Exploratory palynological analysis of Quaternary lacustrine deposits around Damavand volcano, Northern Iran

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(*received: 08/12/2013 ; accepted: 06/07/2014*)

Abstract

Palynological analyses from exposed palaeolacustrine deposits located at the flanks of Damavand volcano, in the central Alborz Mountains in Northern Iran, provide a broad idea of the temporal variation of vegetation according to climate changes during a range of limited time intervals during the Quaternary period. This research reveals that the regional vegetation of the study area had been a semi-arid mountain steppe since the early Quaternary. However, moderate expansions of open woodlands and aquatic/marshy taxa indicate less arid climatic conditions. Some of these comparatively less arid phases during the last 70 ka are contemporaneous with the climatic amelioration phases during previous glacial periods in the Himalayan region. Although the results are scattered through time, they clearly show the potential of the study area for further palynological investigations with the aim of understanding the regional vegetation response on global climate changes in Northern Iran.

Keywords: *Iran, Damavand volcano, Quaternary, pollen, vegetation*

Introduction

Palaeoenvironmental and palaeoclimatic information in the context of Iran is scarce. Being located between the Mediterranean climatic zone and a region influenced by the Indian summer monsoon rains, the Iranian plateau holds great potential for palaeoecological investigations aimed at gaining a better understanding of the long-term atmospheric connections between the different climate systems of SW Eurasia (Djamali *et al*., 2008). The Iranian plateau's vast Quaternary lacustrine deposits would serve as an ideal archive for palynological investigations. There have only been a limited number of studies focusing on the Zagros Mountains in the west of Iran that deal with late Quaternary vegetation history covering the time span including the past 200 000 years (Bobek, 1963; Van Zeist & Wright, 1963; Van Zeist, 1967; Van Zeist & Bottema, 1977; Van Zeist & Woldring, 1978; Bottema, 1986; Djamali *et al*., 2008; Leroy, 2010; Leroy *et al.,* 2011, 2013). These studies have revealed that during the previous glacial periods, *Artemisia* and grass steppes dominated the vegetation of the Zagros Mountains and the Azerbaijan area under a cold and arid climate.

During interglacial periods (the Holocene and the Last Interglacial), oak and juniper woodlands and *Pistacia-Amygdalus* scrubs expanded at the expense of these Irano-Turanian upland steppes (e.g., Bottema, 1986; Djamali *et al*., 2008).

In northern Iran, in the southern section of the Elburz Mountains, Quaternary palynological investigations have been limited to a preliminary examination of the lacustrine deposits of Lar Paleo lake in an outcrop 7 km to the north of Polour, in the southeastern region of Damavand volcano (Von der Brelie, 1961). The present study indicates that during the deposition of this sedimentary profile, the upland vegetation was a dry steppe with a climate more arid than it is today. In the present paper, various outcrops at the flanks of Damavand volcano, northern Iran (Fig. 1) have been explored for their palynological potential in order to further reveal palaeoenviromental information.

Study area

Quaternary lacustrine exposures are present around Damavand volcano, the highest peak (5 670 MASL) in the Middle East. The studied sites are located in the central part of the Reineh Plateau in Mazandaran Province, 60 km northeast of Tehran, Iran and falls within the geographic range of 52° 00' to 52° 15' E and 35° 45' to 36° 00' N (Fig. 1). The detailed geology of this volcanic area has previously been discussed (Davidson *et al*., 2004).

Figure 1: Damavand volcano, view from southern flank. Lar section is situated at the left side of the volcano and Polours section is at the right side, N 35° 49' 56.92", E 52° 02' 00.44" (photograph by Alimohammadian, H.).

The region is characterized by semi-arid climatic conditions. Being located in a high mountainous region, the winter is very cold with rain and snow. Due to high elevation differences, the mean annual temperature of the area ranges between 13.7 and -7.1 °C (mean 7.2 °C; WorldClim dataset), with a mean temperature in the warmest quarter of 19.1 °C (5-25 °C) and a mean temperature in the coldest quarter of -5.4 °C (-19.6-2 °C). Annual precipitation is about 175 mm (149-375 mm) with rainfall at its highest in spring (March to May). Being located in a rain shadow zone – due to the high elevation of Damavand volcano – the area receives considerably less rainfall than in the northern flanks, which only a small distance to the north sees annual precipitation exceeding 1000 mm.

The area is nearly treeless except for a small number of *Salix* and *Carpinus* trees growing along banks of streams in nearby villages. In general, the area is part of the Elburz Range forest steppe ecoregion (Olson *et al*., 2001) and is characterized by Irano-Turanian steppe vegetation (Zohary, 1973) dominated by *Artemisia* spp., with occasional shrubs including *Berberis, Crataegus*, *Rhamnus* and *Paliurus spina-christi.* Xerophytic thorn cushion plants, including *Astragalus* and *Acantholimon* are also an important component of the mountain steppes. Among the riparian vegetation in the valleys in NW Damavand there are *Berberis*, *Salix*, Rhamnaceae and Papaveraceae. Isolated stands of *Juniperus excelsa* occur on calcareous substrates in elevations between 1500-2500 MASL, which at higher altitudes are replaced by *J. communis*. On some geological evaporate formations there are also considerable patches of *Tamarix*. The nearest dense forest is the mesic Hyrcanian forest (Zohary 1973; also referred to as the Caspian Hyrcanian mixed forests after Olson *et al*., 2001), located 50-60 km north to north-east of the studied area.

Lithostratigraphy, chronology and sampling

Three localities with lacustrine deposits exposed at the flanks of Damavand volcano and one locality 25 km away from the Polour section at the south of Damavand volcano (Zan Village), central Elburz Mountains, Northern Iran, were sampled for geochemical and palaeontological purposes (Alimohammadian, 2006). Later, some of these samples were chosen for palynological analyses. The sediments were collected from sections of deposits by digging trenches at Polour, Abe-Ask, Lar Reservoir Lake and Zan Village (Fig. 1).

For ^{14}C dates, 250 to 300 grams of sediments were first treated using the acid-alkali-acid method to remove all impurities and to gain the organic-bound carbon. This organic-bound carbon was converted into benzene and placed in a liquid scintillation counter (LSC) after adding phosphor to it. The LSC detected the rate of scintillations or flashes of light produced by the interaction of ß particles with phosphor. The release of beta particles occurs due to the decay of ^{14}C to nitrogen following the death of an organism and the amount of ^{14}C in the dead organism starts declining with after a half-life of 5 730 years. Thus, the basis of the conventional radiocarbon dating method is the decay of ^{14}C isotopes. Hence, this method is purely a function of time, as the rate of release of beta particles slows as the age of the sample increases. All age information has been compiled in Table 1.

Polour

Polour lies exposed on the southern flank of Damavand volcano, located about 60 km northeast of Tehran. The sediments overlie the Rhaetian/Lias Shemshak formation and are superimposed by trachyandesite lava flows, which have been suggested to hail from the late Quaternary (Holocene) (Allenbach, 1966).More recently, the Quaternary age of sediments has further been confined based on (U-Th)/He radiometric analyses (Davidson *et al*., 2004). Their age, determined from a pumice particle trapped within the lowermost clay layers of Polour Section A is 1.8 Ma (1.77 ± 0.05 Ma). Though whether this particle has been reworked cannot been ruled out, it nonetheless provides a maximum age for sediments from Polour.

Table 1: Compilation of dating results

Site name	Ages	Material	Method	Code	Reference
Zan Village	33.74 ± 1.69 ka	Organic clay	C14	B-2193	Birbal Sahni Institute of Palaeobotany, Lucknow, India
Zan Village	35.58 ± 3.26 ka	Organic clay	C14	B-2194	Birbal Sahni Institute of Palaeobotany, Lucknow, India
Lake Lar	ca. 38.5 ka	Clay			Allenbach (1966)
Abe-Ask	279.9 ± 8.4 ka	Ignimbrite	(U-Th)/He	DMV13	Davidson et al. (2004)
Polour B	77 ka	Bulk sediment	TL	TL1 (PRL)	Physical Research Laboratory, Ahmedabad, India
Polour A	1.77 ± 0.05 Ma	Pumice	(U-Th)/He	DMV131	Davidson et al. (2004)
Polour B	no result (>50	Fossil Wood	C14	B-219-	Birbal Sahni Institute of Palaeobotany, Lucknow, India
Polour B	no result	Pumice	40Ar/39Ar	11m0384	Isotope Geochemistry, University Amsterdam, The

Furthermore, some magnetostratigraphic analyses conducted by Alimohammedian (2006) provided reversed polarity for the lowermost part of the section (Polour A), limiting the age of this part to between 780 and 1.8 Ma. Unfortunately, the Brunhes/Matuyama boundary has not yet been detected and there appears to be a hiatus concerning research in this area. Therefore, the parts Polour A and Polour B have been considered separately in Figures 2, 4.

The existence of this research hiatus appears to have been confirmed by a sample from Polour B, dated to 77 ka using the TL dating method at PRL (pers. comm. A. Singhvi, Physical Research Laboratory Ahmedabad, India), indicating the limit of this methodology (Debenham, 1985; Singhvi *et al.*, 2001). Fossil wood particles from the sequence unsuccessfully dated using the conventional 14C dating method at BSIP (Birbal Sahni Institute of Palaeobotany, Lucknow, India); the ages of these particles exceeded the methodological range of the method. A tuff sample, taken from the upper part of the section for Ar/Ar dating yielded no reliable age information (pers. comm. K. Kuiper, Amsterdam).

Lithologically, the section is characterized mainly by levels of fine silty sands, multiple conglomerate-mudstone deposits and volcanic ash layers (Fig. 2). These deposits extend vertically for 25-30 m directly below the 15-20 m thick trachyandesite lava flows. In total, 24 samples were collected from the section. Of these, 11 yielded pollen, seven from Polour A and four from Polour B; the rest of the samples were either barren or had a too low pollen content for analysis.

Abe-Ask

The distance of the Abe-Ask Section from Polour is about 10 km to the northeast direction of Polour. In this section, 13 m-thick sediments are exposed and have been analysed for pollen studies. The top 3 m of the profile from the surface downwards comprised pyroclastic sediments and tuff, followed by a 1.5 m-thick layer of ignimbrite and 2.5 m-thick pyroclastic layer, below which a mudstone layer was exposed for 6 m. Based on published records, the Abe-Ask ignimbrite was formed at around 280 ka (279.9 ± 8.4 ka; Davidson *et al*., 2004). Among the five samples studied for palynological analyses from this profile, only three samples yielded pollen, while in one sample pollen appeared sporadically. One sample was found barren.

Lake Lar

Lake Lar is located at an elevation of about 2800 m above mean sea level and lies roughly 20 km in a northwest direction from Polour. The section mostly comprises pyroclastic rocks, tuffs and uncompacted lava fragments.

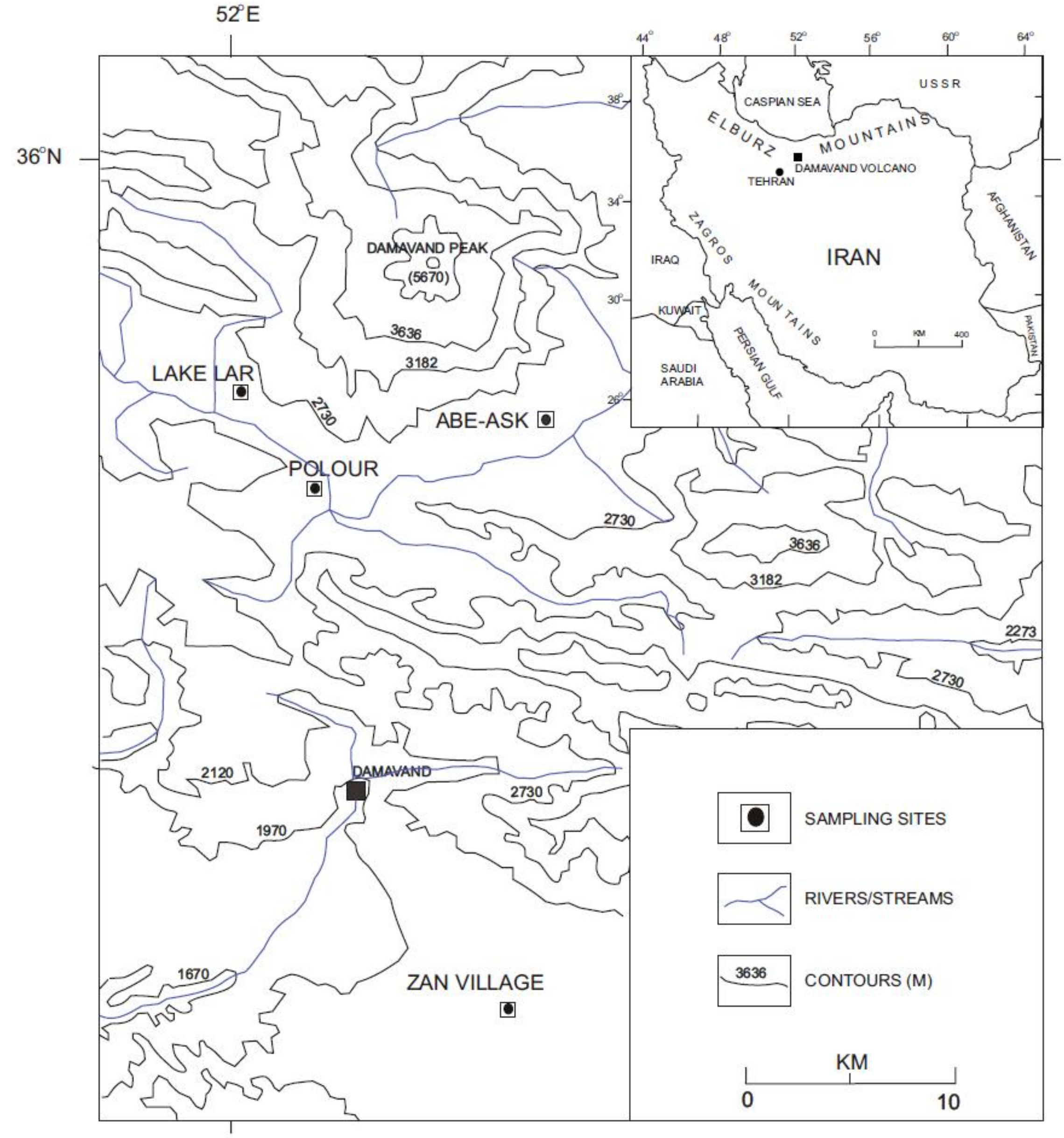

Figure 2: Map of Iran showing the location of Damavand volcano and sampling sites.

Trachyandesite flow is the major rock type and is traceable for a long distance in Lar Valley. The thickness of these flows varies from one area to another; the minimum exposed sections are 10 m. A thin layer of impure volcanic ash is exposed near the surface of the river terraces on the eastern side of Lar Dam.Two samples were collected from these lacustrine sediments. Among them, only one – composed of mixed volcanic ash and clay – yielded pollen. The date for this exposed layer appears to be around 38.5 ^{14}C ka BP, as per published records (Allenbach, 1966).

Zan Village

Zan Village is situated 40 km south of Polour. A small profile 1.70 m in depth was collected near the village. The top 0.30 m from the surface was silty clay, followed by a conglomeratic layer, which was interrupted at three places by intercalations of silty clay rich in organic matter of 0.10 m, 0.05 m and 0.10 m thickness at a depth of 0.30 m, 0.60 m and 0.80 m, respectively. Two samples, dated at the Radiocarbon Laboratory, BSIP from a depth of 0.85 m and 0.625 m yielded ages of 35,580 $\pm$ 3260 ^{14}C yr BP and 33,740 $\pm$ 1690 ^{14}C yr BP, respectively.

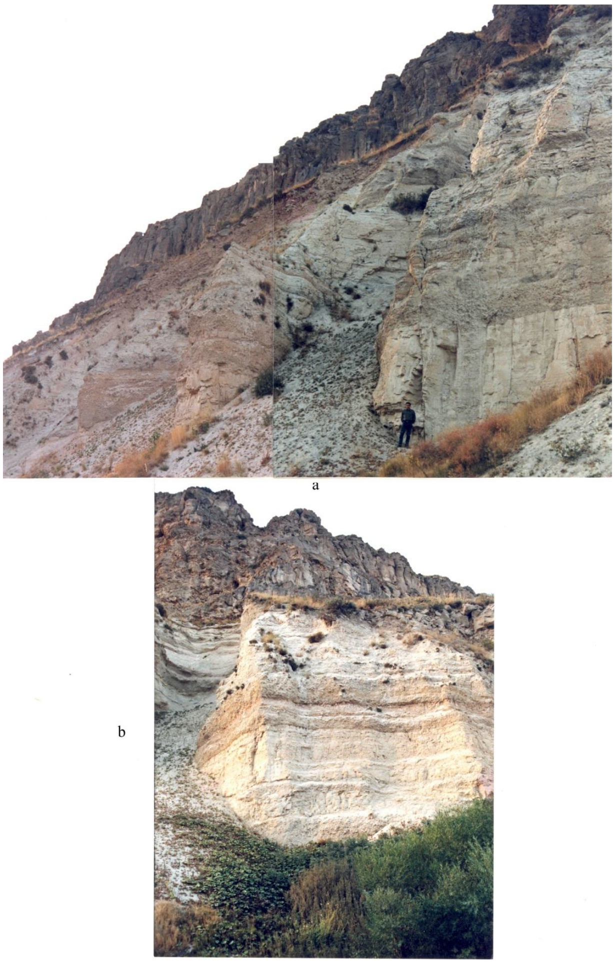
a
b

Figure 3: Panoramic view of Polour Section, a) volcano-sedimentary sequences, b) Thick trachyandesitic lava flow capping the section.

One sample from each of the three organic bands was collected, with two of them providing a sufficient amount of pollen. Further towards the surface, no C-14 dates are available due to a lack of suitable material; corresponding sediments have also been found devoid of pollen grains.

Palynological methods

Samples for pollen analysis were chosen from the available material and processed following the common method of Fægri and Iverson (1989), with slight modifications. As the sediments were low in pollen content, approximately 50 g of sediment per sample was taken and digested in 10% potassium hydroxide (KOH), followed by treatment with 10% warm HCl, HF and an acetolytic mixture. The residue, mixed with 50% glycerine, was stored and used for the quantitative and qualitative estimation of palynomorphs. An Olympus microscope with a 10x eye piece and an objective of either 40x or 60x was employed for counting.

Most of the samples processed had a low pollen count and some were even barren. At various depths, sediments that were rich in calcium carbonate or made up of a coarser texture were found to be unsuitable for palynological analysis. Because of poor pollen preservation, only up to 150 pollen grains were counted for each spectrum.

Based on the morphological characteristics of pollen grains such as shape, size, sculpturing, number and type of apertures, etc., the identification of the pollen grains and spores recovered from the sediments was made by consulting pollen keys and reference pollen slides (e.g., Gupta and Sharma, 1986; Moore & Stevenson, 1982; Moore *et al*., 1991). Pollen percentage diagrams were constructed using the software TILIA and TG View 2.0.2 (Grimm, 2004).

The total number of pollen grains counted per sample was taken as "total pollen count". However, all aquatic and unidentified pollen types, as well as non-pollen grains, were considered in this instance as background elements and were excluded from the "total pollen count" in order to calculate a "pollen sum". To provide the pollen spectra, the percentages of the excluded elements were calculated in respect to the "total pollen count", whereas for other taxa, percentages were calculated in relation to the "pollen sum". Both values, total pollen count and pollen sum, are provided with raw data in Supplement 1.

Results and discussion

Both arboreal and non-arboreal plants were represented by some common taxa in the pollen spectra of the different localities. In these, *Alnus, Betula, Ephedra, Juniperus, Pinus, Salix, Tamarix* and *Ulmus* represented the arboreal constituents, whereas the non-arboreal were mostly represented by *Artemisia,* Asteraceae, Chenopodiaceae, Poaceae*,* Saxifragaceae, and other types (Fig. 4).

Our data generally indicated that non-arboreal taxa were more abundant than arboreal taxa. This might either be due to less-extended tree stands at the sites or as a result of trees growing far from the investigation sites.

However, some samples showed a higher AP/NAP ratio, indicating more extended patches of forest or open woodlands.

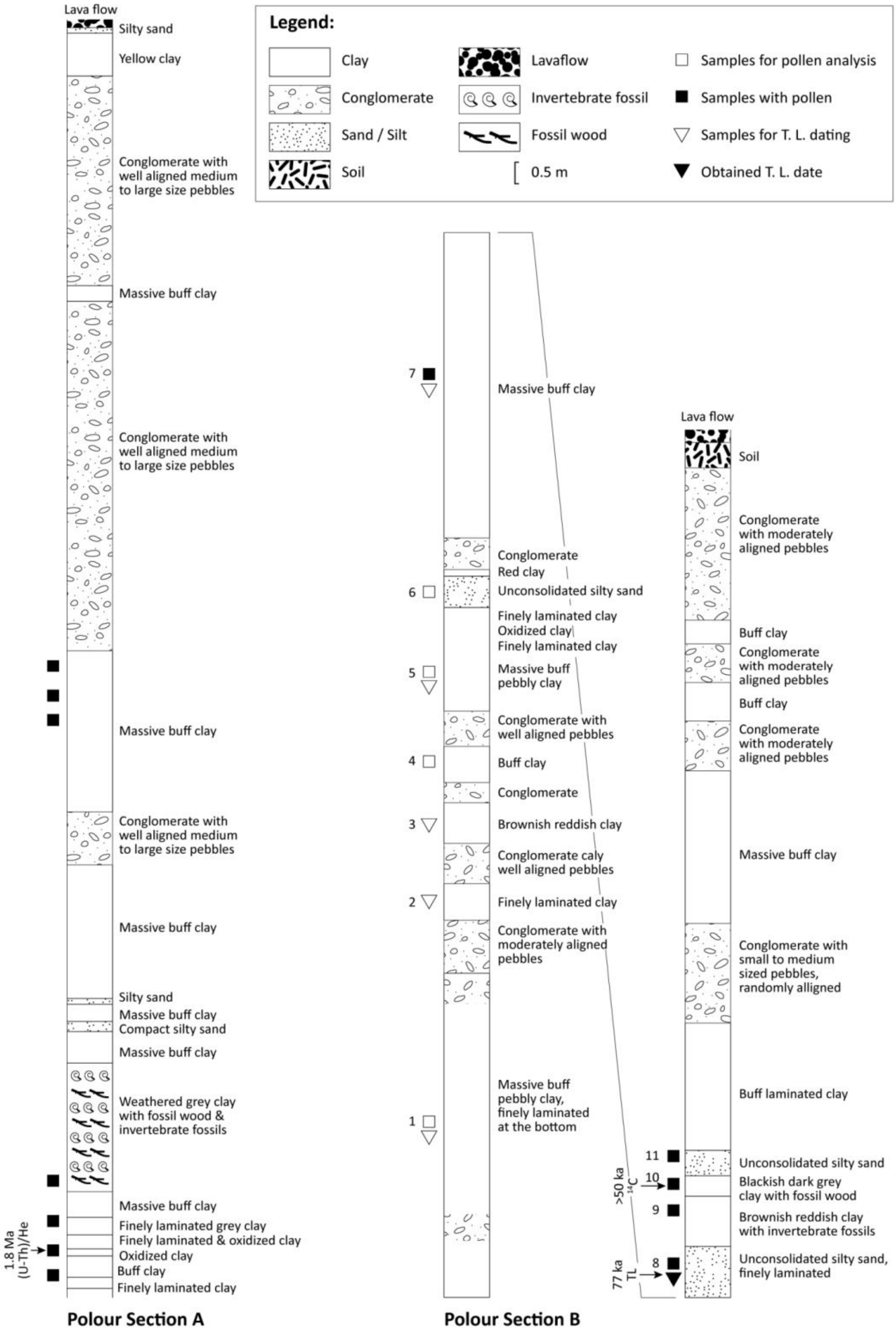

Figure 4: Lithology of profiles Polour A and B with sampling levels for palynology and datings

The pollen diagram, together with the available dates for the different profiles, provided data for giving a first impression of the vegetation and climate in Northern Iran over a range of time intervals during the Quaternary period. From our palynological analysis, data was available for the late Early Pleistocene (< 1.8 Ma; Polour A), Middle Pleistocene (250 ka; Abe-Ask) and Late Pleistocene (77 ka, Polour B; 38 ka, Lake Lar; 33-36 ka, Zan Village).

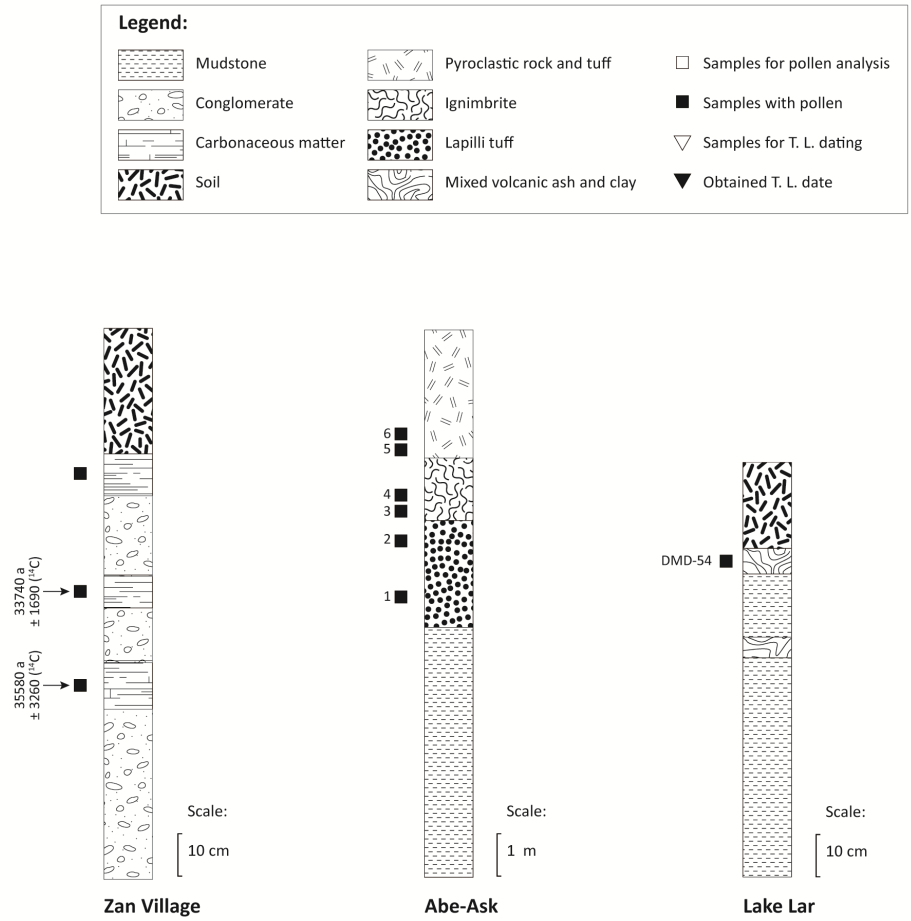

Figure 5: Lithology of profiles Zan village, Abe-Ask and Lake Lar with sampling levels for palynology and dating

Pollen spectra of the lowest part of the Polour A profile (with an age of 1.8 Ma) showed the dominance of aquatic taxa, especially Cyperaceae, over the steppe elements. This likely indicates higher lake levels and a cooler and moister climate than the present. It is interesting to note that even with relatively low pollen counts; the amount of Cyperaceae present was still high. These relatively fragile pollen grains therefore prove the suitable preservation of the organic material in this instance. Additionally, a higher abundance of *Quercus* and *Juniperus* appears to indicate increased humidity and the occurrence of patches of forest-steppes or woodlands. Regarding the good correlation between pollen percentages and tree cover in *Juniper* woodlands (Beer *et al*., 2007), high values of *Juniperus* pollen (>40%) indicates that 1.8 Ma ago, the area had been located within the *Juniperus* woodlands.

The Abe-Ask sequence, dated around 280 ka, showed relatively high *Artemisia*/Chenopodiaceae pollen ratios, which is indicative of a higher availability of soil moisture, compared to the other periods studied (El-Moslimany, 1990; Van Campo *et al*., 1996). This may document the occurrence of more humid climatic conditions in 280 ka ago than during other periods.

However, in the case of Polour B, dated to ca. 77 ka, a peak in *Juniperus* pollen again occurred and suggests that the climatic conditions were less arid. The one sample from Lake Lar, which also showed a high abundance of *Juniperus*, confirmed the prevalence of a cool and moderately moist climate around 38.5 ka, during the Late Pleistocene. High Chenopodiaceae pollen values may have been due to the presence of halophytic chenopods in local saline soils (Moor & Stevenson, 1982), probably at the periphery of the lake. Extraordinarily high Chenopodiaceae pollen values have already been reported from other parts of Iran, such as the Lake Urmia region and have been attributed to the extensive presence of these halophytic communities in local saline environments around the lake, especially during the glacial periods (Djamali *et al*., 2008).

Pollen data from Zan Village covered a time span from around 36 ka BP to ca. 34 ka BP. The pollen spectrum, with an age of 33 740 ± 1690 yr BP showed much more Poaceae pollen and less steppe elements, relative to the age samples of 35 580 ± 3260 yr BP, indicating some important climate fluctuations within the last glacial period. The increasing Poaceae at the expense of *Artemisia* and Chenopodiaceae may be an indication of an increasing spring rainfall (El-Moslimany, 1990).

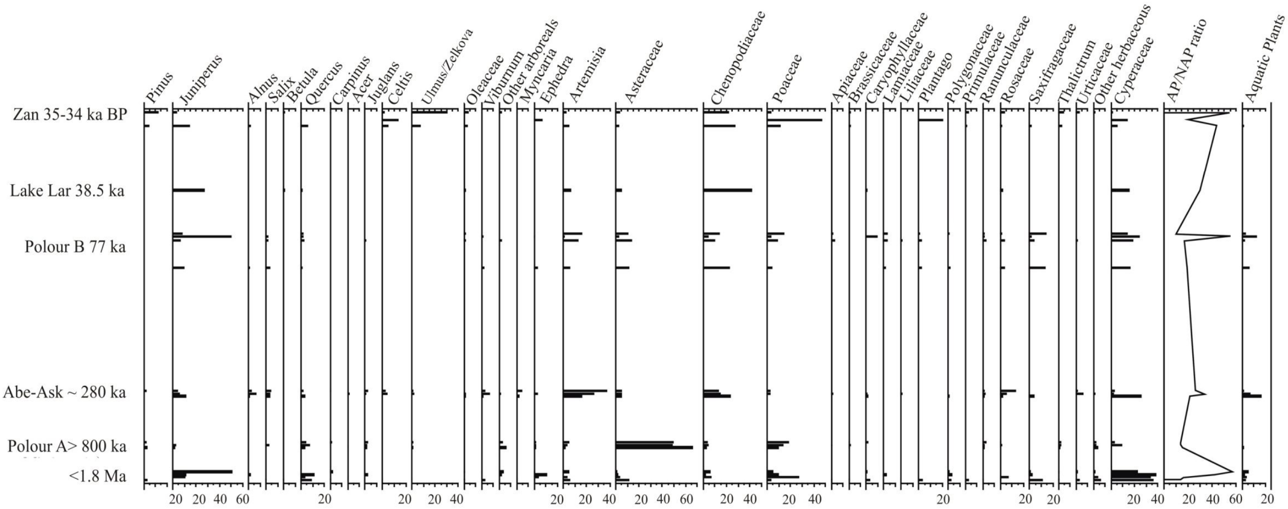

Figure 6: The composite pollen diagram of all studied sections in stratigraphic order

Conclusion

The present exploratory palynological study conducted at the Damavand volcano site and southern parts of the Alburz Mountains provides a fragmented history of vegetation and climatic change at some intervals of the Quaternary period in this region. The presence of steppe elements in the pollen spectra indicates that the climate in general might have been semi-arid throughout the time span of these pollen found in the data. However, the sporadic increase of pollen grains of trees, most importantly *Juniperus* pollen, shrubs and marshy and aquatic taxa at some depths suggest that there were brief periods of comparatively less dry conditions, when these taxa might have migrated to the steppe growing in the vicinity of the site.

Obviously, archives for pollen, i.e., lake sediments, were more abundant during humid phases in such an environment and therefore make provision for the increased probability of preservation. The signals of humidity in all sections appear to indicate that such climatic states are preferentially captured in the fossil record of a semi-arid steppe environment like Northern Iran.

The youngest of these less arid, likely interstadial phases at this region around 36-34 ka and reported in the present study may correspond to the Interstadial of 34-28 ka, which is widely known from SW Europe (Veres, 2007) and NW Europe as the Denekamp Interstadial (Hammen *et al*., 1971; Roger, 1976; Kolstrup, 1980), as the Alesunde Interstadial in Scandinavia (Baumann *et al*., 1995) and as the Krinides Interstadial in Northern Greece (Wijmstra, 1969). There is regional evidence for an almost fully deglaciated Scandinavia during the Middle Weichselian, some 30-40 ka BP (Olsen *et al*., 1996). Recently, Winograd (2001), based on glacial-geologic sea level and benthic $\delta^{18}O$ data, indicated that ice volume at ca. 35 ka BP was approximately 50% of that of the LGM. In NW Iran, a similar interstadial period was described at about 30 ka, characterized by a slight increase of tree pollen in the long lacustrine core sample from Lake Urmia (Djamali *et al*., 2008). Furthermore, such climatic ameliorations have been noted in the Himalayan region. Several periods of amelioration during 34 ka, 32 ka, 30.7 ka and 29 ka are described as having been present in Kumaun in the Lesser Himalayan region (Kotlia *et al*., 1997; 1998, 2000), as well as in Ladakh, in the Trans-Himalayan regions (Bhattacharyya,1989) and appear to correspond to the events from Iran discussed in this paper.

However, for most of our data, a precise correlation with existing data from other regions has not been possible to date, due to the low number of available samples and a lack of further age constraints. In the present study, the samples analysed were not collected unequivocally for palynological analysis and not at closer intervals, which is a prerequisite for obtaining high-resolution information. Nevertheless, this investigation clearly shows the potential of the study area in terms of further palynological investigations and signifies the importance of pollen analyses from this region in deciphering the regional vegetation response on global climate changes in Northern Iran.

Acknowledgement

J. Sharma, H. Alimohammadian, A. Bhattacharyya and P. S. Ranhotra sincerely thank Dr N.C. Mehrotra, Director of BSIP, for giving us permission to conduct this collaborative work. H. Alimohammadian is also grateful to University Grants Commission (UGC), India, for their financial support in relation to fieldwork and other expenses related to this research. A. A. Bruch and S. Scharrer appreciate the support of the Volkswagen Foundation and the ROCEEH Research Centre. 'The role of culture in early expansions of humans' of Heidelberg Academy of Sciences.

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