**Micromorphology of the Lower Pleistocene Loess in the Iranian Loess Plateau and its
paleoclimatic implications**

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Abstract: The loess deposits in Iran are a valuable archive of regional paleoclimatic and paleoenvironmental information. Extensive sedimentological and chronological studies have been carried out on the middle to upper Pleistocene loess successions during the past decades, but there is an absence of comparable research in the older loess deposits. Recently, a 19-m-thick loess-paleosol sequence was discovered in the central Iranian Loess Plateau (ILP), which was paleomagnetically-dated to ~2.4-1.8 Ma and thus represents by far the oldest loess known in northern Iran. Here, we present the results of a detailed micromorphological investigation of these lower Pleistocene loess-paleosol sequences (“red sequence”) from the ILP. Our main findings are as follows: 1) The Agh Band red sequence deposits are an extremely thick soil complex comprising paleosols in different stages of development; 2) the micromorphological index of soil development (MISECA) suggests that the moderately- and well-developed paleosols in the red sequence formed in an environment with mean annual precipitation ranging from around 450 to 650 mm, respectively; and 3) MISECA suggests that the red sequence formed under a semi-arid to sub-humid climate and thus under wetter and more favorable conditions than the overlying late Pleistocene loess and modern soils.

Key words: micromorphology, paleoclimate, loess, Lower Pleistocene, Iran

1. Introduction

Eolian deposits are a valuable archive of regional paleoclimatic and paleoenvironmental information, as evidenced by the Late Pleistocene loess deposits in Iran and elsewhere (Kehl et al., 2005, Frechen et al., 2009). Large areas of northern and northeastern Iran are covered by loess deposits, which are part of the Eurasian loess belt extending from northwest Europe to the Middle East, Central Asia and China (Frechen and Dodonov, 1998, Machalet et al., 2008). During Pleistocene cold stages, northern Iran consisted of a vast area characterized by increased dust accumulation and loess deposition (Pashaei, 1997; Frechen et al., 2009).

During the past decade, last interglacial/glacial loess-paleosol sequences and modern soils derived from loess have been studied in detail at several key sections along the Caspian Lowland. Kehl et al. (2005) studied three loess-paleosol sequences recording a significant climatic change from dry cool to moist warm during the Late and Middle Pleistocene period. Khormali and Kehl (2011) described the morphology, physicochemical properties, micromorphology and clay mineralogy of modern soils derived from loess in Northern Iran and made a comparison with the paleosols described previously. Lauer et al. (2015) applied optically-stimulated luminescence dating of a loess-paleosol succession, and the results of spectroscopic and grain-size analyses of the deposits were used by Vlamincx et al. (2015) to reconstruct paleoclimatic changes.

Locally, loess–paleosol sequences in Northern Iran are underlain by reddish deposits known as the Lower Pleistocene Loess (LPL); however, the mechanism of formation of these red deposits has received almost no attention. The red-colored deposits are most likely significantly older than the loess deposits described in previous studies. Sedimentological evidence suggests that these widespread red-colored sediments are of eolian origin, and the results of

paleomagnetic dating indicate that they accumulated between ~2.4 and 1.8 Ma (Wang et al., 2016). However, the pedogenic features and potential paleoclimatic record of the lower Pleistocene loess in northern Iran remain poorly understood.

Paleosols consist of soils formed under climatic conditions different from the present day (Ruhe, 1965, Yaalon, 1971), and their physical properties are used as an indicator for reconstructing past weathering and climate conditions (Retallack, 1990; Ayoubi, et al., 2006). Micromorphological analysis is an important technique for determining whether or not a particular pedogenic feature reflects a paleosol or diagenetically-transformed sediments (Kemp, 1998; 1999). More recently, micromorphological studies of paleosols have been used to reconstruct past climate and soil-forming conditions (e.g. Khormali et al., 2003; Khademi et al., 2003; Ayoubi et al., 2006; Rellini et al., 2009; Kehl, 2010; Dar et al., 2015b).

Khormali et al. (2003) established a Micromorphological Index of Soil Evolution in highly Calcareous arid to semiarid Conditions (MISECA), in which various micropedological features including the microstructure, b-fabric, and the presence of clay coatings, decalcified zones and Fe/Mn oxides, as well as the degree of alteration of mineral grains were used as criteria to reflect the degree of soil development and thus past climatic conditions and/or the duration of pedogenic processes. Each feature was quantified by the application of a simple grading system that represents the degree of pedogenic evolution, and the sum of the ratings for each horizon gives the value of the index. The MISECA index ranges from 0 to 24 with increasing grade of soil development.

A correlation between the MISECA index and soil properties was recognized along a precipitation gradient in northern Iran (Ghergherechi et al., 2009; Khormali et al., 2012). Shahriari et al. (2015b) studied three loess-paleosol sequences (the Agh Band, Mobarak Abad

and Neka sections) along a climosequence in Mazandaran and Golestan provinces, in northern Iran to investigate the utility of the MISECA index in paleopedological studies. They concluded that the MISECA index clearly resolve pedological changes in different horizons of the studied sequences, and they also found a good correlation between the MISECA index and the amount of precipitation, suggesting its potential usefulness and applicability for paleoclimatic reconstruction.

No previous systematic study of the depositional processes and paleoenvironmental conditions of the ILP has been performed to date. Thus the objectives of the present study are: (1) To conduct a micromorphological investigation to find out the presence of paleosols in the red deposits; to study the degree of paleosol development; and (3) to reconstruct the paleoclimate using micromorphological characteristics.

2. Regional setting

The study was carried out at a section exposed in a limestone quarry located near the village of Agh Band in Eastern Golestan Province, northern Iran (latitude 37.688889° N and longitude 55.158333° E). The sequence underlies an Upper Pleistocene Loess-paleosol (UPL) sequence and covers the Pliocene limestone of the Akchagyl Formation (Fig. 1). The Akchagyl Formation mainly consists of marl and mudstone with thicknesses ranging from 3 m to more than 100 m in the Kopet Dagh sedimentary basin (Forte and Cowgill, 2013).

Fig. 1

The present-day climate of the study area is semi-arid, with mean annual precipitation and temperature of ca. 300 mm and 17°C, respectively. The soil moisture regime is Xeric-Aridic and the temperature regime is Thermic (SWRI — Soil and Water Research Institute of Iran, 2000; USDA, 2014).

3. Materials and methods

3.1. Field descriptions and sampling

The Agh Band LPL has a thickness of 19 m in the quarry under study. In a field campaign in autumn 2014 the morphological characteristics of the section were recorded. Based on field observations, the sequence has been subdivided into 24 units, designated consecutively as U1-U24 from the top of limestone to the bottom of the UPL (Fig. 1). From each unit, representative undisturbed samples for micromorphological analysis and additional bulk samples were taken for laboratory analysis.

3.2. Laboratory analyses

3.2.1. Physico-chemical analyses

After air drying and crushing the samples and sieving using a 2-mm mesh, the soil physico-chemical properties were investigated. Soil pH was measured in a 1:2.5 soil: water suspension using a Digital Conductivity Meter-CC 601 (Jackson, 1975). Organic carbon was determined by wet oxidation with chromic acid and back titration with ferrous ammonium sulfate (Nelson and Sommers, 1982). Equivalent calcium carbonate (CCE) was measured using a titration method (HCl 1M) (Sparks et al., 1996) in the soil science laboratory of Gorgan University of Agricultural Sciences and Natural Resources of Iran.

3.2.2. Mineralogical analyses

The mineralogy of 24 bulk samples was determined by XRD of powdered samples using a Bruker D8 ADVANCE X-ray diffractometer. No chemical pre-treatment was used.

3.2.3 Micromorphological analyses

According to standard techniques described by Murphy (1986), 24 oriented clods were air-dried, impregnated under vacuum with resin, cut into slices, mounted on microscope slides, cut to about 500 μm thickness with a diamond-edged saw, and polished to a thickness of around 25 μm . The final size of the thin sections was approximately 5 cm $\times$ 7 cm. Micromorphological descriptions were done in plane polarised and crossed polarised light (PPL, XPL) using a polarizing microscope and the definitions based on Bullock et al. (1985) and Stoops (2003). The interpretation of micromorphological features followed the standards discussed in Stoops et al. (2010).

4. Results and discussion

4.1. Physico-chemical properties

The amount of equivalent calcium carbonate (CCE) in the section varies from 0 to 16.3 % and the pH varies from 7.15 to 8.9. The average organic matter content is 0.36 % (Table 1).

Table 1

According to Wang et al. (this issue) the grain-size distribution of the Agh Band LPL section is dominated by fine-grained silts.

4. 2. Morphological properties

The Agh Band LPL sequence was subdivided into 24 units in which two or more pedogenic B horizons can be distinguished in each unit. The boundary between these horizons and the adjacent soil units is often unclear, making their distinction rather difficult. Some of the units are enriched by carbonate nodules (up to 20-cm in diameter) with a horizon thickness of 20 to 90 cm (Fig. 2). The ground mass within most of the carbonate nodule-bearing horizons has a reddish color (5YR) indicating that the soil material is highly weathered. Nevertheless due to the presence of secondary carbonate, in some horizons nodules are cemented together comprising a horizon composed exclusively of nodules, or a petrocalcic horizon. This is in accordance with Ahmad and Chandra (2013) and Dar et al. (2015a) who claimed that loess-paleosol sequences are enriched in pedogenic calcium carbonate and subject to recalcification of secondary calcium carbonate in the form of nodules. The source of the pedogenic calcium carbonate is the leaching of carbonate-rich eolian dust and weathering of Ca-feldspar minerals (Ahmad and Chandra, 2013). Horizons with nodular or massive carbonate enrichment have been observed in Upper Pleistocene loess-paleosol sequences in Iran as well (e.g., Kehl et al. 2005; Vlamincx et al. 2015)

Fig. 2

Carbonate-rich or petrocalcic horizons mainly occur at the base of well-developed horizons, indicating the occurrence of mainly vertical water flow within the upper horizons. Since these carbonate-rich zones only occur in some horizons and not throughout the section, they are very likely of pedogenic origin. Sobecki and Wilding (1983) stated that in arid and semi-arid regions the accumulation of pedogenic calcium carbonate is a prominent pedogenic process, while Gile

et al. (1966) concluded that calcium carbonate-enriched horizons, as a result of pedogenic processes, are often the most prominent feature of these soil-types. Sobecki and Wilding (1983), Gunal and Ransom (2006b) and Feng and Wang (2007) noted that pedogenic calcium carbonate forms under a warm, semi-arid climate and under relatively stable surfaces.

The deposits have been subjected to relatively intensive pedogenesis, as demonstrated by the presence of clay skins and Fe–Mn coatings. According to the morphological investigations, five types of B horizon are recognized, namely Bw, Bt, Btk, Bkk and Bkkm. The Bw, Bkk and Bkkm horizons generally have a relatively weak to moderate angular or sub-angular blocky structure; and the Bt and Btk horizons have a moderate to strong angular or sub-angular blocky structure. Strongly prismatic structures are present in some Bt horizons and these horizons contain few to common clay skins and/or dark Fe/Mn coatings; these are present in the most strongly developed horizons. The best-developed soil horizons of the entire LPL sequence are in units U3, U19, U21 and U23 (Fig. 2). Therefore, based on the morphology and the aforementioned comments on pedogenic processes, it can be concluded that the deposits are a loess-paleosol sequence and that they formed under a semi-arid climate (Mo and Derbyshire, 1991, Yakimenko et. al., 2004).

In general the differentiation of the soil horizons is unclear, since the pedogenic A horizon, and the underlying parent material, the C horizon, are usually absent and only the B horizons are easily recognizable in the field. The lack of A horizons in paleosols may be attributed to later erosion or post-burial mineralization of organic matter.

A complete A–B–C sequence is only recognized in some of the paleosols in the overlying UPL. Kehl et al. (2005) and Shahriari et al. (2015a) studied two loess-paleosol sequences at the town of Neka, located on the loess-covered northern footslopes of Alborz Mountains and identified A-B-C horizons in the sections. In a pedological sense, the entire LPL sequence can be

regarded as a thick soil complex. This means that whenever the LPL was affected by pedogenic processes, atmospheric dust was slowly deposited on the soil surface, and therefore the B horizons are accretionary. Similar paleosols are found within the Plio–Pleistocene loess-paleosol sequence of China (Liu, 1985; Kukla and An, 1989; Ding et al. 1998).

The section is mainly characterized by alternations of reddish-yellow (10 YR 6/6) loess layers and brownish-red (7.5 YR 3/6) to reddish (5YR) paleosols. In general, the color of the soil horizons in the red deposits is much redder than that in the overlying UPL (7.5YR vs. 10YR, respectively) (Fig. 1), and this is one of the principal differences between the LPL and the overlying UPL.

4. 3. Micromorphological observations

For each unit a set of key micromorphological features, including the c/f-related distribution, microstructure, voids, b-fabric and pedofeatures consisting of clay coatings, the presence or absence of calcium carbonate, the degree of alteration , and Fe/Mn oxides, were determined (Table 2).

Table 2

The microstructure generally varies from weakly-separated sub-angular (angular) blocky in the soils with a lower degree of development (units U15 and U17), to well-separated sub-angular (angular) blocky (units U1, U3, U18, U20, U21) (Fig. 3). Based on Fanning and Fanning (1989), a well-separated sub-angular blocky structure can be attributed to shrink-well properties, and this is very similar to the microstructure of the paleosols in the UPL (Khormali and Kehl, 2011). In

addition, the existence of a prismatic microstructure in unit U19 demonstrates that this unit is more developed than the others - based solely on microstructure (Table 2).

Fig. 3

The observed voids consist of channels, chambers, planes and vughs with random distribution. Voids in almost all units are dominated by planes which are attributed to shrink and swell forces created by alternating wetting and drying (Kemp, 1985) (Table 2). Channels and chambers are related to biological activity such as growth and penetration of roots into the soils, and faunal activity (Kooistra, 1978, Zarate et al., 2000, Kemp et al., 2004). The occurrence of these kinds of voids reflects the soil-forming conditions (Fig. 3). Khormali et al. (2012) claimed that the voids were affected by major pedogenic processes consisting of clay illuviation and the accumulation of secondary calcite. Furthermore, they suggested that the only types of void which increase in abundance with depth are planar voids.

The c/f-related distribution is open porphyric in all units and the dominant b-fabric of the units is speckled and partly calcitic crystallitic. A crystallitic b-fabric can be seen in units with a higher amount of calcium carbonate (Fig. 4). In units U6, U7 and U10 an undifferentiated b-fabric was recognized, which can be attributed to the impregnation of the groundmass by Fe oxides (Fitzpatrick, 1993) (Table 2). Kemp et al. (2004) reported a speckled b-fabric in the paleosols of Northwest Argentina. Moreover, the b-fabric of the LPL is the same as that of the paleosols of the UPL studied by Khormali and Kehl (2011).

Fig. 4

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241 Various types of calcitic pedofeatures are recognized in these soils, in the form of calcite
242 nodules, infillings, impregnations, hypocoatings, coatings and thin cemented layers (Fig. 4),
243 which occur in units listed in Table (2). Kemp et al. (1996) demonstrated that infillings, coatings
244 and hypocoatings of secondary carbonates around channels or irregular segregations result from
245 secondary carbonate reprecipitation leached from overlying zones, and according to Khormali et
246 al. (2003) and Khormali and Ajami (2011) calcite coatings, hypocoatings and infilling along
247 voids can be attributed to later recalcification processes.

248 Clay pedofeatures were identified, mainly as clay coatings with a yellowish color and
249 speckled limpidity. Clay coatings which result in the formation of an argillic horizon formation
250 demonstrate the process of translocation and subsequent accumulation of clay as a result of water
251 percolation (Brewer, 1976; McKeague, 1983; Fedoroff et al., 1990). The source of silicate clay
252 in paleosols is the parent material and/or the in situ weathering of minerals and clay
253 neoformation (Dar et al. 2015a). Shiny surfaces in the field, identified as clay coatings, were
254 observed in most of the units, but in thin sections the more pronounced clay coatings occur only
255 in units U1, U3, U18, U21 and U23 (Fig. 5).

256 In argillic horizons the principal factor responsible for the lower amount or lack of clay
257 coatings is disruption by swelling and shrinking in soils with high clay content (Mermut and
258 Jongerius, 1980; Verheye and Stoops, 1973; Kemp and Zarate, 2000). Based on the findings of
259 Khormali et al. (2012) an udic soil moisture regime and mesic soil temperature regime, which
260 generates a speckled b-fabric, are the best conditions for forming clay coatings. Gunal and
261 Ransom (2006a) noted an increase of the abundance and thickness of clay coatings with mean
262 annual precipitation in loess soils of Kansas and Kademi and Mermut (2003) and Khormali et al.

(2003) stated that the argillic horizons with clay coatings in arid and semi-arid regions of Central and Southern Iran developed under moister conditions than the present day. Therefore, the best-developed and preserved clay coatings are seen in the units listed above, occurring in voids (Fig. 5). They are the result of the higher soil moisture, weaker shrink and swell properties, and their better preservation.

Fig. 5

The micromorphological observations of Dar et al. (2015a) indicate that the accumulation of pedogenic calcium carbonate and clay illuviation are the dominant processes in loess–paleosol profiles; and Pal et al. (2003) concluded that the processes of pedogenic calcium carbonate precipitation and clay illuviation occur simultaneously in a semi-arid climate.

One of the most characteristic pedofeatures is calcite depletion zones. Decalcified zones exhibit a speckled b-fabric in a groundmass otherwise dominated by a crystallitic b-fabric. Depletion pedofeatures vary from extensive in units U17 and U22 to very few or non-existent in units U4, U5, U8, U13, U14, U19, U21, U23 and U24 (Fig. 4).

Various forms of Fe/Mn pedofeatures are present in all of the units, the most notable being coatings, quasiccoatings, hypo-coatings, nodules and impregnative pedofeatures (Table 2, Fig. 4, 5). Their presence demonstrates that all of the units have been periodically saturated (McCarthy et al., 1998). Dar et al. (2015a) claimed that the existence of iron concretions in thin sections of paleosols suggest wet conditions that resulted in the collapse of the soil structure. The presence of gypsum crystals in some of the well-developed units is recognized as infillings and coatings.

All of the above-mentioned features confirm the occurrence of pedogenic processes in the LPL sequence and therefore that the units are paleosols. This is also confirmed by comparison of the micromorphological observations of the UPL presented in Khormali and Kehl (2011), since there is a high degree of similarity between them (especially between the LPL and the paleosols of the UPL).

4.4. Mineralogical properties

The X-ray diffraction patterns indicate that the typical mineral composition of the Agh Band LPL samples includes quartz, feldspar, calcite, mica and other clay minerals. Quartz is the dominant mineral and clay mineral peaks are not recognizable due to the high intensity peaks of other minerals. The quartz/feldspar (plagioclase) ratio, as an indicator of the intensity of chemical weathering, was calculated for each unit of the LPL section based on peak height intensities. According to this ratio, the most strongly weathered or developed unit is U19, while U22 has the lowest ratio (Table 2). A decreased intensity of the feldspar peak in U22, compared to U19, as well as the absence of a calcite peak, can be attributed to the weathering of feldspar and the more intense leaching of calcite under a wetter climate.

There is a good correlation between the quartz/feldspar ratio and the MISECA index (Fig. 6), and therefore it can be concluded that for the LPL both parameters can be used as an indicator of the degree of chemical weathering related to climatic conditions.

Fig. 6

4. 5. Degree of soil development and paleoclimate

Based on the MISECA index the studied units are categorized into moderately- and strongly-developed soils (Table 2). The MISECA values range from 10 in unit U17 to 18 in units U19, U21 and U23. Therefore, units U18, U19, U21 and U23 are well-developed and the others are classified as moderately-developed. This is in a good agreement with field observations, since the soils in U18, U19, U21 and U23 units were noted as being significantly more developed than the other units, on the basis of their much more reddish color, and more abundant and thicker clay skins. It is noteworthy that based on MISECA all of the units are moderate to highly developed soils.

With an increasing degree of soil development (as demonstrated by the MISECA index), the soil structure progresses from massive to blocky-prismatic (Kemp and Zarate, 2000). In addition the soil b-fabric progresses from crystallitic to speckled, as observed by Gunal and Ransom (2006a) in soils from Kansas. Our observations are in accordance with these conclusions.

Khormali et al. (2012) concluded that the degree of the soil development as indicated by the MISECA index is strongly related to the climatic gradient and exhibits a significant increasing trend with increasing rainfall and decreasing temperature. Thus, well-developed soils are mainly formed in the more humid areas of the climatic gradient. In addition, according to the significant correlation between the MISECA index and the amount of rainfall, as suggested by Shahriari et al. (2015b), strongly- and moderately-developed paleosols are formed under an annual precipitation of ~650 mm and ~450 mm, respectively (Fig. 7). As a result, based on the amount of rainfall during the interval of soil formation in the upper loess-paleosol sequence (400 mm) (Shahriari et al., 2015b) and current precipitation (300 mm), it can be concluded that the climate

at the time of Agh Band LPL formation varied from semi-arid to sub-humid and the precipitation was greater than during the formation of the overlying loess and the modern soils.

Fig. 7

5. Conclusions

We have conducted the first detailed macro- and micromorphological study of the red deposits of the Lower Pleistocene Loess (LPL) deposits in Iran. The following conclusions can be drawn:

- (1) The micromorphological approach applied here reveals that, due to pedological changes which are clearly observed in thin sections, the red-colored deposits in the Iranian Loess Plateau are an extremely thick soil complex comprising paleosols in different stages of development. Furthermore, some of the morphological properties (such as color, structure, clay skins and Fe/Mn coatings) confirm the degree of soil development and the presence of paleosols.
- (2) According to the MISECA index, the degree of development of the paleosols ranges from moderately developed to strongly developed.

The annual precipitation during the formation of the reddish-colored moderately-developed and well-developed paleosols in the Lower Pleistocene Loess in northern Iran, based on the MISECA index, is suggested to range from around 450 mm to 650 mm, respectively. Thus, the red sequence formed under a semi-arid to sub-humid climate with wetter and more favorable conditions compared with both that of the Upper Pleistocene Loess and the present day.

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Figure captions

Fig. 1 Golestan Province in northern Iran (A); mosaic of satellite images from Google Earth, including the location of the study section (B); stratigraphy and studied units of the Agh Band lower Pleistocene loess section (units U1 to U24) (C).

Fig. 2 Carbonate nodules in Bkk horizons (A); Bw horizon in one of the moderately-developed units (B); strong prismatic, angular blocky structure and dark Fe–Mn coatings in one of the Bt horizons (C, D) of the LPL.

Fig. 3 Well-separated angular blocky microstructure (PPL) in U20 (A); channel (Ch) and chamber (Chm) voids (PPL) in U1 (B).

Fig. 4 Calcitic crystallitic b fabric, calcite coating and quasi Fe/Mn coating (XPL) in U15 (A); crystallitic (Cry), speckled (Sp) b-fabric, Mn nodule (Mn) and thin cemented calcium carbonate layer (Ca-m) (XPL) in U20 (B); calcite hypo-coating in U20 under PPL (C) and XPL indicated by yellow arrows (D); calcite nodule (XPL) in U6 (E).

Fig. 5 Clay coating (XPL) in U18 (A, B); Fe/Mn nodule (PPL) in U20(C); and in U22 (D), indicated by yellow arrows.

602 **Fig. 6** MISECA index versus quartz/feldspar ratio for samples of the Agh Band Lower
603 Pleistocene Loess.

604 **Fig. 7** Estimated paleoprecipitation during the formation of the reddish LPL in northern Iran
605 based on the significant correlation between MISECA index and the amount of rainfall, as
606 observed by Shahriari et al. (2015b).

607

Strata (m)

Legend

Upper Pleis. Loess

Lower Pleis. Loess

Paleosol

Carbonate Horizon

Limestone

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

Fig.7

Table 1. Some properties of the Agh Band Lower Pleistocene Loess

UNIT	U1	U2	U3	U4	U5	U6	U7	U8	U9	U10	U11	U12	U13	U14	U15	U16	U17	U18	U19	U20	U21	U22	U23	U24
CCE	14	1.5	11.4	5	15	13.1	14.2	14.1	14	15.4	16	16	15.4	16.1	8.6	16.1	16	0.8	2.1	2.3	16	1.5	2.1	12.8
OM	0.61	0.81	0.13	0.47	0.54	0.42	0.39	0.41	0.42	0.47	0.34	0.34	0.37	0.41	0.27	0.34	0.13	0.20	0.31	0.32	0.27	0.23	0.34	0.07
pH	8.9	8.3	8.39	8.39	8.3	7.37	7.5	7.2	7.3	7.41	8.4	8.1	7.53	7.33	8.59	8.3	8.4	8.2	7.7	7.51	7.97	7.15	7.76	7.84

Table 2. Micromorphological description, degree of soil development and quartz/feldspar ratio of the Agh Band Lower Pleistocene Loess

Unit	C,F related	Microstructure	Voids	b-fabric	Pedofeature	Clay coating	Decalcified zone (%)	Alteration degree	Fe,Mn oxides	MISECA	Degree of soil development	Q/F Ratio
U1	Por	Well sep sbk	Ch-Cm-Pl	Spk	Fe, Mn hypo coating	Few	>90	2	Few	16	moderately developed	2.4
U2	Por	Well sep sbk	Ch-Cm-pl	Spk=cry	Fe, Mn hypo coating-calcite nodules	--	50	1	Few	10.2	moderately developed	1.8
U3	Por	Mod sep abk	Ch-Cm-Pl	spk (70%)-cry(30%)	carbonate coating-calcite sparite	Few	70	2	Few	15.5	moderately developed	2.8
U4	Por	Mod sep abk	Pl	Spk	carbonate coating, infilling	-	>90	1	Few	13	moderately developed	2
U5	Por	Mod sep abk	Pl	Spk	calcite nodules-carbonate coating, hypo coating, diffuse	-	>90	1	very few	12	moderately developed	1.8
U6	Por	Mod sep abk=sbk	Pl	spk (70%)-cry(30%)	calcite nodules	-	70	2	common	12.5	moderately developed	1.9
U7	Por	Mod sep abk	Pl	Und= spk		-	>90	2	common	12.5	moderately developed	1.9
U8	Por	Mod sep sbk	Pl	Spk	carbonate infilling	-	>90	2	Few	14	moderately developed	2.3
U9	Por	Well sep sbk	Pl	Spk=cry		-	50	2	Few	11.2	moderately developed	2.2
U10	Por	Well sep sbk	Ch-Cm-Pl	und= cry	calcite nodules, carbonate coating	-	>90	2	Few	11.5	moderately developed	1.5
U11	Por	Well sep sbk	Pl	spk(80%)-cry(20%)	calcite nodules, carbonate infilling	-	80	2	common	13.6	moderately developed	2.1
U12	Por	Well sep sbk<vu	Pl-Vu	Spk=cry	carbonate hypo coating, Fe impregnative	-	50	2	Few	10.2	moderately developed	2
U13	Por	Wea sep sbk<vu		Spk		-	>90	2	Few	13	moderately developed	2
U14	Por	Mod sep sbk>vughy	Vu	Spk	calcite nodules with impregnating	-	>90	2	common	13.5	moderately developed	1.8
U15	Por	Wea sep sbk<vu	Ch-Cm	Spk=cry	Fe coating, Fe, carbonate hypo coating	-	50	1	Few	12	moderately developed	1.8
U16	Por	Well sep sbk	Pl	Spk=cry	calcite nodules	-	50	1	Few	10.2	moderately developed	1.2
U17	Por	Wea sep sbk<vu	Pl	Cry		-	-	1	very few	10	moderately developed	2.5
U18	Por	Well sep sbk	Pl-Vu	spk(70%)-cry(40%)	calcite nodules	Few	70	2	Few	17	well developed	2.8
U19	Por	Well sep abk>pr	Pl	Spk		-	>90		Few	18	well developed	3.3
U20	Por	Well sep abk=sbk	Pl	Spk=cry	Calcite, Fe nodules, carbonate coating, hypo coating, carbonate impregnative	-	50	2	Few	11.2	moderately developed	2
U21	Por	Mod sep abk=sbk	Pl	Spk	carbonate coating	Few	>90	2	Few	18	well developed	18
U22	Por	Vu	Pl	Cry	Fe nodules, Fe impregnative, carbonate coating, infilling	-	-	2	Few	12	moderately developed	12
U23	Por	Well sep abk	Pl	Spk	Fe hypo coating	Few	>90	2	Few	18	well developed	2.7
U24	Por	Well sep sbk	Pl-Vu	Spk	carbonate coating	-	>90	2	common	14	moderately developed	2.5

por: porphyritic; Mod: moderately; wea: weakly; sep: separated; abk: angular blocky; sbk: sub angular blocky; pr: prismatic; vu: vughy microstructure or vugh void; ch: channel; cm: chamber; pl: plane; spk: speckled; cry: crystallitic; und: undifferentiated