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Lake Aguelmame Sidi Ali, Middle Atlas Morocco, Holocene diatom analyses.

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Abstract

Lake Sidi Ali (33° 03'N, 5° 00'E) is a natural Lake at high altitude (2080 m) in Moroccan Middle Atlas. A long core of 20 m by 38 m deep in the south-western basin was obtained using the coring device UWITEC. This core provided a continuous Holocene record, and analyzed diatoms contained in the sediments. The Sidi Ali diatom screening provides valuable information concerning aquatic paleohydrology and corresponding hydroclimatic changes in the Middle Atlas. The relative amount of shallow-water indicating epiphytic and littoral species is a proxy for former lake levels. In the entire record planktonic *Cyclotella* sp. are dominant indicating relative humid and oligosaline conditions in the closed lake basin. However, *Cyclotella* species change and shallow-water indicating variations in lake-level and salinity. An open taxonomy is adopted for those diatoms which do not fit precisely to any defined taxa. This is the case for *Cyclotella* species, which predominate in the core during the Holocene particularly *Cyclotella* sp.3, *Cycltella* sp.1 and also for the specimens *Cyclotella* sp.4. These taxa are separated by their structure and ultra structure and it's a new taxonomic and ecological identity. Diatom study shows the species found in the sediments have persisted in the same lake and can provide a direct modern analogue for interpretation. Diatom record provided information on the water-level and on changes in water chemistry. Our observations allow us to reconstruct the main evaluative phases of *Aguelmame* Sidi Ali Lake: A shallow oligosaline lake occupied the core site during the Younger Dryas. *Cyclotella* sp. 3 is dominant. During the first half of the Early Holocene diatom assemblage reflects an important lake level. A small regression of the lake level with shallow water the course of the second half of the Early Holocene and is characterized by variations in morphologies and sizes and the abundance of diverse species indicate a high variability of the hydroecological setting. Fresh water to Oligosaline Lake occupied the core site during the second half of the Mid Holocene. This stage reflects a noticeable inflow of dilute waters into the lake basin and a rapidly rising lake level due to the dominance of planktonic littoral *Cyclotella* sp. 4 indicate a change in hydrology and temperature. Late Holocene : the diatom evidence reflects high lake levels due to the dominance of planktonic *Cyclotella* sp. type 3 which reaches its absolute maximum at the onset. Anthropocene is characterized by the high quantities of littoral species and of epiphytic indicate increasing aridity reveal evidences for a low lake level and higher aridity and represent the phases of significant human impact. The diatom study of the sediment sequence *Aguelmame* Sidi Ali allowed a detailed reconstruction of past hydrology and environments during the Holocene. The regional climatic changes have been the major driving factor on ecological and hydro biological changes in Middle Atlas lakes.

Keywords: Younger Dryas, Holocene, Diatom, *Cyclotella*, *Aguelmame* Sidi Ali, Middle Atlas, Morocco.

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Le Lac *Aguelmame* Sidi Ali, Moyen Atlas, Maroc, Diatomées de l'Holocène: Ecologie, Paléoécologie, Taxonomie.

Résumé: Ce travail est, pour le Maroc, les premières études détaillées des diatomées de séquences lacustres de l'Holocène (*Aguelmame* Sidi Ali & *Tigalmamine*) continues et datées. Cette présente étude porte sur les diatomées de l'Holocène du lac *Aguelmame* Sidi Ali (33° 03'N, 5° 00'E, 2080 m) situé dans le Moyen Atlas, au Maroc. Dans le cadre d'un projet international Allemand Britannique Marocain le prélèvement en septembre 2012 sous 36 mètres d'eau d'un sondage dans la partie la plus profonde du bassin *Aguelmame* Sidi Ali a produit une séquence lacustre de 19,63 m d'âge 12.300 ans BP. La séquence lacustre est analysée, la composition des groupements de diatomées, et leur succession de bas en haut de la séquence sédimentaire holocène est étudiée. Les changements d'associations de diatomées sont attribués à des fluctuations des conditions de milieu et permettent néanmoins de distinguer et de suivre les principales étapes de l'évolution du lac Sidi Ali. Les sédiments organiques limoneux généralement homogènes, légèrement stratifiées sont riches en fossiles aquatiques. Les diatomées analysées donnent des informations taxonomiques et écologiques. Une taxonomie ouverte est adoptée pour les diatomées qui ne correspondent pas exactement à des taxons définis. Tel est le cas pour les espèces appartenant au genre *Cyclotella*, et qui prédominent au cours de l'Holocène particulièrement *Cyclotella* sp. type 3, *Cyclotella* sp. type 1 et *Cyclotella* sp. type 4. Ces taxons trouvés dans les sédiments ont persisté dans le lac et peuvent fournir des analogues modernes pour l'interprétation paléoenvironnemental. Le rapport des taxons planctoniques et des taxons littorales (rapport P/L) abondant permet de reconstruire la profondeur du site d'étude et peut être considéré comme proxy. Chronologiquement les stades majeurs sont distingués. Durant le Dryas récent le lac est peu profond et la flore variée est dominée par les *Cyclotella*. Le Début de l'Holocène montre une augmentation du plan d'eau illustré par une augmentation des diatomées. La seconde moitié de l'Holocène précoce se caractérisée par une dominance des planctoniques et des variations observées de la morphologie et de la taille des *Cyclotella* ainsi que le mélange et l'abondance de taxons qui indiquent une grande variabilité des paramètres hydro écologiques. L'Holocène moyen suggère un changement climatique inscrit par des bas niveaux du lac avec des environnements marécageux et de plantes aquatiques. La seconde moitié de l'Holocène moyen reflète un afflux notable des eaux douces dans le bassin et le niveau du lac augmente rapidement en raison de la domination des planctoniques littorales *Cyclotella* sp. type 4 qui pourrait indiquer un lac peu profond. La fin de L'Holocène montre un maximal du rapport diatomée P /L et pointe vers un haut niveau du lac. *Cyclotella* atteint son maximum absolu. Anthropogène : Les conditions écologiques récentes représentent les phases de l'impact humain, une baisse du niveau du lac progressive et une aridité croissante.

Mots clés: Dryas récent, Holocène, Diatomées, *Cyclotella*, *Aguelmane* Sidi Ali, Moyen Atlas, Maroc.

1. Introduction.

This study of diatoms is a contribution to the knowledge of the paleolimnology of Lake Sidi Ali located in the Middle Atlas, Morocco .The upland lakes in Middle Atlas represents a privileged area for the understanding the Holocene environmental responses to climate change and global change. Diatoms, biological indicators, provide information on habitat types and water depth and on the total and specific salinity. The plankton and sediments of lake *Sidi* Ali reveals a rich and varied flora of diatoms but dominated by the genus *Cyclotella*. In order to obtain high quality palaeo-environmental data it is necessary to knowledge of the taxa and their answers to the ecological conditions. Diatoms analyses show new data for some species of *Cyclotella* genera. In this study an open taxonomy is adopted for those diatoms which do not fit precisely to any defined taxa. This is the case for *Cyclotella* species, which predominate in the core during the Holocene particularly *Cyclotella* sp. af. *comensis* type 3, *Cycltella* sp. af. *comensis* type 1 and also for the specimens *Cyclotella* sp. af. *ocellata* type 4. These taxa are separated by their structure and ultra structure and are new taxonomic and ecological identity.

2. Sample site.

Lake *Aguelmame* Sidi Ali (33°05′N, 005°00′W) (Figure 1) is a natural lake at high altitude (2080 m) in Moroccan Middle Atlas, without surface outlet, determined by the dam of a basalt flow. With an apparent catchment of 15.6 km2, it is fed by runoff and karsts springs. The site comprises two basins (figure 2) which are periodically separated by a basalt ridge. Sidi Ali lake surface area 40 km², maximal depth 36m is alkaline with a recorded pH 9.1, but is relatively dilute with a conductivity of 1200-1600 $uScm^{-1}$. A long core of 20 m by 36 m deep in the south-western basin was obtained in september 2012 in the lake Sidi Ali and also sediments which were collected in 1991 (Barker & al., 1994; El Hamouti, 2003) reveal a rich and varied flora of diatoms but

dominated by the genus *Cyclotella* Sediments core are characterized by horizontally bedded, faintly laminated, calcareous to lime silicic gyttia, with aquatic macrofossils including aquatic plant fragments (*Potamogeton*) and ostracods rich in diatoms. The vegetation of the area has been described by Lecompte (1986). It includes spiny xerophytic matorral, with scattered *Juniperus thurifera* L. An open, heavily degraded forest of *Cedrus atlantica* (Endl.). A number of limnological and palaeolimnological studies have been under taken in the Middle Atlas region (El Hamouti et al., 1991, Barker et al. 1994, Lamb et al. 1995, Cheddadi et al. 1998).

Figure 1 – Lake *Aguelmame* Sidi Ali. (Cliché : Fletcher, W.J, septembre 2012)

3. Materials and Methods

A long core of 20 m by 38 m deep in the south-western basin Sidi Ali was obtained using the coring device UWITEC. This core provided a continuous Holocene record, sediments consist are of horizontally bedded, faintly laminated, organic silts, with aquatic fossils. Sampling for diatom was conducted at 100 cm intervals, were analyzed for 21 levels for preliminary characterization of the major evolutionary stages.

3.1 Preparation of diatoms

For each sample, a quantity of approximately 5 g of sediment was first treated with hot hydrochloric acid to remove calcium carbonate and later with hydrogen peroxide to eliminate organic matter. The argillaceous fraction in suspension was eliminated by successive decantation phases. The residue was diluted in distilled water and one drop suspension was spread out over cover lips and stuck to the Nafrax resin.

The observation of the covers lips was carried out under the optical microscope (x 1000). The relative frequency of a species was calculated after counting of 300 valves, distributed on four blades. All samples were treated and the residual product was observed under optical microscope. A selection of samples was prepared and stored for future scanning electronic microscope studies.

4. Resultats.

4.1 Ecology of genus *Cyclotella*.

Analyses of these diatoms provided information on the water-level and on changes in water chemistry. The genus *Cyclotella* is known from plankton and sediment samples from middle Atlas lakes. All lakes are alkaline with Ca, Mg, or Na being the common cation. Chloride and sulphate concentrations are highest in lake Sidi Ali (Flower & al.,1990). High frequencies (≥ 50 %) of the following species were identified in this study:

Cyclotella azigzensis Flower, Gasse & Hakansson 1990, a fresh water species, dominates in the plankton and sediment samples from lake *Azigza* (Flower & al., 1989) and many lakes in the Middle Atlas. The species is abundant (50%) in *Aguelmame* lake where it lives in fresh (water) to slightly oligosalines (conductivity 600-840

µScm-1), alkaline (pH 8.8), bicarbonate type water, rich in calcium and magnesium (El Hamouti, 2014, p. 712). Optimal condition(s) for the development of *Cyclotella azigzensis* : pH : 8.02 & conductivite : 420 µScm-1 (Gasse et al. (1995).

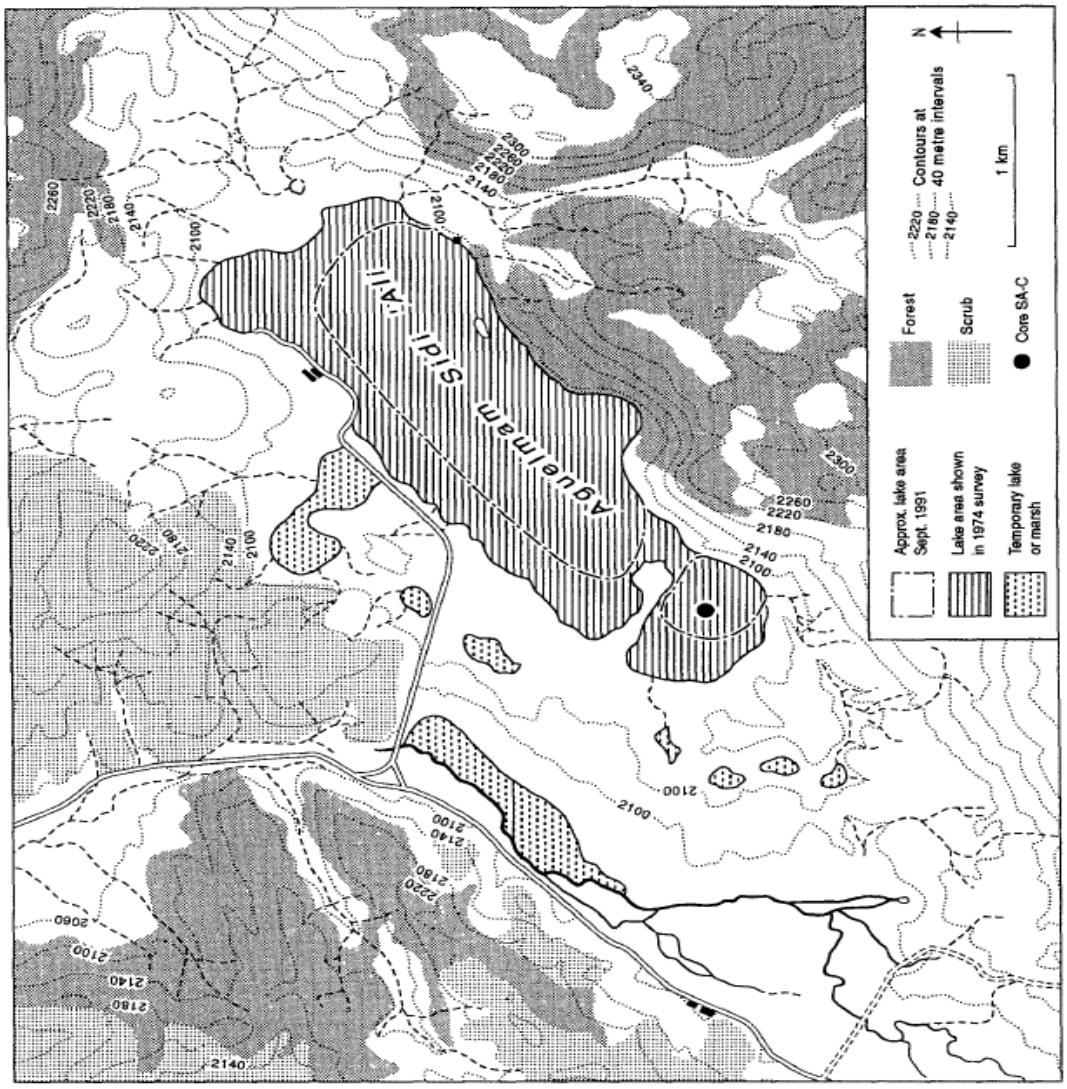

Figure 2 - *Aguelmame* Sidi Ali: map of the lake showing its extent in 1974.
By 1991 the lake had shrunk to the limits shown by the broken line (Barker & *al*. 1994).

***Cyclotella* sp. type 1** (Figure 3) dominates in the planktonic zone of the larged basin of lake Sidi Ali (pH : 9.2, conductivity of 1200 to 1600 µS/cm and dominates in the planktonic zone of the small basin of Lake Sidi Ali (Barker 1994). In Lake Sidi Ali *Cyclotella* sp. aff. *comensis* type 1 is growing in alkaline water (pH 9.1) with conductivity of 1200 to 1400 µS/cm (El Hamouti, 2003, 2014). *Cyclotella* sp. aff. *comensis* type 1 is described by Barker et al (1994) as *Cyclotella* af. *Comensis* Grunow with an abundance in the small Lake Sidi Ali of 60% at the lake bottom (14 m depth) and a relative abundance of 20% at the margin of the small lake (Barker et al. 1994: 227). The ecological data of *Cyclotella* af. *Comensis* Grunow deduced from the literature are typical for planktonic zones in alpine and subalpine lakes (Hustedt, 1930, Krammer-Lange Bertalot, 1991). According to Gasse et al. (1995) the optimal ecological conditions for *Cyclotella comensis* are indicated by pH 8.96 and a conductivity of 515 µS/cm. Hence, this is not in perfect agreement with the ecological data distribution of

Cyclotella sp. aff. *comensis* type 1 (El Hamouti, 2003, 2014) which is equally to *Cyclotella* af. *Comensis* Grunow (Barker & al. 1994) at Lake Sidi Ali.

***Cyclotella* sp. type 3** (Figure 4) is a planktonic species, is described by Barker et al (1994) as *Cyclotella* sp.1. Currently, *Cyclotella* sp. aff. *comensis* type 3 is abundant (50-80%) in the large basin of Lake Sidi Ali with alkaline conditions (pH 9.2), a conductivity of 1200-1600 µS/cm (El Hamouti, 2014) and a temperature water surface of 20° C. *Cyclotella* sp. aff. *comensis* type 1 dominates in the Holocene core of larged Lake *Aguelmane* Sidi Ali and in sediments *Early and Mid Holocene from 16, 10.4 to 7 cal ka BP* of lake *Tigalmamine* (El Hamouti, 2003).

***Cyclotella* sp. type 4** (Figure 5): the taxonomic delimitation of some *Cyclotella* taxa (*Cyclotella krammeri* Håkansson, *Cyclotella ocellata* Pantocsek and *Cyclotella comensis* Grunow) is difficult, because of the polymorphism of the valve. Currently in the Middle Atlas, *Cyclotella* sp. aff. *ocellata* type 4 is a planktonic species of shallow environments, the species lives in alkaline water (pH 8.9), conductivity 680 µS/cm (El Hamouti 2003). Hence, we interpret *Cyclotella* sp. aff. ocellata type 4 at Sidi Ali as an indicator for fresh water input with reduced salinity.

Cocconeïs placentula (figure 6), a littoral epiphyte of aquatic plants species considered as an indicator of shallow conditions. *Mastogloïa smithii* is littoral species oligohaline to mesohaline water forms.

Diatoms from Lake aguelmame Sidi Ali :
Diatomées du lac Aguelmame Sidi Ali

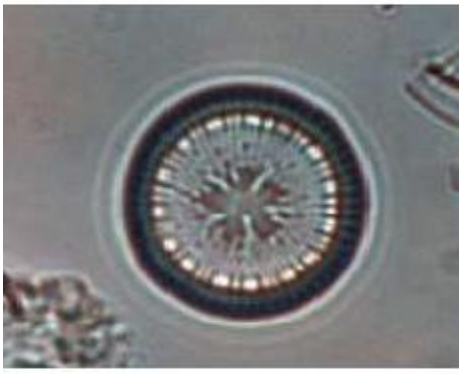

Figure 3

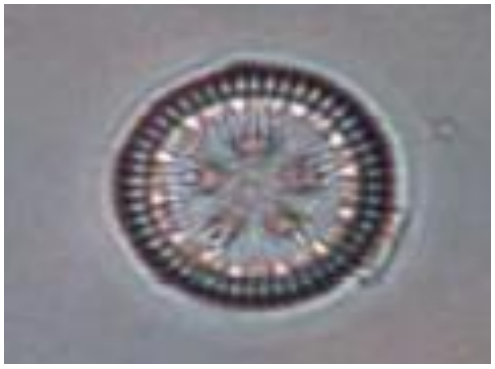

Figure 4

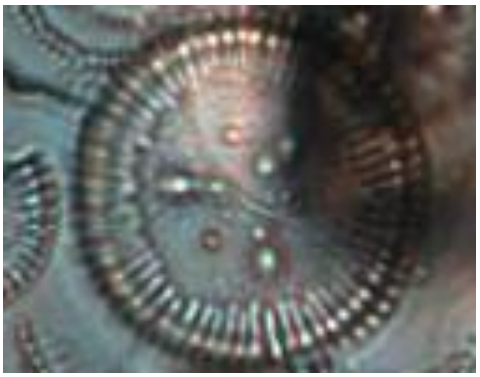

Figure 5

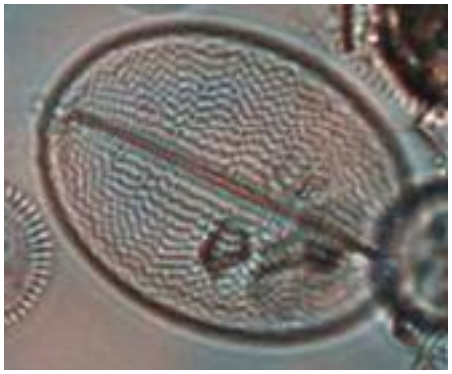

Figure 6

Fig. 3: Individuals of *Cyclotella* sp. type 1 from *Aguelmame* Sidi Ali core.
Fig. 4: Individuals of *Cyclotella* sp. type 3 from *Aguelmame* Sidi Ali core.
Fig. 5: Individuals of *Cyclotella* sp. type 4 from *Aguelmame* Sidi Ali core.
Fig. 6: Individuals of *Cocconeïs placentula* from *Aguelmame* Sidi Ali core.

4.2. Hydrological events.

Diatom study of core from Lake *aguelmane* Sidi Ali shows that hydrologic events are recorded by species changes (Figure 7) and give valuable information concerning salinity water and the climatic history. Five major statements can be made from our results:

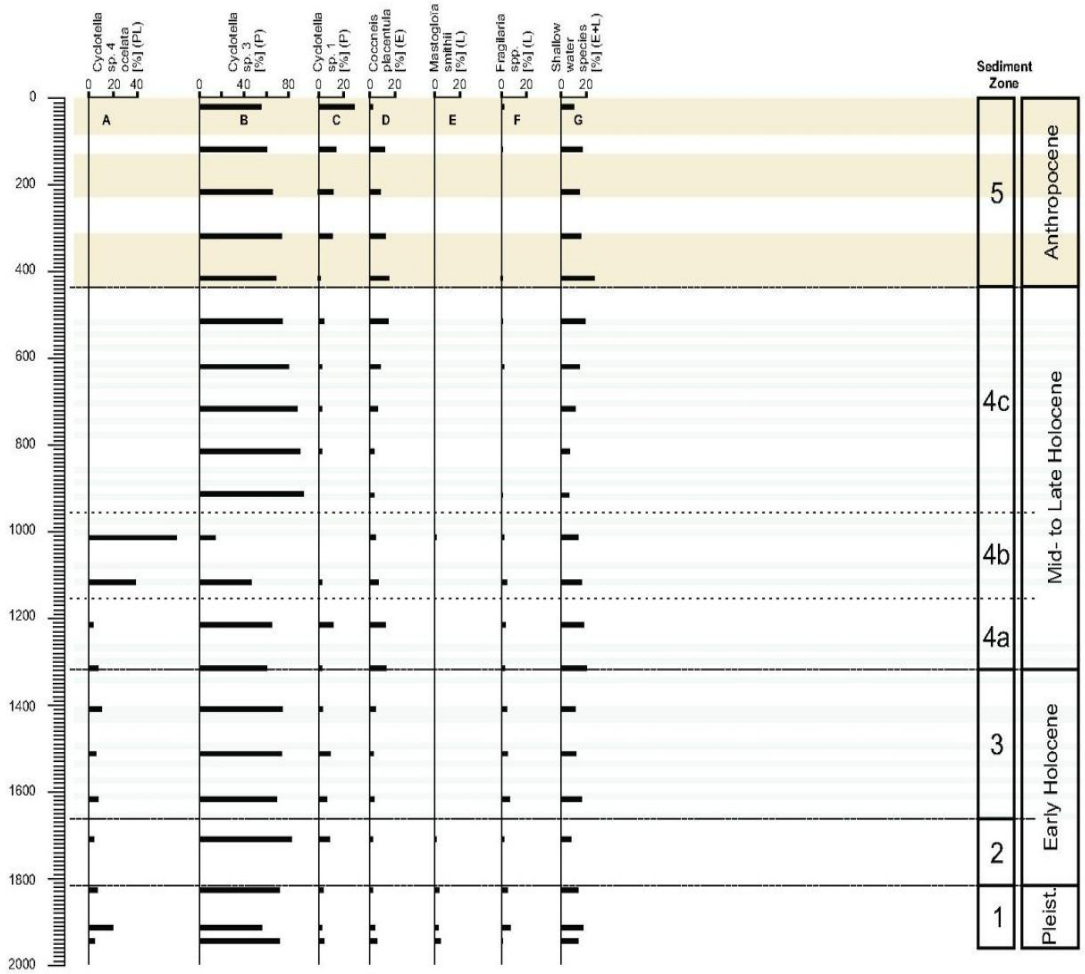

Figure 7 - The vertical distribution of the most abundant diatoms of *Aguelmane* Sidi Ali core

STAGE 1: The Younger Dryas.

A shallow oligosaline lake occupied the core site during the Younger Dryas. *Cyclotella* sp. type 3 is dominant (73-57%). *Cyclotella* sp. aff. *ocellata* 4 (08-20%), *Cocconeïs placentula* (5%) and *Mastogloïa smithii* (2-4%) are abundant in the diatom assemblage.

STAGE2 STAGE 3: Early Holocene

During the first half of the Early Holocene (stage 2) diatom assemblage reflects an important lake level due to low amounts of littoral species (8-18%) and high amounts of planktonic *Cyclotella* sp. aff. *comensis* type 3 (84-94%). Increased littoral diatom types point to a small regression of the lake level with a shallow water the course of the second half of the Early Holocene (stage 3). The unit is characterized by a dominance *Cyclotella* sp.3 and the abundance of diverse littorals species indicate unstable conditions of the ecological setting.

STAGE 4: The Mid- to Late Holocene.

The diatoms frustules are fragmented except the *Cyclotella*. A shallow oligosaline lake with a diversity of species during the first half of the Mid-Holocene is reveals by abundances of epiphytic *Cocconeïs placentula* (10-18%) which indicate low lake levels rich in aquatic plants (stage 4a). The mixture of *Cyclotella* type aff.

ocellata 4 (2-38%), *Cyclotella* sp. type 1 (66-46%), *Fragilaria brevistriata* (2%), and *Fragilaria construens* (2%) reflect instability conditions.

During the second half of the Mid Holocene fresh water to Oligosaline lake occupied the core site. This stage reflects a noticeable inflow of dilute waters into the lake basin and a rapidly rising lake level due to the dominance of planktonic littoral *Cyclotella* sp. aff. *ocellata* type 4 (72%) (stage 4b) indicate a change in hydrology and temperature.

The Late Holocene (stage 4c) from 4.224 cal ka BP coincides with disappearance of *Cyclotella* sp. aff. *ocellata* type 4. This stage corresponds to a long lacustrine episode which reflects a wet period generally wetter than today with intercalated phases of drought. The current flora is therefore installed. *Cyclotella* sp.aff. *comensis* type 3 (80-94%) generally point to oligosaline and relatively deep conditions. However, the high quantities of littoral species and of epiphytic *Cocconeïs placentula* indicate aridity with a low lake level at the transition from unit.

STAGE 5: Anthropocene.

Anthropocene is characterized by the dominance of planktonic *Cyclotella* sp.aff. *comensis* type 3 reflecting recent ecological conditions. Noticeable amounts of *Cocconeïs placentula* and high quantities of littoral species reveal evidences for a decreasing lake level and more aridity. The water level stage is recorded by the development of planctonic species (74-94%). *Cyclotella* sp. aff. *comensis* type 3 (56-80%), *Cyclotella* sp. aff. *comensis* type 1 (4-14%) and *Cyclotella azigzensis* (2-8%).

4. Discussion

The hydrologic change can be approximately deduced from our P/L ratio diatom study from Lake. Five major statements can be made from our results.

The Holocene corresponds to a long lacustrine episode which reflects climatic conditions generally wet. Oligosaline water, were maintained during Holocene. A sudden filling of the lake basin by dilute water occurs during the middle Holocene. Optimal humidity and thermic conditions are reached. Three regressive events are recorded in the Middle Atlas, where probably de first one appear to be synchronous with the northern Sahara and in several African tropical lakes, a second, less severe regression occurred at stage III. The third rich in aquatic plants are recorded at stage V.

Sidi Ali is an ideal site for applying the P/L model as an indicator of water depth. This study highlights the need for fine sampling of Core Lake for good limnological histories, especially used indicators of water depth and salinity.

Many similarities in environmental conditions are observed in the Middle Atlas lakes. The several Hydrological and hydrobiological changes recorded during the Holocene indicate that regional fluctuations in precipitation and evaporation have been the major driving factor on ecological and hydrobiological changes in lakes of middle atlas.

Conclusions

This diatom work covering the Holocene, has synthesized the main hydrologic and climatic changes. The results show a good fit with regional knowledge paleoclimate. This work shows usually relatively wet conditions were maintained during the Holocene, although interrupted by events arid.

The resemblances between environmental changes recorded at Sidi Ali and in Lake *Tigalmamine*, situated 105 km northwards and 400 m higher in elevation, indicate that regional climatic changes have been the major driving factors on ecological and hydrobiological changes in lakes of Middle Atlas.

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