Revista Mexicana de Ciencias Geológicas, v. 21, núm. 1, 2004, p. 48-53

Soils of arid ecosystems of Kalmykia in the late Holocene

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ABSTRACT

Several dark-colored buried paleosols are studied in balkas (valley) in the south of Russia (Kalmykia Republic). The paleosols differ from modern soils by chemical and physical properties that indicate differences in the character of soil-forming processes in the past and in the present. The paleosols are buried under colluvial and eolian deposits, whose intensive accumulation followed the late Holocene climatic optimum (about 1,000 years ago). We hypothesize burial was caused by landscape erosion associated with social developments within this territory. One reason for simultaneous burial of soils within the large study area probably was catastrophic landscape erosion caused by immense flocks of sheep kept by tribes that occupied the territory of the collapsed Khazar state.

Key words: paleosols, interaction of nature and society, ecological crisis, southern Russia.

RESUMEN

Varios paleosuelos sepultados de color obscuro se estudian en balkas (valle) en el sur de Rusia (Republica de Kalmykia). Los paleosuelos difieren de los suelos modernos en sus propiedades químicas y físicas, las cuales indican variaciones en el carácter de los procesos formadores de suelo, tanto en el pasado como en el presente. Los paleosuelos están sepultados bajo depósitos coluviales y eólicos, cuya acumulación intensa siguió al óptimo climático del Holoceno tardío (hace cerca de 1,000 años). Hipotéticamente, el sepultamiento se debió a la erosión del paisaje, asociada con desarrollos sociales dentro de este territorio. Una razón para el enterramiento simultáneo de los suelos dentro de la amplia área de estudio fue, probablemente, la catastrófica erosión del paisaje, causada por los inmensos rebaños de ovejas a cargo de tribus que ocuparon el territorio del colapsado estado de Khazar.

Palabras clave: paleosuelos, interacción de la naturaleza y sociedad, crisis ecológica, sur de Rusia.

INTRODUCTION

This study reconstructs stages of the interaction between nature and society in the south of Russia during the late Holocene. The first results on this topic were presented in a recent paper where a part of the balka Mu-Sharet was studied in detail (Golyeva *et al.*, 2003). In this paper we present new results from new sites in the same balka and from another two balkas spread over a large geographic area that contain paleosols with similar properties. Our results indicate that the dark-colored paleosol initially studied in Mu-Sharet balka is not an atypical finding. Here we present new data on the history of this territory, the age of the paleosols, and the evolution of the paleosols and modern surface soils.

The southern territories of Russia have been studied by many scientists who have made climatic reconstructions for the second half of the Holocene (Ivanov, 1992; Demkin *et. al.*, 1998; Spiridonova and Aleshinskaya, 1999). Some authors conclude that environmental conditions within the last 2,500 years were comparable with the modern environment (Kiseleva, 1976; Gennadiev and Puzanova, 1994). Others argue that the conditions changed from dry at about 1,000 yr BP to humid in the interval 800 – 600 yr BP (Ivanov, 1992; Demkin *et al.,* 1998). Varushchenko *et al.* (1987) conclude that the interval from the 8th to 14th century AD was favorable to society: not very hot and relatively humid.

We studied paleosols in balkas because we agree with the hypothesis of Alexandrovskiy (1996) that data on upland paleosols allow reconstruction only of major periods of soil–landscape evolution. The analysis of paleosols in valley floors is more informative because they can provide evidence for reconstructing short-term processes (Sycheva, 1999). Terhorst (2000) has studied such paleosols in southern Germany and found that ancient Chernozems were buried as a result of agriculture-induced erosion about 5,000 yr BP and therefore preserve evidence of human-induced land degradation processes. Thus, observations on paleosols in valleys allow us to reconstruct not only the ancient soil cover and environmental conditions, but also the origin of sedimentary deposits (natural or anthropogenic).

Several studies on paleosols of valleys were conducted within the central Russian Upland (Alexandrovskiy, 1996; Sycheva and Chichagova, 1999) and the formation of colluvial deposits was considered as a result of climate change and deforestation in the Middle Age. In this study we argue that significant degradation of the landscape, especially in the dry steppe, results from the pasture-induced degradation and deflation of soils beginning in the middle of the first millennium BP (Nikolaev, 1997; Golyeva 2001). Many authors conclude that soils in the south of Russia have experienced anthropogenic pressure for at least two to three thousand years (Kiseleva, 1976; Dinesman, 1976). We agree with the opinion of Rosen (1995) that the combined impact of climatic and social factors on the landscape must be considered during the second half of the Holocene.

STUDY AREA

The study area is located in Kalmykia, in the south of the Russian Plain, 1,300–1,500 km south of Moscow, in the arid zone (Figure 1). Modern climatic conditions are dry and warm, with mean annual precipitation of 350 mm and mean annual temperature of 11.1º C. Light chestnut soils (Kastanozems) with different degrees of solonetz features occur under modern steppe vegetation represented by fescue–wormwood communities. We described modern surface soils and buried paleosols. Attention was focused on soils of balkas at the eastern slope of the Ergeni Upland. Several balka systems located at a significant distance from each other and spread over a distance of >200 km from north to south were observed (Table 1). Paleosols were found in each studied balka, and in some cases (*e.g.*, balka Bulgun) they occur in all geomorphological positions including upland, terraces, and floodplain. All paleosols have dark thick humus (A) horizons, which clearly differentiate them from modern surface soils, which have thin and light colored A horizons.

People have lived in this area since the Neolithic Age. In the Bronze Age (from the 4th to the 3rd millennium BP), Jama and Katakomba cultures alternated each other. In the 2nd millenium BP, Scythian and Sarmat tribes populated the territory. The Khazar state existed there from the 14th to 10th century BP and was destroyed by Russian prince Svyatoslav in 985–910 yr BP. According to historical documents, a deep social crisis occurred at that time (Artamonov, 1962). Then, Guzes, who kept large sheep flocks, occupied this area. Tatar-Mongolian nomads lived there in 5–7th centuries BP. Kalmyks have lived in this territory since 1657 year (History of Kalmyks, 1967).

METHODS

Soil samples of about 3 kg were collected from each soil horizon identified in a profile. Specimens of humic acids (HA) and benzene were prepared using standard techniques and modifications developed in the laboratory of the Institute of Geography, Russian Academy of Sciences (IGRAS) (Chichagova and Cherkinsky, 1988; Alexandrovskiy and Chichagova, 1998). The HA were extracted from soils by the pyrophosphate method (Chichagova and Cherkinsky, 1988). The ^{14}C age of HA was determined using liquid scintillation counting. The dates were calibrated using the program CAL 20 (van der Plicht, 1993). The calibration is necessary for transferring ^{14}C ages from the radiocarbon scale to calendar ages. Calibration programs are based on ^{14}C ages for annual rings of trees of known age (dendrochronological scale).

The measured physical and chemical properties of soils include pH in water, organic carbon content (by oxidation with dichromate), particle size distribution (by the pipette method), and $CaCO_3$ content.

RESULTS

Radiocarbon dating of organic matter of the upper 10 cm of paleosols located in different geomorphological positions in several balkas shows that all these paleosols were buried within a short period after 1,160–900 ^{14}C yr BP (Table 2). The calibrated ages indicate that paleosols were buried about 1,100–720 yr BP. In comparison with modern soils, the paleosols have a higher humus content, lower $CaCO_3$ content, and lower pH (Table 3).

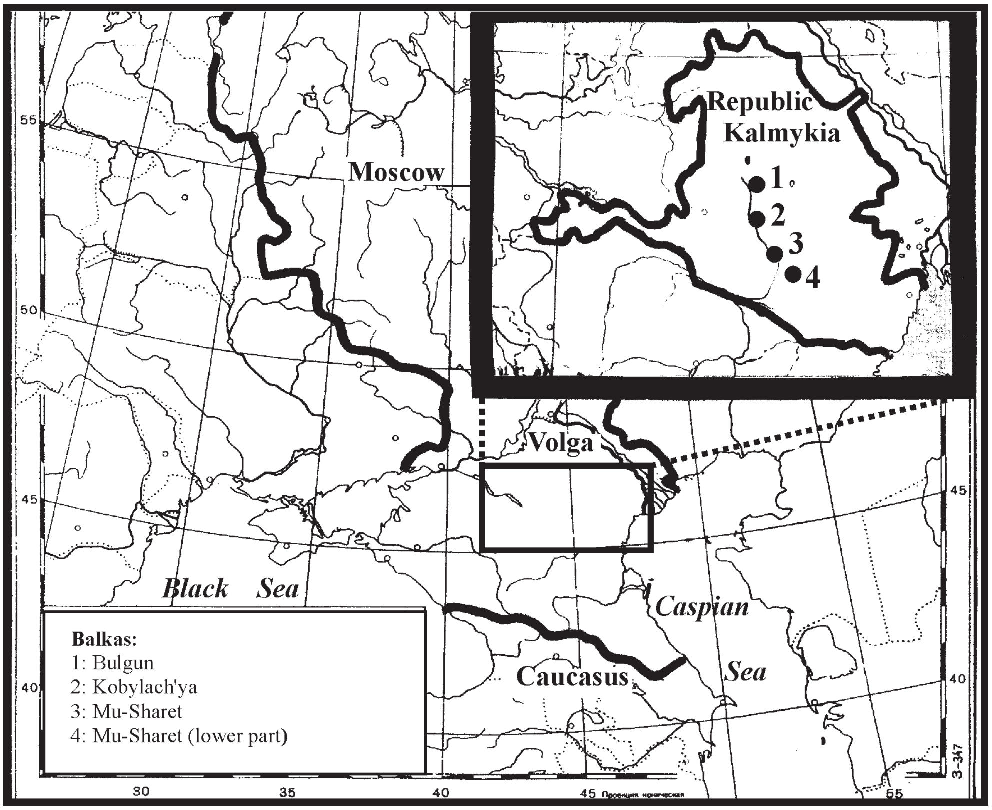

Figure 1. Location map showing the sites (Balkas 1–4) where paleosols were studied.

Balka Mu-Sharet (upper part)

The paleosol differs considerably from the modern soil by a thicker humus (A) horizon, less carbonates, and lower pH values (Table 3). This paleosol is practically decalcified. Particle size analyses of the upper horizons indicate a clay content of 18–20% that increases with depth to 38% (Table 3). The humus content is greater in the upper buried horizons than in the overlying colluvium. The buried paleosols of the valley floors are morphologically Chernozem-like Phaeozems. Colluvial deposits in the balka bottom consist of several layers with different texture and carbonate content. The lower layer (M1) has a clay content of almost 15–16%, and sand content of 30–33%. The next colluvial layer (M2) contains more clay (22–24%) and less sand (20–22%). The upper layer is more mixed and has an indistinct boundary with the modern surface soil.

Balka Mu-Sharet (lower part)

The buried paleosol differs from the modern surface soil by higher humus content, thicker humus horizon, lower pH, and the absence of carbonates. The modern soil is characterized by an increased content of clay (from 16% to 24%) in the BA horizon. This is typical for the illuvial horizons of modern soils and is indicative of their formation in conditions of arid climate and increased salinity. The paleosol profile is less differentiated by clay content and, therefore, we believe, formed under different conditions.

Balka Kobylyach'ya

The paleosol is characterized by considerably higher humus content and a thicker humus horizon in comparison with those in the modern surface soil. The pH values are slightly lower in the paleosol, while differences in the content of $CaCO_3$ are significant. While the modern soil has the maximum concentration of carbonates within the upper 10-cm-thick layer, the paleosol has a carbonate-free humus layer with a calcareous horizon at a depth of 105 cm (or 45 from the buried surface). The colluvial layers differ in humus and $CaCO_3$ content. In the balka Kobylyach'ya, like in the balka Mu-Sharet, the profile of the modern surface soil is distinguished by a clay content maximum in the sub-humus horizon. This is indicative of recent solonetz-forming processes, which is a typical soil process in arid regions (Kovda and Rosanov, 1988).

Balka Bulgun (upland landscape position)

The humus content in the paleosol is lower than in

Table 1. Physicogeographical characteristic of study objects.

Sites with buried soils	Geographic location of sites	Geomorphological position of buried soils
Bulgun	46°25'17" N 44°14'28" E	Flat watershed of the Ergeni Upland
	same	Upper terrace
Kobylyach'ya	46°17'50" N 44°16'32" E	The upper one-third of the eastern slope of the Ergeni Upland
Mu-Sharet (upper part of balka)	45°41'23" N 44°31'55" E	Lower terrace
Mu-Sharet (lower part of balka)	45°40'31" N 44°33'27" E	Upper terrace

the modern surface soil. This is explained by the humus decomposition in the buried soil and also by its coarser texture. The paleosol is formed in sandy parent material, while the modern soil is formed in silty parent material. Organic carbon storage in sandy soils is always lower in comparison with that in loamy soils (Kovda and Rosanov, 1988). Like the above described paleosols, this one has lower pH values than the modern soil and does not contain calcium carbonate. According to the particle size data, the sandy paleosol is buried by sandy colluvium that is overlain by silty sediment. We consider the silty sediment most probably of eolian origin because the site is located on the upland where colluvial deposition is not possible.

DISCUSSION

All paleosols were formed by processes different from modern soil forming processes. The intensity of humus accumulation was greater, while solonetz-forming processes typical for modern soils are not evident. Judging from the age of HA of paleosols, the final stage of their formation occurred about 1,000 years ago. After that period, the soils were buried. The features of colluvial layers within one soil profile (balka Mu-Sharet, upper part) indicate that colluvium was brought from different places and/or at different times.

According to climatological data (Ivanov, 1992; Demkin *et al.,* 1998; Sycheva, 1999), the period around 1,000 yr BP is the Late Holocene climatic optimum, which was characterized by a decrease in humidity and an increase in temperature within European Russia. While natural climate change could induce landscape erosion that resulted in soil burial, we hypothesize humans played a role. Our hypothesis is rooted in the dynamic history of this region during the period 1,160–900 yr BP and later. The Khazar state collapsed within a period between 1,040 and 980 yr BP. Following the collapse, the territory was first occupied by Guze, who were followed by other tribes. Guzes came with large flocks of sheep. In terms of the harmful impacts to the environment, sheep are more destructive than cattle and horses (Armand *et al.*, 1999). It is likely that sheep of Guses or other tribes trampled and destroyed the grass cover, which induced desertification and made the land more vulnerable to water and wind erosion processes. In particular, we believe that wind erosion was probably active because of the strong winds usual for this area. Considerable amounts of fine mineral material were transported by water and wind and accumulated in depressions, terraces, and on uplands. The soil cover was buried under the sheet of eolian and colluvial deposits. In some locations these deposits became the parent materials of modern soils, which morphologically are quite different from the paleosols.

CONCLUSION

The time of burial of paleosols in balkas and uplands of Kalmykia took place after 900–1,160 ^{14}C yr BP. We hypothesize that burial of the paleosols resulted from significant anthropogenic pressure that caused water and wind erosion of sensitive soils. Most modern soils of this

Table 2. Results of ^{14}C dating of the humus horizons (upper 5–10 cm) of paleosols from balkas in Kalmykia.

Specimen number IG RAS	Specimen description	Material	^{14}C age (BP)	Calibrated age per 1σ Smooth calibration curve
2104	Mu-Sharet (upper part) [A1], 91–95 cm	HA	1,070 ± 40	CAL AD 925 – 992 CAL BP 1,025 – 958
2379	Kobylyach'ya, [A1], 62–72 cm	HA	1,160 ± 50	CAL AD 846 – 925 CAL BP 1,104 – 1,025
2385	Bulgun, watershed, [A1], 90 cm	HA	900 ± 90	CAL AD 1,037 – 1,229 CAL BP 913 – 721
2387	Bulgun, terrace, [A1], 60 cm	HA	1,020 ± 50	CAL AD 951 – 1070 CAL BP 999 – 880

Table 3. Some properties of modern and buried soils.

Horizon	Depth (cm)	Sand 0.05–2.0 mm (%)	Silt 0.001–0.05 mm, (%)	Clay <0.001 mm (%)	$CaCO_3$ (%)	pH, H_2O	C (%)
Balka Mu–Sharet (upper part)							
A	0–6	4.0	74.7	21.3	0.09	8.65	1.60
BA	6–13	5.7	64.2	30.1	0.27	8.85	2.65
B	17–23	16.4	59.5	24.1	1.26	8.05	0.93
	30–35	13.2	57.9	28.9	1.86	8.85	0.83
M2	40–45	20.9	56.2	22.9	1.95	8.60	0.62
	50–55	22.4	55.6	22.0	1.88	8.75	0.65
	60–65	22.6	53.1	24.3	2.04	8.35	0.67
M1	70–75	32.9	50.3	16.8	1.98	8.75	0.40
	80–85	30.6	46.8	14.6	2.24	8.30	0.36
II A	91–95	21.7	59.7	18.6	0.03	7.85	1.16
	95–102	21.1	59.0	19.9	0.03	7.70	1.34
	102–109	24.5	57.7	17.8	0.01	7.70	1.34
II AB	109–118	22.6	59.3	18.1	0.01	7.80	1.10
	120–125	23.1	52.2	24.7	0.00	7.85	0.48
	125–130				0.02	7.60	
II BA	130–135	17.1	45.0	37.9	0.05	7.40	0.51
	135–140	17.8	43.7	38.5	0.07	7.50	
Balka Mu–Sharet (lower part)							
A	0–7	24.0	59.6	16.4	0.45	8.3	1.61
BA	7–15	33.7	42.1	24.2	0.96	8.6	0.66
M1	15–32	26.4	57.3	16.3	0.90	8.5	1.25
II A	32–34	17.9	70.4	11.7	0.06	8.3	2.39
	32–40	17.4	69.4	13.2	0.06	8.2	2.77
II AB	40–54	19.8	63.6	16.6	0.03	8.2	2.00
II BA	54–61	24.7	52.3	23.0	0.05	8.0	1.12
Balka Kobylyach'ya							
A	0–10	17.2	61.2	21.6	1.54	8.3	1.28
BA	10–20	16.4	60.1	23.5	1.31	8.7	1.19
B	20–30	20.6	61.3	18.1	0.44	8.7	1.22
M3	30–40	22.4	58.6	19.0	1.08	8.8	1.08
M2	40–50	22.5	63.1	14.7	0.70	8.8	0.95
M1	50–60	20.8	63.0	16.2	0	8.6	1.62
II A	60–70	14.0	64.1	21.9	0.06	8.5	2.27
	70–80	14.9	62.5	22.6	0.05	8.5	1.87
II AB	80–90	12.8	63.7	23.5	0	8.4	1.36
II BA	90–100	16.8	59.2	24.0	0.04	8.3	1.31
II B	105	28.0	48.7	23.3	2.37	8.3	0.56
II BCa	110	30.0	51.9	18.1	2.33	8.3	0.56
Balka Bulgun (watershed)							
A	0–2	60.4	32.2	7.4	0.2	8.2	0.93
BA	2–36	38.4	51.6	10.0	0.7	9.0	0.62
B	36–56	23.9	66.5	9.6	0.6	8.0	0.68
M1	56–90	88.2	7.3	4.5	0.07	8.5	0.18
II A	90–106	71.2	22.3	6.5	0.03	7.4	0.48
II BA	106–119	93.6	2.4	4.0	0	8.2	0.11
C	119–150	98.2	0.8	1.0	0	8.4	0.04

Note. M3–M1: Late Holocene colluvial layers

area have formed since the time of the paleosol burial in conditions of a continuous anthropogenic pressure, and their parent materials and soil properties differ from those of the paleosols. At least part of the modern surface soil cover of Kalmykia is not older than 1,000 years.

Climate change and human activity within the last 1,000 years was significant and can explain the observed changes in the landscape. Historical documentation along with evidence from paleosols and sediments suggests to us that soil evolution within the late Holocene in southern Russia was more strongly controlled by the anthropogenic factor rather than by climate change. Social crisis that accompanied the fall of the Khazar state and the impact of numerous sheep brought by Guse and other tribes led to degradation of the soil cover, a severe ecological crisis, erosion intensification, and soil cover burial under eolian and colluvial deposits.

ACKNOWLEDGEMENTS

This work was supported by the Russian Foundation for Basic Research, projects NN 01-05-64403 and 01-06-80242. We thank our reviewers for a substantial and favorable analysis of our paper.

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Manuscript received: June 25, 2002
Corrected manuscript received: January 5, 2003
Manuscript accepted: March 19, 2003