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

Vahid, Feizi*[1], Ghasem, Azizi[2],Habib, Alimohammadian [3], Maryam Mollashahi [4]

1- Ph.D. Dep. of Geography, Climatology, Tehran University, Vahid.feizi62@gmail.com
2- Professor., Dep. of Geography, Climatology, Tehran University, ghazizi@ut.ac.ir
3- Assistance Prof, Environment Magnetic Laboratory, Dep. of Geology and Mineral Exploration halimohammadian@gmail.com
4- *Assistant Professor of Forestry in Arid regions, Faculty of Desert Study, Semnan University, Iran* maryam.mollashahi@semnan.ac.ir

**-Corresponding Author: Feizi,Vahid. Email: vahid.feizi62@gmail.com Tell: 00989127985286*

Abstract

The loess-paleosol sequences in the northeastern part of Iran serve as a high-resolution natural archive documenting climate and environmental changes. These sequences offer evidence of the interaction between the accumulation and erosion of aeolian and fluvial sediments during the Middle and Late Pleistocene periods. In this particular study, the Azadshar (Nowdeh Loess Section) site was chosen to reconstruct Late Quaternary climate shifts. A sampling of the Nowdeh loess/paleosol sequences, with a 24-meter thickness, was conducted for magnetic and geochemical analysis. The sampling involved 237 samples taken systematically at high resolution (10 cm intervals). The magnetic susceptibility of all samples was measured at the Environmental and Paleomagnetic Laboratory of the Geological Survey of Iran in Tehran. Selected samples, corresponding to peaks in magnetic susceptibility, underwent geochemical analysis to aid in the interpretation of paleoclimatic changes indicated by the magnetic signals. The magnetic susceptibility results of the loess/paleosol deposits revealed low values during cold and dry climate periods (Loess) and high values during warm and humid climate periods (paleosol). The comparison of magnetic and geochemical data showed that variations in geochemical weathering ratios corresponded to changes in magnetic parameters. A high level of correlation was observed between the magnetic susceptibility intensity and ratios such as Rb/Sr, Mn/Ti, Zr/Ti, and Mn/Sr.

~~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).

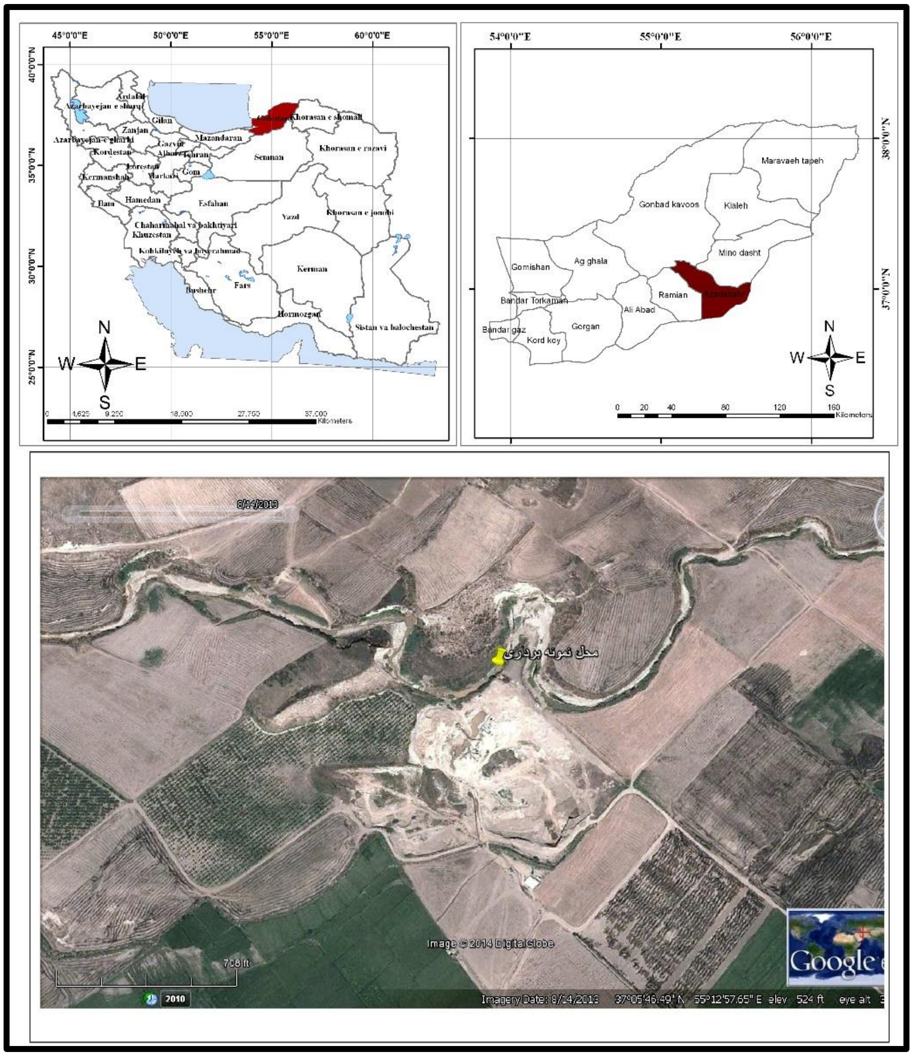

Figure 1: Map of Iran and the location of Nowdeh loess-paleosol sequence.

Figure ۲: A view of the sedimentary section of the Nowdeh and the layers formed in it

Methodology

In this particular research, the Azadshar (Nowdeh Loess Section) site in northern Iran was chosen for studying the climate changes during the Late Quaternary period. The Nowdeh loess section, approximately 24 meters thick, was sampled meticulously at 10 cm intervals for magnetometry and geochemical analysis. The sampling location and method were determined following a detailed study of the area. Magnetic susceptibility measurements of all samples were conducted at the Environmental and Paleomagnetic Laboratory of the Geological Survey of Iran in Tehran. Magnetic susceptibility is indicative of the collective response of diamagnetic, paramagnetic, ferrimagnetic, and imperfect antiferromagnetic minerals present in the samples. Each sample was placed in a 11 cm^3 plastic cylinder for use in magnetic measurement devices. The measurement of magnetic susceptibility was performed using the Kappabridge model MFK1-A instrument manufactured by AGICO company.

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.

The determination of Saturation Isothermal Remanent Magnetization (SIRM) was carried out to assess the concentration of ferromagnetic and imperfect antiferromagnetic minerals in the samples. The calculation of the Hard Isothermal Remanence (HIRM) magnetization was performed to identify magnetically significant components such as hematite in the samples using the following formula: 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

In Figure 3, the relationship between susceptibility, NRM (Natural Remanent Magnetization), SIRM (Saturation Isothermal Remanent Magnetization), HIRM (Hard Isothermal Remanence Magnetization), and S−0.3T in the Nowdeh section is illustrated. The variability in the magnetic susceptibility signal within the Nowdeh section indicates fluctuations in climate conditions and associated mechanisms during the Late Quaternary period. The rock magnetic records exhibit a strong correlation with the lithology observed in the Nowdeh section. Generally, the paleosol layers exhibit higher magnetic signal intensities compared to the loess layers. The values of magnetic susceptibility (χ) in the Nowdeh section range from 28.17 to 203.13 (in units of 10^-8 m^3 kg^-1). The maximum χ values (203.13) are found in the lower paleosol layer at 19.4 meters depth, while the minimum values are observed in the uppermost loess layer at 7.4 meters depth.

~~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 m3 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 magnetic susceptibility exhibits significant variance within the depth range of 22-23.7 meters, with a noticeable decrease specifically at 22.1 meters depth. This variation range gradually decreases until reaching a depth of 20 meters. A drastic change in magnetic susceptibility is observed within the depth interval of 20 to 16 meters. Subsequently, the χ values decrease steadily from 16 to 10 meters depth, followed by another notable variation in χ from 10 to 8 meters depth.

~~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.~~

The paleosols exhibit higher magnetic susceptibility (χ) values compared to the loesses, with magnified magnetic enhancement observed in the Bw, Bt, and Btk horizons, while the underlying C (loess) horizon displays lower χ values. This difference is likely attributed to the precipitation of iron oxides in the Bw horizon, resulting in a higher concentration of pedogenetic magnetite in comparison to the C horizon (Jordanova et al., 2013; Hosek et al., 2015). The χ values in the lower and middle sections of the Nowdeh profile, approximately 53-80 and 120-140 thousand years ago (Ka), respectively, represent intermediate values between unweathered loesses and weathered paleosols.

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 indicate that the Natural Remanent Magnetization (NRM) is consistent with the variance in magnetic susceptibility, particularly notable at lower depths, with the highest recorded value of this parameter observed at 13.1 meters depth in the BW, BWK horizon. Variations and discrepancies in magnetic susceptibility align closely with the Saturation Isothermal Remanent Magnetization (SIRM) of the Loess sequence. As magnetic susceptibility decreases, SIRM also shows a corresponding decrease. In the interval between 20 to 50 thousand years ago (ka), during which much of the upper Loess formation occurred, magnetic susceptibility shows minimal variation, a pattern mirrored in the SIRM diagram for this period. The elevated values of the Hard Isothermal Remanent Magnetization (HIRM) in Figure 2 suggest an increase in the concentration and frequency of magnetic deterrent minerals such as Goethite, maghemite, or hematite.

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.

The comparison between the lower values of saturation (S) (-0.3 T) (between 0.6 to 0.12 Am/m) and the higher values of Hard Isothermal Remanent Magnetization (HIRM) (between 2 to 5 Am/m) indicates that the proportion of minerals with lower saturation, such as magnetite, is significantly lower than the proportion of minerals with higher saturation in paleosols. This pattern contrasts with the composition of loess deposits.

~~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.~~

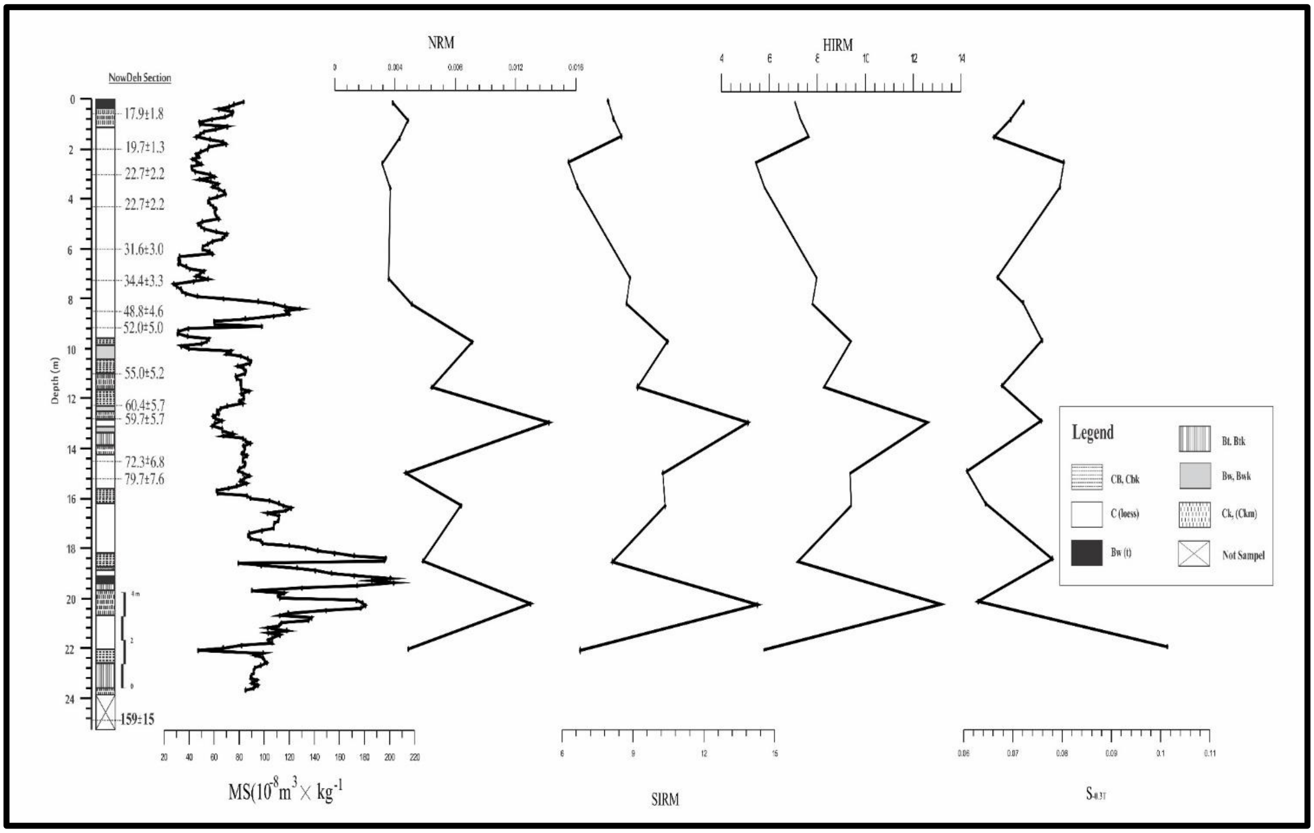

Figure 3: Basic magnetic parameters for Nowdeh section.

Element stratigraphy

Figure 4 illustrates the correlation between the concentration of selected elements (Sr, Rb, Zr, Ti, and Mn) and magnetite susceptibility in the Nowdeh section. The figure indicates significant variations in the concentration of these elements with noticeable differences between them. Sr and Rb exhibit similar trends along the Nowdeh section. At a depth of 2.9 meters, there is a notable increase in the concentration of these two elements, corresponding to an age of 22 thousand years ago (ka). Following this point, the concentration of Sr and Rb decreases.

~~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 concentrations of elements were recorded at a depth of 8.5 meters, corresponding to an age of 48.8 thousand years ago (ka). After this depth, there is no significant variation in the concentration of these elements until the depth of 18 meters, where the highest concentration of these elements is recorded in the Nowdeh section.

~~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 exhibit approximately similar trends in the diagram. These elements show little variation in concentration at the beginning of the section.

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

The variation in concentration of these elements begins to increase from a depth of 6.2 meters, corresponding to an age of 31.1 thousand years ago. It reaches the highest value in this zone and peaks at the depth of 8.5 meters (equivalent to 34.4 ka). This is followed by a decrease at the depth of 9.3 meters. These elements are the primary focus in this part of the Nowdeh section. There is little variation in the concentration of these elements up to a depth of 16.7 meters. From the depth of 16.7 meters to the bottom of the section, the concentration of elements exhibits a zig-zag pattern.

~~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.~~

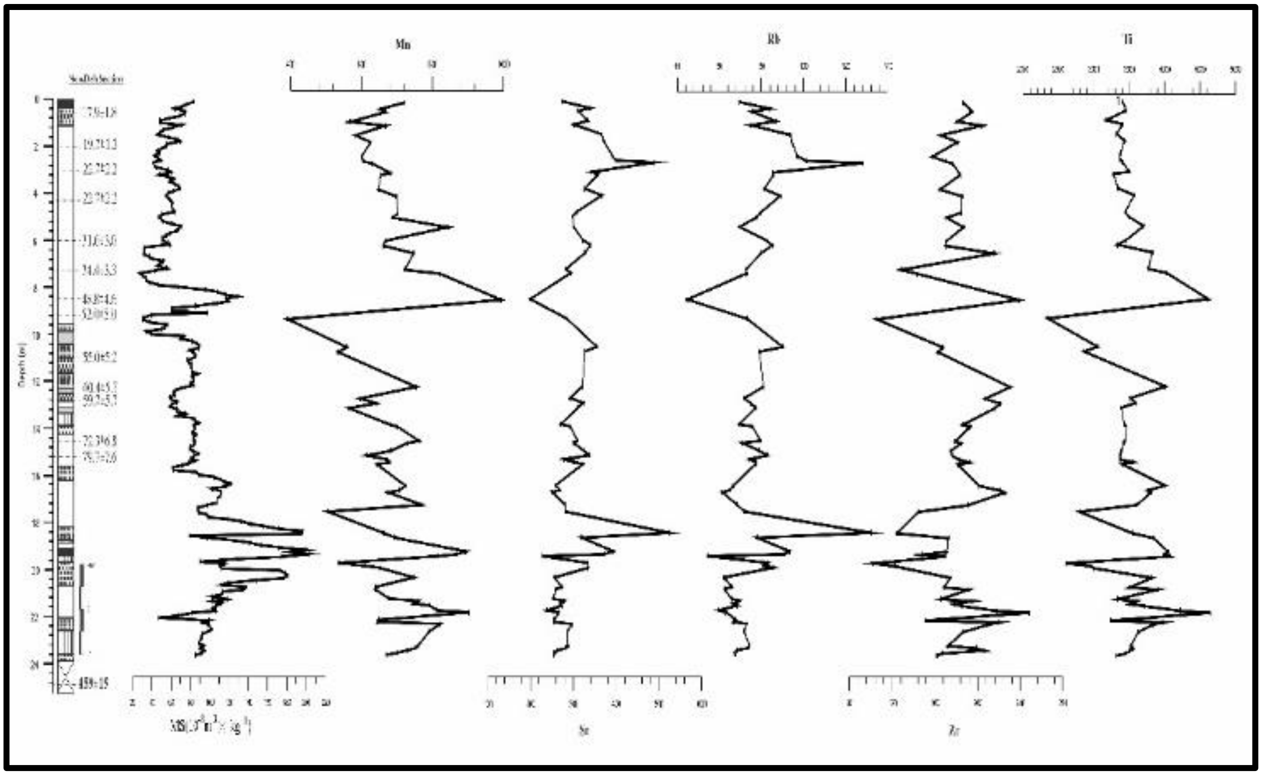

Figure 4: shows depth series of selected element concentrations for Nowdeh section.

Trace element ratio

The variation of the Si/Ti ratio generally follows the magnetic susceptibility pattern, except for the lower part of the section (23-24 meters). The ratios of Mn/Sr, Zr/Ti, and Mn/Ti show almost no change, except for at a depth of 8.5 meters, corresponding to an age of 48.8 thousand years. The Rb/Sr ratio exhibits an opposite pattern to the magnetic susceptibility, especially at the depths of 8.5, 16, 19, and 22 meters. The Ba/Rb ratio generally follows the magnetic susceptibility pattern, except at depths of 13, 15, 19, and 22.8 meters where they vary oppositely. Figure 5 shows the depth series of selected element ratio concentrations for the Nowdeh section along with the frequency-dependent magnetic susceptibility.

~~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.~~

The variation in the Si/Ti ratio does not exhibit a consistent relationship to the sequence of loess/palaeosol layers, as defined by the magnetic susceptibility, in the Nowdeh section. On the other hand, the Mn/Ti ratio tends to show elevated values in the palaeosols, likely due to the concentration of Mn oxide in the finer sediment fraction (Bloemendal et al., 2008). This suggests that the presence of Mn oxide plays a significant role in influencing the Mn/Ti ratio in the sediments, particularly in the palaeosol layers.

~~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).~~

The curves of Zr/Ti, Mn/Ti, Rb/Sr, and Mn/Sr ratios in the sediment samples from the Nowdeh section exhibit a clear pattern of elevation in the palaeosols, and their high degree of similarity is noteworthy. Rb/Sr has been suggested by several researchers as an indicator of pedogenic intensity in loess, based on the differential weathering of the major host minerals, specifically K-feldspar for Rb and carbonates for Sr. In the case of Mn/Sr, the higher values observed in the palaeosols are likely a result of the combined effects of grain size on Mn concentration, as well as the loss of Sr through solution processes. This indicates that these ratios can serve as important indicators of pedogenic processes and weathering dynamics in the sedimentary record of the Nowdeh section.

~~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.~~

In a study by Chen et al. (1999), a comparison was made between the Rb/Sr ratios and magnetic susceptibility values in the uppermost (last glacial/interglacial) sections of the Luochuan and Huanxian regions. The researchers noted a remarkable correspondence between the amplitudes of variation in magnetic susceptibility and Rb/Sr ratios. This finding suggests a close relationship between magnetic susceptibility variations and the Rb/Sr ratios in these regions during the last glacial and interglacial periods.

~~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.~~

At a depth of 19.4 meters, which is commonly identified as a strongly developed palaeosol indicative of a past warm and humid climate, the magnetic susceptibility values are higher. Surprisingly, despite the indication of favorable climate conditions, the Rb/Sr ratios at this depth exhibit only moderate values. This discrepancy suggests that additional factors or processes may be influencing the Rb/Sr ratios in the sediments at this specific depth, potentially beyond the climatic conditions that typically lead to high Rb/Sr ratios in pedogenic sequences.

~~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.~~

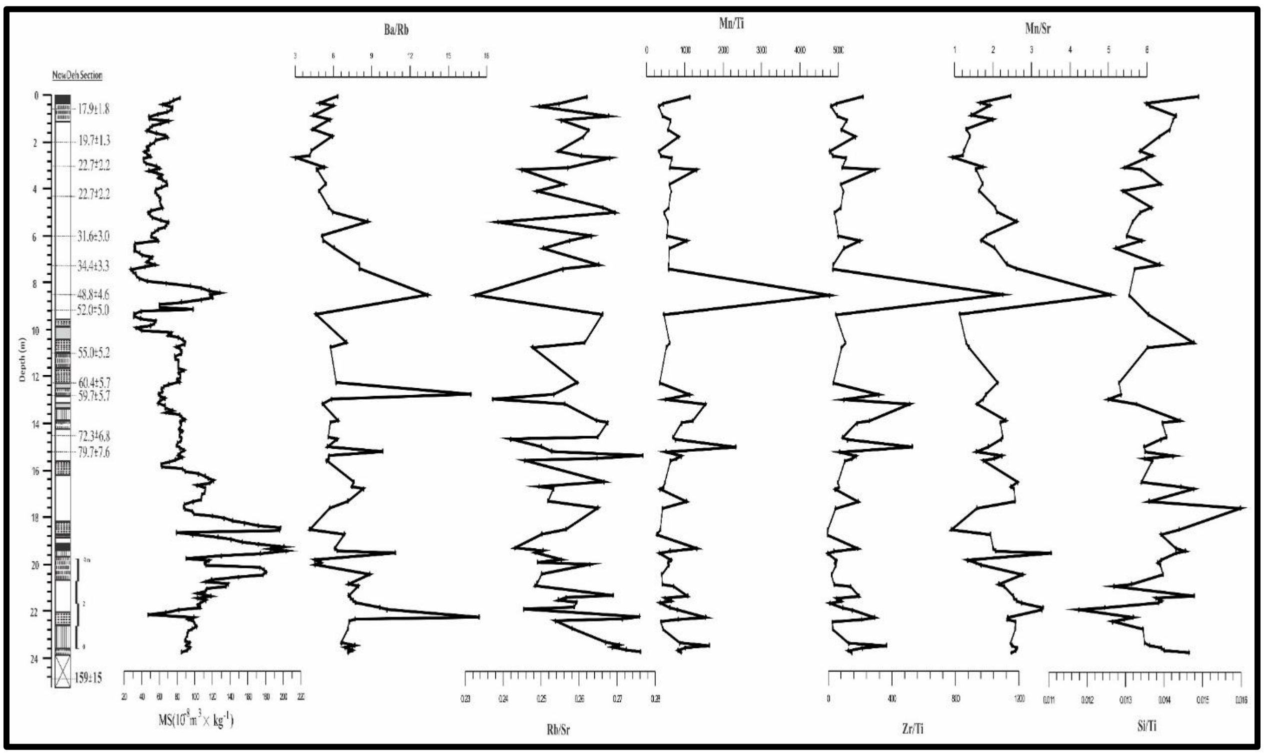

Figure 5: show selected element ratios in Nowdeh section

Discussion

Over the entire 159 Ka sequence at the Nowdeh site, there appears to be a reasonable first-order co-variation between the magnetic and geochemical indicators of weathering and soil formation, particularly with magnetic parameters reflecting variations in ferrimagnetic content and Sr-based ratios. However, upon closer detailed examination based on individual loess and palaeosol layers, an inconsistent relationship is observed between the amplitudes of individual peaks and troughs of magnetic and geochemical parameters. This suggests that while there is an overall correlation between these indicators at a broader scale, at a finer resolution within specific layers, the relationship becomes more complex and inconsistent. Additional factors or processes may be influencing the variations in magnetic and geochemical parameters within the individual stratigraphic units.

~~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, it is possible that the suggestions by some researchers regarding a consistent response of loess magnetic mineralogical and geochemical properties to weathering and soil formation are valid for the post-159 Ka period.

~~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.~~

To investigate the relationship between climate change and the magnetic properties of sediments, magnetic susceptibility measurements were conducted on loess sediments in the Nowdeh section. The results of the magnetic susceptibility analysis at Nowdeh revealed distinct sequences corresponding to cold and dry periods as well as warm and humid conditions. These variations in magnetic susceptibility align with the alternating Loess-paleosol sequences, indicating a relationship between the magnetic properties of the sediments and past climate changes in the Nowdeh region.

~~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.~~

According to Song et al. (2008), sediment loess is formed under cold and dry climate conditions, leading to lower magnetic susceptibility due to the absence of significant weathering processes. In contrast, in paleosols formed as a result of pedogenic processes, the level of oxidation increases, resulting in an increase in magnetic susceptibility records. It is widely observed, according to global standards, that in a loess/paleosol sequence, paleosols exhibit higher magnetic susceptibility than the adjacent loess layers.

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).

The formation of strong magnetic minerals, such as iron oxides, in soils through pedogenesis processes includes minerals like Fe3O4, γ-Fe2O3, and Fe2O3 - ∝. In contrast, the mineral magnetism of loess layers is influenced by the grain composition of the aeolian sources depositing the sediments. This distinction in magnetic mineral content between soils undergoing pedogenesis and loess layers sourced from aeolian deposits contributes to the differences in magnetic susceptibility observed between paleosols and loess layers in sediment sequences.

Because pedogenes possess accuse to strong magnetic minerals formation of Iron Oxide in soils includes of; Fe3O4, γ-Fe2O3, Fe2O3 - ∝. Whereas mineral magnetic of Loess layer related to grain variation of aeolian resource.

In Fig 3, the brown layer sequences of dark and light paleosols in the loess deposits demonstrate distinct weathering processes that closely resemble the patterns observed during glacial and interglacial periods in the middle and late Pleistocene. The paleosols in the Nowdeh section exhibit higher magnetic susceptibility compared to the surrounding loess layers. This difference is more prominent at lower depths, indicating greater weathering variability during those periods. At a depth of 21 meters, a significant decrease in magnetic susceptibility suggests a cold and dry season during that timeframe. The magnetic susceptibility chart for the Nowdeh section reveals approximately 8 distinct periods of increasing magnetic susceptibility, reflecting periods of temperature and humidity elevation. In accordance with the standard global loess characteristics, paleosols consistently exhibit higher magnetic susceptibility values compared to adjacent loess layers due to pedogenesis and oxidation processes, as highlighted by Maher (2011).

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 are typically formed during cold and dry weathering periods, and the mineral magnetic resources in these sediments are derived from aeolian sources. The increase in magnetic susceptibility observed in paleosols, along with the presence of mineral magnetic materials associated with aeolian deposits, suggests that the formation of iron oxide minerals in the sediments is influenced by the development of paleosols. Research studies and findings on magnetic susceptibility support this interpretation, as indicated by Maher (2011) and Spassov (2002).

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).

In Figure 4, the magnetic susceptibility during cold glacial periods (corresponding to loess layer deposition) differs from that during warm interglacial periods (associated with paleosol formation). The Natural Remanent Magnetization (NRM) results suggest a decrease during loess formation and an increase during paleosol formation. This pattern demonstrates a relationship between NRM and magnetic susceptibility. A decrease in NRM indicates dry and cold weather conditions, consistent with the deposition of loess layers, while an increase in NRM represents warmer and more humid weather conditions, corresponding to paleosol formation.

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.

The probable justifications for the low alteration in magnetic susceptibility and isothermal remnant magnetization between 20 to 50 thousand years ago can be attributed to two main factors:

Decreased Pedogenesis due to cold and dry periods.

Reduction in the influx of magnetic particles into loess layers.

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

2.1. Reducing magnetic entering to loess layers

During the last 20 thousand years, there seems to be a correlation between magnetic susceptibility variations in the surface soil layer and climatic conditions. This period coincides with the transition from cold weather to the current warm and humid climate in the northern region of Iran. As a result, the soil's magnetic properties, specifically the saturation isothermal remanent magnetization (SIRM), have likely increased during this time frame. However, since the SIRM samples were only collected at magnetic susceptibility peak points, they may not capture the full extent of variations.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.

Comparing these findings with the research by Antoine et al. (2013) on loess/paleosol sediments in Central Europe reveals a close relationship, particularly around 32 thousand years ago. At this age, there appears to be evidence of a climate change event, marked by a decrease in magnetic susceptibility around 30 thousand years ago at the onset of loess deposition, indicating a cold and dry climate. Conversely, an increase in magnetic susceptibility around 32 thousand years ago suggests the onset of a warm and moist climate.

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 charts can serve as useful indicators of weather patterns, as they can highlight different levels of weathering severity. In the study of loess deposits, certain chemical ratios can be utilized to reconstruct variations in paleoclimate (Ding et al., 2001).

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).

Variations in the concentrations of manganese (Mn), zirconium (Zr), and titanium (Ti) in the soil reflect a clear stratigraphic pattern, with higher values seen in paleosols and lower values in the loess layers (Bloemendal et al., 2008). This pattern is influenced, in part, by carbonate dilution/concentration effects, as a significant portion of the variability in these elements disappears when expressed on a carbonate-corrected basis.

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 the Nowdeh section, the amount of rubidium (Rb) in paleosols was lower compared to its concentration in loess layers. This discrepancy can be attributed to the higher solubility of Rb in warm and humid climates, typical of interglacial periods. Gallet et al. (1996) observed significant depletion of Rb in the paleosols, supporting this interpretation.

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 indicate that the Mn/Ti, Zr/Ti, and Mn/Sr ratios tend to exhibit higher values in the paleosols. According to Ding et al. (2001), elevated Mn/Ti values in paleosols may result from the concentration of iron (Fe) and manganese (Mn) oxides in the finer sediment fractions. They also noted that the Rb/Sr and Mn/Sr ratios show a clear pattern of elevation in the paleosols, which aligns with the findings of our study. The Rb/Sr ratio has been proposed by various researchers as an indicator of pedogenic intensity in loess deposits, based on the differential weathering of major host minerals such as K-feldspar for Rb and carbonates for Sr. The higher Mn/Sr values in paleosols may be attributed to grain-size effects on Mn concentrations and the solubilization loss of Sr.

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 parts of the Luochuan and Huanxian sections, revealing a significant correspondence between the variations in magnetic susceptibility and Rb/Sr ratios. This suggests a link between weathering intensity and magnetic properties in these sediments.

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 context of the Nowdeh sedimentary section, the magnetic parameters were compared with those from other studies conducted in various regions of the world, further contributing to our understanding of paleoclimatic variations and weathering processes in loess deposits.

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 comparison of magnetic receptivity results from the Nowdeh sedimentary section with the pollinological data from sedimentary cores of Urmia Lake (Djamali et al., 2008) and the oxygen-18 isotope analysis from Arabian Sea sedimentary cores (Tzedakis, 1994) has provided valuable insights into past climate conditions.

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 the analysis, an increase in the AP/NAP index in the lakes corresponded with the presence of ancient soil layers in the seedling sedimentary section. This increase signifies warmer temperatures and higher humidity levels, conducive to the growth of trees and shrubs. Conversely, a decrease in the AP/NAP index indicates a decline in temperature and humidity, leading to the disappearance of trees and shrubs and changes in surface vegetation cover. This correlation suggests that the weather conditions and their fluctuations in western Iran align with the sedimentary deposition at Nowdeh.

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.

Moreover, the oxygen-18 isotope analysis of the Arabian Sea exhibited a strong agreement with magnetic receptivity data. A decrease in the oxygen-18 index points to warmer weather conditions, while an increase indicates colder conditions. The relationship between magnetic susceptibility and oxygen-18 levels in the Arabian Sea sediments, as shown in Figure 6, demonstrates that an increase in magnetic susceptibility corresponds with a decrease in oxygen-18 levels, indicating warmer climate conditions. This alignment further supports the connection between the recorded pollinology data of Lake Urmia, oxygen-18 isotope data from the Arabian Sea, and the sequence of ancient loess-soil sediments in the Nowdeh sedimentary section.

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.

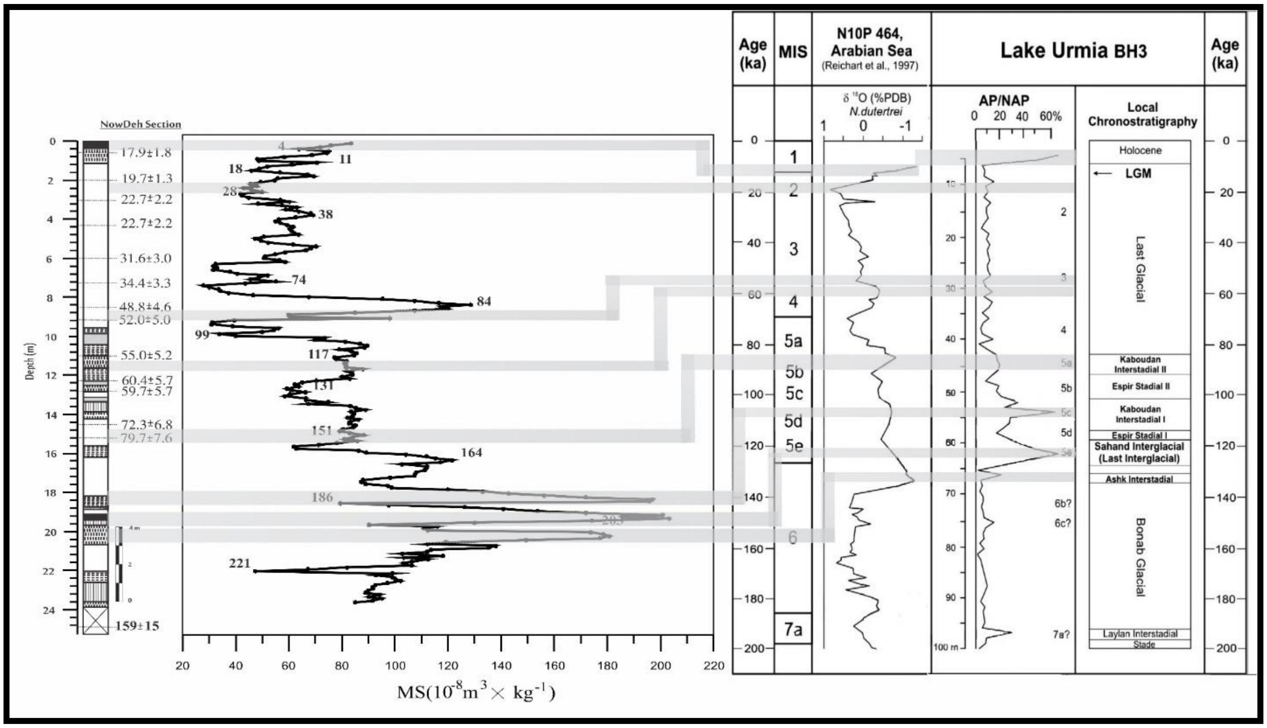

Figure 6: Correlation between recorded pollinological data of Lake Urmia (Djamali et al, 2008) and oxygen isotope 18 of Arabian Sea sediments (Tzedakis, 1994) with the Loess-Paleosol sediment sequence of Nowdeh sedimentary section.

The results of your current research demonstrate a significant correlation with the studies conducted by Fuchs et al. in 2013 and Hosek et al. in 2015 on ancient loess-soil deposits in Central Europe. Figure 7 depicts consistent patterns in the magnetic receptivity parameter over the past 45, 73, 90, 104, and 108 thousand years across the study sections.

Around 45 and 73 thousand years ago, there is a clear increasing trend in magnetic receptivity observed in all analyzed layers, indicating a shift towards warmer and more humid climate conditions compared to earlier periods. This increase in magnetic susceptibility can be attributed to the higher presence of iron oxides in the soil resulting from increased chemical weathering.

Conversely, during the periods of 90, 104, and 108 thousand years ago, a decrease in magnetic receptivity is evident across all regions, signifying colder and drier climatic conditions during these time intervals.

While the older sediments also show a significant association 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. Nonetheless, the consistent patterns in magnetic receptivity across different time periods provide valuable insights into past climate fluctuations and their impact on soil properties in these regions.

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.

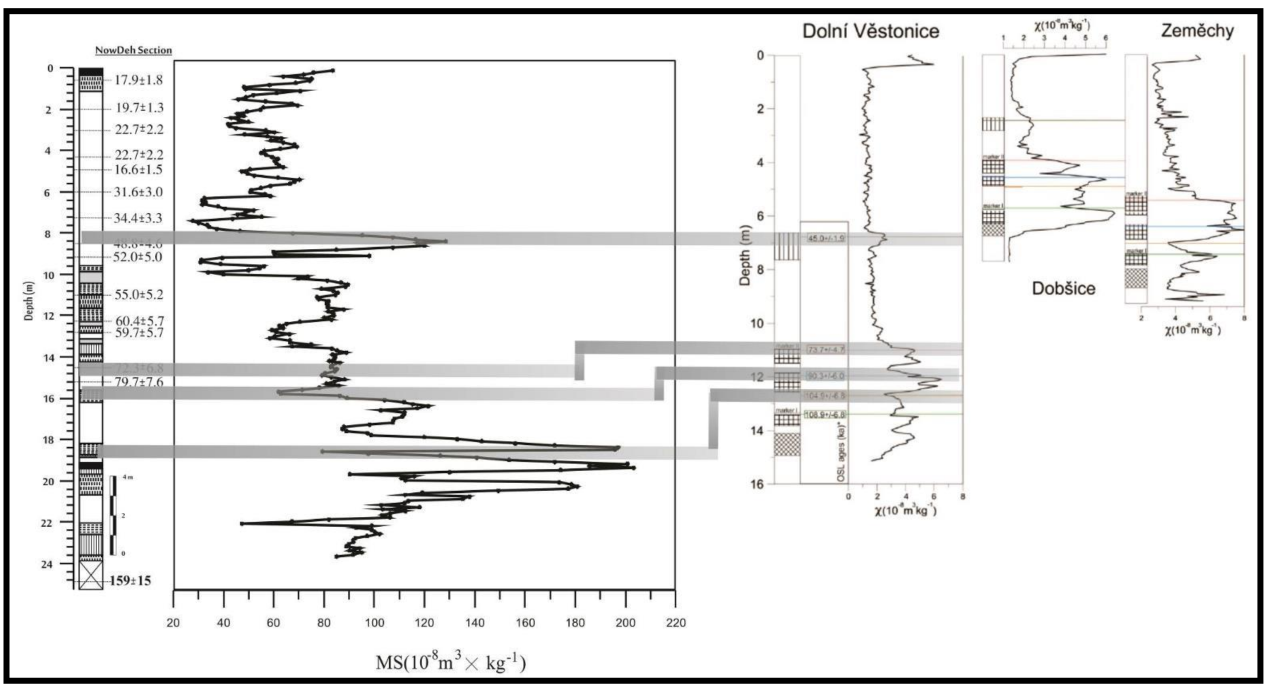

Figure 7: Comparison of changes in magnetic receptivity of Dolní Věstonice sedimentary section, Fuchs et al, 2013, Dobsice and Zemechy section, Hošek et al, 2015, with Nowdehh sedimentary section

The comparison of magnetic receptivity trends as recorded in sedimentary sections of Beiyuan, Heimugou, Biampo, and the oxygen isotope records by Imbrie et al. (1984) in Figure 8 reveals a high agreement with the Nowdeh sedimentary section. This alignment indicates similar weather conditions across different locations in the Northern Hemisphere.

The consistency in magnetic receptivity trends among these various sites suggests a commonality in the climatic conditions experienced during the corresponding time periods. This synchronization in magnetic susceptibility patterns further supports the notion that these regions were subjected to comparable environmental changes and fluctuations in the past.

Additionally, the correlation observed between the magnetic receptivity data and the oxygen isotope records underscores the close relationship between climatic factors and sedimentary deposition patterns across these sites. By examining these geological proxies, researchers can gain valuable insights into the past climate dynamics and variations that have affected the Northern Hemisphere over time.

~~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.~~

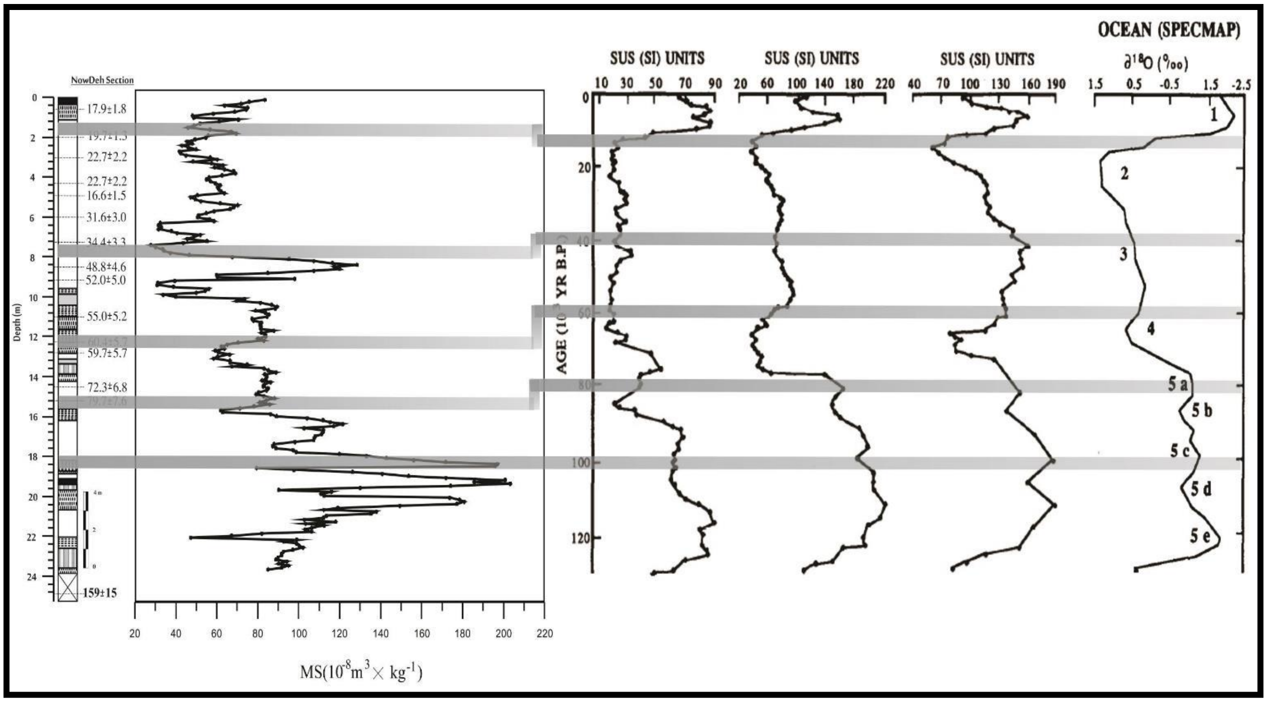

Figure 8: Comparison of magnetic receptivity changes of Beiyuan, Heimugou, Biampo, An et al, 1991, records of oxygen isotope 18 Imbrie et al, 1984 with Nowdeh sedimentary section

The findings of Mehdipour et al. in 2012 in the realm of fine loess exhibit a close resemblance to the results presented in your research, as illustrated in Figure 9. In their study, they employed both magnetic and geochemical approaches to assess different climatic periods, and the outcomes align significantly with the findings of your research. The comparison in Figure 9 reveals a strong consistency in the magnetic receptivity trends between the Nowdeh section and the Neka sedimentary section analyzed by Mehdipour et al.

Between 48 and 20 thousand years ago, notable similarities are observed in the fluctuations of magnetic receptivity in both sedimentary sections. Whenever there is an increase in magnetic receptivity, it indicates a warm and humid period with the formation of ancient soil layers. This shared pattern implies a synchrony in climatic conditions between the two regions during this time frame, showcasing the utility of magnetic susceptibility as a proxy for understanding past environmental changes and soil development processes.

~~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.~~

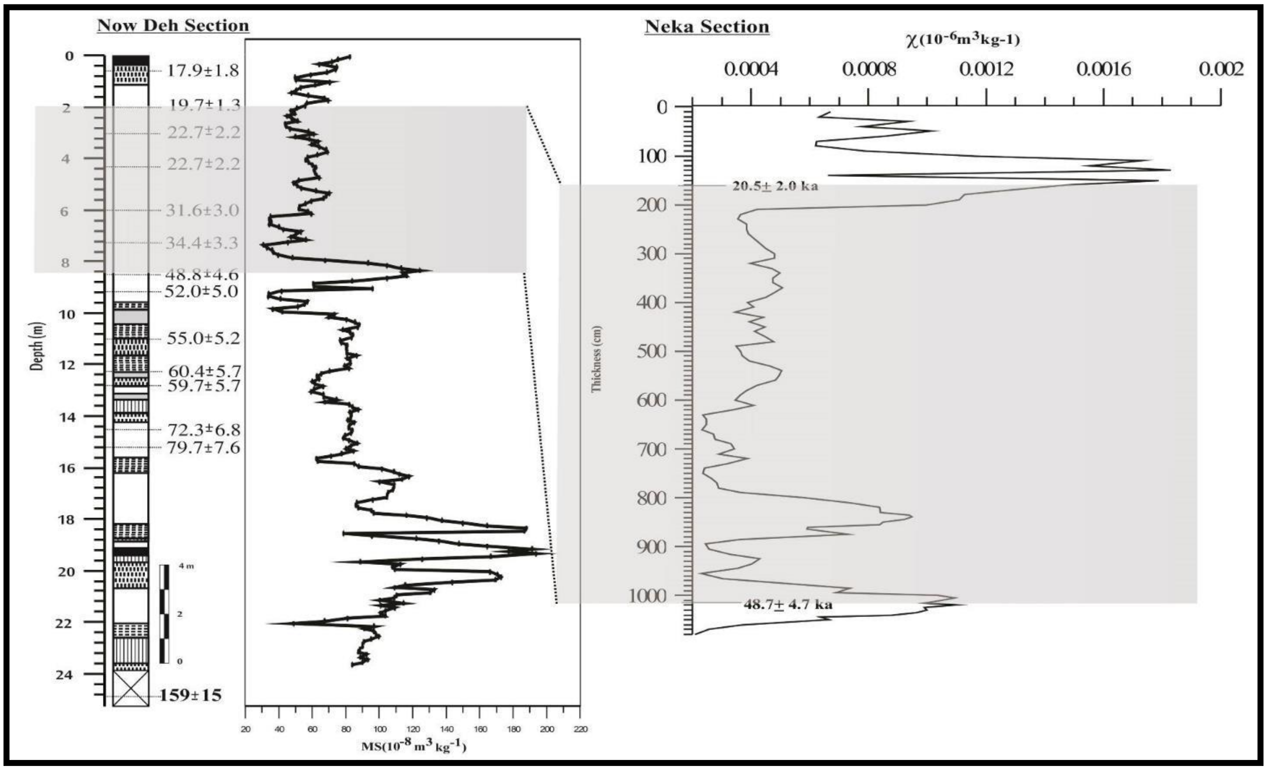

Figure 9: Comparison of magnetic receptivity diagram of Nowdeh sedimentary section with Neka sedimentary section (Mahdi et al., 201۲)

The results of this research exhibit strong consistency with the findings of Beer and Sturm in 1995 regarding beryllium saturation in the Zaifang sedimentary section and oxygen isotope 18 in marine sediments. In both cases, a clear correlation is observed between the fluctuations in beryllium saturation, oxygen isotope 18, and magnetic receptivity.

When beryllium saturation and oxygen isotope 18 decrease, there is a corresponding decrease in magnetic receptivity, indicating colder and drier weather conditions. Conversely, an increase in beryllium saturation and oxygen isotope 18 is accompanied by an increase in magnetic receptivity, signifying warmer and more humid periods.

The high agreement between the climatic periods identified based on these parameters in the Zaifang sedimentary section and marine sediments, and the magnetic receptivity trends observed in the Nowdeh sedimentary section, highlights the synchrony of similar weather events in the past across different locations. This consistency further supports the robustness of magnetic susceptibility as a proxy for understanding past climate variations and environmental changes.

~~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).~~

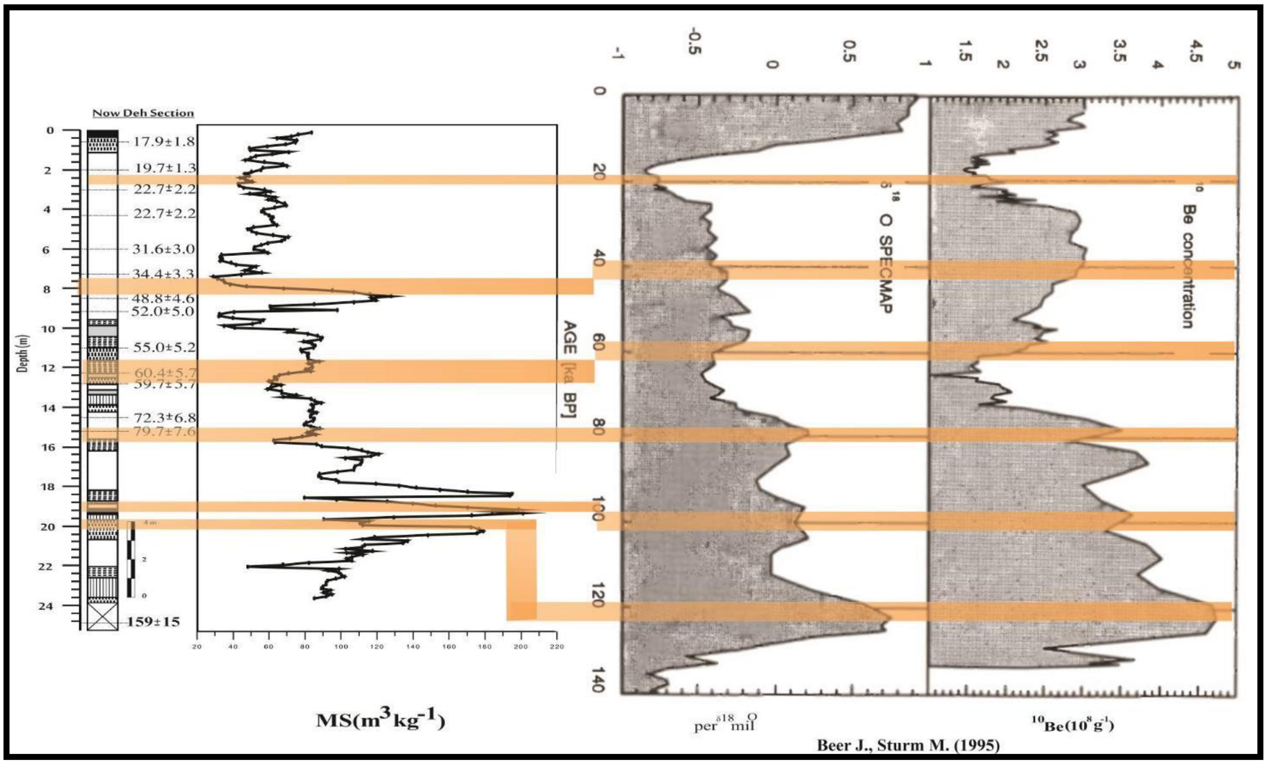

Figure 10: Comparison of magnetic receptivity results of Nowdeh sedimentary section in comparison with oxygen 18 and barium 10 isotope results of Xifeng sedimentary section (Beer and Sturm, 1995).

Conclusion

In conclusion, the loess/paleosol sequences from Northeastern Iran serve as a valuable archive for studying the paleoenvironmental changes during the Upper Pleistocene. By employing a multi-proxy approach that integrates sedimentological, magnetic, and geochemical methods, the following key insights have been revealed:

1. The stratigraphy of the studied section aligns well with the typical pattern of Upper Pleistocene loess/paleosol successions in the region, providing valuable insights into the past environmental conditions.
2. Magnetic parameters show a strong correlation with climate conditions, making them effective variables for reconstructing climate change patterns in the region.

3. Comparisons between magnetic and geochemical data indicate that variations in geochemical weathering ratios mirror changes in magnetic weathering parameters, such as magnetic susceptibility, further enhancing our understanding of past environmental dynamics.
4. The high degree of coherence observed between the amplitudes of magnetic susceptibility and various geochemical ratios, including Rb/Sr, Mn/Ti, Zr/Ti, and Mn/Sr, reinforces the reliability of magnetic susceptibility as a proxy for tracking environmental changes and provides additional insights into the interplay between magnetic and geochemical processes.

Overall, this comprehensive multi-proxy analysis enhances our understanding of the paleoenvironmental changes in Northeastern Iran during the Upper Pleistocene period and emphasizes the importance of integrating sedimentological, magnetic, and geochemical data to unravel past climatic fluctuations and environmental dynamics.

~~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.~~

References

1. Ahmad, I., Chandra, R, 2013, Geochemistry of loess-paleosol sediments of Kashmir Valley, India: Provenance and weathering, Journal of Asian Earth Sciences 66, 73-89.
2. Antoine, P., Rousseau, D.D., Degeai, J.P., Moine, O., Lagroix, O., Kreutzer, S., Fuchs, M., Hatte, CH., Gauthier, C., Svoboda, J, and Lisa , l., 2013, High-resolution record of the environmental response to climatic variations during the Last Interglacial Glacial cycle in Central Europe: the loess-palaeosol sequence of Dolní V_estonice (Czech Republic), Quaternary Science Reviews, 67, PP 17-38.

3. Baumgart, P., Hambach, U., Meszner, S., Faust, D., 2013. An environmental magnetic fingerprint of periglacial loess: records of Late Pleistocene loess paleosol sequences from Eastern Germany. Quat. Int. 296, 82–93.
4. Bloemendal, J., Xiuming L., Youbin, S., Ningning L., 2008. An assessment of magnetic and geochemical indicators of weathering and pedogenesis at two contrasting sites on the Chinese Loess plateau, Palaeogeography, Palaeoclimatology, Palaeoecology 257 ; 152–168.
5. Bronger, A., 2003. Correlation of loess-paleosol sequence in East and Central Asia with SE Central Europe: toward a continental Quaternary pedostratigraphy and paleoclimate history. Quaternary International 106/107, 11–31.
6. Buggle, B., Hambach, U., Glaser, B., Gerasimenko, N., Markovic, S., Glaser, I., Zöller, L., 2009. Stratigraphy, and spatial and temporal paleoclimatic trends in Southeastern/Eastern European loess–paleosol sequences. Quat. Int. 196, 186–206.
7. Chen, J., An, Z.S., Head, J., 1999. Variation of Rb/Sr ratios in the loess–paleosol sequences of central China during the last 130,000 years and their implications for monsoon paleoclimatology. Quaternary Research 51, 215–219.
8. Chen, T., Xie, Q., Xu, H., Chen, J., Ji, J., Lu, J., Lu, H and Balsam, W, 2010, Characteristics and formation mechanism of pedogenic hematite in Quaternary Chinese loess and paleosols, Catena 81, 217-225.
9. Chlachula, J., Little, E., 2011, A high-resolution Late Quaternary climatostratigraphic record from Iskitim, Priobie Loess Plateau, SW Siberia, Quaternary International 240 , 139e149
10. Ding, Z.L., Ranov, V., Yang, S.L., Finaev, A., Han, J.M., Wang, G.A., 2002. The loess record in southern Tajikistan and correlation with Chinese loess. Earth and Planetary Science Letters 200, 387e400.
11. Ding, Z.L., Yang, S.L., Sun, J.M., Liu, T.S., 2001. Iron geochemistry of loess and Red Clay deposits in the Chinese Loess Plateau and implications for long-term Asian monsoon evolution in the last 7.0 Ma. Earth and Planetary Science Letters 185, 99–109.
12. Fischer, P., Hilgers, A., Protze, J., Kels, H., Lehmkuhl, F., Gerlach, R., 2012. Formation and geochronology of Last Interglacial to Lower Weichselian loess/palaeosol sequences — case studies from the Lower Rhine Embayment, Germany. E & G Quat.Sci. J. 61, 48–63.
13. Fitzsimmons, K.E., Marković, S.B., Hambach, U., 2012. Pleistocene environmental dynamics recorded in the loess of the middle and lower Danube Basin. Quat. Sci. Rev. 41,104–118.
14. Forster, T., Evans, M.E., Havlíček, P., Heller, F., 1996. Loess in the Czech Republic:magnetic properties and paleoclimate. Stud. Geophys. Geod. 40, 243–261.
15. Frechen, M., Kehl, M., Rolf, C., Sarvati, R., Skowronek A., 2009, Loess Chronology of the Caspian Lowland in Northern Iran, Quaternary International, No. 198, pp. 220-233.
16. Frechen, M., Oches, E.A., Kohfeld, K.E., 2003. Loess in Europe—mass accumulation rates during the Last Glacial Period. Quaternary Science Reviews 22, 1835–1875.
17. Gallet, S., Jahn, B.M., Torii, M., 1996. Geochemical characterization of the Luochuan loess-paleosol sequence, China, and paleoclimatic implications. Chemical Geology 133, 67–88.
18. Gocke, M., Hambach, U., Eckmeier, E., Schwark, L., Zöller, L., Fuchs, M., Löscher, M., Wiesenberg, G.L.B., 2014. Introducing an improved multi-proxy approach for

paleoenvironmental reconstruction of loess–paleosol archives applied on the Late Pleistocene Nussloch sequence (SW Germany). Palaeogeogr. Palaeoclimatol. Palaeoecol. 410, 300–315.

19. Guanhua. L, Dunsheng. X, Ming. J, Jia. J, Jiabo. L, Shuang Z,Yanglei. W, 2014, Magnetic characteristics of loessepaleosol sequences in Tacheng, northwestern China, and their paleoenvironmental implications, Quaternary International, 3, 1-10.
20. Guo, Z.T., Ruddiman, W.F., Hao, Q.Z., Wu, H.B., Qiao, Y.S., Zhu, R.X., Peng, S.Z., Wei, J.J., Yuan, B.Y., and Liu, T.S., 2002. Onset of Asian desertification by 22 Myr ago inferred from loess deposit in China. Nature Vol. 416, pp. 159–163.
21. Heller, F., Liu, T., 1984. Magnetism of Chinese loess deposits. Geophys. J. R. Astron. Soc. 77, 125–141.
22. Hošek, J. Hambach, U. Lisá, L. Matys G. T. Horáček, I., 2015, an integrated rock-magnetic and geochemical approach to loess/paleosol sequences fromBohemia andMoravia (Czech Republic): Implications for the Upper Pleistocene paleoenvironment in central Europe, Palaeogeography, Palaeoclimatology, Palaeoecology 418, 344–358.
23. Jary, Z., Ciszek, D., 2013. Late Pleistocene loess–palaeosol sequences in Poland and western Ukraine. Quat. Int. 296, 37–50.
24. Jordanova, D., Grygar, T., Jordanova, N., Petrov, P., 2011. Palaeoclimatic significance of hematite/goethite ratio in Bulgarian loess–palaeosol sediments deduced by DRS and rock magnetic measurements. In: Petrovsky, E., Ivers, D., Harinarayana, T., Herrero- Bervera, E. (Eds.), the Earth's Magnetic Interior. IAGA Special Sopron Book Series. Springer-Verlag, Berlin.
25. Karimi, A., Khademi, H., Ayoubi, A., 2013, Magnetic susceptibility and morphological characteristics of a loess–paleosol sequence in northeastern Iran, Catena, 101, pp. 56-60.
26. Karimi, A., Khademi, H., Jalalian, A., 2011, Loess: Characterize and application for paleoclimate study, Geography Research,Volume 76, pp1-20.
27. Karimi, A., Khademi, H., Kehl, M., Jalaian, A., 2009, Distribution, Lithology and Provenance of Peridesert Loess Deposits in Northeast Iran, Geoderm, No.148, pp. 241-250.
28. Kehl, M., Frechen, M., Skowronek, A., 2005, Paleosols Derived from Loess and Loess-like Sediments in the Basin of Persepolis, Southern Iran, Quaternary International, No.140/141, pp.135-149.
29. Kehl, M., Sarvati, R., Ahmadi, H., Frechen, M., Skowronek, A., 2006, Loess / Paleosolsequences along a Climatic Gradient in Northern Iran, Eisxeitalter und Gegenwart, No. 55, pp.149-173.
30. Lateef, A.S.A., 1988. Distribution, provenance, age and paleoclomatic record of the loess in Central North Iran. In: Eden, D.N., Furkert, R.J. (Eds.), Loess – its Distribution, Geology and Soil. Proceeding of an International Symposium on Loess, New Zealand, 14–21 February 1987. Balkema, Rotterdam, pp. 93–101.
31. Mehdipour, F, 2012, Investigation of paleoclimate in late quaternary western alborz using of technical applied and magnetism parameters, Geology and Mineral Exploration, master science thesis.
32. Nabavi, Mehdi, 1976, Introduction geology of Iran, pp1-109.
33. Okhravi, R. Amini, A., 2001, Characteristics and Provenance of the Loess Deposits of the Gharatikan Watershed in Northeast Iran, Global and Planetary Change, No. 28, pp.11-22.

34. Pashaei, A., 1996, Study of Chemical and Physical and Origin of Loess Deposits in Gorgan and Dasht Area, Earth Science, 23/24, pp. 67-78.
35. Prins, M.A., Vriend, M., Nugteren, G., Vandenberghe, J., Huazu, L., Zheng, H., Weltje, G.J., 2007. Late Quaternary aeolian dust input variability on the Chinese Loess Plateau: inference from unmixing of loess grain-size record. Quaternary Science Reviews 26, 230–242.
36. Schatz, A.-K., Scholten, T., Kühn, P., 2014. Paleoclimate and weathering of the Tokaj (NE Hungary) loess–paleosol sequence: a comparison of geochemical weathering indices and paleoclimate parameters. Clim. Past Discuss. 10, 469–507.
37. Song, Y., Shi, Z., Dong, H., Nie, J., Qian, L., Chang, H. & Qiang, X., 2008- Loess Magnetic Susceptibility in Central Asia and its Paleoclimatic Significance. IEEE International Geoscience & Remote Sensing Symposium, II 1227-1230, Massachusetts.
38. Spassov, S., 2002. Loess Magnetism, Environment and Climate Change on the Chinese Loess Plateau. Doctoral Thesis, ETH Zürich, pp. 1–151.
39. Taylor, S.R., McLennan, S.M., McCulloch, M.T., 1983. Geochemistry of loess, continental crustal composition and crustal model ages. Geochimica et Cosmochimica Acta 47, 1897–1905.