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Loess-soil sequence at Toshan (Northern Iran): Insights into late Pleistocene climate change

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ABSTRACT

The knowledge of palaeoclimate in Iran is still limited. However, insight into the timing and the dynamics of Quaternary climate change in Iran might offer valuable information to improve the global palaeoclimate record. The loess-soil sequence of Toshan provides the first high-resolution record of late Pleistocene climate dynamics in Iran and complements the hitherto known sections at Neka, Now Deh and Agh Band to establish a pedostratigraphic record of the north-eastern Caspian Lowland. Our spectroscopic and grain-size analysis are combined to propose (i) a pedostratigraphical scheme for the sequence at Toshan, (ii) describe and estimate the degree of soil development of selected stratigraphical units, (iii) infer palaeoclimatic information, and provide (iv) a correlation with previous loess-palaeosol records of N-Iran as based on pedostratigraphic assumptions. The section at Toshan hosts a strongly developed reddish-brown argillic palaeosol (Bt) as well as eight moderately to weakly developed brownish palaeosol horizons lacking clay illuviation features (Bw/Bwk). These remnants of fossil soils are separated by finely textured loess and horizons that host characteristics of both loess and mineral subsoils (CB/CBk), giving evidence for syngenetic soil formation. The stratigraphical succession of palaeosols, loess and syngenetically altered sediments, covering the last ca. 130 ka, gives evidence for recurrent climate changes as well as fluctuations between dominance of soil formation or dust accumulation in relation to changes in moisture regime. The formation of Bt and Bw/Bwk-horizons is related to relatively humid and warm conditions likely corresponding with interglacial and interstadial climate.

1. Introduction

Loess deposits constitute a sensitive terrestrial archive, as their formation involves processes governed by climate such as the production and deflation of (mainly) silt-sized particles, their aeolian transport and deposition as well as syn- and post-depositional alterations (e.g. Pécsi, 1990; Kemp, 2001; Smalley et al., 2005). Traditionally the accumulation of dust forming loess is thought to occur mainly during cold and arid intervals of glacial periods (stadials) (Kemp, 2001). In contrast climatic conditions during interglacials and interstadials are characterized by higher average temperature and precipitation, which promoted the growth of vegetation, the intensity of chemical weathering and pedogenesis. Hence, under relatively stable geomorphodynamic conditions, soils formed on the dust covered landscapes of the past. Their burial under new layers of dust resulted in vertical successions of loess layers and intercalated palaeosols often preserved as remnants of the original soil. The kind and intensity of soil forming processes are mainly driven by climatic and soil-environmental conditions.

According to Jenny (1941), soil-formation is a function of climate, organic activity, relief, parent material and time, which is expressed by, e.g. the function S = f(climate [cl],organic matter [o],relief [r],parent material [p]). Though afflicted with restrictions, palaeoclimatic inferences can be drawn from comparison of palaeosols with the modern (Holocene) soil, forming under known

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climatic conditions (Kehl, 2010). In order to study the effect of climate on soil formation other factors of pedogenesis than climate have to be kept constant (Khormali and Kehl, 2011). Kemp (2001) states that the differentiation of a climatic influence from other soil-forming factors within the “clorpt”-concept of Jenny (1941) is subject to problems. A differentiation is justified if the modern Holocene soil has derived from a substrate (=pt) in a comparative geomorphic position (=r), with a similar granulometric and mineralogical composition like the parent material of the intercalated palaeosols (Kehl et al., 2005; Kehl, 2010). Hence, if the factors “r” and “pt” are constant the function of Jenny (1941) can be simplified to S = f(cl,o), and soils can be defined as climatophytomorphic (Bronger et al., 1994, 1998).

Within the Eurasian loess belt, most scientific attention has been attributed to loess-soil sequences of south-eastern (SE) Europe and Central Asia (e.g. Frechen and Dodonov 1998; Mestdagh et al., 1999; Machalett et al., 2008; Markovic et al., 2008; Antoine et al., 2009; Buggle et al., 2009; Markovic et al., 2009), while comparatively little information is available about respective terrestrial archives in Iran (Kehl et al., 2005; Frechen et al., 2009). However, additional analysis of northern Iranian loess-soil sequences may play a crucial role in correlating European and Central Asian findings, and thus closing this spatio-temporal gap. Therefore, an elaborate and well understood pedostratigraphy of north-eastern (NE) Iran is necessary, consisting of several loess-soil sequences. The loess-soil sequence at Toshan completes the pedostratigraphic record of the Caspian Lowland (NE Iran) and is described in detail below.

Within the glacial intervals of the Quaternary, northern Iran represented an extensive depositional environment for windblown dust and loess formation (Frechen et al., 2009), covering particularly the northern foot slopes of the Alborz Mountains. Descriptions of the hitherto known loess-soil sequences of the Caspian Lowland were provided by Kehl et al. (2005), Frechen et al. (2009), and Kehl (2010) while modern soils formed on loess were described by Khormali and Kehl (2011) and Khormali et al. (2012). The profiles Neka, Now Deh and Agh Band are located along a climatic gradient, ranging from subhumid conditions in the west near Neka to semiarid conditions towards the north and north-east at Agh Band (Fig. 1). The profiles represent a climosequence including climatophytomorphic modern soils which show differential degrees of soil formation, as expressed by their respective morphology, clay mineralogy and their physicochemical properties corresponding to decreasing humidity from W to E (Khormali and Kehl, 2011). Moreover Kehl et al. (2005) and Kehl (2010) identified differences in grain size distribution and thickness of loess layers, as well as the amount and type of palaeosols along this transect. The profile at Agh Band hosts a moderately developed Bw(t) horizon, whilst a strongly developed Bt horizon and strongly developed AhBtk horizons were found in Now Deh and the section at Neka, respectively (Kehl et al., 2005; Kehl, 2010). According to IRSL-age estimates of Frechen et al. (2009), these soils are covered by thick deposits of last glacial loess and probably formed during the last interglacial period. Their different degrees of development suggest an increased soil development during the last interglacial from Agh Band to Neka, whereas dust accumulation rates during the last glacial experienced the opposite trend (Kehl et al., 2005).

The recently studied climosequence of loess and soil sequences is now supplemented by detailed loess-soil investigations for the section at Toshan, located near the City of Gorgan. In this paper, we give the first lithological and pedological descriptions of the sequence, including preliminary results of micromorphology, high resolution records of grain-size distribution, color and the $CaCO_3$ content. The aim of this study is to propose (i) a pedostratigraphical scheme for the sequence, (ii) describe and estimate the degree of soil formation of selected stratigraphical units, (iii) compare Toshan section with previously published loess-soil sequences in Northern Iran, the loess profiles at Remisowka, Kazakhstan (Machalett et al., 2008) and Tagidjar, Tajikistan (Mestdagh et al., 1999), as well as pollen records from Lake Urmia, Iran (Djamali et al., 2008) and Lake Van, Turkey (Litt et al., 2014), and (iv) infer palaeoclimatic information from the sequence at Toshan. The chronological framework of the sequence as based on a luminescence dating study is discussed by Lauer et al. (in press).

2. Study area

In NE Iran near Gorgan, the loess deposits of the Caspian Lowland form smooth hills covering the northward facing slopes of the Alborz mountain range (Fig. 1). The landscape is dissected by the River Gorgan and its tributaries, draining the Alborz Mountains. The geological basement consists mainly of Paleozoic and Mesozoic limestone. Loess serves as raw material for brick production and is intensively quarried. Thus local geomorphology is shaped by the interaction of anthropogenic and natural processes. The loess-soil sequence of Toshan (N 36°49′01″/E 54°25′25″) is located on a watershed position in a quarry south-west of the City of Gorgan, 145 m above sea level. In this area, the loess deposits attain

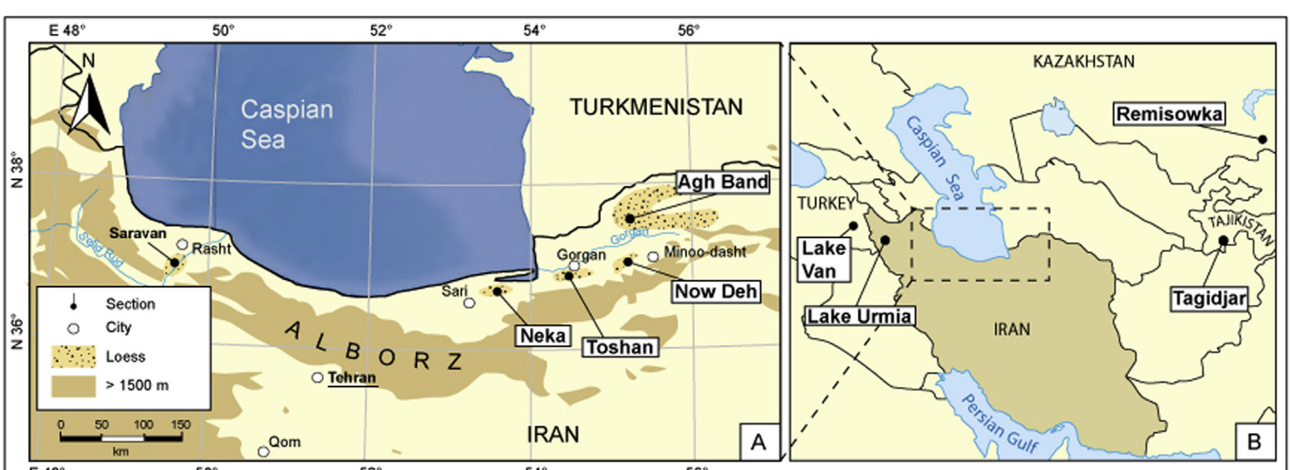

Fig. 1. A: Northern Iran with locations of loess-soil sequences studied by Kehl (2010). The section at Toshan is located within the suburban zone of Gorgan City. B: Central Asia with locations of Lake Van (Litt et al., 2014), Lake Urmia (Djamali et al., 2008) and loess-palaeosol sequences of Remisowka (Machalett et al., 2008) and Tagidjar (Mestdagh et al., 1999).