Mineralogy and geochemistry of loess-soil sequences in Northern Iran

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Introduction

In Northern Iran, loess deposits, up to 80 m thick, are found along a pronounced climatic gradient from the semi-deserts of the Turkmen steppe (annual precipitation r < 250 mm) towards the subhumid foothill zone of the Alborz mountains (r = ~600-800 mm). The climatic gradient has a strong influence on the horizon differentiation, clay content, organic matter and clay mineralogical composition of modern loess soils (Khormali et al., in preparation), and different kinds of loess palaeosols (Kehl et al. 2006; Frechen et al., 2009) also suggest differential degrees of soil formation and weathering in the past. These are closely linked to past climatic conditions, if other factors of pedogenesis were constant. In that case, the palaeosols could be defined as climaphytomorphic (e.g., Bronger et al., 1998) and would represent excellent archives of past climate change.

For palaeoclimatic reconstructions based on palaeosol types and weathering degrees, the lithologic homogeneity of the parent materials must be tested. So far, little information has been published on the mineralogical and geochemical compositions of loess deposits in northern Iran (e.g., Ohkravi & Amini, 2002; Karimi et al., 2008). We therefore characterised the mineralogical and geochemical composition of the three loess key sections at Neka, Now Deh and Agh Band (Kehl et al., 2006).

Methods

The palaeosols selected range from weakly developed steppe soils, represented by CBk, Ah or Bwk horizons to strongly developed forest soils (Bht, Bt horizons). Based on pedostratigraphic reasoning and luminescence age estimates (Frechen et al. 2009) and correlation with other geo-archives of past climate change (Kehl 2009), these palaeosols can be correlated with interstadial or interglacial phases. 38 Samples of the different palaeosol horizons and corresponding parental loesses were analysed including the mineralogical composition of the carbonate-free silt and clay fractions by X-ray diffraction. Bulk samples were also analysed for their calcium carbonate equivalent (volumetric method), gypsum percentage (extraction with ethanol), and contents of major and minor elements (X-ray fluorescence) as well as free (Fe_d) and total (Fe_t) iron (ICP-OES).

Results

The grain size distribution (Kehl et al., 2006) and the mineralogical and geochemical composition of northern Iranian loess deposits closely resemble those of typical European or Central Asian loesses. Carbonate contents of unweathered (primary) loess layers range from

8-20 %. Loess of Agh Band section is comparatively coarse-grained and contains elevated gypsum percentages, up to 12 % high.

The mineral assemblage of the lime-free sand+silt fraction is dominated by quartz (33-47 %) and plagioclase (19-27 %), with minor proportions of K-feldspar (6-11 %), illite/muscovite (7-20 %) and chlorite (6-13 %). In addition, hornblende (< 5 %) and rutile and anatase (1 %) were found. The ratio of quartz/plagioclase (Qu/Plag) ranges from 1.2 to 2.5. There is a slight tendency of reduced absolute plagioclase contents in strongly developed Bt horizons, compared to parental loess or other soil horizons. Overall, the relative proportions of minerals and the Qu/Plag ratio do not exhibit consistent differences between loess and/or paleosol layers. The comparatively low variation in quartz percentages by weight suggests a petrologic homogeneity of the soil horizons and parental loesses.

The coarse clay fraction is mainly composed of illite (55-75 %) and primary chlorite or vermiculite (10-45 %), the latter occurring only in samples of the Neka section. Smectite and kaolinite often occur in traces and attain maximum amounts of 10 % and 20 %, respectively. The absolute amounts of illite and chlorite/vermiculite are in general higher in the soil horizons than in the corresponding parental loesses. The fine clay fraction (<0.2 µm) is mainly composed of illites (35-75 %), smectite and/or mixed-layer expandable clay minerals (Sm/ML, 15-40 %) as well as chlorite and/or vermiculite (Chl/V; 10-25 %). Kaolinite occurs in traces. In the fine clay, Sm/ML are relatively enriched probably as a result of both, pedogenetic clay formation and enrichment of fine clay by clay illuviation. Absolute amounts of clay minerals increase considerably in well-developed Bw(t) and Bt horizons compared to the parental loesses. In these soil horizons, Sm/ML values rise in a sequence from Agh Band over Neka to Now Deh. This indicates that under the climatic (semi-arid) conditions of Now Deh, smectite formation and illuviation was favored.

The major elements SiO_2, Al_2O_3 and CaO are found in high concentrations, while the contents of Fe_2O_3, MgO, Na_2O and K_2O are moderate, and those of MnO, TiO_2, P_2O_5 and SO_3 are low on average (Table 42). The large variation of the CaO content (y) is explained mainly by the $CaCO_3$ equivalents (x) of the samples, which result from different primary carbonate contents of loesses and from differential carbonate leaching and secondary carbonate enrichment. The two variables exhibit a strong positive correlation ($y = 0.064x + 1.51$; $r^2 = 0.996$, $n = 38$) and the SiO_2 contents decrease with increasing CaO contents.

A comparison of the geochemical composition of the parental loesses shows that the highest average SiO_2 contents are found in loess from the section at Agh Band, which also shows slightly higher SiO_2/Al_2O_3, SiO_2/Fe_2O_3 and Na_2O/Al_2O_3 ratios than loesses at Neka and Now Deh. These differences are related to larger proportions of quartz and higher concentrations of soluble salts such as NaCl at Agh Band. In addition, the SO_3 concentrations are significantly higher at Agh Band, owing to high gypsum contents. The K_2O/Al_2O_3 ratio does not show significant differences between the loesses and ranges from 0.16 and 0.20 for all samples, including those taken from soil horizons. Most minor elements are slightly to strongly enriched in palaeosol horizons compared to the parental loesses, except for La and Sr, showing an indifferent reaction or a strong depletion, respectively.

Free iron (Fe_d) is enriched in palaeosols compared to parental loesses. The enrichment was largest at Neka section, and considerably less at Agh Band and Now Deh. In addition, the Bt and Bw(t) horizons gave, except for one soil, consistently higher absolute enrichments than Bwk or CBk horizons.

Overall, the mineralogical composition and geochemical data suggest that the weathering intensity even of the most strongly developed soils is still limited. Differences between the soil horizons are mainly due to different degrees of carbonate leaching and loss in major and minor elements, such as sodium, magnesium and strontium. A near-neutral pH in decalcified horizons of modern soils underlines a still initial stage of mineral weathering, which probably applies also to all palaeo-Bt horizons even before partial recalcification from the overlying loess.

Conclusions

The parental loesses are mineralogically and geochemically more or less homogenous. Differences in the mineralogical composition of palaeosols are small, whereas the geochemical composition shows differential degrees of weak to moderate weathering which indicate different climatic conditions during interglacials and interstadials of the Quaternary in Northern Iran. The differential degree of pedogenesis during the last interglacial suggests a similar soil climosequence like the one at the present land surface.

High-resolution studies of granulometry, rock magnetics, stable isotopes and luminescence age estimates may identify more fluctuations in edaphic moisture of the past. The Northern Iranian loess-soil sequences are excellent archives of Quaternary climate change and landscape evolution in this ecologically diverse area.

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