Magnetic properties and geochemistry of loess/paleosol sequences at Nowdeh section northeastern of Iran

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Abstract

The loess-palesols sequences in the northeastern of Iran are high-resolution natural archive of climate and environmental change, providing evidence for the interaction between accumulation and erosion of aeolian and fluvial sediments during the Middle and Late Pleistocene. In this study, Azadshar (Nowdeh Loess Section) was selected to reconstruct Late Quaternary climate change. The Nowdeh loess/ paleosol sequences with 24 m thickness were sampled for magnetic and geochemical analysis. The section systematically and with high resolution (10 cm intervals) were sampled and totally 237 samples were taken. Magnetic susceptibility of all samples were measured in Environmental and Paleomagnteic laboratory based at Geological Survey of Iran, Tehran, Iran. The geochemical analysis of selected samples (peak of magnetic susceptibility) were included to assist the paleoclimatic interpretation of the magnetic signals. The result of magnetic susceptibility of Loess/paleosol deposits show low magnetic susceptibility values in cold and dry climate periods (Loess) and high magnetic susceptibility values in warm and humid climate periods (paleosoil). Comparison of magnetic and geochemical data show that the results of geochemical weathering ratio variations such as magnetic parameters variations are with magnetic susceptibility. High degree of coherency between the intensity of magnetic susceptibility and Rb/Sr, Mn/Ti, Zr/ Ti and Mn/ Sr ratio are confirmed.

Keyword: Loess/paleosols sequences, Climate, Magnetic parameters, Geochemical proxies, Northeastern of Iran.

Introduction

Reconstruction of the Quaternary climate is an important constraint for the development of climate models that lead to a better understanding of past and present and prediction of future, climate development. Loess–paleosol sequences are now recognized as one of the most complete terrestrial records of glacial–interglacial cycles of the Quaternary Period (Porter, 2001; Muhs and Bettis, 2003, Pierce et al, 2011).

Aeolian sediments with paleosol layer enumerate as a best sediment records for paleoclima especially for Quaternary evidence in continents (Guo et al, 2002). Loess/paleosols sequence are one of the important natural climate change archives in continents and have been used for reconstruction of Quaternary climate and geomorphological changes (Karimi et al., 2011; Frechen et al., 2003; Prins et al., 2007).

Loess deposits have covered large areas of the northeast, east central, north and central parts of Iran which are part of loess belt that cover the Middle East and extend further northward into Turkmenistan, Qazakistan and Tajikistan (Okhravi and Amini, 2001).The extensive and thick loess deposits in northern Iran have been recently studied in detail setting up a more reliable chronological framework for the last interglacial/glacial cycle (Lateef, 1988; Pashaee, 1996; Kehl et al., 2006; Frechen et al., 2009, Karimi et al, 2009, Karimi et al, 2013, Okhravi and Amini, 2001, Mehdipour et al, 2012).

Paleoclimatical studies of loess deposits based on rock magnetism and combination of magnetism and geochemistry of loesses around the world have attained appreciable advances in the past few decades (Heller and Liu, 1984; Forster et al., 1996; Ding et al., 2002; Guo et al., 2002; Chlachula, 2011; Bronger, 2003; Baumgart et al., 2013, Guanhua, et al, 2014).

These provide a relatively loess-paleosols sequence records that cover the area of Chinas loess plateaus, Germany, Poland, Tajikestan, Austrian, Ukraine, Danube catchment (Hosek et al, 2015,Ahmad and Chandra, 2013, Chen, 2010; Jordanova et al., 2011; Buggle et al., 2009; Fitzsimmons et al., 2012; Fischer et al., 2012; Jary and Ciszek, 2013; Baumgart et al., 2013; Schatz et al., 2014; Gocke et al., 2014).

Geographical latitude of North of Iran is similar to middle Asia and China.

These are very limited records of concerning loess deposits of Iran in compare to other places of world, and therefore this study attempt to explore the potential of loess deposits in reconstruction of northern Iran during late quaternary.

Study area

The Nowdeh section is exposed at about 20 km southeast of Gonbad-e Kavus and east of Azadshahr city. The Nowdeh river dissects more than 24 m thick sequence of dull yellowish brown (10 YR 5/4) loess covering northeast weathered limestone dipping.

The study area falls between 37° 05' 50" N and 55° 12' 58"E coordinates. This section is in Alborz structure and its sediment sheet is includes of north of Caspian Sea. Nabavi (1976) said that "sediment structure of this section is in Gorgan-Rasht zone and Paratetis district". This zone includes of regions that locate in north of Alborz fault and south of Caspian Sea. Toward the east, Gorgan-Rasht zone cover with thick layers of loess.

Attention to above statements, deal with to identifying of segment for sampling. After searching, Nowdeh section that has been used for soil study in before years by Kehl et al (2005) and Frichen et al (2009) were selected. One of another reason to selection this section was having 12 dating that have done in before studies (Figure1).

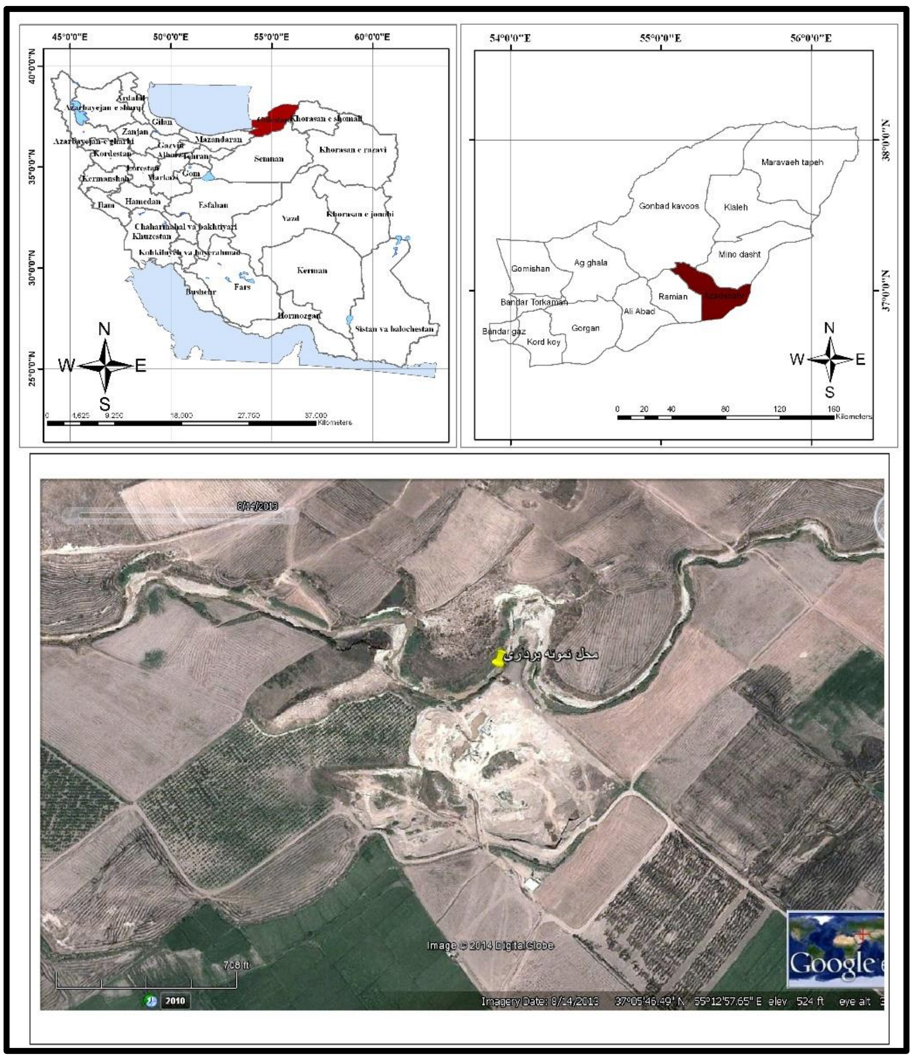

Figure 1: Map of Iran and the location of Nowdeh loess-paleosol sequence.

Figure 2: A view of the sedimentary section of the Nowdeh and the layers formed in it

Methodology

In this study, Azadshar (Nowdeh Loess Section) was selected to reconstruct Late Quaternary climate change in the north Iran. The Nowdeh loess section with an about 24 m thickness were sampled in detailed 10 cm intervals with magnetometry and geochemical of the analysis. For this aim, sampling location and method was determined after consecutive study area. Magnetic susceptibility of all samples was measured in Environmental and Paleomagnteic laboratory based at Geological Survey of Iran, Tehran, Iran. The magnetic susceptibility represents the integrated response of diamagnetic, paramagnetic, ferrimagnetic and imperfect antiferromagnetic minerals. All samples were placed in an 11 cm^3 plastic cylinders to be used in magnetic measurement instruments. Magnetic susceptibility was measured using AGICO company made Kappabridge model MFK1-A instrument.

Saturation isothermal remnant magnetization (SIRM) were determined which reflects the concentration of ferromagnetic and imperfect antiferromagnetic minerals. The HIRM ('hard' isothermal remanence) magnetization is calculated to determine the magnetically based component such as hematite in samples following the formula:

$$HIRM = 0.5(SIRM + IRM_{-0.3T})$$

Where $IRM_{-0.3T}$ is the remanence after application of a reversed field of 0.3 T after growth and measurement of SIRM. The HIRM reflects the contribution specifically of the imperfect antiferromagnetic minerals hematite and goethite (Bloemendal *et al*., 2008).

The $S_{-0.3T}$ value, or S_{-ratio}, is calculated as

$S_{-0.3T} = 0.5[(-IRM_{-0.3T}/SIRM) + 1]$

And is ranged between 0 and 100%. It reflects the ratio of ferrimagnetic to imperfect antiferromagnetic minerals (Bloemendal *et al*., 2008).

Base on the results of magnetic susceptibility, the geochemical proxies of chemical weathering of selected 70 samples (trace elements) are included to assist the paleoclimatic interpretation of the magnetic signals.

Results

Magnetic properties

Figure 3 show relationship of susceptibility, NRM, SIRM, HIRM and $S_{-0.3T}$ in Nowdeh section. The variation of magnetic susceptibility signal in the Nowdeh section suggests variation in climate conditions and mechanisms during the Late Quaternary. The rock magnetic records correlate well with the lithology in Nowdeh section. In general, the paleosols are characterized by an enhancement of the magnetic signal compared to loess. The values of χ (in 10^{-8} m^3 kg^{-1}) vary from 28.17 to 203.13 in Nowdeh section. Maximum χ values (203.13) occur in the lower paleosol layer (19.4 m) and minimum values occur in the top loess layer (7.4 m).

The variance of this parameter is at the depth of 22-23.7 m and had a salient decrease at the depth 22.1 m. Then the variation range decrease until 20 meter of depth. Severe variation of magnetic susceptibility has been observed at the depth of 20 to 16 m. After that χ decrease until 16 to 10 m of depth and then again variation in χ has observed from 10 to 8 meter of depth respectively.

Paleosols showing higher values of χ than loesses, where the magnetic enhancement occurs in the Bw, Bt, Btk, whereas the underlying C (loess) horizon is characterized by lower values of χ. This is very likely caused by the precipitation of iron oxides in Bw horizon and consequently a higher amount of pedogenetic magnetite in comparison with the C horizon can be observed (Jordanova et al., 2013, Hosek et al, 2015). The χ-values of the lower and middle part of Nowdeh section, approximately 53-80 and 120-140 Ka representing intermediate values between unweathered loesses and weathered paleosols.

The results showed that NRM is consonant with magnetic susceptibility variance. This consonant variation especially is so in lower depth and the highest record of this parameter occurred in 13.1 meter of earth surface that posed in BW, BWK horizon. Variations and differences in magnetic susceptibility are very agreed with

SIRM of Loess sequence. As magnetic susceptibility decrease, SIRM also decrease and overhand. Between the 20 to 50 ka, which most of upper Loess has formed, the magnetic susceptibility show no variation likewise SIRM diagram show that in this median. High value of HIRM in fig 2 reflects concentration and frequencies of magnetic deterrent minerals such as Goethite, maghemite or hematite has increased.

Comparison of lower values of S ($_{-0.3\ T}$) (between0.6 to 0.12 Am/m) and higher value of HIRM (between2 to 5 Am/m) show that the ratio of minerals with lower (such as magnetite) is very lower than the ratio of minerals with high in paleosols. This is in contrast with loess deposit.

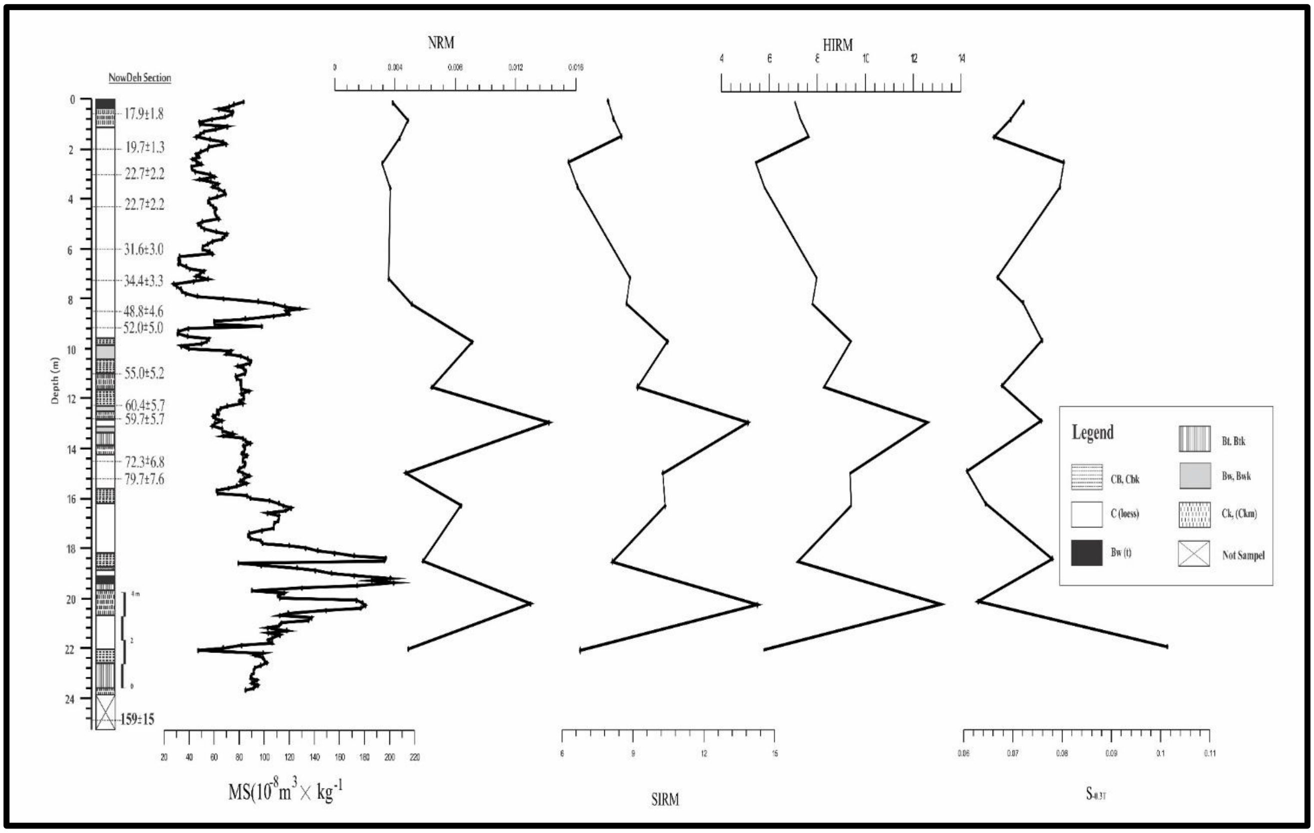

Figure 3: Basic magnetic parameters for Nowdeh section.

Element stratigraphy

Figure 4 shows correlation between concentration of selected element (Sr, Rb, Zr, Ti and Mn) and magnetite susceptibility in Nowdeh section.

As it is clear from this figure variation in concentration of these elements are high with differences in between. Sr and Rb have similar trend along Nowdeh section. At the depth of 2.9 m of depth, there is an increase in concentration of these two elements. Which corresponds with an age of 22 ka. The concentration of these two elements is decreased right after this point.

The lower concentration of elements has recorded at the depth of 8.5 meter with 48.8 ka in age. There is no variation in concentration of these elements after this depth (8.5 meter) in concentration of these elements have occurred at the depth of 18 meters. These elements is the highest record of concentration in Nowdeh section.

Ti, Zr and Mn show approximately similar trend in diagram. These elements show little variation in concentration in outset of the section.

But from depth of 6.2 meter and with an age of to31.1. The variation in concentration begin to increase and attain the highest value in this zone. Concentration of these element at the depth of 8.5 m (34.4 ka). Followed by decrease at the depth of 9.3 meter, are the main elements in this part of Nowdeh section. This is a little variation in concentration of these elements up to the depth of 16.7 meter. From the depth of 16.7 m up to the bottom of the section in concentration of elements show zig-zag pattern.

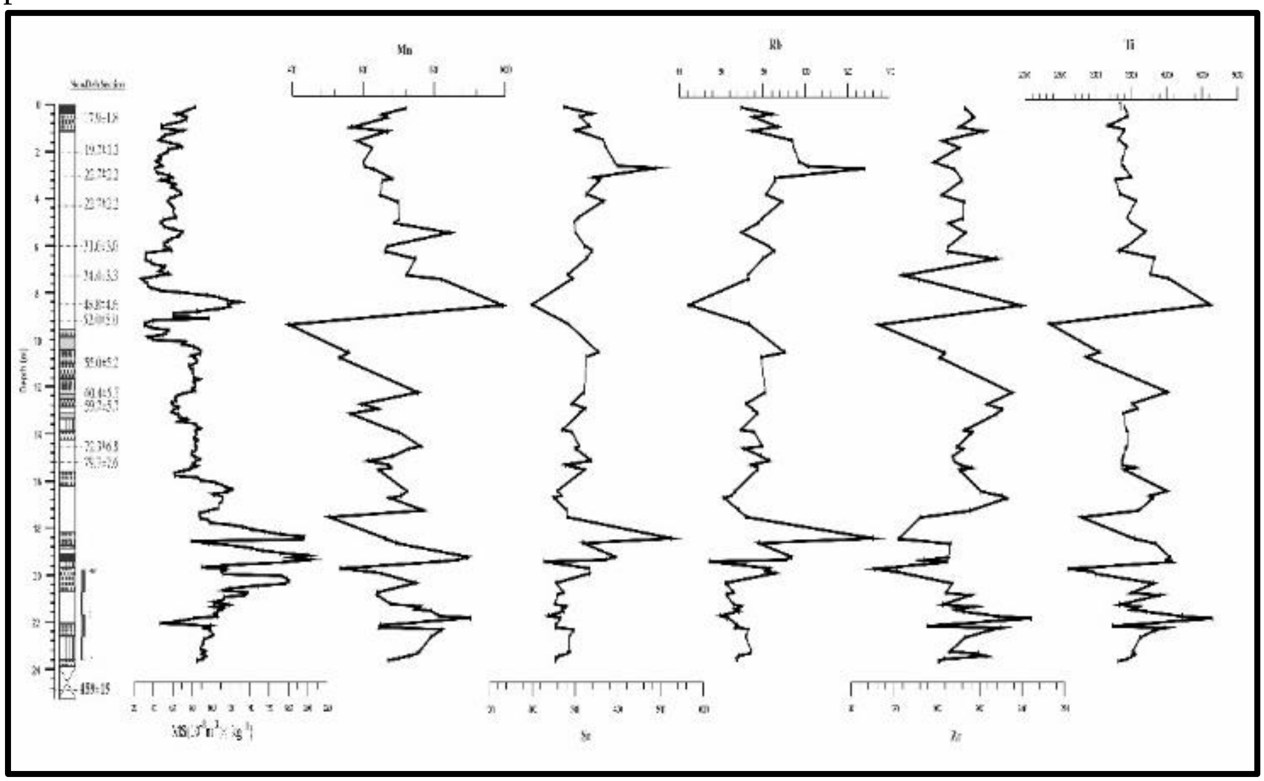

Figure 4: shows depth series of selected element concentrations for Nowdeh section.

Trace element ratio

The variation of Si/Ti ratio is following magnetic susceptibility except for lower part of the section (23-24m). The variation of Mn/Sr, Zr/Ti and Mn/Ti almost show no change except for depth 8.5 m corresponding to 48.8 ka in age. The variation of Rb/Sr ratio is almost opposite of MS pattern especially at the depth of 8.5, 16, 19 and 22 m. the variation of Ba/Rb ratio is also following MS pattern except at depth of 13,15, 19 and 22.8 m which are opposite to each other. Figure 5 show depth series of selected element ratio concentrations for the Nowdeh section with the frequency dependent magnetic susceptibility.

Si/Ti variation in these ratio do not show any consistent relationship to the sequence of loess/palaeosol layers (as defined by the magnetic susceptibility) at Nowdeh section. Mn/Ti — this ratio tend to be show elevated values in the palaeosols, probably as the result of the concentration of Mn oxide in the finer sediment fraction(Bloemendal , et al, 2008).

Zr/Ti, Mn/Ti, Rb/Sr and Mn/Sr—the curves of these ratios show a very clear pattern of elevation in the palaeosols, and their high degree of similarity is noteworthy. Rb/Sr has been proposed by several workers as an indicator of pedogenic intensity for loess based on the differential weather ability of the major host minerals — K-feldspar for Rb and carbonates for Sr. In the case of Mn/Sr, the higher value in the palaeosol will result from the effect of grain-size on the Mn concentration, as noted above, and the solution loss of Sr.

Chen et al. (1999) compared Rb/ Sr and magnetic susceptibility in the uppermost (last glacial/interglacial) parts of the Luochuan and Huanxian sections, and found a striking correspondence between the amplitudes of variation in magnetic susceptibility and in Rb/Sr.

In deep of 19/4m, which is often referenced as a strongly developed palaeosol and which is taken to represent an interval of warm and humid climate and magnitude susceptibility is higher, shows only moderate Rb/Sr ratios.

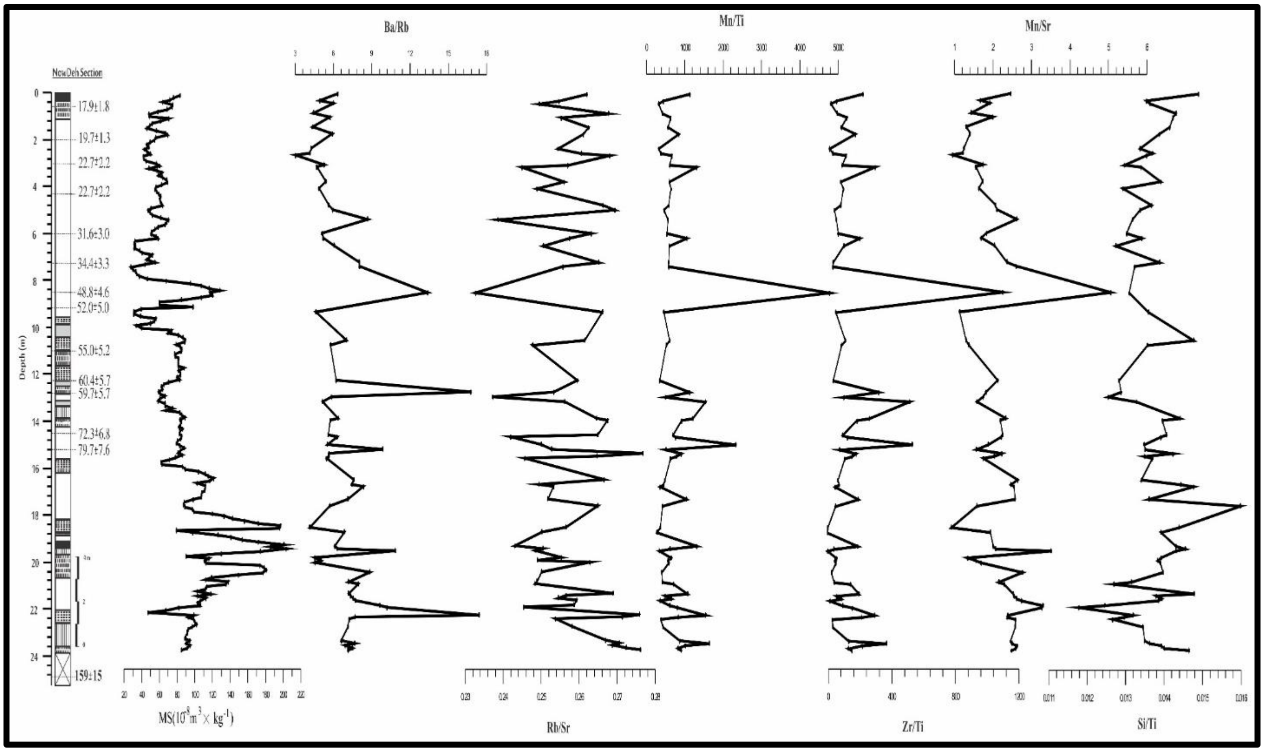

Figure 5: show selected element ratios in Nowdeh section

Discussion

Considering the entire 159 Ka sequence at the Nowdeh site there is reasonable first order co-variation of the magnetic and geochemical indicators of weathering and soil formation – especially in the case of magnetic parameters reflecting variations in ferrimagnetic content and the Sr based ratios. However, detailed comparison on the basis of individual loess and palaeosol layers shows that there is an inconsistent relationship between the amplitudes of individual peaks and troughs of magnetic and geochemical parameters.

Therefore, suggestions by some workers of a consistent loess magnetic mineralogical and geochemical response to weathering and soil formation clearly possible on the post 159 Ka period.

For identification of relationship between climate change and magnetic properties of sediments, magnetic susceptibility of loess sediments in Nowdeh section experimented. Nowdeh magnetic susceptibility results showed cold and dry and warm and humid sequence that related to Loess-paleosol sequence respectively.

Sediment loess formed in cold and dry climate conditions that have low magnetic susceptibility. Whereas in paleosols regarding to pedogenes process, amount of oxidation increase and so magnetic susceptibility records increase. Accordance to global standard, always in loess/paleosol sequence, paleosols has higher magnetic susceptibility than adjacent loess. (Song et al, 2008).

Because pedogenes possess accuse to strong magnetic minerals formation of Iron Oxide in soils includes of; Fe_3O_4, γ-Fe_2O_3, Fe_2O_3 - $\propto$. Whereas mineral magnetic of Loess layer related to grain variation of aeolian resource.

Regarding to fig 3, brown layers sequence of dark and light palesosols in Loess demonstrate different process of weather that it is so similar to glacial and interglacial periods in middle and last of Poliostocene. Paleosole of Nowdeh section has higher magnetic susceptibility than loess. This content has seen more in low and old depth that mean of high weather variation on that season. In 21 meter in depth magnetic susceptibility has a considerable decreasing that indicate a cold and dry season in this time. Also regarding to magnetic susceptibility chart, in Nowdeh section magnetic susceptibility increasing has been seen in about of 8 periods. This indicate temperature and humidity increasing in these times. In each section of standard global Loess, always, regarding to pedogenes and oxidation, paleosoles have higher in magnetic susceptibility than adjacent Loess layers (Maher, 2011).

Loess units formed in cold and dry weathering periods and mineral magnetic resource belong to Aeolian sediments. Whereas, because of magnetic susceptibility content increasing in paleosols, plus mineral magnetic with Aeolian resource, mineral magnetic (iron oxide of soil) of sediments weathering should form by improvement of paleosole formation. Studies and researches achievement on magnetic susceptibility confirm this purports (Maher, 2011,. Spassov, 2002).

Fig 4 show that magnetic sustainability in cold glacial periods (time of loess layering) is different with magnetic sustainability in warm interglacial periods (time of paleosole formation). Results of NRM indicate it's decreasing by loess formation and it's increasing by paleosols formation. This illustrate relationship between natural remnant and magnetic susceptibility. So, NRM decreasing express dry and cold weather condition that is concomitant with loess layers sedimentation. NRM increasing either represent warm and humid weather conditions.

There are two probable reasons for Justification of magnetic susceptibility and isothermal remnant magnetization low alternation in 20 to 50 years ka that includes of

1. Pedogenes process reduce because of cold and dry period
2. Reducing magnetic entering to loess layers

One of another magnetic susceptibility and isothermal remnant magnetization coincidence is related to 20 last ka. Regarding to magnetic susceptibility variation in surface layer of soil can say that probably this period of time accordance to compietion of cold weather and todays weather creation in north of Iran (warm and humid) and SIRM content has increased. Because of SIRM samples just selected at peak point of magnetic susceptibility so, they don’t show details of variations.

The comparison of results of this research with the results of Antoine et al., (2013) on Loess/paleosol sediments of Central Europe, show a close relationship especially at an age of 32 Ka, which show a climate change has taken place at this age. In both sections, this change is recorded by decreasing in magnetic susceptibility approximately in 30 Ka, at the base of deposition of loess, indicating dry and cold climate in this period and increase in magnetic susceptibility in 32 Ka, which means appearance of warm and moist climate.

Geochemical chart can use as weather indexes. Because they can display various weathering with different severity. In loess studies, there are several chemical ratio that can use for reconstruction of paleoclima variations (Ding et al., 2001).

Mn, Zr and Ti—variations in the bulk concentrations of soil elements show a straight forward pattern of stratigraphic variability with higher values in the palaeosols and lower values in the loess layers (Bloemendal et al., 2008). This reflects in part carbonate dilution/concentration effects, since a significant amount of the variability disappears when the elements are expressed on a carbonate-corrected basis.

In Nowdeh section, amount of Rb in paleosols was lower than its amount on loess layers. This occur by high soluble capability of Rb in warm and humid climate conditions as interglacial period. Gallet et al. (1996) found that Rb was significantly depleted in the palaeosols.

Our results show that Mn/Ti, Zr/Ti and Mn/Sr ratios tend to be show higher values in the palaeosols. Ding et al., 2001said that Mn/Ti has had elevated values in the palaeosols, probably as the result of the concentration of Fe and Mn oxides in the finer sediment fractions. Also, they said that Rb/Sr and Mn/Sr ratios curves show a very clear pattern of elevation in the palaeosols same as results of this study. Rb/Sr has been proposed by several workers as an indicator of pedogenic intensity for loess based on the differential weatherability of the major host minerals — K-feldspar for Rb and carbonates for Sr. Mn/Sr, the higher values in the palaeosols will result from the effect of grain-size on the Mn concentrations, as noted above, and the solutional loss of Sr.

Chen et al. (1999) compared Rb/Sr and magnetic susceptibility in the uppermost (last glacial/interglacial) parts of the Luochuan and Huanxian sections, and found a striking correspondence between the amplitudes of variation in magnetic susceptibility and in Rb/Sr (Bloemendal et al., 2008).

In the continuation of the discussion, the results obtained from the magnetic parameters section of the Nowdeh sedimentary section were compared with other studies conducted in different parts of the world.

The magnetic receptivity results of the Nowdeh sedimentary section were compared with the pollinological results of sedimentary cores taken from Urmia Lake (Djamali et al, 2008) and with the results of oxygen 18 isotope analysis on Arabian Sea sedimentary cores (Tzedakis, 1994). In this comparison, it was observed that in the mentioned lakes, an increase in the AP/NAP index corresponded to the appearance of ancient soil layers in the seedling sedimentary section. An increase in the AP/NAP index indicates rising temperature and humidity, leading to the proliferation of trees and shrubs in the environment. Conversely, a decrease in this index signifies a drop in temperature and humidity, resulting in the destruction of trees and shrubs and the alteration of the surface cover. Therefore, it can be inferred that the weather conditions and their fluctuations in the western parts of Iran coincided with the sedimentary deposition at Nowdeh.

Furthermore, the oxygen isotope 18 of the Arabian Sea exhibited a strong agreement with the magnetic receptivity. A decrease in this index indicates warm weather conditions, while an increase suggests cold weather conditions. As depicted in Figure 6, the rise in magnetic susceptibility aligns with the decline in oxygen isotope 18 in the sediments of the Arabian Sea. Figure 6 illustrates the correlation between the recorded pollinology data of Lake Urmia and the oxygen isotope 18 of the Arabian

Sea sediments with the sequence of ancient loess-soil sediments of the Nowdeh sedimentary section.

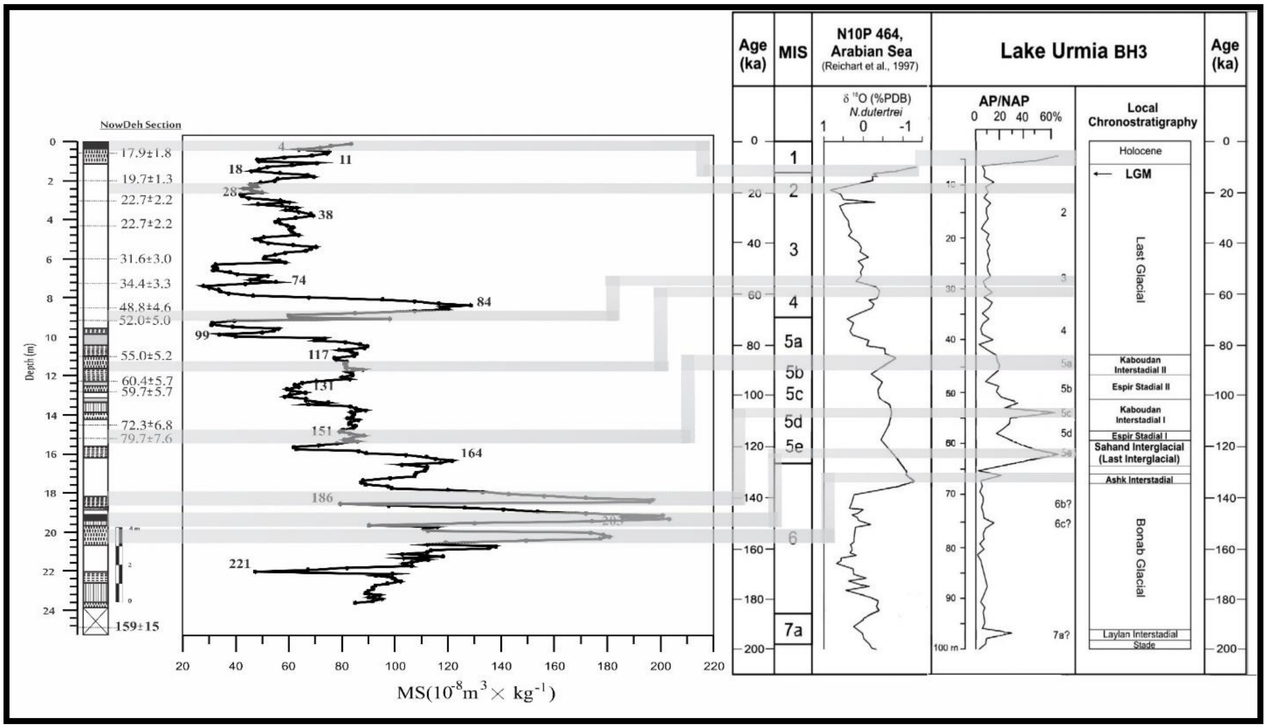

Figure 6: Correlation between recorded pollinological data of Lake Urmia (Djamali et al, 2008) and oxygen isotope 18 of Arabian Sea sediments (Tzedakis, 1994) with the Loess-Paleosol sediment sequence of Nowdeh sedimentary section.

The results of the current research exhibit a strong correlation with the studies conducted by Fuchs et al. in 2013 and Hosek et al. in 2015 on the ancient loess-soil deposits of Central Europe. As illustrated in Figure 7, over the past 45, 73, 90, 104, and 108 thousand years, the recorded fluctuations in the magnetic receptivity parameter showed consistent patterns across the study sections. Around 45 and 73 thousand years ago, a notable increasing trend in magnetic receptivity can be observed in all the analyzed layers, as depicted in the figure. The findings suggest a shift in weather conditions during this period towards a warmer and more humid climate compared to preceding periods. Consequently, the increased presence of iron oxides in the soil due to chemical weathering led to a rise in magnetic susceptibility. Furthermore, in the periods of 90, 104, and 108 thousand years ago, a decrease in magnetic receptivity was noted across all regions, indicating colder and drier climatic conditions during these intervals. While older sediments also demonstrate a significant relationship with climate variations in Central Europe and the Nowdeh area, the absence of radiometric dating in these older sediments introduces some uncertainty when interpreting these findings.

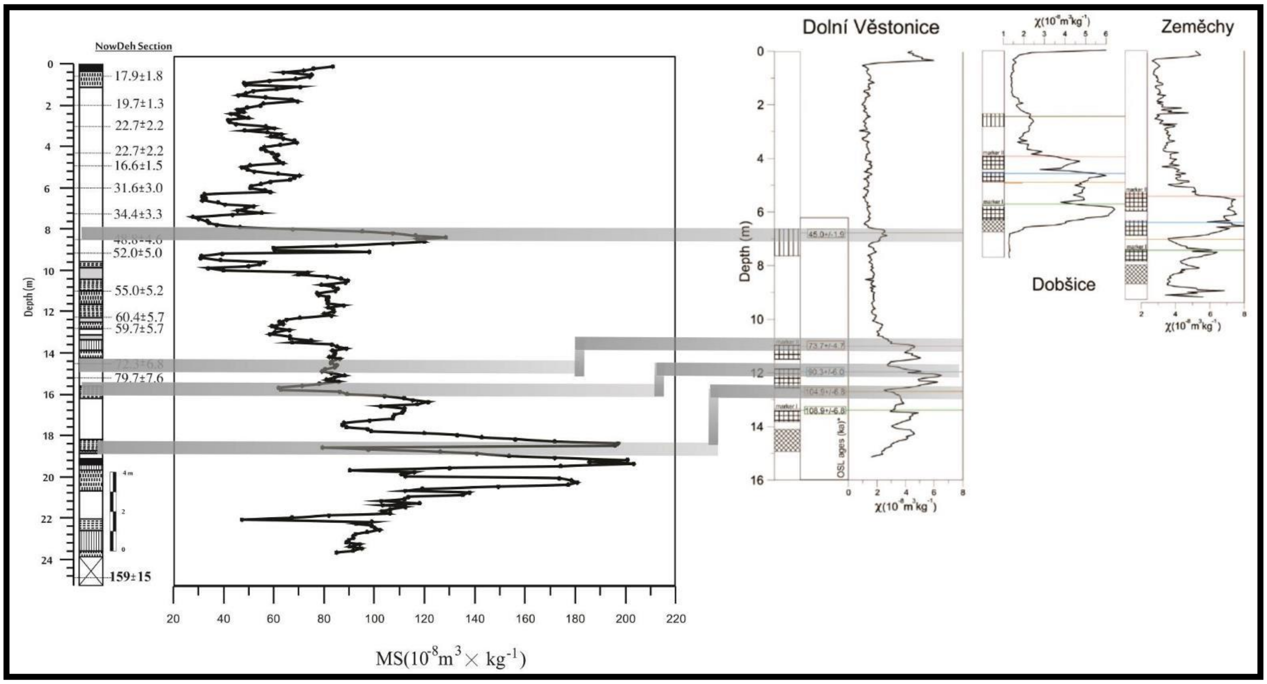

Figure 7: Comparison of changes in magnetic receptivity of Dolní Věstonice sedimentary section, Fuchs et al, 2013, Dobsice and Zemechy section, Hošek et al, 2015, with Nowdehh sedimentary section

Based on Figure 8, it can be seen that the trend of magnetic receptivity recorded in sedimentary sections of Beiyuan, Heimugou, Biampo, An et al, 1991, oxygen isotope records 18Imbrie et al, 1984 has a high agreement with Nowdeh sedimentary section. This issue shows the same weather conditions in different compared places in the Northern Hemisphere.

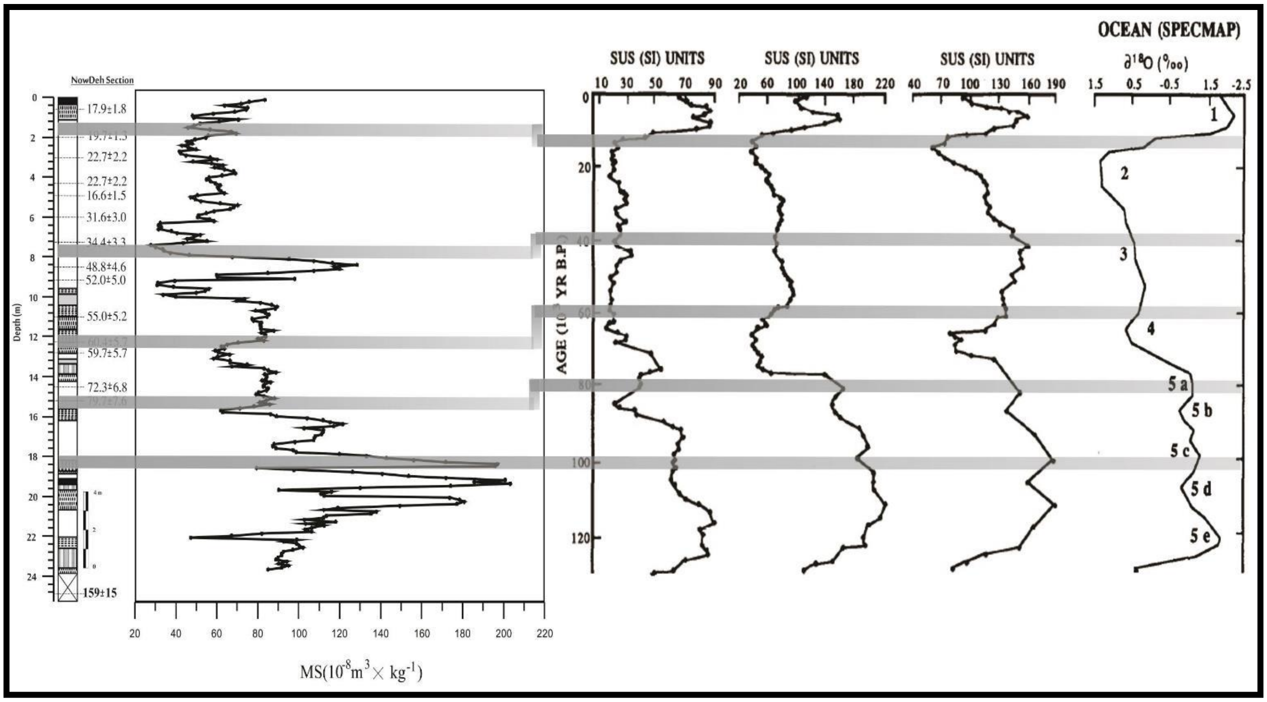

Figure 8: Comparison of magnetic receptivity changes of Beiyuan, Heimugou, Biampo, An et al, 1991, records of oxygen isotope 18 Imbrie et al, 1984 with Nowdeh sedimentary section

The results of Mehdipour et al. in 2012 in the field of fine loess are also very close to the results presented in this research (Figure 9). In their research, they have used two methods of magnetic and geochemical acceptance and have identified different climatic periods based on these two methods. In the current research, the results obtained have a lot of overlap with the mentioned research. As it can be seen in the figure, the results of the magnetic receptivity of Nowdeh section are completely consistent with the Neka sedimentary section obtained by Mehdipour et al. Between 48 and 20 thousand years ago, it can be seen that the changes in magnetic receptivity were the same in both sedimentary sections, and wherever this amount increased, there was a warm and humid period with the formation of an ancient soil layer.

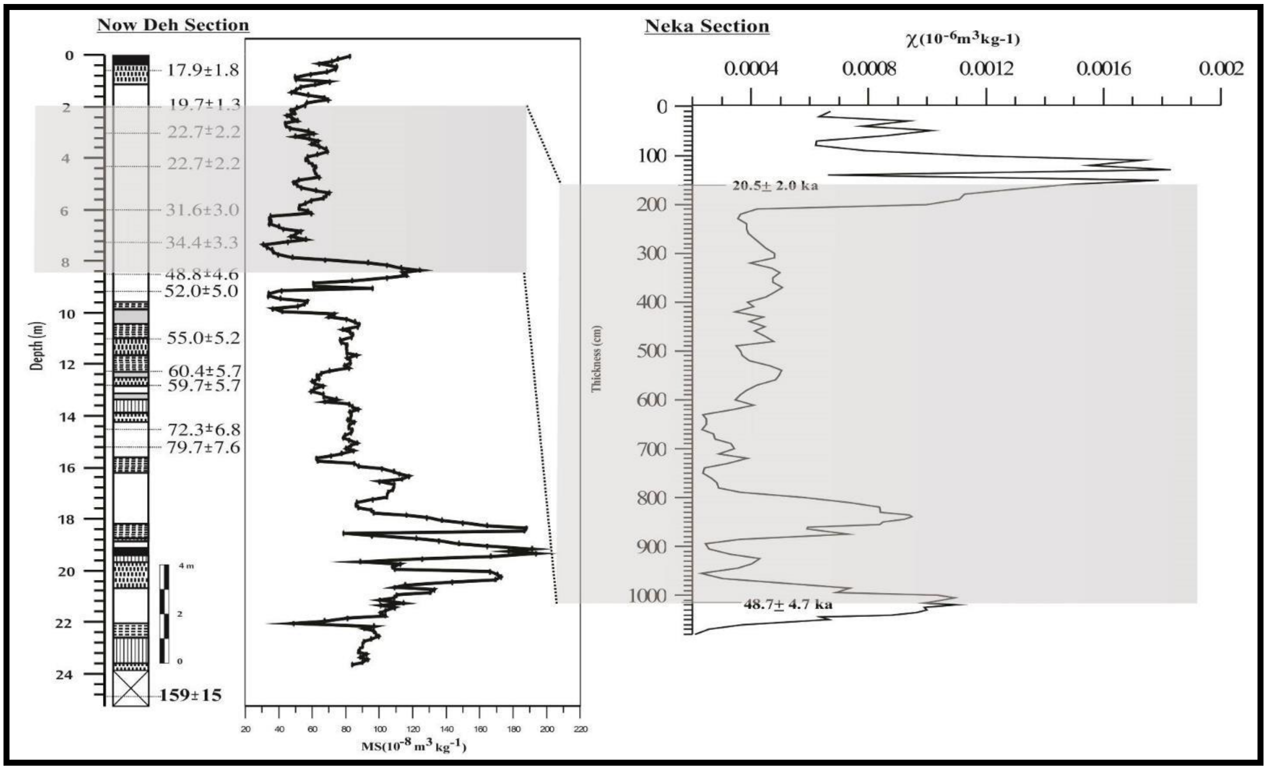

Figure 9: Comparison of magnetic receptivity diagram of Nowdeh sedimentary section with Neka sedimentary section (Mahdi et al., 2012)

Also, the results of this research are very consistent with Beer and Sturm's research in 1995 regarding the beryllium saturation of Zaifang sedimentary section and the results of oxygen isotope 18 of marine sediments. In both cases, simultaneously with the reduction of beryllium and oxygen isotope 18, the amount of magnetic receptivity also decreases, and with the increase of these parameters, the amount of magnetic receptivity increases. In both mentioned cases, hot and humid and cold and dry weather periods have a high agreement with the results obtained from the sedimentary section of Nowdeh, and it shows the simultaneity of similar weather events in the past (Figure 10).

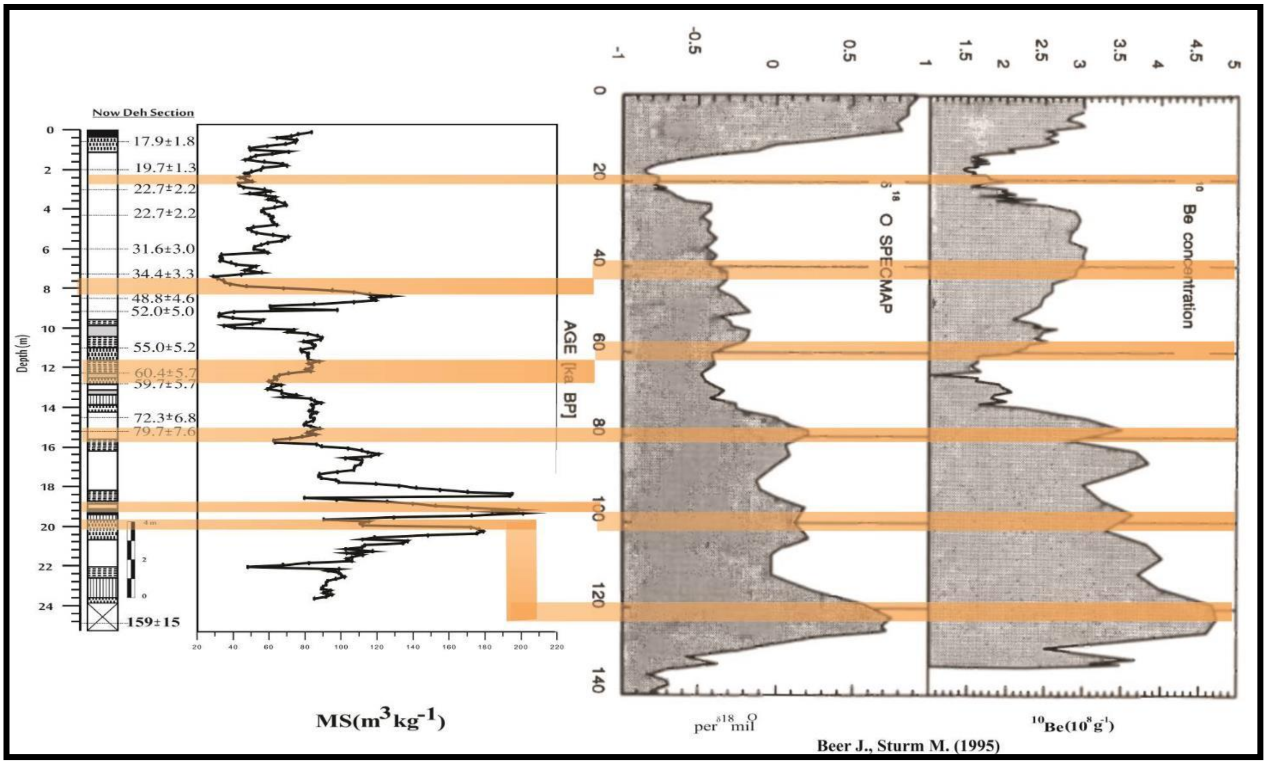

Figure 10: Comparison of magnetic receptivity results of Nowdeh sedimentary section in comparison with oxygen 18 and barium 10 isotope results of Xifeng sedimentary section (Beer and Sturm, 1995).

Conclusion

Loess/paleosols sequences from Northeastern of Iran provide a suitable archive for a detailed study of the Upper Pleistocene paleoenvironmental changes. Using a multi-proxy approach combining sedimentological, magnetic and geochemical methods—we demonstrate that:

- The stratigraphy of the studied section conform well to the general pattern of the Upper Pleistocene loess/paleosol successions in the relatively loess of Northeastern of Iran.
- Because of high relationship between magnetic minerals and climate conditions, magnetic parameters are an efficient variables for reconstruction of climate change.
- Comparison of magnetic and geochemical charts show that the results of geochemical weathering ratio variations are same as magnetic weathering parameters variations such as magnetic susceptibility.
- High degree of coherency between the amplitudes of magnetic susceptibility and Rb/Sr, Mn/Ti, Zr/ Ti and Mn/ Sr ratio are confirmed.

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