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Late Pleistocene Climatic Variations in Siberia Based on Loess-Palaeosol Records

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ABSTRACT. Loess-palaeosol records in Siberia represent a significant source of proxy data for reconstruction of past climates and climate change in the Northern Hemisphere. A series of high resolution loess sections recently studied in the Ob, Yenisei and Angara River basins within a 1500 km W-E continental transect shows patterned climatic variations and uniformity of natural environments across this territory during the Late Pleistocene. The key Late Quaternary Siberian record from Kurtak (Sections 29 and 33) in the Northern Minusinsk Basin provides evidence for a strongly fluctuating climatic change in the northern Eurasia during the Late Quaternary, with maximum deviation amplitudes between 130 and 10 ka BP. Magnetic susceptibility (low-frequency and FD%) records with other palaeoenvironmental proxy data (grain size, % Ca CO_3 and % organic carbon variations) show a globally diagnostic palaeoclimatic trend for the last glacial - interglacial cycle, and an environmental uniformity across southern Siberia.

The last interglacial (sensu lato) includes several relatively short warm as well as very cold intervals (correlated with OIS 5e-5a), with a strongly continental warm climate culminating around the peak of the last interglacial (OIS 5e) and a gradual shift to more humid and cooler conditions during the following interstadial stages (OIS 5c and 5a). Due to its pronounced continentality, the Siberian loess record provides an excellent source of high-resolution palaeoclimatic proxy data of regional as well as global significance.

KEY WORDS: loess-paleosol records, magnetic susceptibility, climatic change, Siberia, OIS 5.

Introduction

Palaeoclimatic loess records in Siberia, although still less known than those in Europe or China, have already provided important information on past climatic variations in this part of Eurasia (Chlachula et al., 1997, 1998; Chlachula, 1999; Zykina, 1999). Loess and loess-like deposits are widely distributed mainly in the southern part of the Siberian territory, covering a broad geographical area of about 800,000 km^2 between the Ob and Angara River basins north of the Altay and Sayan Mountains. They represent a continuation of the Eurasian loess belt spanning from Western Europe across the Russian Plains to the north-central China Loess Plateau. They range in thickness from a few metres in the Angara and Lake Baykal area in the eastern part of Siberia to maximum of 40 m in the Yenisei River valley and reaching up to 150 m on the Ob River (Priobie) loess plateau in the west. The loess is often locally intercalated with other aeolian, alluvial and colluvial deposits (sands, clays and silts) and it documents the complex nature of the Quaternary environments in this part of Asia. Following

the initial investigations of the Late Quaternary loess-palaeosol sequences (Chlachula et al., 1997, 1998), the focus of the present study is aimed at the high-resolution last interglacial climatic records and the related palaeoenvironmental evolution of landscape and biota.

Methods and material studied

Study section

The broader study area encompasses a 1500 km belt of the southern part of Siberia, north of eastern Kazakhstan and Mongolia, comprising the Novosibirsk, Altay, Krasnoyarsk and Irkutsk Regions. It is bordered on the west by the Western Siberian Lowland; the Altay and Sayan Mountains on the south and the Transbaykal Range on the east. The present climate is strongly continental with cold and dry winters with little snow cover, and warm to hot summers with mean annual temperature from -0.5 to -2 °C. The best preserved and most complete sections are located in the upper Yenisey River valley in the steppe zone of the Northern Minusinsk Depression on the western side of the Krasnoyarsk reservoir. Here, 30 years of lake erosion has exposed a nearly complete Late Quaternary geological record, including rich early cultural finds and fossil fauna remains.

The principal, 37-m high section (Kurtak, 33) is situated in the central part of the Kurtak area (55.1°N, 91.4°E) with the thickest loess deposits intercalated with a series of buried palaeosols. The 20–40 m thick local loess-cover mantles relics of Early Pleistocene alluvial terraces and includes aeolian as well as partly colluviated loess and loess-like deposits. A total of 32 variably-developed pedogenic horizons, described as single stratigraphic units, have been previously recognised in the area (Chlachula et al., 1997; Chlachula, 1999).

The loess mineralogy is characterised mainly by quartz (54–72%) and feldspar (10–23%), with some calcite (4–7%), chlorite (3–6%), biotite (2–3%) and other minerals. This mineralogical composition and the fresh surface morphology of the fine silt fraction indicate a local provenance of the sediment. The massive structure and angularity of most silt grains indicate the subaerial accumulation of the Kurtak loess, partly distorted by solifluction and other periglacial deformation phenomena. Colluviated loess facies with a laminated structure suggest cyclical (seasonal?) patterns of loess sedimentation under cold and humid conditions.

Methods and approaches

Chronostratigraphic studies included field description, sampling and subsequent laboratory analyses. Samples were taken in 8 cm^3 plastic boxes at 2.5 cm intervals focusing on the middle part of the study section (Kurtak, 33), 6.5 m high, corresponding to the last interglacial (OIS 5). Palaeopedological studies at Kurtak were aimed at specifying the nature and rate of pedogenic processes and to reconstruct environmental conditions prior to, during and after formation of the fossil soils. The principal study aspects used as indicators of the past climatic change in the buried pedogenic horizons were the amount of organic matter accumulation (the total organic carbon content); $CaCO_3$ content and secondary carbonate precipitates; grain size and mineralogy of the sedimentary matrix; fossil periglacial features (solifluction, cryoturbation, frost wedge casts); and magnetic

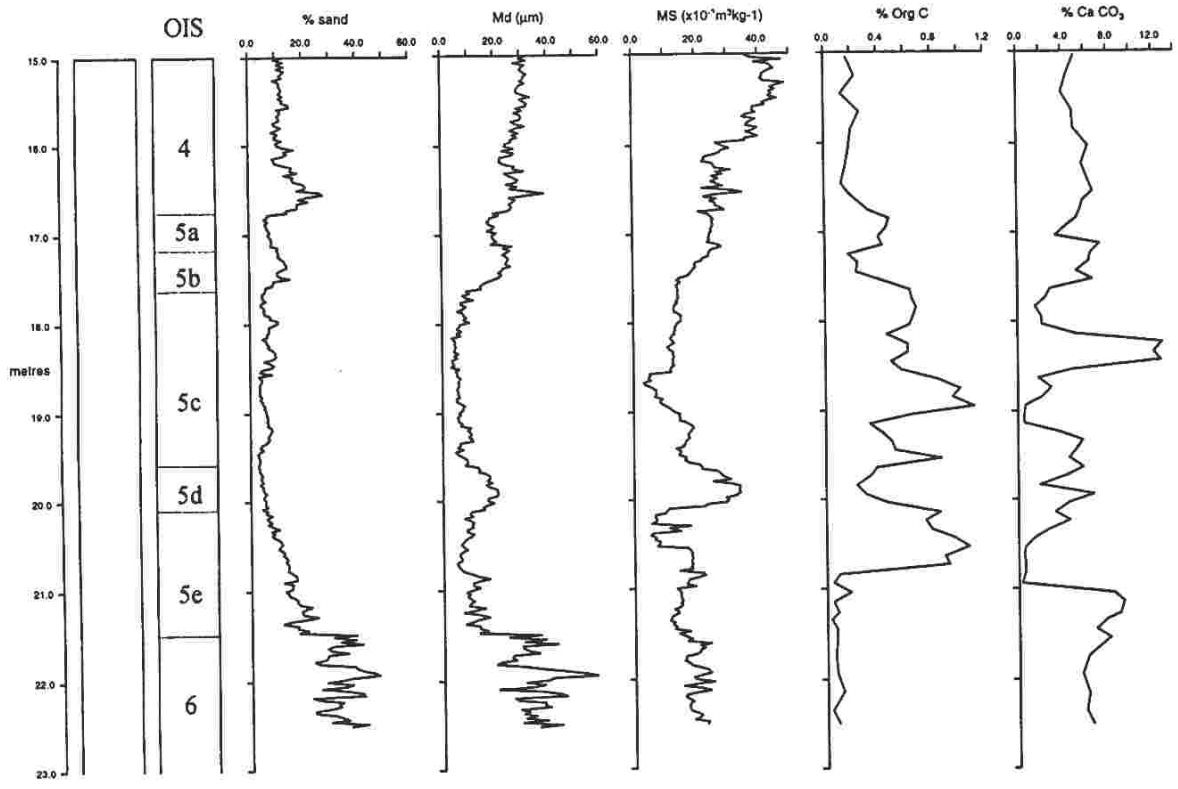

Fig. 1. Kurtak Section 33. Palaeoclimatic evolution during the last interglacial (OIS 5e-a) based on the analysed proxy data (% grain size, LF magnetic susceptibility, % organic carbon and % Ca CO_3).

susceptibility. Particular attention was paid to magnetic susceptibility, low-frequency (LF) and frequency-dependent (FD%), as this has proven to be a reliable indicator of the past climatic change in the larger study area (Chlachula et al., 1997, 1998; Chlachula, 1999).

Results and discussion

The palaeosol sequence at Kurtak comprises a series of climatically diagnostic soils. The initial pedogenic alteration of parent material is expressed by incipient gleying in a cold, humid environment within a seasonally waterlogged setting within a cold periglacial tundra. A progressive leaching of calcium carbonate from the loessic substratum accompanied by organic matter accumulation reflects a gradual increase of summer temperatures and surface stability that contributed both to prolonged weathering processes and formation of brunisolic (forest-tundra) and, under more warmer conditions, of chernozemic (park-land-steppe) soils.

A similar palaeoclimatic pattern is documented in the Late Pleistocene loess sections in western Siberia (Zykina, 1999), with reactivated soil formation processes during surface stabilisation under warmer conditions and subsequent solifluction and cryoturbation due to climatic cooling and increased humidity.

The stratigraphic succession of palaeosol horizons during the last interglacial documents a gradual decrease of temperatures following the climatic optimum (OIS 5e), a shorter duration of intensive pedogenesis and transition to colder and more humid natural conditions. Deep ice wedge casts in the buried palaeosols, particularly chernozems, attest to relatively short, but very cold episodes during the interglacial periods. The major drop in temperature occurred during the OIS 5d as evidenced by up to 1.5 m deep frost wedge casts in loess above the underlying OIS 5e chernozem TL dated to 125 ka (Sib1-LLUQAM) and corresponding to the Berdsk soil of Western Siberia (Zykina, 1999). A warm continental climate prevailed during the following interstadial (OIS 5c) resulting in formation of two-three chernozemic and brown forest-tundra soils. An intensified periglacial activity with some solifluction and cryoturbation indicative of a less continental and more humid climate is apparent at the end of this interval. A reactivated accumulation of loess and a subsequnt final climatic amelioration characterises the end of the interglacial (OIS 5b-a). Following the last interglacial, the climate in southern Siberia became more pronounced with very cold and dry stadials during the last glacial stages (OIS 4 and 2) interspersed with moderate mid-last glacial interstadials (OIS 3).

The results have confirmed a marked and patterned fluctuation of susceptibility values throughout the stratigraphic record (Chlachula et al., 1997) (Fig. 1). The relationship between the climatic change and magnetic susceptibility fluctuation is clearly evident, with the LF susceptibility maxima corresponding to the intervals of the most intensive loess deposition and the minima correlating with the most developed chernozemic palaeosols. An intense wind activity leading to accumulation of greater quantities of larger ferrimagnetic (mainly magnetite) grains is believed to account for the magnetic susceptibility increase during cold (stadial) intervals (Chlachula et al., 1998). A similar pattern has been observed in loess on the western Siberia (the Ob Plateau). The total magnetic susceptibility capacity of palaeosol horizons is clearly not a function of weathering intensity and time, as in Europe or China, but depends a priori upon the quantity and quality of primary magnetic minerals within the unaltered parent material inherited from original geological sources.

Conclusions

The loess - palaeosol stratigraphic sequence from the Yenisei area provides a unique evidence of complex and highly fluctuating climatic variations in central southern Siberia. The key investigated loess-palaeosol section at Kurtak, comprising a continuous high-resolution record for the last glacial - interglacial cycle, documents history of the past climatic change and environmental shifts in north-central Asia, but also exhibits a global palaeoclimatic evolution pattern corresponding to the Oxygen Isotope Stages 7–1. Magnetic susceptibility has proven to be a very sensitive indicator of climate change in the region.

In respect to the geographical location and a geomorphological isolation with largely reduced atmospheric effects of the world's oceans, the loess - palaeosol records from Siberia have a global significance for mapping of the Quaternary climatic change and the principal mechanisms behind this process. It is also of major importance for establishment of a correlation framework between the European, Central Asian and Chinese loess.

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