Last Glacial climate variability in eastern and central Europe as recorded in loess deposits

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Summary

Climate change is a hot topic these days. It may harm our economies and even our safeties. However, climate has always changed. New insight in the functioning of our climate and the resulting changes on scales of centuries to millennia is therefore possible from information about past climate changes. Such research is only possible when information from past climate changes is registered somewhere. Ocean floor sediments and land ice record climate changes relatively well and may provide a database of the climate of the past. The climate of the last glacial, or last ice age, is therefore very well registered in land ice and ocean floor deposits, mainly in the North Atlantic region. The records are very complete in time as signal forming processes continuously take place and erosion processes play hardly any role on these deposits.

New insights on relatively short-scale climate changes require information from the land. However, finding suitable information carriers on land is not that easy. Many deposits are the product of discontinuous processes, while destructive erosion processes are common. Very thick deposits of eolian dust in China seem to provide a resolution that potentially registered these oscillations. However, the information on short scale climate changes during the last glacial in China cannot reliably be linked to information from the North Atlantic. This thesis investigates the eastern and central European loess as a possible carrier of information on millennial scale climate oscillations during the last glacial. It is tested to what extent information from these loess deposits may function as a bridge between China and the North Atlantic. Besides, conclusions are drawn on the climate conditions, mainly wind directions, in central Europe during the last glacial.

Thick loess deposits are best suitable for this purpose, as they indicate a high time resolution. Paleosols, soils developed during the accumulation history of a loess deposit, may indicate slower deposition rates and thus lower resolution. They are therefore unwanted. Loess deposits are mainly found as blanket deposits on relatively low altitudes in the landscape, sometimes as relics of fluvial erosion. Exposures are often fluvial erosion cliffs or (former) brickyards.

For this research eight loess sections of last glacial age were sampled in 5-cm resolution. Three sections are situated on the west side of the Carpathian Mountains, in the Pannonian or Carpathian Basin: two in northern Serbia and one in southern Hungary. Five sections were sampled on the east and north side of the Carpathians: three in Ukraine and two in southeastern Poland. In northern Serbia, northern Ukriane en southeastern Poland two sections that are situated close to each other were sampled, in order to make comparisons possible. The section with the highest average resolution, with a total thickness of 20 m last glacial deposits, was found in Serbia.

Several signals (or proxies), sensitive for climate changes, were measured in the loess. They show a certain vertical variability through a loess section. During the research it became clear that correlating the wiggles of the different proxies between two sections is impossible without very precise dating techniques. However, dating techniques for the loess provide at present only about 8-10% uncertainty within one standard deviation (optical stimulated luminescence or OSL). This is not accurate enough to match millennial scale oscillations of the last glacial age (between 75 and 12 ka BP).

Chapter 1 describes a pilot study of a first step towards reliable matching of two records using a multi-proxy approach. Three, more or less independent proxies (grain-size fraction <5.5 μm, magnetic susceptibility and the Ba/Sr ratio (see also Chapter 2)) were used in two Serbian sections that are separated only 6 km. First, different single-proxy record combinations were matched, using the available datings and field information. Using only this information, generally up to five wiggles can be matched. However, in most cases there are different matching possibilities; never more than two matches are unique and thus relatively reliable.

Finally all three proxy records were combined before the matching. In this way, more information is assembled for each wiggle. This gives a significantly better result: 8 matches could be established now, while all are unique. To conclude, two records with comparable sedimentation conditions can be matched reliably only when sufficient information on sediment properties is available. In this way, larger distances may be bridged in correlating the paleoclimatic variation from different regions.

Chapter 2 deals with new ways of extracting climate information from loess records. Grain-size is accepted as a reliable proxy for wind intensities, generally associated with cold periods. Proxies for temperature and precipitation, generally associated with warm periods, are more difficult to interpret. For example, magnetic susceptibility is accepted as a proxy for paleo-precipitation. However, the signal is unreliable in some environments and it is also sensitive for post-depositional processes that breakdown the signal. Therefore, new proxies that are relatively easily measured are more than welcome in terrestrial paleo-climatology. Pedo-chemical elements may be used as such a proxy. They weather from primary minerals and have different solubility in acid, percolating rainwater. Ratios from hardly soluble elements and well soluble elements may provide a new proxy for the amount of percolating water through the loess column in the past, and thus for paleo-precipitation. Ratios were made in the elemental sequence Ca-Sr-Ba, and applied on four locations in Serbia and Ukraine with different present-day climate conditions. The Ba/Sr and Sr/Ca ratios show high similarities with magnetic susceptibility and the clay fraction. Sr/Ca is mainly sensitive in the Ukrainian test sites. Ba/Sr shows the similarity at all locations and is therefore a promising proxy for paleo-weathering intensity, especially paleo-precipitation. Further research may point out the further applicability of this ratio in different paleo-climatic environments.

Chapter 3 also focuses on new proxies that may indicate warm climate conditions. The climate dependent $\delta^{13}C$-value of CO_2 in the air is transferred via plants to soil organic matter and than to soil carbonates where it is recorded. Water plays a controlling role in the type of plants (C3 or C4) that register the $\delta^{13}C$-signal from the air, so this signal may well be interpreted as a registration of paleo-precipitation. In the continuous and relatively well dated section Titel in Serbia $\delta^{13}C$ of both soil organic matter ($\delta^{13}Csom$) and soil carbonate ($\delta^{13}Csc$) are measured, next to total organic carbon, the $CaCO_3$ content and the C/N ratio. The $\delta^{13}C$ signals are compared to the clay fraction (grain-size <5.5 μm), magnetic susceptibility and Ba/Sr records. The results are remarkable, as the $\delta^{13}Csc$ correlates very well to these proxies, while the $\delta^{13}Csom$ does not at all. As the signal in soil carbonate is registered via the soil organic matter, it must be concluded that post-depositional processes have affected the signal in the soil organic matter. The reliability of the $\delta^{13}Csc$-signal was checked by comparing it to the $\delta^{18}O$ signal, and confirmed. This study suggests that $\delta^{13}Csc$ may very well be a good proxy for paleo-precipitation, while care should be taken when using $\delta^{13}Csom$ as a proxy.

Chapter 4 describes an overview of the paleoclimatic results as derived from all sampled loess sections. Especially the grain-size information from these sections is used to reconstruct atmospheric circulation patterns during the last glacial. The reconstruction is based on the assumption that loess is a mixture of aeolian deposits from different origins and transport mechanisms. Sand and coarse silt are transported by saltation and in very low suspension, while medium-fine silt is transported in suspension clouds up to a few hundreds of meters above the ground surface. The bulk of these sediments can therefore not pass large water surfaces and mountain ranges. Very fine-grained loess, on the contrary, can be transported in dust plumes high in the atmosphere and can even cross oceans.

An end-member model separates the loess samples in coherent groups, or end-members. The mass accumulation rate was calculated for the Weichselian Early, Middle and Late Pleniglacial for each section. The end-member proportions and mass accumulation rates through time were related to the topography of the region. A large difference in mass accumulation rates is derived between the Early-Middle and the Late Pleniglacial east of the Carpathian Mountains. This difference, low accumulation rates in the Early and Middle, and high rates in the Late Pleniglacial, was not found on the west side of the Carpathians. There the sedimentation rates shows more equal rate over time. This distribution of loess in space and time can not be explained by distance to the proglacial zone in front of the Scandinavian ice cap alone. A dominantly western wind during the Early and Middle Pleniglacial and a northwestern wind during the Late Pleniglacial in combination with the position of the Carpathians explains the observed loess distribution in the study area over time and space.

The distribution of the end-member results can also be interpreted – assuming that the proportions of fine endmembers increase and the proportion of coarse endmembers decreases downwind – from this change in wind directions in the Early-Middle and Late Pleniglacial, confirming the hypothesis.

In the Synthesis it is concluded that it is probable that millennial scale oscillations of the last glacial climate are registered in the eastern and central European loess. It is also probable that these oscillations are related to the same climate oscillations that were responsible for variations in proxies from the Greenland ice sheet and from North Atlantic ocean floor deposits. However, problems still rise with attempts to match the wiggles in the proxy records on a long distance. Slight upscaling of wiggle-match distance, using many datings and proxies, may give new insight in the stability of a climate signal through a region.

New proxy information on the eight locations in eastern and central Europe, that is presented in this thesis, has contributed to the knowledge on the climate of the last glacial in this region. Mainly large differences in mass accumulation rates through time have pointed out that the total amount of dust transport varied more than was expected, while it could confirm modelled wind directions during this period. Also pilot studies on new proxies indicating post-depositional processes show promising results. They may also contribute to more reliable wiggle matching in the future. In this way, newly established proxy information may open new ways for the development of a better insight in the spatial influence of millennial scale climate oscillations.