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ARTICLE

Loess soil distribution and properties in Mongolia

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Abstract: Loess and loess-like soil formations are distributed in 3 regions across Mongolia. The lower part of the Orkhon and Selenge river basin in North Mongolia is the main loess area and another two are located in east Mongolia, in the Onon and Ulz river basins and the Khalka Gol river area. Loess-like soil covers a total of 109,000 sq.km or 6.95 per cent of the territory of the country. Loess soil properties have been studied on the basis of 8 sections and 83 samples. Fine sand fraction is predominant in the loess granulometric composition and its mean value is 51.3 per cent, and silt content mean value is about 34.9 per cent. A typical loess is a non-stony silt or fine sand, but there are also gravel loess. The average stone gravel content in the loess sediments is 8.1 per cent, sandy loess doesn't contain any stone, but coarse fragment is high (20.5 per cent) in gravel loess. There is higher sand content (57.0 per cent) in gravel loess as compared to sandy loess (47.4 per cent). Mongolian loess soil average calcium carbonate content is 2.9 per cent, and Organic Matter (0.93 per cent) is higher than Chinese loess (0.41 per cent). Using ^{14}C isotope data analysis and sediment properties we have tried to define the loess stratigraphy. Lower base section of fine sand silty loess sediments or about 1-3 meter thick layers were mostly formed during the mid-Holocene (7.5-3.0 ka) period. Upper parts of silty loess or 1.0-0.7 meter top layers were accumulated in the late Holocene (3ka BP to present) period. Kastanozem topsoil humus horizon (15-30 cm) formation starts at 1.5-1.0 ka BP. Mid-Holocene period probably witnessed the most active loess accumulation with a warm and dry windy condition prevailing. Sandy loess with a thickness of 1-2 meters predominate in Mongolia, and in some places loess thickness reaches up to 20-30 meters.

Keywords: *Loess; loess properties; Mongolia; soil; silt;*

INTRODUCTION

Loess distribution in Mongolia was a problematic issue until recently and there are not many publications on the topic, but the study into and publication of research articles on loess increased after the 1990s. Many scientific data results have confirmed the existence of loess in the Orkhon-Selenge region in northern Mongolia.

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Vol. 62 No 01 (241) 2022
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The first information of loess-like sediment in Mongolia was dated to 1900-1901 by a famous Russian scientist *Obruchev* (1916). In his notes on expeditions to Mongolia, he has described the existence of loess-like porous silty material yellowish and dark brown colors with a mix of some gravels in the west Khentii mountain area [1]. Most researchers write about China loess accumulation, which were windborne from Mongolia [2, 3]. During the geological investigation of Altanbulag area of Selenge aimag in 1980, a Mongolian geologist Khosbayar (2005) found loess sediment in the Khyraan river area [4], who together with Chinese researchers [5] later conducted a detailed investigation of 40 meter thick Shaamar loess section. *Lehmkuhl* (1997) has briefly described loess-like sediments in the mountains of Central Asia, including in Mongolia [6]. In the 1990s, a Mongolian scientist *Dashjamts* (2010) studied loess sediment of north Mongolia with geotechnical properties for the purpose of basement construction [7].

There are few studies about loess related soil properties. Soil scientists are mostly concerned with soil classification, fertility, degradation and conservation issues [8, 9]. Paleo geographical researchers are mostly concerned about loess genesis, properties related to climate change history, Quaternary geology and stratigraphic problems [4,5,10]. The goal of our research is to study the properties of loess and loess-like soil formation, their specific features and distribution in Mongolia. The result of our study is based on 8 loess soil profiles in the lower parts of the Orkhon-Selenge river basins and laboratory analysis data.

MATERIALS AND METHODS

Study area

Loess soil research was carried out in the Orkhon-Tuul river basin in central-north Mongolia. Fieldwork was conducted in 2018-2019 and 8 loess soil sections (Figure 1) were investigated at a depth ranging from 1 to 3 meters. Loess distribution in North Mongolia is characterised by broad river valleys, undulating plains, hillocks and small medium mountain topography. The north-eastern parts border with the Khentii forest taiga mountains massif and the western parts with the Buteel and Buren forested mountain ranges. The average altitude is 800-1200 meters above sea level. Northern Mongolia is forested, while other parts of the country is steppe land and it becomes driers towards the south. Kastanozem soils dominate in the steppe area, and Umbrisols are distributed in the forest areas. Mongolia's climate is continental with long cold winters and short warm summers. Annual average air temperature is -2° to -4°C and the annual rainfall ranges from 200 mm to 300 mm. Yearly amplitude of temperature is high, from +40°C in summer to -40°C in winter [11]. The Orkhon-Tuul region is the most important agriculture and livestock area in Mongolia, and large industrial cities such as Darkhan and Erdenet are located in the Orkhon river basin, while human negative impact is increasing.

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PMAS
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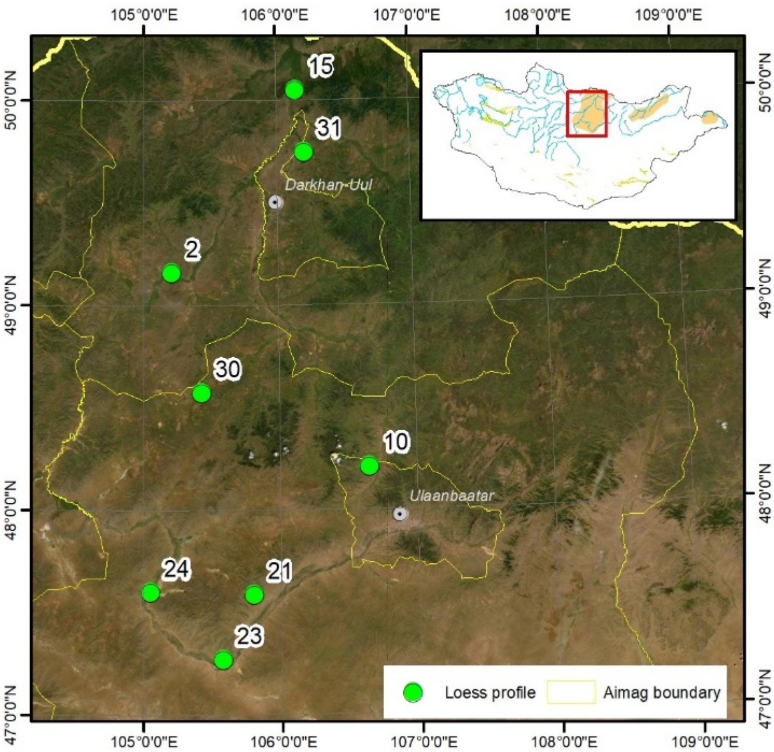

Figure 1. Study area and sampling points

Loess sections

Study sites and loess soil sections are mostly located in the intermountain wide plains and foot slopes in Orkhon-Tuul river basin area (Table 1).

Table 1. Loess section location, description and coordinates

Section No. Location	Description	Longitude, (E)	Latitude, (N)	Elevation meter, a.s.l
15. Selenge aimag Shaamar soum	Eastern part of Orkhon river, 40 meter high terrace, Kastanozem soil. Non-stony sandy loess 40 m.	106º 14’ 49”	50º 04’ 09”	646
31. Selenge aimag, Javkhlant soum	North of Shariin Gol river, undulated plain, Kastanozem soil. Non-stony sandy loess 2 m.	106º 12’ 19”	49º 44’ 42”	687
2. Selenge aimag, Sant soum	North of Orkhon river, terrace, Kastanozem soil. Gravel loess 7 m.	105º 12’ 35"	49º 09’ 38”	730
30. Tuv aimag, Tseel soum	Slightly inclined wide plain. Kastanozem soil. Gravel loess 1 m.	105º 25’ 48”	48º 31’ 23”	1013
10. Tuv aimag, Partisan	Foot slope. Kastanozem soil. Non stony silty loess 4 m.	106º 38’ 59”	48º 07’ 30”	1265
21. Tuv aimag, Khustai	Slightly inclined plain. Kastanozem soil. Non-stony sandy loess 2.5 m.	105º 48’ 00”	47º 35’ 18”	1225
24. Tuv aimag, Undurshireet	North part of Tuul river plain. Kastanozem soil. Gravel loess 2.5 m.	105º 03’ 08”	47º 36’ 02”	1022
23. Tuv aimag, Ulkhiin Bulan	North part of Tuul r River terrace. Kastanozem soil. Gravel loess 4 m.	105º 34’ 17”	47º 16’ 12”	1074

Vol. 62 No 01 (241) 2022
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PMAS
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Laboratory analysis

A total of 83 soil sediment samples were taken from morphologically identical horizons following the MNS3298 standard. Laboratory analysis was done in the Soil Laboratory of the Institute of Geography and Geoecology of the Mongolian Academy of Sciences using standard methods (MNS ISO 114648., MNS 3310). Soil samples were sieved by 2 mm for further laboratory analysis. Organic matter (OM) content was analysed using the Walkley & Black method; pH and electrical conductivity (EC) were measured in 1:2.5 ratio suspensions; calcium carbonate ($CaCO_3$) by volumetric methods; particle (sand (2-0.05 mm), silt (0.05-0.002mm), clay analysis (<0.002mm) fractions) were done usingy hydrometric methods and stone gravel contents smaller than 2 mm in dimension were measured using the gravimetric method.

The 12 soil samples containing organic materials were analysed for (^{14}C isotope) radiocarbon dating using the AMS method. The analysis was conducted at the Center for Collective Use at the Institute of Geography of the Russian Academy Sciences (Laboratory of Radiocarbon Dating and Electron Microscopy) and in the Center for Applied Isotope Study, University of Georgia, USA. The calibration of the ^{14}C-dates was performed using the “CALIB REV7.1.0” programme and the Reimer curve [12]. Laboratory analysis data was processed using SPSS soft and calculated descriptive statistics, independent samples t-test analyses.

RESULTS AND DISCUSSION

Loess distribution

Ten per cent of Earth's land area is covered by loess or similar deposits [13]. Largest loess covered areas, such as the Yellow River basin in China, in Europe and in North Americ, are places where historically human civilisation developed. But in Mongolia, loess distribution was problematic [10] and just recently, more evidence of loess in Mongolia were published. We have specifically identified 3 regions of Mongolia with loess and loess-like soil formations (Figure 2). The Orkhon-Selenge region is the main loess accumulation area of the country, covering an area of 71,100 sq. km. This is the most studied area and several researchers have published studies into loess properties and the genesis [4,5,13,16].

In the Onon-Ulz region, with an area of 26,300 sq. km., there are non-stony loess-like silty sediments with a thickness of 1-2 meters and in some places with a thickness of up to 10 meters. Another loess-like sediment distribution place is the Khalkha Gol River and the Buir lake region in east Mongolia, covering an area of 11,600 sq. km. Loess in the Onon-Ulz and Khalkh Gol river areas have been the least studied, and only soil related publications are available [14,15]. In Mongolia, a total of 109.000 sq. km. area or 6.95 per cent of the territory of the country is covered by loess-like soil covers. This is an approximate estimation of loess area of the country and further detailed investigations will help throw more light on this data.

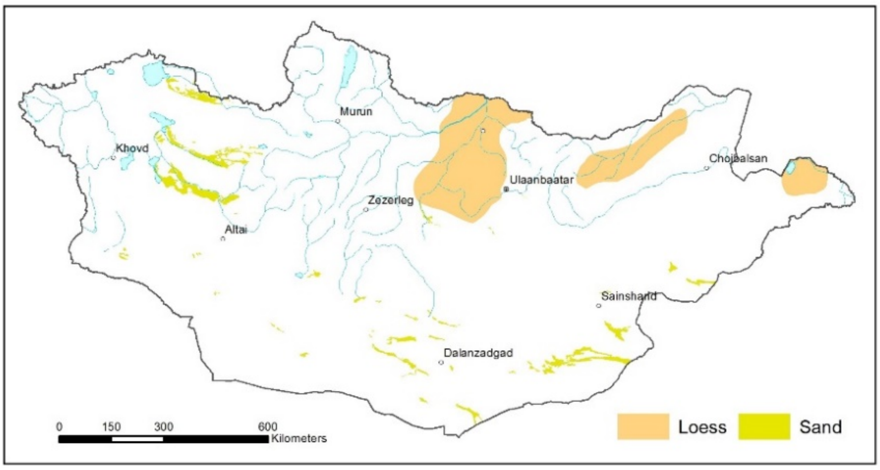

Figure 2. Loess distribution area in Mongolia

Vol. 62 No 01 (241) 2022
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Loess properties

Loess is wind accumulated dust sediment formed on the earth's surface, which is directly connected with soil properties and fertility. According to Pye (1995), four fundamental requirements are necessary for the formation of loess: dust source, adequate wind energy to transport the dust, a suitable accumulation area, and a sufficient amount of time [16].

Loess soil formations are typically non-stony fine sand, porous silt, loose sediment material of yellowish brown colour. An example of loess soil sections is shown in Figure 3. Section-31 Shariin Gol area. There are 7 layers in the Shariin Gol section with a depth of 200 cм, and the entire section does not contain any calcium carbonate ($CaCO_3$) and rock fragment. The upper 0-70 cm of the section has 3 different layers, however, pH (~8.1), EC (~0.08 dS/m), OM (~0.7 %) content, and texture have an approximate value. Below 70 cm, the value of pH, EC, and OM are reduced by a similar pattern. In a layer between 120 and 145 cm, OM and pH increased to 0.35 and 7.96 per cent, and then below 145 cm, both values decreased. Whereas, EC value increased to 0.075 dS/m at the bottom of the section. The texture loamy at the upper and bottom parts of the section, and sand-size particles increased at the middle of the section. The Shariin Gol section is dated as 4741±20 year BP at a depth of 170 cm. C14 analysis at a depth of 60 cm shows 506±20 year BP, which is indicative of recent loess accumulation intensity.

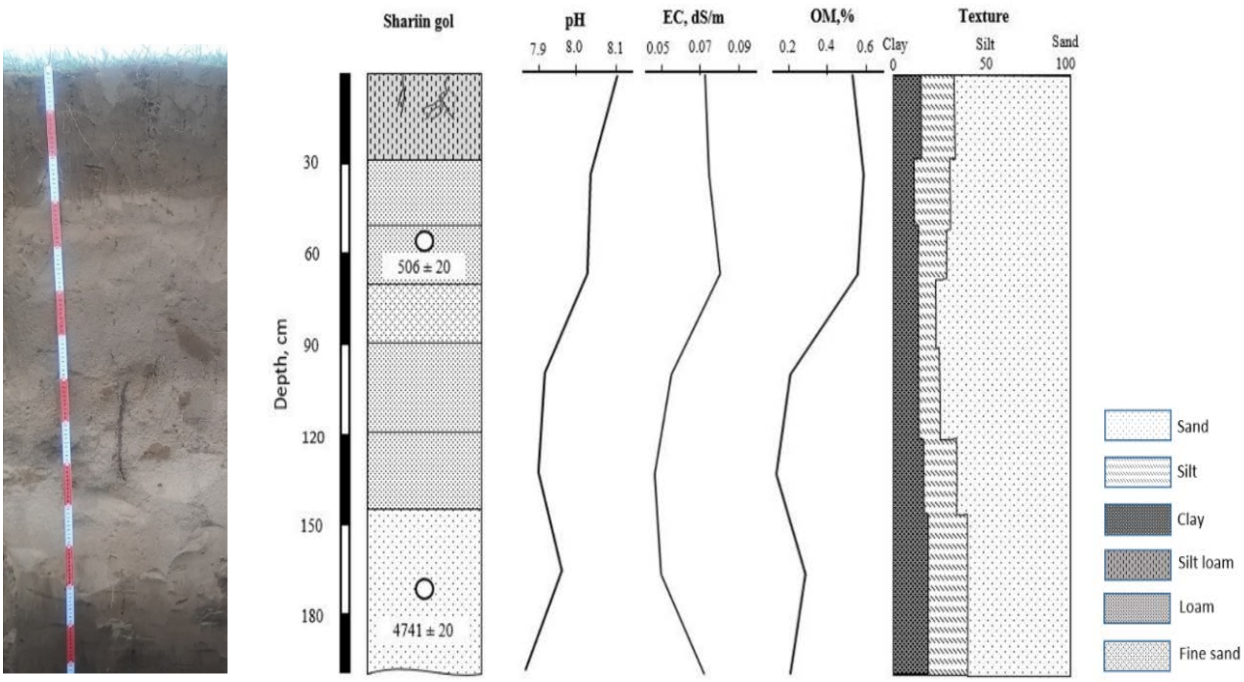

Figure 3. Sandy loess soil profile characteristics in Shariin Gol river area (Section-31)

Loess expert Muhs (2007) pointed out that loess sediment experienced varying degrees of weathering and pedogenesis, soil-forming processes [17]. Loess soil formations in our study area also have the influence of weathering and we distinguished two groups of loess by stone gravel content. One group is non-stony sandy loess and the other is the gravel loess. Typical loess is non-stony silty or fine sandy. Stone gravel loess sediments are mostly distributed in the boundary or edge of loess covered places. Foot slope and river terrace area loess sediments contain some amount of stone gravel as a product of surface erosion and fluvial activity.

PMAS
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Table 2. Statistical analysis of loess soil properties

Variables	Loess (n=83)				Sandy loess (n=50)		Gravel loess (n=33)		F ratio
	Mean	Range	SD	CV	Mean	SD	Mean	SD	
pH	8.2	9.2-7.4	0.3	0	8.1	0.3	8.3	0.3	0.0
$CaCO_3$, (%)	2.9	20-0	4.2	1.5	2.2	2.8	3.9	5.6	5.8*
OM, (%)	0.93	5.0-0.1	0.87	0.9	0.87	0.89	1.01	0.83	0.2
EC, (dS/m)	0.48	3.6-0	0.8	1.7	0.20	0.21	0.89	1.16	80.1***
Sand, (%)	51.2	80-22	14.3	0.3	47.4	11.9	57.0	15.7	3.5*
Silt, (%)	34.9	64-4	14.8	0.4	39.6	12.4	27.8	15.4	2.2
Clay, (%)	13.9	18-8	2.5	0.2	13.0	2.6	15.2	1.7	10.9***
Gravels, (%)	8.1	66-0	15.9	2.0	0.02	0.2	20.5	19.7	143.4***

Significantly different at 0.1, * Significantly different at 0.001*

In granulometric content of loess sediments of Orkhon-Tuul area, there is predominantly sand fraction with a mean value 51.2 per cent, the silt content is about 34.9 per cent, and clay is 13.9 per cent (Table 2).Sand content of gravel loess (57.0 per cent) is higher than in sandy loess (47.4 per cent). For sandy loess, silt content is higher and clay is lower than in gravel loess (Figure 4).

Figure 4. Boxplot of loess types by sand (a) and silt (b) content

Stone gravel content in loess sediments on an average is 8.1 per cent, sandy loess do not contain any stone (0.02 per cent) but the average value of gravel loess coarse fragments is high (20.5 per cent). Loess soil OM mean value is 0.93 per cent, which is lower than the typical steppe Kastanozem soils OM [9,15,16]. But when we compare it with Chinese loess, we found that the Mongolian loess OM is higher [18]. Soil fertility and land values are highest at sites with thicker and siltier loess [19]. Mongolian loess is sandy and the loess silt content is lower than Chinese and European loess, but the OM is higher. OM is an important component of soil fertility, therefore, it is possible to conclude that Mongolian loess soil nutrient properties are not lower than European and Chinese loess soils. Loess soils contain Calcium carbonate ($CaCO_3$) with a mean value 2.9 per cent. Gravel loess calcium carbonate is higher than the sandy loess variant. The mean data values of silty loess and gravel loess properties were compared using independent samples t test analyses. A most highly significant difference (p-0.001) has been the gravel content, electrical conductivity or salinity; clay values also have a highly significant difference.

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Calcium carbonate ($CaCO_3$) mean value difference is lower (p-0.1) while there is not much difference in other properties.

Loess stratigraphy

Loesses in Mongolia are similar to that in Siberia, since they have originated from the mountains and were delivered by several river systems to the northern plains and then transported by wind to the zones between the mountains and plains slightly southward [20]. Loess sediment stratigraphy differed by geography, topography position, inclination, slope, aspect and local erosion specifics. Some sections have well preserved loess accumulation layers, buried soil horizons, but indicator layers are missing in other sections possibly due to erosion or unsuitable conditions for accumulation. We have attempted to describe chronology of loess sections stratigraphy specifics using 7 loess profiles (Figure 5) from North Mongolia. For sediment formation time period assumptions used the results of radiocarbon data analysis (Table 3).

Table 3. Results of radiocarbon dating (AMS dates were measured at Laboratory of Radiocarbon Dating & Electronic Microscopy of the Institute of Geography, RAS and Center for Applied Isotope Studies at University of Georgia, USA)

No.	IG RAS	(cm)	Material	Method	(^{14}C yr BP)	(cal yr BP)
21	6796	230	Sediment	AMS	12450±30	14586±30
23	6797	170	Sediment	AMS	5905±25	6720±25
30	6801	70	Sediment	AMS	2440±20	2475±20
31	6802	70	Sediment	AMS	440±20	506±20
31	6803	200	Sediment	AMS	4200±20	4741±20
10	6804	260	Sediment	AMS	12245±30	14141±30
2	6462	12	Sediment	AMS	1340±20	1284±20
2	6790	120	Sediment	AMS	2880±20	3003±20
2	6791	144	Sediment	AMS	3530±20	3793±20
2	6792	168	Sediment	AMS	4870±25	5606±25
2	6793	204	Sediment	AMS	5865±25	6691±25
2	7069	216	Sediment	AMS	6600±25	7493±25

Late Pleistocene records were documented in Section-21 “Khustai” in paleosol depths 220 cm (14586±20 calBP), and in Section-10 “Mandal” paleosol depths 225 cm (14141±30 calBP). Some researchers have studied loess accumulation in Mongolia pertaining to the late Pleistocene period [5, 10]. Uppermost loess soil formations with a thickness of 1-2 meters mostly occur in the Holocene period. The beginning and the end of the Holocene periods were marked by a wetter climate than its middle part [21]. Abrupt climatic events were recorded in the Gun Nuur lake and the data 2.8, and 7,2 ka BP correspond to the mid-Holocene time interval [22].

In the mid-Holocene (7.5-3.0 ka) period, 1-3 meter thick layers of loess accumulation were formed. In Section-2 “Sant”, Section-31 “Shariin Gol” lower boundary of mid-Holocene period, the accumulation could possibly be deeper. Golubtsov (2017) noticed aridisation of climate, sand and silty loess accumulation process activity In the Selenge River basin area in the mid-Holocene period [23]. Loess accumulation thickness is about 1.0-0.7 meter in the late Holocene (3ka BP to present) period. Dry windy condition and more thick silty material accumulation were presumably predominant in the first half of (3.0-1.5 ka BP) this period.

Vol. 62 No 01 (241) 2022
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Aeolian sediments at around 2.3 ka indicate an increase in open landscape with a decrease in vegetation cover caused by higher aridity [10]. After 1.5-1.0 ka BP, soil forming condition started. According to loess soil sections stratigraphy, Holocene active loess accumulation period was around 7.5–2.0 ka cal BP. Kastanozem topsoil humus layers formation starts at 1.5-1.0 ka BP and the thickness varies from 15 to 30 cm.

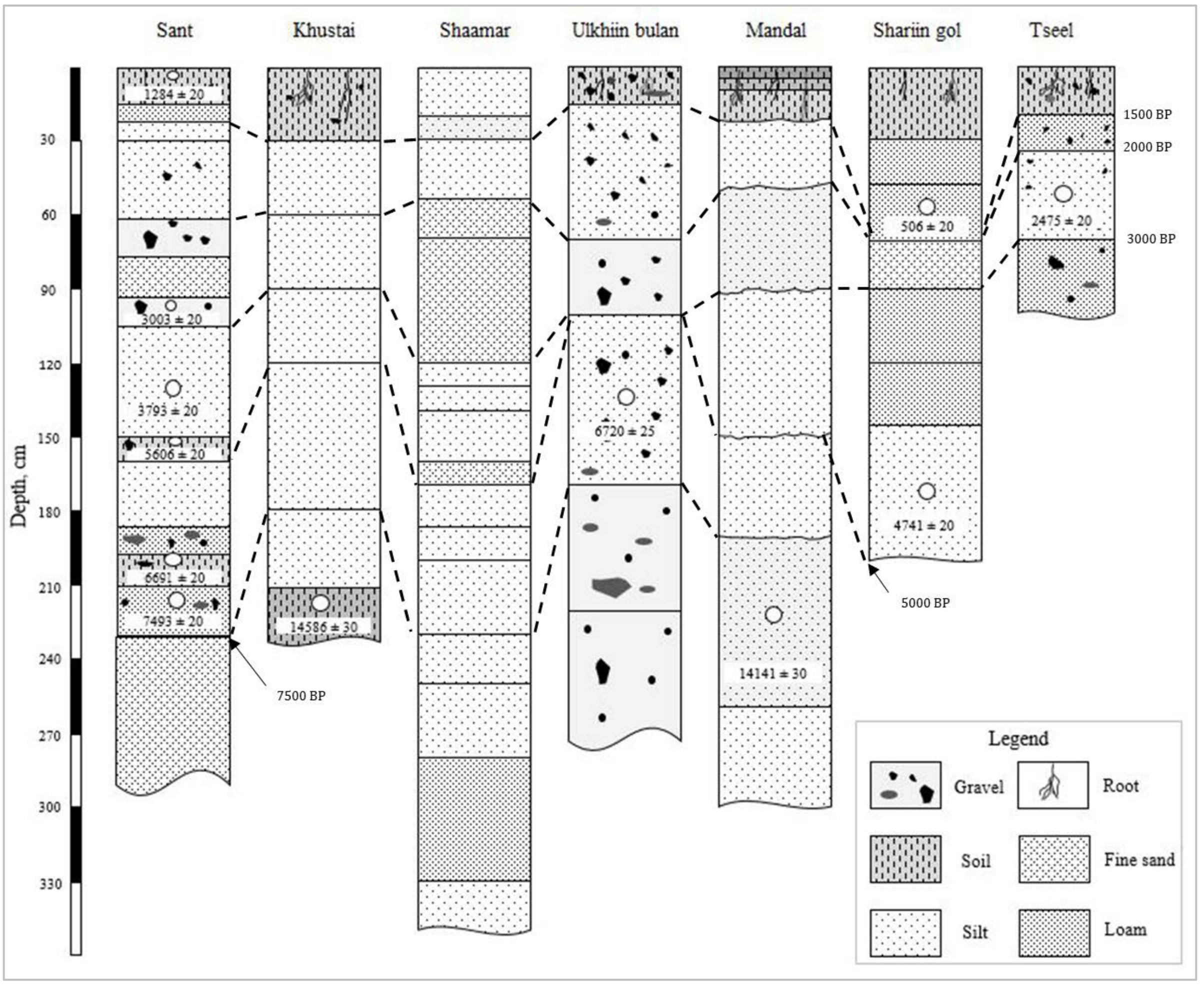

Figure 5. Loess sections stratigraphy and chronology

Windblown fine sand silty material accumulation process is continuing in the entire Holocene period with different intensities, depending on climate conditions. Mid-Holocene period with a prevailing warm dry windy condition was probably a time where loess accumulation was most active. In the late Holocene period, the climate became colder and recent soil development started, and intensification of eolian deposit accumulation was less as compared to the previous period. Mongolian Loess genesis and stratigraphy continue to be complicated and there is a need to carry out more data and detailed investigation.

CONCLUSIONS

In Mongolia, loess and loess-like soil formations are distributed in a wide area, including, in the lower parts of the Orkhon and Selenge River basins, where sandy loess with a thickness of 1-2 meter are predominant, while in some places loess thickness reaches up to 20-30 meters. Sand fraction is dominant in loess granulometric content, with an average values of up to 51.3 per cent, and silt content is less at 34.9 per cent. In terms of stone gravel content, loess soil formations can be divided into two parts: sandy loess and gravel loess.

PMAS
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Typical loess is non-stony silty or fine sandy. Sand content in gravel loess (57.0 per cent) is higher than the sandy loess (47.4 per cent). Average stone gravel content in Loess sediments is 8.1 per cent, sandy loess do not contain any stone, but the average value of gravel loess coarse fragments is high (20.5 per cent). Loess soil means value of organic matter (OM) which is 0.93 per cent, and calcium carbonate 2.9 per cent. Mongolian loess OM is higher than Chinese loess (0.41 per cent). OM is an important component of soil fertility, therefore, it is possible to conclude that Mongolian loess soil nutrient properties are in no lower than the European and Chinese loess soils. Using C14 isotope data analysis, we attempted to define loess stratigraphy. 1-2 meter interval loess layers were formed in the mid-Holocene (7.5-3.0 ka) period In the late Holocene (3ka BP to present) period, the loess accumulation thickness is about 1.0-0.7 meters in the upper most layers. Kastanozem topsoil humus layer (15-30 cm) formation starts at 1.5-1.0 ka BP. Mid-Holocene period was probably a time of the most active loess accumulation with a warm, dry and windy condition prevailing. In the late-Holocene period, the climate become colder and recent soil development began, and intensification of eolian deposit accumulation was less severe than in the previous period.

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