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Characterization of paleosolis by multiparameter analysis

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ABSTRACT

In the course of systematic investigations of Austrian loess deposits multiparameter analysis of a loess profile at Stiefern, Lower Austria, has been performed. The concentration of Mn, Na, K, U, Th and the magnetic susceptibility of a sequence of 44 sediment samples from the whole profile have been determined by applying physical methods. This data set was combined with the results from standard sedimentological techniques and correlation analysis of these data records were performed. High correlations of the Mn-content, the magnetic susceptibility and the clay to silt ratios reflect the effects of weathering processes. It could be demonstrated that the parameters analyzed are useful for a detailed classification of the weathering degree of pedogenic horizons. The anti correlation of the sodium content with the clay to sand ratio and with the silt concentration and its positive correlation with the sand content is interpreted as an indication for the different sources of the sand and the silt fraction of the sediment samples.

The improved classification of the pedogenic horizons in the Stieferm profile by employing the results of the correlation analysis containing quantitative paleoclimatic information is discussed.

Key words: Paleosoils, multiparameter analysis.

INTRODUCTION

Loess deposits contain valuable information about the regional climatic history. The deposition of the aeolian sediments is correlated to cold and arid conditions whereas the development of soils is a consequence of a warmer and more humid climatic situation. Therefore loess profiles, the alternating layers of loess sediments and paleosoils, represent important terrestrial archives of the paleo-climate comparable to those in deep sea sediments, although the possible occurrence of a hiatus in the deposition sequence always must be considered.In the vicinity of Vienna (Austria) several loess deposits are easily accessible. Systematic sedimentological studies of a typical profile (height $\simeq$ 14m) near the village Stiefern (Lower Austria) were started some years ago. A map of the geographical position of the loess formation under investigation is shown in Fig.1. A sequence of 44 sediment samples was taken covering the whole accessible depth of the profile. For loess layers larger sample distances were selected than for paleosoils, because higher accumulation rates compared to soil formation are to be expected. By applying nuclear methods and susceptibility measurements as additional means of analysis, it was the aim of the present study to achieve better information concerning the paleoclimate and the conditions of soil formations, than with standard sedimentological methods alone.

EXPERIMENTAL

Standard sedimentological investigations

The grain size distribution of the 44 sediment samples was determined for the estimation of the relative abundance of sand (= 2mm-63 m), silt (= 63 m-2m) and clay (< 2m). Soil colors were compared with Munsell standard soil color charts and the calcium-carbonate concentration was determined by the modified method of Scheibler (ÖNORM L 1084-88). Complete data are given by Rehberger (1988).

Determination of manganese and sodium concentrations by neutron activation analysis

For the determination of the element concentration of sodium and manganese sample amounts of 100 g were irradiated in the thermal neutron flux of an $^{241}Am/Be$ source for 27h. The radioisotopes ^{24}Na ($T_{1/2}$ = 15.03h) and ^{56}Mn ($T_{1/2}$=2.58h) were produced via (n,) nuclear reactions and their aclivities were measured with a HPGe-spectrometer. The spectrometer system was calibrated with standard dilutions of MnO_2 and Na_2CO_3 (Merck, reagent grade (p.a.)) in quartz, which were also irradiated with thermal neutrons under the same conditions as the samples.

Determination of uranium,thorium and potassium by low-level-spectromentry

The concentrations of uranium, thorium and potassium were measured according to a procedure described by Meakins *et al*. (1979). A 3"x3" NaJ (TI) derector was surrounded by a container filled with 500g-600g of the sediment, depending on the density of the sample, and shielded with 6cm lead against background radiation. The characteristic-energies of 1.764 MeV of ^{214}Bi (daughter product of ^{238}U) and 2.614 MeV of ^{208}TI (daughter product of ^{232}TH) were used for the determination of the activities of the parent products. Secular equilibrium of the radioactive decay chains was presumed. The potassium content of the sediment was determined via the 1.461 MeV-activity of ^{40}K. Corrections for different self-absorption caused by variations of the sample densities were performed and the enhanced shielding of the detector due to the high sample amounts was considered in background corrections. The system was calibrated by using IAEA standards RGU-1, RGTh-1 and RGK-1 and dilutions of these standards with quartz and sodium chloride of high purity and accordingly low content of radioactivity.

Some samples were measured with an 1"x$1_{1/2}$" NaJ (TI) detector in a similar configuration because of a lack of material. Used sample amounts of 120g to 140g resulted in a lower statistical accuracy of the activity measurements in reasonable acquisition times (Table -1).

Determination of the magnetic susceptibility

Since 1984 the susceptibility of Chinese loess profiles, which depends on the concentration and the grain size of magnetic minerals, has been investigated systematically (Heller and Liu, 1984, Kukla, 1987, Kukla *et al*, 1988). It has been shown that variations of the susceptibility records from loess deposits in China and Alaska are almost parallel to those of the deep sea δ ^{18}O records (Kukla *et al*, 1988 Begét & Hawkins, 1989). A direct link between the aeolian record of the V21-146 Pacific deep sea core with the loess deposits of Xifeng, China, and δ ^{18}O timescale was demonstrated by Hovan *et al*. (1989). In the present investigation the relative magnetic susceptibility of the 44 sediment samples was determined by an inductive method.[1]

RESULTS AND DISCUSSION

Table -1 shows the results of routine sedimenological investigations of the sediment samples from the Stiefern loess profile together with the relative magnetic susceptibility and the concentrations of U, Th, K, Mn, and Na, which were determined by applying the additional methods described above. The grain size distribution is characterized by the ratios of clay to silt and of clay to sand. The clay, silt and sand content together with the calcium-carbonate concentration has been used for a coarse sedimentological classification of the sediment types considering also the sediment color (Rehberger 1988).

In this study correlation analysis of the complete data set has been performed. The correlation matrix is presented in Tab. 2. High correlations of the clay to silt ratio with the manganese concentration and the magnetic susceptibility of the samples are obvious. These findings can be explained by the effects of weathering processes in sediments. Soil formation is generated by an increase in vegetation and chemical and physical processes during warm and humid periods. These climatic conditions do not only cause a grain size reduction due to the physical weathering, but also chemical alterations in the mineral compositions of the sediments as a consequence of various leaching, precipitation and oxidizing processes, e.g. the formation of secondary clay minerals and of Fe (III)-and Mn(III, IV)-oxides. The presence of higher amounts of Fe (III)-oxides is visible by a brown or red coloring of the weathered sediment horizons, Mn(III, IV) –oxides produce a black coloring. Higher abundances of Fe (III)-and Mn (III, IV)-oxides and of clay minerals induce also a higher magnetic susceptibility.

Another result from correlation analysis of the data set is the striking anti correlation of $CaCO_3$ with nearly all other parameters. This is again an effect caused by weathering of the primary loess sediment. $CaCO_3$ is easily leached by water containing H_2Co_3 during pedogenesis. The dissolved calcium carbonate is transported to deeper sediment layers until the partial pressure of CO_2 is lowered and secondary $CaCO_3$ is precipitated, forming the so-called Ca-horizons of soils. These horizons are generally enriched in carbonate compared to the parent loess material, whereas the corresponding paleosoils are depleted in carbonate.

The observed anti correlation of sodium to the clay/sand ratio indicates that a great portion of the Na content is bound to the coarse grain fraction (sand) of the sediment. This is confirmed by further analysis which showed that the sodium content of the sediment samples is correlated to the sand content and anti correlated to the silt concentrations. Therefore it may be presumed that sand and silt do not originate from the same location,

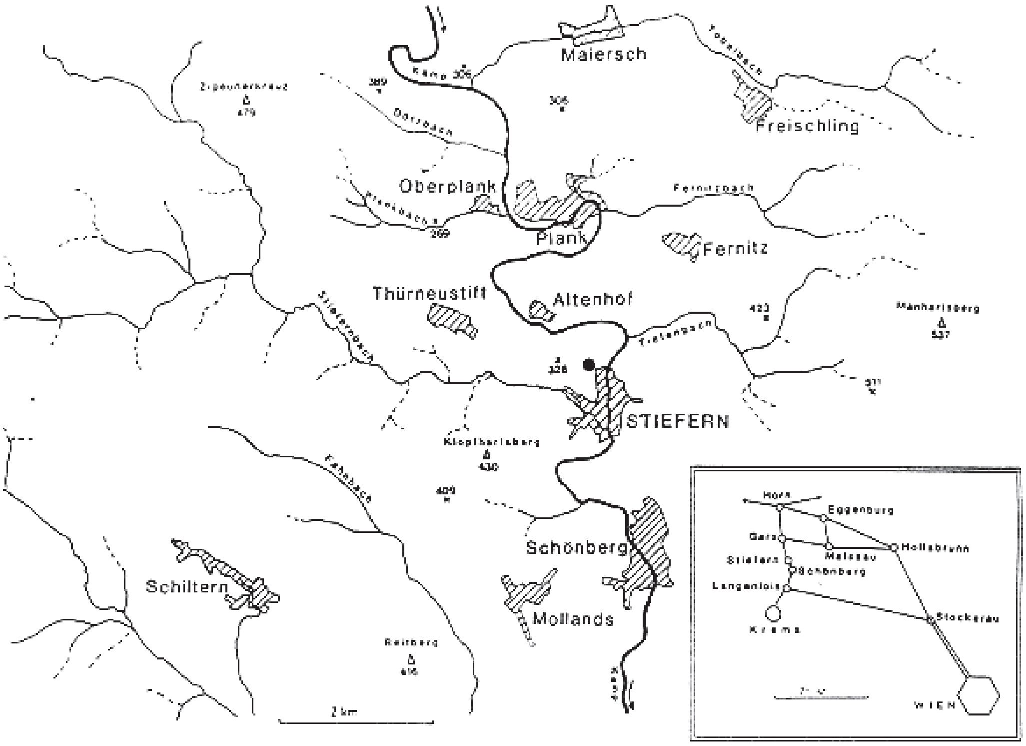

Fig. -1: Map of the vally of the river Kamp. The location of the loess profile is indicated by a dot (Ï%) near the village Stiefern. The insert displays a road map of the region from Krems to Vienna.

Table - 1: Multiparameter data bse for the 44 sample from the sifefern profile. Errors are standard deviations

Sample number	U (ppm)	Th (ppm)	Na (%)	K (%)	Mn (%)	Magnetic Suscept.	Clay/silt (%)	Clay/sand (%)	$CaCO_3$ (%)
1	3.202 ± 0.087	16.165 ± 0.174	1.205 ± 0.0318	1.630 ± 0.013	0.809 ± 0.063	9.3840	0.374	0.681	22.5
2	3.311 ± 0.088	15.372 ± 0.175	1.122 ± 0.0319	1.599 ± 0.013	0.712 ± 0.063	7.7139	0.286	0.356	25.4
3	3.805 ± 0.090	16.463 ± 0.179	1.206 ± 0.0324	1.664 ± 0.013	0.723 ± 0.059	8.2793	0.281	0.699	21.6
4	3.901 ± 0.089	16.559 ± 0.177	1.262 ± 0.0195	1.710 ± 0.013	0.806 ± 0.069	9.6162	0.327	0.825	18.3
5	4.153 ± 0.089	16.699 ± 0.178	1.206 ± 0.0266	1.609 ± 0.013	0.790 ± 0.067	10.622	0.355	0.859	16.2
6	4.054 ± 0.108	17.397 ± 0.183	1.183 ± 0.0293	1.625 ± 0.013	1.027 ± 0.069	19.7064	0.713	1.383	11.2
7	3.635 ± 0.090	17.881 ± 0.181	1.081 ± 0.0252	1.621 ± 0.013	1.020 ± 0.055	20.5021	0.716	0.968	6.6
8	3.984 ± 0.087	17.687 ± 0.174	1.078 ± 0.0199	1.693 ± 0.012	1.060 ± 0.078	21.8206	0.674	1.580	2.9
9	3.316 ± 0.087	16.621 ± 0.173	0.990 ± 0.0280	1.646 ± 0.016	0.974 ± 0.065	21.6140	0.642	1.374	4.1
10	4.010 ± 0.088	17.197 ± 0.175	0.954 ± 0.0396	1.652 ± 0.012	0.940 ± 0.073	19.5748	0.706	2.066	10.4
11	2.992 ± 0.089	14.355 ± 0.175	0.705 ± 0.0265	1.449 ± 0.012	0.735 ± 0.058	12.7705	0.618	1.195	21.2
12	2.595 ± 0.088	11.907 ± 0.172	0.599 ± 0.303	1.335 ± 0.012	0.478 ± 0.068	3.8673	0.467	2.348	36.0
13	3.156 ± 0.090	13.024 ± 0.174	0.649 ± 0.0215	1.448 ± 0.012	0.498 ± 0.063	3.8673	0.467	2.348	36.0
14	3.670 ± 0.089	18.228 ± .0178	0.887 ± 0.0220	1.925 ± 0.013	0.656 ± 0.063	5.2975	0.303	0.953	16.1
15	3.623 ± 0.090	16.117 ± 0.177	1.051 ± 0.0438	1.794 ± 0.018	0.766 ± 0.055	6.8305	0.455	1.386	16.9
16	3.964 ± 0.091	16.530 ± 0.179	0.957 ± 0.0311	1.904 ± 0.013	0.692 ± 0.065	5.9117	0.346	0.906	17.1
17	3.645 ± 0.127	17.011 ± 0.252	0.988 ± 0.0280	1.890 ± .018	0.715 ± 0.071	5.8872	0.299	0.816	13.2
18	3.576 ± 0.089	18.621 ± 0.180	1.311 ± 0.0257	2.233 ± 0.013	0.762 ± 0.059	5.7836	0.403	0.443	9.1
19	4.228 ± 0.090	19.957 ± 0.182	1.222 ± 0.0345	2.128 ± 0.013	0.741 ± 0.067	6.0942	0.292	0.446	12.1
20	5.091 ± 0.772	13.812 ± 1.330	1.310 ± 0.0191	1.914 ± 0.161	0.817 ± 0.069	8.6470	0.264	0.779	11.2
21	4.430 ± 0.740	14.723 ± 1.270	1.250 ± .0260	1.683 ± 0.154	0.886 ± 0.067	14.3498	0.606	0.918	13.7
22	3.357 ± 0.717	17.489 ± 1.234	1.214 ± 0.0466	1.666 ± 0.149	0.867 ± 0.069	14.3785	0.541	0.706	17.5
23	2.884 ± 0.697	16.780 ±1.192	1.418 ± 0.0278	1.660 ± 0.145	0.951 ± 0.074	19.3168	0.667	0.954	3.9
24	3.179 ± 0.083	14.402 ± 0.164	1.324 ± 0.0392	1.474 ± 0.011	0.888 ± 0.072	15.8129	0.696	0.755	13.5
25	2.664 ± 0.084	11.908 ± 0.164	1.201 ± 0.0372	1.333 ± 0.012	0.757 ± 0.072	13.5804	0.705	0.863	23.4
26	3.508 ± 0.087	12.946 ± 0.171	1.306 ± 0.0430	1.460 ± 0.012	0.792 ± 0.074	11.8896	0.536	0.362	19.8
27	3.296 ± 0.086	14.527 ± 0.170	1.257 ± 0.0372	1.570 ± 0.012	0.740 ± 0.058	10.7792	0.569	0.537	12.7
28	4.466 ± 0.772	13.845 ± 1.343	1.249 ± 0.0341	1.8710 ± 0.161	0.810 ± 0.054	8.2152	0.497	0.469	19.1
29	3.380 ± 0.125	15.518 ± 0.247	1.462 ± 0.0401	1.948 ± 0.018	0.867 ± 0.075	10.4848	0.456	0.441	6.4
30	3.241 ± 0.085	16.627 ± 0.0170	1.409 ± 0.0250	1.978 ± 0.012	0.810 ± 0.071	9.7694	0.538	0.495	7.1

Table - 1 continues

31	3.843 ± 0.708	14.454 ± 1.209	1.323 ± 0.0391	1.844 ± 0.148	0.832 ± 0.061	9.9413	0.510	0.582	9.0
32	3.154 ± 0.085	17.500 ± 0.170	1.317 ± 0.0235	1.990 ± 0.012	0.788 ± 0.057	9.8322	0.489	0.574	7.5
33	3.956 ± 0.114	20.838 ± 0.221	1.110 ± 0.0306	1.846 ± 0.012	0.799 ± 0.060	10.8586	0.612	0.789	11.8
34	3.370 ± .084	19.750 ± 0.172	1.176 ± 0.0266	2.088 ± 0.012	0.845 ± 0.070	9.6851	0.656	0.593	5.4
35	4.553 ± 0.097	23.310 ± 0.172	1.247 ± 0.0360	1.676 ± 0.012	0.953 ± 0.065	14.0675	0.451	0.597	12.9
36	3.550 ± 0.082	18.412 ± 0.165	1.192 ± 0.0256	1.626 ± 0.014	0.927 ± 0.061	14.5216	0.535	0.817	13.9
37	3.948 ± 0.089	22.336 ± 0.182	1.218 ± 0.0439	1.681 ± 0.019	1.118 ± 0.066	20.7001	0.899	0.994	9.4
38	4.143 ± 0.0702	15.308 ± 1.196	1.261 ± 0.0405	1.634 ± 0.146	0.977 ± 0.079	22.8424	1.081	0.563	6.6
39	3.488 ± 0.085	18.935 ± 0.173	1.296 ± 0.0310	1.798 ± 0.012	1.3420 ± 0.053	22.3202	1.066	0.892	7.1
40	5.392 ± 0.769	15.720 ±1.323	1.369 ± 0.0283	1.850 ± 0.160	1.141 ± 0.080	23.9935	0.866	0.679	3.7
41	3.685 ± 0.695	16.154 ± 1.185	1.465 ± 0.0214	1.633 ± 0.144	1.074 ± 0.067	25.8743	0.955	0.600	3.7
42	3.580 ± 0.720	17.230 ± 1.240	1.547 ± 0.0253	2.127 ± 0.151	0.949 ± 0.059	12.2617	0.582	0.476	3.5
43	4.069 ± 0.100	21.892 ± 0.210	1.561 ± 0.0461	2.128 ± 0.011	0.890 ± 0.072	11.5767	0.712	0.548	1.2
44	4.475 ± 0.741	19.778 ± 1.278	1.568 ± 0.0368	1.720 ± 0.154	1.049 ± 0.071	19.6960	1.048	1.005	0.0

1) in relative units

Table - 2: Correlation matrix of the complete data set

	U	Th	Mn	Suscept.	K	Na	Clay/silt	Clay/sand	$CaCO_3$
U	1.0000	0.3020	0.3706	0.2146	0.3416	0.3150	0.0779	-0.2002	-0.3674
Th	0.3020	1.0000	0.4300	0.1966	0.4975	0.2791	0.1624	-0.2155	-0.5263
Mn	0.3706	0.4300	1.0000	0.8768	0.0916	0.5335	0.7352	-0.1882	-0.7360
Suscept.	0.2146	0.1966	0.8768	1.0000	-0.2537	0.3193	0.8360	0.0455	-0.5913
K	0.3416	0.4975	0.0916	-0.2537	1.0000	0.4266	-0.1934	-0.4703	-0.5420
Na	0.3150	0.2791	0.5335	0.3193	0.4266	1.0000	0.2875	-0.7174	-0.6725
clay/silt	0.0779	0.1624	0.7352	0.8360	-0.1935	0.2875	1.0000	0.0937	-0.4934
clay/sand	-0.20002	-0.2155	-0.1882	0.0455	-0.4703	-0.7174	0.0937	1.000	0.3901
$CaCO_3$	-0.3674	-0.5263	-0.7360	-0.5913	-0.5420	-0.6725	-0.4934	0.3901	1.0000

but have been transported over different distances according to their grain size differences and the wind velocity. One possible speculation is that the source of the sand fraction in the sediment is in the vicinity of the deposit, e.g. the sand bars of the river Kamp, whereas the silt material might be the more far-travelled matter. Its origin is perhaps the alluvium of the river Danube, which has a different chemical composition. (A consequence of this speculation would be that the sodium content and the sand and silt concentration in the sediment stand proxy for the wind velocity.)

The results of the correlation analysis, especially the three weathering indicators, i.e. the Mn-concentration, the magnetic susceptibility and the clay/silt ratio were used for the distinction of loess and soil horizons in the Stiefern loess profile. Fig.2 shows the standardized (deviations from the mean value in units of the standard deviation) records of these parameters. Soil formations identified with standard sedimentological methods alone are marked in an additional curve indicating loess samples by the value 1, whereas for paleosoils the index 3 and for weak pedogenic

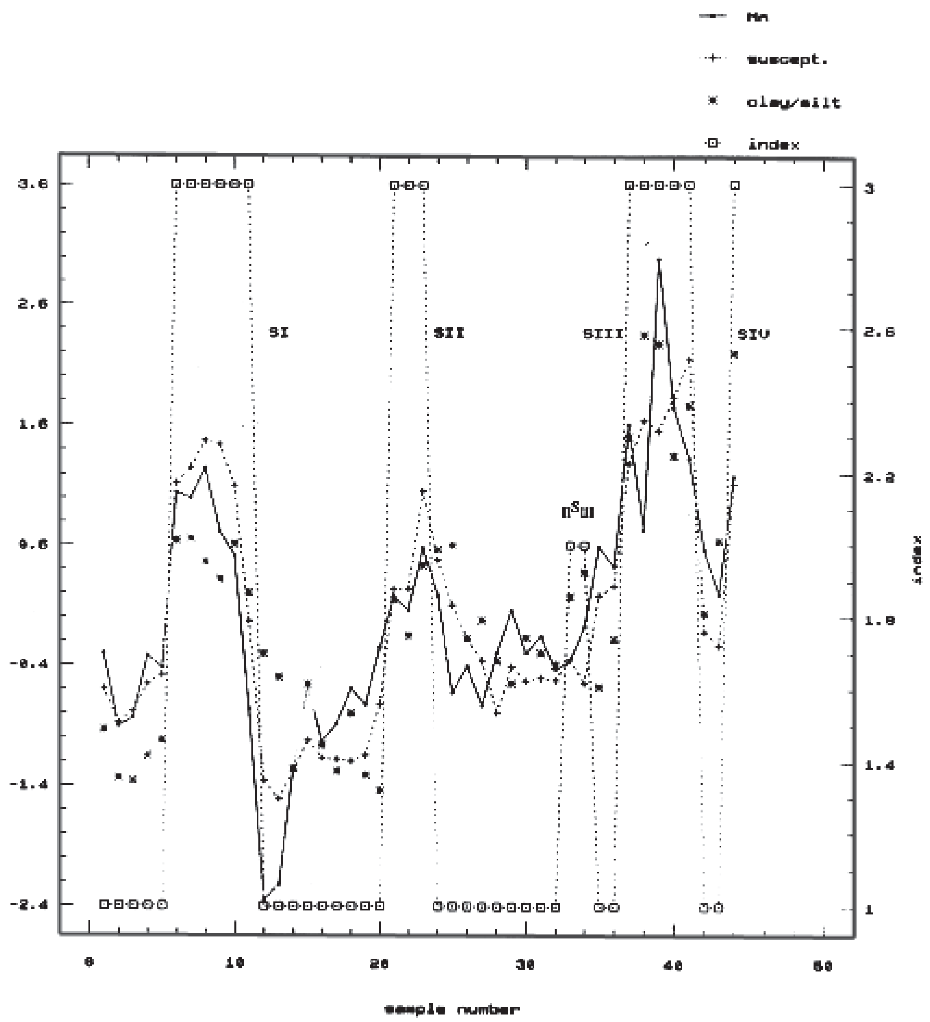

Fig.2.: Standardized records of the manganese content, the magnetic susceptibility and the clay to silt ratio of the stiefern loess profile (44 samples) together with the index chosen for the classification of the sediment (see text). The identified paleosoils are markby by SI to SIV and the weak pedogenic formation by ${}_{II}S_{III}$.

formations the index 2 was chosen. It is evident that the maxima of all three parameters are concordant with soil formation for the first two paleosoils SI and SII. The pedogenic horizon represent by samples 33-35 shows a peak in the clay/silt ratio. This horizon was classified as a paleosoil by standard methods (Rehberger 1988). The records of the two other parameters do not exhibit maxima in this region of the profile. Therefore the original characterization (Rehberger 1988) was revised and the horizon is now identified as a weak pedogenic formation $_{II}s_{III}$ (indicated also in Fig.2), reflecting favorable climatic conditions but not sufficient for the full development of a soil horizon. Relative maxima of the three variables were determined at samples 37-41 and the pedogenic horizon identified as third paleosoil SIII. The course of the $CaCO_3$ record in this horizon does not exhibit the typical shape of soil layers, i. e. a lack of carbonate in the soil core and an associated Ca-horizon under the paleosoil. From this part of the profile to its bottom the $CaCO_3$ content decreases continually to almost zero. This effect may be due to leaching of the $CaCO_3$ by ground water.

The last sediment sample 44 from the profile shows also high values in the three weathering indicating parameters and was identified as part of a paleosoil (SIV). Because of technical difficulties the lower edge of this soil was not accessible during the survey of the profile.

The origin of the susceptibility signal in aeolian sediments has been discussed by various authors. Kukla *et al*. (1988) postulated an inverse proportionality between the magnetic susceptibility and the sedimentation rate of loess and paleosoil sequences caused by a fluctuating dilution of a constant magnetic mineral flux with non-magnetic bulk loess components. The source of the magnetic minerals is left open in this model, which was the base of a time scale for the loess sequences. It was shown that the susceptibility records from China are almost parallel with the oxygen-isotope records of the deep sea sediments (Kukla *et al*, 1988). Begét and Hawkins (1989) in their study of loess deposits in central Alaska stated that the variations in the magnetic susceptibility records reflect the changes in the wind velocity-more far traveled loess is depleted in magnetic minerals relative to the susceptibility of loess deposits near to the dust source. The striking difference to the Chinese loess and paleosoil sequences is that the paleosoils of Alaska are characterized by a lower susceptibility than the loess sediments.

Zhou *et al.* (1990) compared the magnetic susceptibility of paleosoils and of recent soil formations. They found that the magnetic minerals in soils are partially formed during pedogenesis and concluded that a time scale based on a relative simple magnetic influx model is inadequate. According to the high correlation of the susceptibility time scale with the deep sea chronology Kukla *et al*. 1990 in their work on Chinese Loess concluded that, although pedogenic formation of magnetite takes place, the largest part of the susceptibility variations are due to fine magnetite of high altitude atmospheric provenience.

However Beer *et al*. (1993) recently proved the in situ production of the main fraction of the susceptibility signal from soils by comparing of the ^{10}Be flux with the magnetic susceptibility flux in a Chinese loess profile. It could be demonstrated that up to 80% of the susceptibility signal (during θ ^{18}O isotope stage 5) originates from pedogenic production during warm and humid climatic conditions, whereas the pedogenic fraction is almost zero in loess layers.

The investigations summarized above indicate significant regional differences in the susceptibility records presumably due to different climatic influences, which may be extracted in studying loess deposits from various areas.

The results of the present study - the determined correlation of the weathering markers in the sediments- are also an indication for the in situ formation of the magnetic minerals. In the Stiefern profile the investigated paleosoils are B_t-horizons, which are characterized by an enrichment of clay minerals dislocated from the corresponding A-horizon of the soil. A-horizons are normally not preserved in loess deposits from this area. As described above the susceptibility is highly correlated to the fine grain mineral fraction, which in the case of the soil horizons also includes the secondary built clay minerals. Therefore it can be presumed that at least part of the magnetic minerals must be generated during pedogenesis and the susceptibility record displays both, the primary wind transported magnetic minerals and the secondary pedogenic fraction.

Conclusion

The results of the presented investigation of the Stiefern loess profile show the capability for a better quantitative characterization of paleosoils than with standard sedimentological methods alone. Catt (1988) in his work on paleosoils and the climatic ranking of interglacials referred to the lack of quantitative information concerning processes of soil development in loess under different climatic régimes. We hope that the multiparameter analysis presented - the combined information of standard sedimentological methods and of the additional physical methods described above - will improve the study of paleosoils in order to reveal the climatic conditions during their genesis. This might be of interest for a comparison of the regional climatic history and of local climatic conditions with global aspects of the paleoclimate. In addition the multiparameter analysis of the loess profile described here seems to offer the possibility of very precise relative dating. As discussed by Leitner-Wild, Aref-Azar & Hille (1993) this may be achieved by extracting principle components from the data set, which can be matched with orbital parameters of the Earth, especially with the obliquity.

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