imilchil basin

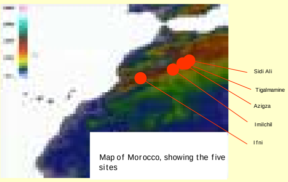
Four distinct compositional groups emerge:

Springwaters (S1) in the higher part of the Imilchil basin show low salinity (~300 mg/l)

Springwaters (S2) in the in the lower part of the Imilchil basin are a mixture of the water from the two lakes and the local aquifer.

At Tislit (T) and Isli (I) lakes, the major elements, apart from Ca, are high in comparison to groundwater.

Note the low Ca concentration in both lakes, due to precipitation of calcite and aragonite.

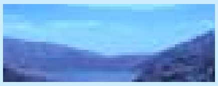


Map of Morocco, showing the five sites

Fig. 1 Five sites with eight lakes were investigated:
- Sidi-Ali (main lake, sub-lake)
- Azigza
- Tigalmamine (Admer, main lake, scar lake)
- Imilchil (Islit, Isli)
- Ifni

Tislit, 32°02'N, 05°38'W (High Atlas). 2252 masl, 17 maximum depth.

Isli, 32°N13'N, 05° 32'W (High Atlas), 2270 masl. At almost 2.15 km^2 in area, it is one of the largest, and the deepest (95m), natural lakes in North Africa



Ifni lake, 31°02'N, 0753'W (High Atlas), lies to the south of Marrakech, about 5 km from Toubkal (4167 masl), the highest mountain in North Africa

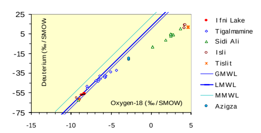


Fig. 4. Relationship between δD and $\delta^{18}O$ in precipitation, groundwater, and lake water for various sites.

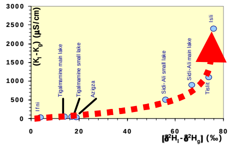


Fig. 5. Chemical and isotopic responses of waters from eight lakes Of differing hydrology to the the same climatic trends .
K: specific conductivity; l: lake water; g: groundwater

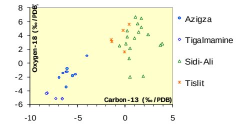


Fig. 6: Stable isotope content of shell calcite of modern ostracods (*Candona fabaeformis*) from four Moroccan lakes.

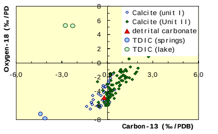


Fig. 7: $\delta^{13}C$ vs. $\delta^{18}O$ for authigenic calcite in lake Tislit from about 4000 to 2700 ^{14}C yr BP (unit I) and from 2700 ^{14}C yr BP to the present

A) Meteoric and non-evaporated groundwater lie slightly above the GMWL (Global Meteoric Water Line). The very good linear relationship which exists between δ^2H and $\delta^{18}O$ values of precipitation (snow and rain) in the High-Atlas is $\delta^2H = 8\delta^{18}O + 13$. This line is considered as the Local Meteoric Water line (LMWL). Rain-producing air masses in the Atlas Mountains have two origins - Atlantic and Mediterranean.
Modern lake water isotopic contents shows a clear evaporation trend in Moroccan lakes. Resulting ^{18}O enrichment varies from about 1‰ (Ifni) to about 14 ‰ (Isli and Tislit).

B) Because of different residence times, hydrological responses to the same climatic trends differ from site to site.

C) The isotopic signal in ostracod calcite is a close function of the water isotopic composition and the local climatic conditions, but with a large amount of spread in the data for Sidi-Ali lakes.

D) For inorganic calcite the dominant controls on $\delta^{13}C$ and $\delta^{18}O$ are evaporation fractionation, temperature of calcite precipitation, photosynthetic activity, exchange with atmospheric CO2 and detrital input.

Stable isotopes sequences from three lake sites

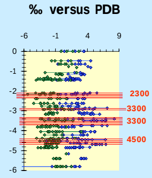


Fig. 8. Sidi Ali: $\delta^{18}O$ and $\delta^{13}C$ values of 2-8 individual ostracod shells (*Candona fabaeformis*) from core SA-C, 7000 ^{14}C yr BP to present.

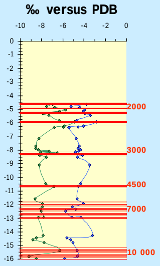


Fig. 9. Tigalmamine: $\delta^{18}O$ and $\delta^{13}C$ values of three ostracod valves (*Candona fabaeformis*) from Tigalmamine central core.

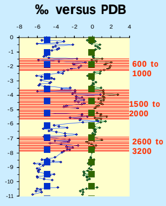


Fig. Tislit lake: $\delta^{18}O$ and $\delta^{13}C$ values from authigenic Carbonate, 4000 ^{14}C yr BP to present.

Red bars indicate low lake-level intervals.
🟩 Bedrock isotopic content
◆ $\delta^{18}O$
◆ $\delta^{13}C$

Conclusions

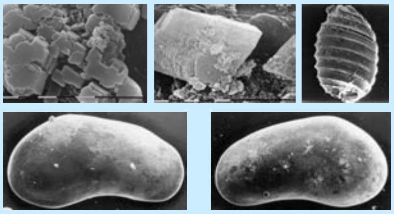
Isotopic responses to the same climatic change differ from site to site:

A) For Sidi Ali, with a large amount of spread in the modern data, numerous analyses on individual valves may show some general trends.

B) At Tigalmamine, an open system with a short residence time and dilute water, the isotopic composition of biogenic calcite reflects that of the water and hence the climatic conditions.

C) The isotopic composition of authigenic carbonate reflects local hydro-climate. However, during wet periods the effect of detrital input is clear: $\delta^{13}C$ and $\delta^{18}O$ values are influenced by the isotopic composition of the catchment bedrock.

Materials used for $\delta^{18}O$ and $\delta^{13}C$ analysis



Materials used for $\delta^{13}C$ and $\delta^{18}O$ analysis in Moroccan lakes: a and b) Authigenic calcite crystal; c) Charophyte gyrogonite, *Chara hispida* d) *Candona fabaeformis*, rigt valve (male); e) *Candona fabaeformis*, left valve (male).

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