Short Paper

A late Pleistocene long pollen record from Lake Urmia, NW Iran[1]

Morteza Djamali[a,*], Jacques-Louis de Beaulieu[a], Madjid Shah-hosseini[b], Valérie Andrieu-Ponel[a], Philippe Ponel[a], Abdolhossein Amini[c], Hossein Akhani[d], Suzanne Leroy[e] , Lora Stevens[f], Hamid Lahijani[b], Simon Brewer[g]

[a]*Institut Méditerranéen d'Ecologie et de Paléoécologie UMR 6116 du CNRS – Europôle Méditerranéen de l'Arbois – Pavillon Villemin – BP 80, 13545 Aix-en-Provence Cedex 04, France*
[b] *Iranian National Center for Oceanography (INCO), No.9 Etemad Zadeh St., West Fatemi Ave, 14155-4781 Tehran, Iran*
[c]*School of Geology, College of Science, University of Tehran, 14155-6455 Tehran, Iran*
[d] *Department of Botany, School of Biology, College of Science, University of Tehran, 14155-6455 Tehran, Iran*
[e]*Department of Geography and Earth Sciences, Brunel University, Uxbridge, Middlesex UB8 3PH, UK*
[f]*Department of Geological Sciences, California State University, Long Beach, CA 90840-3902, USA*
[g]*Institut d'Astrophysique et de Géophysique, Université de Liège, Bat. B5C, 17 Allée du Six Août, B-4000, Liège, Belgium*

Abstract

A palynological study based on two 100-m long cores from Lake Urmia in northwestern Iran provides a vegetation record spanning 200 ka, the longest pollen record for the continental interior of the Near East. During both penultimate and last glaciations, a steppe of *Artemisia* and Poaceae dominated the upland vegetation with a high proportion of Chenopodiaceae in both upland and lowland saline ecosystems. While *Juniperus* and deciduous *Quercus* trees were extremely rare and restricted to some refugia, *Hippophaë rhamnoides* constituted an important phanerophyte, particularly during the upper last glacial sediments. A pronounced expansion in *Ephedra* shrub-steppe occurred at the end of the penultimate late-glacial period but was followed by extreme aridity that favoured an *Artemisia* steppe. Very high lake levels, registered by both pollen and sedimentary markers, occurred during the middle of the last glaciation and upper part of the penultimate glaciation. The late-glacial to early Holocene transition is represented by a succession of *Hippophaë, Ephedra*, *Betula*, *Pistacia* and finally *Juniperus* and *Quercus*. The last interglacial period (Eemian), slightly warmer and moister than the Holocene, was followed by two interstadial phases similar in pattern to those recorded in the marine isotope record and southern European pollen sequences.

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[1] This work is dedicated to Sytze Bottema for his outstanding contribution to late Quaternary palynology of the Near East.

Keywords: Near East; Long pollen record; Climate change; Last interglacial period; Lake Urmia; Iran

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Introduction

Long pollen sequences that span multiple glacial-interglacial cycles provide rare glimpses of changes in plant communities across periods of similar climate or climatic transitions (e.g., glacial/interglacial). A number of these records have been studied in Southern Europe over the last few decades (Wijmstra, 1969; Wijmstra and Smit, 1976; Woillard, 1978; de Beaulieu and Reille, 1984, van der Wiel and Wijmstra, 1987a,1987b; Follieri et al., 1988; Tzedakis, 1993, 1994, 1999). These records have been correlated successfully to marine isotope stages and orbital parameters (Tzedakis et al., 1997; Magri and Tzedakis, 2000; de Beaulieu et al., 2001; Tzedakis, 2005). Some of them have also permitted quantitative climate reconstructions (Guiot et al., 1989, 1993; Cheddadi et al., 1998; Klotz et al., 2003, 2004).

Unlike Europe, the history of vegetation and climate change in the Near East is poorly understood. Although direct physical evidence of multiple glacier extensions has been reported for several parts of the Iranian Plateau (Wright, 1961; Kuhle, 2004), the timing of major climatic events and resultant changes in the vegetation and landscape has not been well studied. The number of late-glacial and Holocene pollen records is slowly increasing, mainly located in the Zagros Mountains and Anatolian Plateau (van Zeist and Bottema, 1977; Bottema and Woldring, 1984; Bottema, 1986; Wick et al., 2003; Woldring and Bottema, 2003), but longer pollen sequences have not been available. Prior to this study, the longest continuous pollen record from the region was from Lake Zeribar, western Iran (van Zeist and Bottema, 1977), but this only extends back to the last glacial period (42,000±3600 ^{14}C yr BP). This study presents a preliminary pollen record, nearly 200 ka-long, from Lake Urmia, northwestern Iran. The data, compiled from two cores, 100-m in length, provide the first continuous pollen record covering the entire last interglacial period and the early to middle Holocene in the semi-arid continental interior of the Near East.

Physical setting

Lake Urmia is a large (*ca* 5000 km^2), shallow (8-12 m), hypersaline (>200 g/l) lake (Kelts and Shahrabi, 1986) situated in a subsiding tectonic basin (Berberian and Arshadi, 1975) in northwestern Iran. It is similar in physical, chemical and biological aspects to the Great Salt Lake in Utah, U.S.A. (Kelts and Shahrabi, 1986; Eimanifar and Mohebbi, 2007). The lake water is supplied by direct precipitation and inflow from thirteen permanent rivers and is geochemically homogeneous due to mixing by strong water currents, particularly during spring (Alipour, 2006). At several locations, abandoned terraces show evidence of large fluctuations in lake level during the Pleistocene (Kelts and Shahrabi, 1986). Historical documents and analysis of recent satellite images also show the fluctuations on the order of 1 to 3.5 meters, with an estimated lowest lake level during the Little Ice Age (Kelts and Shahrabi, 1986; Sharifi, 2002; Alipour, 2006).

Lake biota are restricted to a few hyperhalophilous phytoplankton and the crustacean macrozooplankton *Artemia urmiana*, which feeds on decaying algal remains (Eimanifar and Mohebbi, 2007). Aragonitic fecal pellets of *Artemia* form the most important biochemical sediment of the lake (Kelts and Shanrabi, 1986; Shah-Hosseini, 2003).

Modern vegetation of the Urmia region is heterogeneous. Salt marshes and saline flats are covered by halophilous vegetation dominated by Chenopodiaceae species (Asri and Ghorbanli, 1997). The submontane zone of the surrounding mountains is characterized by *Artemisia* steppe (mostly *A. fragrans*), which is replaced by thorny cushion formations in montane and subalpine zones. Remnants of *Pistacia atlantica* subsp. *mutica*, *Rhamnus pallasii*, and scattered *Juniperus excelsa* on islands in the lake are indicative of the potential natural vegetation (Zehzad, 1989). A true woodland consisting of Rosaceae species, *Acer*, *Ficus*, *Rhamnus*, *Lonicera* and *Pistacia* occurs 12 km west of the lake. Oak species (*Quercus infectoria* and *Q. libani*) are found further west and south, close to the Iraqi and Turkish borders and in Kurdistan province (Browicz, 1982).

The climate regime is Mediterranean pluviseasonal-continental in the Global Bioclimatic Classification System (Rivas-Martinez et al., 1999). Mean annual temperature and precipitation in the city of Urmia, 10 km west of the lake, are 11.2°C and 341 mm, respectively (Fig. 1, inset). Mean maximum and minimum temperatures occur in July (23.9°C) and January (-2.5°C), respectively. The wet season begins in October, but maximum precipitation occurs as spring rainfall from March to May. Prevailing winds are westerlies during winter, northeasterlies during summer, and strong southwesterlies during spring.

Materials and Methods

Coring took place during geotechnical investigations of the bottom sediments in 2000 prior to the construction of the Shahid Kalantari Causeway. Four cores (BH1-4), each approximately 100 m in length, were recovered from the centre of the lake with a digital

Dutch Piezo Cone with hydraulic driving unit (Fig. 1). The cores are currently archived at the School of Geology, University of Tehran. Lack of refrigeration for the cores after their recovery led to desiccation prior to sampling for pollen analysis. Two cores (BH2 and BH3) were sub-sampled every 1 m for palynological investigations. Sedimentary components, mineralogy, and carbonate content were also described for core BH2. Pollen extraction was performed following Moore et al. (1991). Pollen identifications were made using the IMEP reference collection, pollen atlases of Reille (1992, 1995, 1998) and pollen types of western Iran (van Zeist and Bottema, 1977). At least 500 pollen grains were counted per sample, and nearly all grains were in excellent condition. Pollen concentration values were calculated by adding *Lycopodium* tablets to weighed sediment samples (Stockmarr 1971). Aquatic plants and Chenopodiaceae were excluded from the total pollen sum. Only the percentages of Chenopodiaceae were calculated by including them in the pollen sum. Pollen diagrams were created in TGView (Grimm 2004, 2005). Principal component analysis was used to identify the major changes in the data set of pollen percentages (R Development Core Team, 2006). Two radiocarbon dates were obtained at the Laboratoire Saclay, Gif-sur-Yvette from bulk samples collected at 8 and 18.5 m depth in core BH2 (Table 1). The younger age was calibrated using Calib 5.0.2 (Stuiver et al., 1998), and the older age was calibrated according to Hughen et al. (2005).

Results and interpretation

The pollen diagrams were subdivided into five major pollen zones based on visual inspection of major variations in the Arboreal Pollen/Non-Arboreal Pollen (AP/NAP) curve (Fig. 2). The close match between the AP/NAP curve and the first axis of the PCA indicates that this ratio is a good representative of the overall variation in both diagrams and can therefore be used as a good criterion for pollen zonation (Fig. 2).

Ur-A pollen zone covers only the lowermost part of the BH3 diagram (Fig. 2). Its upper part contains a high AP/NAP values(up to 22.5%) . The sample was highly calcareous. The next zone Ur-B is characterized by low arboreal values (<15%), high herbaceous pollen values, notably *Artemisia*, Poaceae, Chenopodiaceae, Asteraceae (subfamilies Asteroideae and Cichorioideae), *Cousinia*, and a slight increase in percentages of the xerophytic sub-shrubs *Atraphaxis*, *Nitraria* and *Pteropyrum*. Near the end of the Ur-B zone, aquatic plants and algae increase. The sediment of Ur-B zone is composed of laminated siliciclastic muds with thin, widely-dispersed carbonate crusts containing *Artemia* fecal pellets. Zone Ur-C is characterized by increased AP/NAP, starting with a peak of *Ephedra* and *Quercus* (Ur-C1) that is followed by a very short period of high *Artemisia* values (Ur-C2). The next zone, Ur-C3 is characterized by a continuing increase of AP/NAP as a succession of *Betula*, *Pistacia*, *Juniperus* and *Quercus*, and *Ulmus*/*Zelkova carpinifolia*. Aragonitic muds, with *Artemia* fecal pellets and carbonate crusts intercalated by siliciclastic muds, dominate the sediment of zone UR-C.

During Ur-D zone, AP/NAP ratio decreases again, and herbaceous taxa, primarily *Artemisia,* Poaceae, and Chenopodiaceae, become dominant. However, further subdivision of this pollen zone will require higher resolution analysis. A remarkable feature of this zone is the presence of *Hippophaë rhamnoides* as the dominant tree species, especially towards the end of the zone. Zone Ur-E is characterized by a slight increase in tree pollen, including peaks of *Ephedra*, *Rheum ribes*, and *Sisyrinchium*-type pollen, and the decline of

Hippophaë rhamnoides values. A succession of tree taxa, similar to that in subzone Ur-C3, is observed as the ratio of carbonate to siliciclastic sediments increases.

Discussion

In the absence of absolute age determinations earlier than *ca* 29150 cal yr BP (Table 1 and Fig. 2), an attempt is made here to establish a temporal framework by correlation of the Urmia record with the nearest well-studied long sequences: the Arabian Sea isotopic record (Reichart et al., 1997) and a long pollen record from Greece (Tzedakis, 1993, 1994). Local names are also proposed for the main chronostratigraphical units distinguished in the diagrams and a correlation to the European equivalents is proposed (Table 2). As BH3 presents a longer and more complete record than BH2, it has been selected for this correlation (Fig. 3).

Penultimate interglacial period

The BH3 record appears to start at the ending phase of the penultimate interglacial period, and its upper part is most likely synchronous with the MIS 7a (*ca* 190 ka). This period can be interpreted as a modest expansion in the Zagros Mountains and Azerbaijan Plateau of a steppe-forest dominated by *Quercus* and *Juniperus* with *Pistacia* as a subordinate tree.

Penultimate glacial period (Bonab Glacial)

The steppe-forest described above was replaced by a steppe dominated by *Artemisia* and grasses, which remained the major vegetation types during the course of the penultimate glacial period (Fig. 2). The greater abundance of desert shrubs *Nitraria*, *Pteropyrum* and *Atraphaxis* may indicate generally harsher semi-desertic conditions than the last glaciation. Our interpretation of the Chenopodiaceae curve is made with caution because both halophytic and xerophytic upland species can produce the same pollen types (van Zeist and Bottema, 1977; Bottema, 1986). The predominance of Chenopodiaceae in the halophytic communities around the lake (Asri and Ghorbanli, 1997) complicates any interpretation. The increases in Chenopodiaceae may therefore reflect lower lake levels and the resultant extension of suitable habitats for the colonization of halophilous Chenopodiaceae.

Increasing values of Cyperaceae and *Sparganium*-type pollen, *Pediastrum* and particularly dinoflagellate cysts, in addition to lower Chenopodiaceae pollen values, indicate low salinities and high lake levels in the upper penultimate glacial stage. Dinoflagellate cysts (core BH2, 76.5 m), were identified as *Spiniferites belerius*, a species that currently prefers brackish water. It has been reported from the Holocene age sediments of the Black Sea (Marret et al., 2007), Caspian Sea (Leroy et al., submitted), Kara-Bogaz Gol (Leroy et al., 2006) and the Aral Sea (Marret et al., 2004). High pollen percentages of this species in Lake Urmia during the penultimate late-glacial period strongly suggests high lake levels that diluted the water body from hypersaline to brackish concentration. Deposition of a black, organic-rich clay corresponding with the dinoflagellate-rich zone suggests decreased vertical circulation due to greater water depth. It should be noted here that the high lacustrine terraces reported from the Urmia Basin (Kelts and Shahrabi, 1986) might have been deposited during the glacial highstand phases of the lake.

Last Interglacial (Sahand Interglacial) and ensuing interstadial periods (Kaboudan I and II)

The late penultimate glacial period is marked by the expansion of an *Ephedra* shrub-steppe (Ashk Interstadial, Fig. 3). This is then followed by a severe arid period dominated by *Artemisia* steppe just before the start of the last interglacial period (LI). This peculiar vegetation type (*Ephedra* shrub-steppe) never reoccurs to the same extent in the rest of the Urmia record. The analogue of this vegetation type occurs today in the foothills of the central, north-central, and northeastern mountains of Iran and is replaced by *Artemisia* steppe where aridity is higher. Dynamics of forest tree expansion during the penultimate glacial to last interglacial transition appear to be similar to the late-glacial-Holocene (Bottema, 1986). Nevertheless, the spread of *Zelkova carpinifolia*, an extremely under-represented plant in the modern pollen rain (Djamali, 2004; Kvavadze and Connor, 2005), suggests that the climatic conditions of the LI must have been optimal for this species, compared to the Holocene. This mesic, thermophilous, Euxino-Hyrcanian relict element (Budnar-Tregubov, 1972; Leroy and Roiron, 1996) indicates milder winters and periods of more spring or summer rainfall. Remnant populations of this species and *Pterocarya fraxinifolia* have been recently documented in the Zagros Mountains (Browicz, 1982, Akhani and Salimian, 2003). *Zelkova* pollen has not been reported from the Holocene sediments of Lake Urmia (Bottema, 1986). The LI (Fig. 2, BH3: 59-64 m) is followed by two stadial and two interstadial periods before giving way to the last glaciation. The interstades are equivalent to MIS 5c (Fig. 2, BH3: 52-57 m) and 5a (Fig. 2, BH3: 43-47 m) and the western European interstades St Germain I and II (de Beaulieu and Reille, 1992). The absence of *Z. carpinifolia* suggests that they never reached the same optimum climatic conditions as those described above for the LI. During the LI and the following interstades, the lithology, which consists of aragonitic muds with *Artemia* fecal pellets, is similar to that of the Holocene. In contrast, siliciclastic muds with gypsum crystals dominate the stadial intervals, suggesting that productivity is greater during interglacial/interstadial events.

Last glacial period

During the last glaciation, the vegetation composition was similar to that of the penultimate glaciation and consisted of *Artemisia* and grass steppe. However, the herbaceous vegetation composition was slightly different, and *Hippophaë rhamnoides* was more prominent in the last glaciation. Today, this species is found in higher elevations north of Lake Urmia, in the Central Alborz Mountains, and more frequently in the Caucasus and Afghanistan (Meusel et al., 1978; Browicz, 1986). This tree is a pioneer species and can grow on unstable soils and river beds and bars. Its presence during the last glacial period in the Urmia region indicates lower winter temperatures than today, July temperatures above 11° to 12°C (Kolstrup, 1980), and probably high fluvial activities due to intense erosion in the absence of a well developped vegetation cover.

The sedimentation during this zone is dominated by siliciclastic input from the strongly eroded, poorly vegetated slopes. High lake stands are indicated by carbonate and organic matter deposition and peaks of aquatic plants and *Pediastrum,* which are consistent with lower salinities and higher surface water temperatures. High stands during the last glacial period are also known from other lakes in the region, such as the Dead Sea (Bartov et al., 2002) and Konya Lake (Roberts, 1983).

Late-glacial and Holocene

A detailed picture of late-glacial–Holocene (Fig. 2) vegetation dynamics cannot be given here because of the low resolution of this study and the incompleteness of the Holocene record. However, general trends in pollen frequencies are in agreement with those published by Bottema (1986). The abrupt increase in tree pollen is probably a signal of the expansion of Zagros oak forests (van Zeist and Bottema, 1977) at the transition from early to mid-Holocene. The replacement of the *Pistacia-Quercus* forest-steppe by the Zagros oak woodland took place just prior to *ca* 6500 cal yr BP at Lake Zeribar (van Zeist, 1967). This event occurred around 7500 varve yr BP at Lake Van (Wick et al., 2003). Carbonate dominates sedimentation during the Holocene due to high rates of chemical and biochemical precipitation of calcite and aragonite, especially in summer months (Kelts and Shahrabi, 1986). At the same time, lower input of terrigenous siliciclastic sediments resulted from decreased erosion on vegetated slopes. The loss of the uppermost meters of the cores does not permit the reconstruction of the vegetation during the late Holocene.

Conclusions

The pollen diagrams from Lake Urmia are the longest record of past vegetation from the continental interior of the Middle East. Correlation of NAP/AP values with marine isotope records and long pollen sequences from southeastern Europe indicates that the Urmia record covers a period spanning the last 200 ka. Siliciclastic materials dominate the sediment deposited during glacial periods when there was sparse vegetation, strong soil erosion, and low biochemical activity in the surface water. During interglacials, however, lake sediment was dominated by chemically and biochemically-precipitated calcite and aragonite. During the penultimate and last glaciations, the upland vegetation consisted of steppe dominated by *Artemisia* and grass species. The herbaceous composition of the steppe vegetation was slightly different during the penultimate and last glacial periods suggesting slight climatic differences between these two periods. The last interglacial appears to have been slightly warmer and moister than the Holocene as inferred from the higher abundance of *Zelkova* forest stands. This period was followed by two interstades comparable to western European St Germain I and II interstades.

High-resolution analyses with better dating control are required to study the higher-frequency changes in vegetation and climate during both glacial and interglacial periods. Increased resolution will allow more precise correlations with other terrestrial and marine records.

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Table and Figure captions:

Table 1 Radiocarbon ages of core BH2. The Calib 5.0.2 software (Stuiver et al., 1998) was used to calibrate the younger age. The older age was calibrated using the calibration curve proposed by Hughen et al. (2005).

Table 2 Proposed local geologic-climatic units for Urmia sequence correlated with two long terrestrial sequences of Greece (Wijmstra, 1969; Wijmstra and Smit, 1976; van der Wiel and Wijmstra, 1987a,1987b; Tzedakis, 1993, 1994, 1999).

Figure 1. Relief map of Lake Urmia with its geographical location in the Middle East and the location of the studied cores. Upper right inset shows the climate diagram of the Urmia meteorological station (data from the Iran Meteorological Organization (1951-2005)). Dotted area of the climate diagram represents the period of relative drought and vertically hatched areas indicate the wet period. The black area on x-axis represents months with mean daily minimum temperature below 0°C and hatched areas show months with absolute minimum temperature below 0°C i.e. with early or late frosts.

Figure 2. Pollen percentage diagrams and AP concentrations of Lake Urmia cores BH2 and BH3. Lithology and carbonate content of core BH2 have also been displayed. PCA axis 1 explains 11.73% of the variance in BH2 and 10.03% BH3. Facies A: Laminated calcareous mud with abundant *Artemia* fecal pellets; alternation of light grey and greenish grey laminae, Facies B: Light grey to greenish grey calcareous mud with abundant *Artemia* fecal pellets and intercalations of carbonate crusts, Facies C: Laminated mud with gypsum layers; alternation of greenish grey and brown mud with gypsum layers with or without the organic rich laminae, Facies D: Greenish grey calcareous mud with dark coloured bands and carbonate crusts.

Figure 3. Correlation of the AP/NAP curve of BH3 pollen diagram with the Indian Ocean isotopic records and a long pollen record from northwest (Ioannina) Greece. Local chronostratigraphical names are proposed here for the distinct glacial/interglacial and stadial/interstadial stages instead of the commonly used European glacial terminology (Lowe and Walker, 1997).