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Paleoclimate change during the last 450ka imprinted in the magnetic properties of Kaolinovo loess-paleosol sequence

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Key words: magnetism, iron oxides, loess – paleosol sediments, paleoclimate, Quaternary

Abstract

Loess-paleosol sediments are among the best terrestrial recorders of Quaternary climate change. Magnetic properties of continuously sampled profile near Kaolinovo (NE Bulgaria) are studied for revealing the evolution of the local environmental conditions during the last 450ky. Magnetic characteristics, including magnetic susceptibility, frequency dependent magnetic susceptibility and laboratory induced anhysteretic and isothermal remanences, were measured for continuously sampled section. Variations with depth of all parameters show their high sensitivity to cyclic alteration between cold glacial and warm interglacial stages during the Middle Pleistocene in the region. The relative magnetic enhancement of paleosol units points to changing humidity of the past four interglacials, consistent with the records of global climate change.

Палеоклиматични изменения за последните 450 хил.г., записани в магнитните свойства на льосово-почвения профил Каолиново

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Ключови думи: магнетизъм, окиси на желязото, льосово-почвени седименти, палеоклимат, кватернер

Резюме

Льосово-почвените сеидменти са едни от най-добрите архиви на измененията на климата през кватернера. Изследвано е поведението на магнитните свойства в дълбочина по льосово-почвен профил от района на Каолиново (СИ България) за изучаване измененията в околната среда за последните 450 хил.г. Проведени са измервания на набор от магнитни параметри, включващи магнитна възприемчивост, честотно-зависима магнитна възприемчивост и лабораторно създадени безхистерезисна и изотермична намагнитености за всички нива от опробвания непрекъснато профил. Вариациите на всички магнитни характеристики показват висока чувствителност спрямо редуването на льосови и палеопочвени хоризонти, които са свързани с цикличната смяна на студени глациални с топли интерглациални епохи през средния плейстоцен. Относителната степен на педогенно магнитно обогатяване на палеопочвените хоризонти показва наличието на изменения в хумидността на интерглациалите, съответстващо и на общите тенденции в глобалните климатични изменения за този геоложки период от време.

Introduction

Loess sediments are common terrestrial Quaternary deposits in the mid-latitudes. The most typical feature of the loess sediments is the dominance of the silt fraction (between 60 and 90%) in their grain size distribution. Build up of sequences of successive loess deposits and interbedded paleosols are the response of the Earth's system to global climate oscillations during the Quaternary (Pye, 1995; Muhs, 2013). European loess deposits are valuable source of palaeoclimatic information (Forster et al., 1996; Jordanova and Petersen, 1999; Panaiotu et al., 2001; Jordanova et al., 2007; Antoine et al., 2013; Markovic et al., 2015 and references cited therein). With the pioneering work of Heller and Liu (1984) the research on magnetic properties of the loess/paleosol sediments as records of past climate changes started. Notwithstanding the numerous valuable research on this

topic (Markovic et al., 2015), there are still fundamental problems to solve, such as revealing the exact mechanism of the pedogenic iron oxides formation in response to pedogenesis that starts as climate change from glacial to interglacial (interstadial). Widely applied quantitative paleoclimate reconstructions based on the magnetic enhancement of paleosols are based on the assumption that soil formation is accomplished through continuing dust accumulation (Maher et al., 2003). In such regime, pedogenesis and formation of pedogenic iron oxides proceed through the assimilation of the newly settled dust during the pedogenic development itself. This finding allows making a direct correlation between the magnetic signature and climate components, considering that the other soil-forming factors (time and parent rock) do not change during that period and do not influence the soil properties. This requires that the process of pedogenic magnetic enhancement reaches saturation relatively fast so that it realistically reflects environmental conditions during the soil formation (Maher and Thompson, 1995). In this contribution we show new mineral and rock-magnetic data for a loess-paleosol sequence at Kaolinovo (NE Bulgaria) which reveal the history of climate change and eolian dust dynamics in the area during the last 450 ky.

SITE DESCRIPTION AND METHODS

Loess deposits in Bulgaria are part of the lower Danube loess area, which belongs to the European loess belt (Haase et al., 2007) (Fig. 1a).

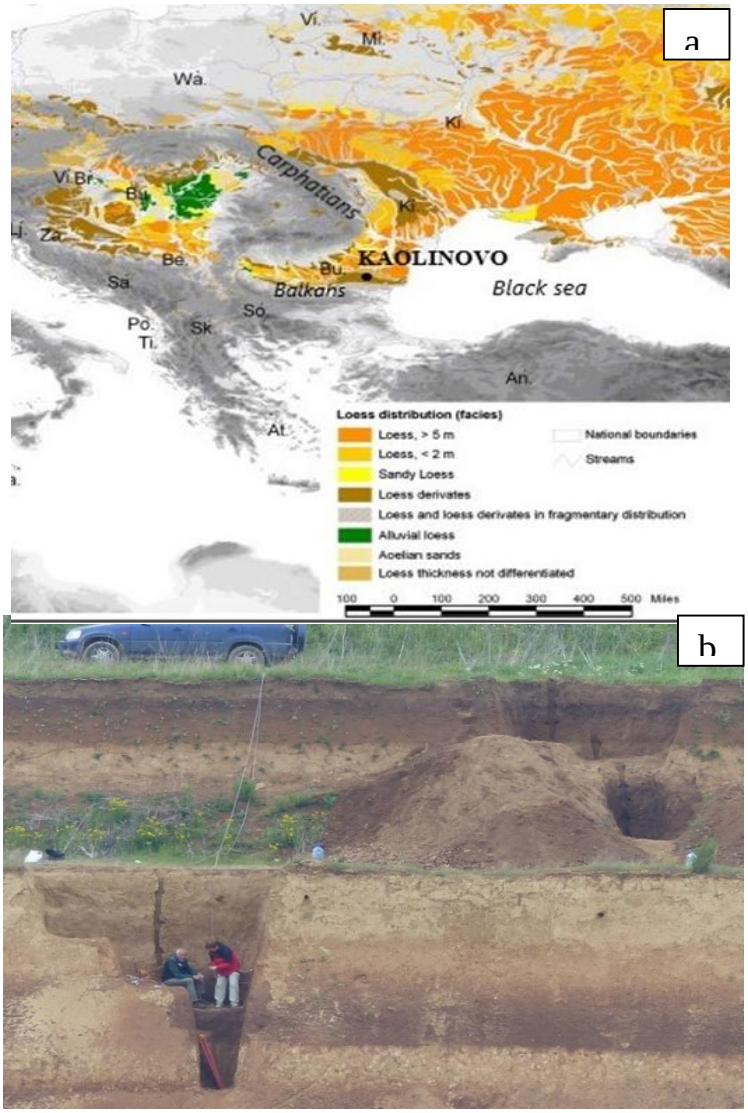


Figure 1. a) Loess cover in Bulgaria in the context of the spread of European loess belt (modified from Haase et al., 2007); b) Photograph of the upper part of the loess-paleosol sequence at Kaolinovo quarry.

The full loess paleosol complex in NE Bulgaria is represented by the Holocene soil (So), seven loess horizons (L_1 to L_7) and six interbedded paleosols (S_1 to S_6) (Evlogiev, 2007). Inspite of the already published works on other profiles from the Bulgarian loess (Jordanova et al., 2008, 2011), establishment of new records improve significantly our robust knowledge on the role of regional, local and global environmental factors in determining the magnetic signature of loess-paleosol sediments.

Kaolinovo profile was sampled in an open pit quarry for kaolin extraction (Fig. 1b). The sampling covers the uppermost 12m of the deposits, which encompass S_0, L_1, S_1, L_2, S_2, L_3, and S_{3-4} units. Vertical sections were cleaned from the surficial weathered material, removing about 50cm thick layer. Profile was described and bulk loose material was continuously sampled at 2cm resolution. After laboratory air drying, material was sieved through 2mm sieve and used for laboratory magnetic measurements.

Magnetic susceptibility of the bulk material was measured on MFK – 1A susceptibility bridge (AGICO, Czech Republic) at 200 A/m field and two working frequencies – 976 Hz and 15616 Hz. The material was filled into standard 10 cm3 plastic cylinders. Low-field mass specific magnetic susceptibility (χ) is calculated using sample's weight and the measured susceptibility at lower frequency. Frequency-dependent magnetic susceptibility χ_{fd} is calculated as the difference between the measured susceptibilities at low and high frequencies. This parameter is commonly used as an indicator for the presence of viscous superparamagnetic ferrimagnetic iron oxides (Дунлоп анд Оздемир, 1997). Laboratory magnetic remanences were measured on cubic samples with standard 2x2x2 cm size. The samples were prepared by mixing 2 g of dry powdered material with gypsum and water and left to harden in plastic molds, which were subsequently removed.

Anhysteretic remanent magnetization (ARM) was imparted using a Molspin AF demagnetizer with a 100 mT AF field superimposed on a 0.1 mT DC field. Isothermal remanent magnetization (IRM) in 2 T field and subsequent -100 mT and -300 mT back fields have been acquired along the z-axis in IM-10-30 pulse magnetizer (ASC Scientific, USA). Magnetic remanences were measured on JR-6A automatic spinner magnetometer (AGICO, Czech Republic) with a sensitivity of $2x10^{-6}$ A/m

Magnetic mineralogy was deduced by continuous thermal demagnetization of magnetic susceptibility (thermomagnetic analysis) (K(T)) with heating from room temperature up to 700°C and cooling back at heating rate of 10deg/min using CS-23 furnace attached to KLY-2 kappabridge (AGICO, Czech Republic). Curie (Neel) temperatures of the main iron oxides are identified through their unblocking and K-decrease at certain mineral-specific characteristic temperatures.

RESULTS AND DISCUSSION

Robust interpretation of variations of magnetic parameters along loess-paleosol profiles as paleoclimate proxies require firm identification of the type and grain size of the strongly magnetic iron oxides, carrying the pedogenic magnetic signal. This task is accomplished in the present study by thermomagnetic analysis of magnetic susceptibility (Fig. 2). Representative results for loess and paleosol samples are shown, revealing major drop of the signal at 580 – 600°C, characteristic as Curie point of magnetite (oxidized magnetite). Recent soil So exhibits also another noticeable K-decrease at 450°C, suggesting the occurrence of thermal transformation of unstable strongly magnetic maghemite to weakly magnetic hematite (Dunlop and Özdemir, 1997). The increase of susceptibility upon cooling reflects probably appearance of new magnetite like minerals as a product of thermal destruction of initial clay minerals in the presence of organic matter. Such strong transformations are not observed in the samples from the lower part of S_1 and loess L_2, probably because of significantly lower content of secondary clay minerals and organics. The results point out that pedogenic magnetite and maghemite are the major carriers of the enhanced magnetic properties. Consequently, depth changes in the concentration of magnetite and maghemite will reflect qualitatively the contrast between more humid interglacial conditions from arid and cold glacials.

Depth changes of a set of concentration dependent magnetic parameters and ratios are shown in Fig. 3. Magnetic susceptibility (χ), frequency-dependent magnetic susceptibility (χ_{fd}), ARM, IRM_{2T} show synchronous behavior with depth. Each one of these parameters is sensitive to the presence of ferrimagnetic fraction in a certain magnetic domain state. Namely, the superparamagnetic (SP) fraction dominates in χ_{fd}; single domain (SD) fractions contribute the most to ARM; multidomain (MD) grains have major share in IRM_{2T} (Liu et al., 2012). Increase of these magnetic parameters are observed in all soils (Holocene soil and the three paleosoils) (Fig. 3) as generally observed in most loess-paleosoil sequences elsewhere (Maher, 2016).

The highest pedogenic magnetic enhancement is expressed by maxima within the S_1 and S_2 paleosols (Fig. 3). Lower pedocomplex (S_{3-4}) is characterized by smaller enhancement.

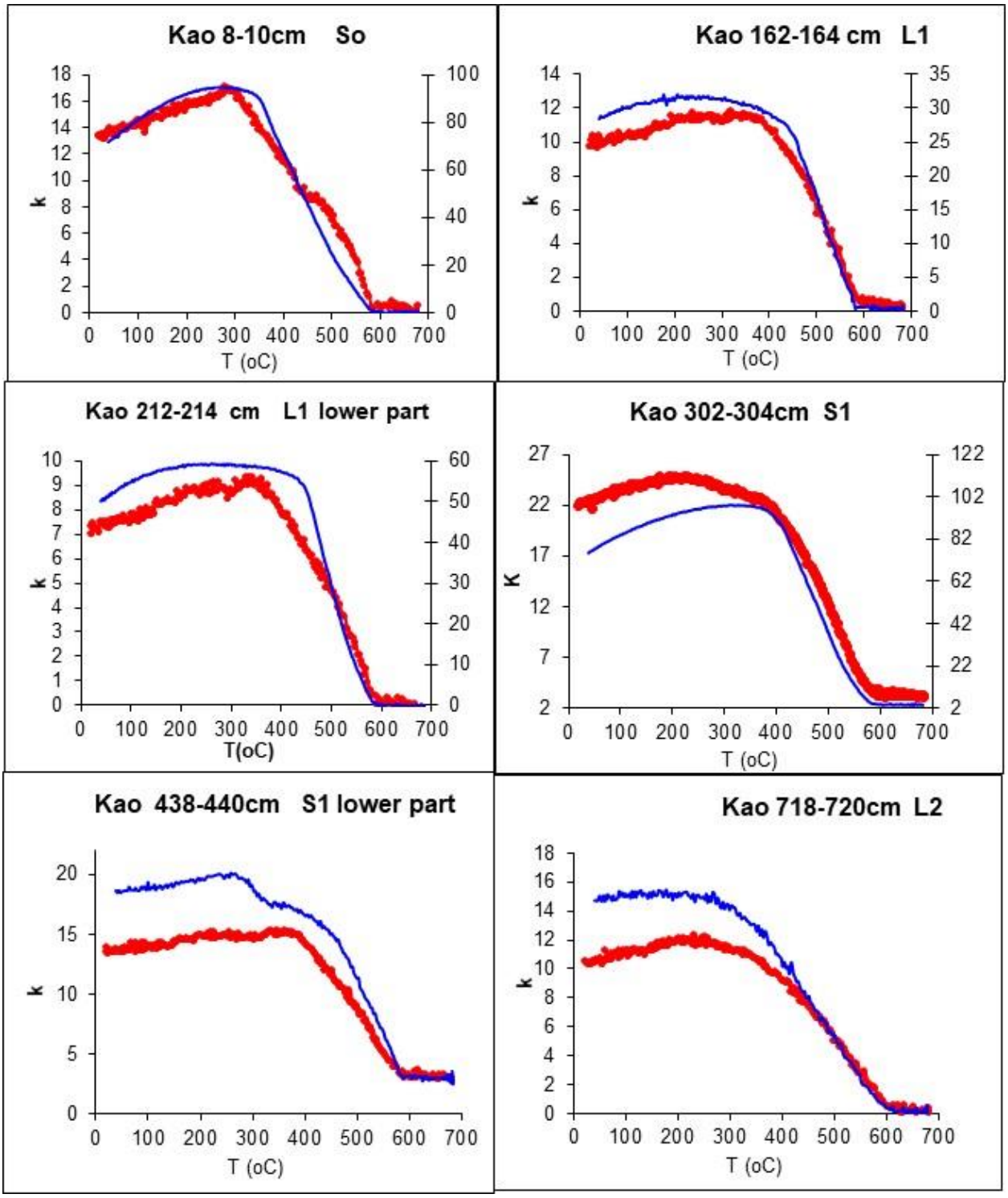


Figure 2. Thermomagnetic analysis of magnetic susceptibility k ($x10^{-6}$ SI) for representative samples from the uppermost 7m of the loess paleosol profile at Kaolinovo. Heating curve is shown in red, cooling – in blue color. Right y-axis corresponds to susceptibility during cooling in cases when strong mineralogical changes at high temperature cause increasing susceptibility as a result of appearance of a new heating-induced strongly magnetic phase.

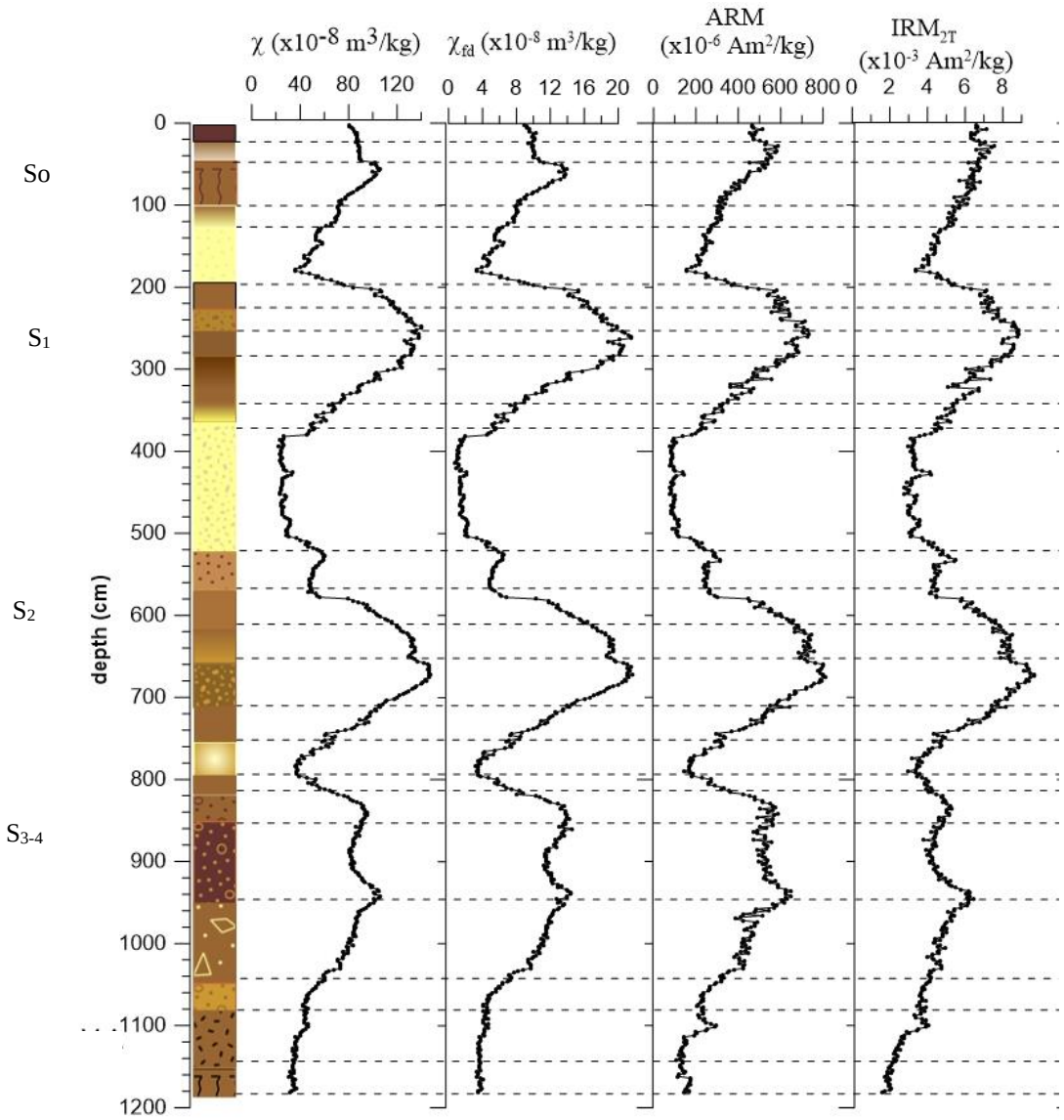


Figure 3. Depth variations of concentration dependent magnetic parameters along Kaolinovo profile. Enhanced content of pedogenic strongly magnetic fraction is deduced by systematically higher values in paleosols' horizons.

The observed clear stratigraphic distinction between loess horizons and paleosols allow for reliable correlation of Kaolinovo profile with the available paleoclimate records of global sea surface temperature (stacked oxygen isotope record ^{18}O of bentic foraminifera by Lisiecki and Raymo, 2005). Further important age constrains of the section are available through carried out IRSL dating of the upper three loess horizons by Balescu et al. (2020). The obtained ages of 45±2ka for L_1; 167±7ka for L_2 and 296±17ka for L_3 suggest that these loesses were formed during cold marine isotope stages MIS 2-4, MIS 6 and MIS 8. The proposed correlation of Kaolinovo record with earlier paleomagnetically studied Viatovo profile (Jordanova et al., 2008) and global paleoclimate record is shown in Fig. 4. Similar behavior of magnetic characteristics along depth of the Holocene soil and S_1 paleosol along with their matching in field description suggest that much higher maximum magnetic enhancement in S1 is due to persistence of more humid and warm conditions during the last interglacial period as compared to modern climate. This conclusion is consistent with the observations in other European paleoclimate records (Maher, 2016). Similarly, high magnetic enhancement in older paleosol S_2 formed during MIS7 is also indicative for a more humid climate, while lower enhancement in S_{3-4} points to some degree of aridization during MIS 9-11. Such a trend could be deduced only for MIS 11 in Viatovo record, suggesting that local conditions for dust accumulation and pedogenesis may influence the paleoclimate significance of magnetic susceptibility.

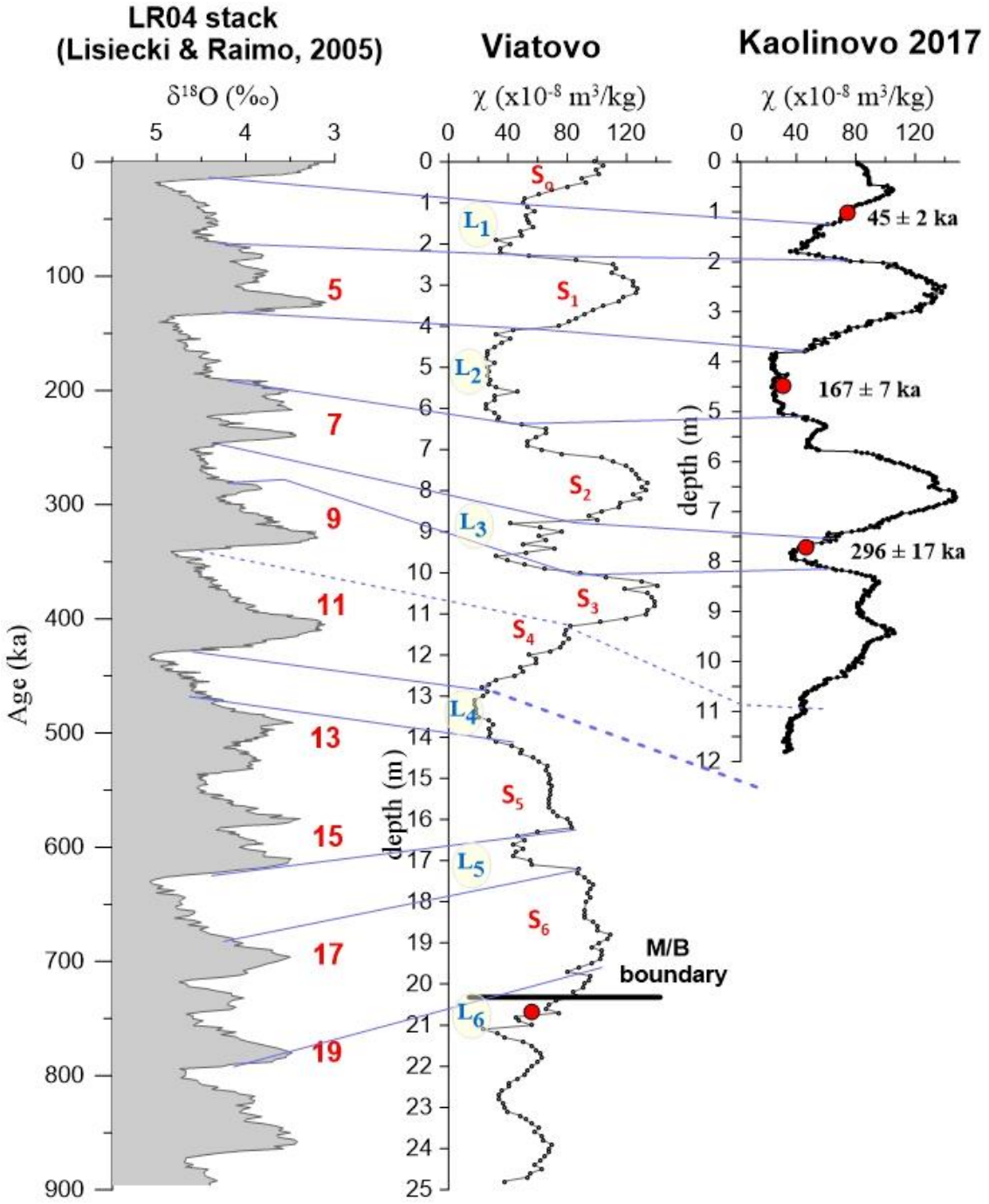


Figure 4. Correlation of magnetic susceptibility record along Kaolinovo profile with global stacked LR04 record of bentic $\delta^{18}O$ for the last 800ka (Lisiecki and Raimo, 2005) and magnetic susceptibility record from Viatovo quarry (Jordanova et al., 2008) along with paleomagnetically identified Matuyama/Brunhes (M/B) geomagnetic reversal. The three PIR-IR dates of Kaolinovo profile (Balescu et al., 2020) are also shown. Dashed line indicates the level of dense $CaCO_3$ concretions levels in Viatovo and Kaolinovo, marking the position of pedogenically transformed or eroded loess unit L4. Warm interglacial stages are indicated by red numbers.

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