Revista Mexicana de Ciencias Geológicas, v. 21, núm. 1, 2004, p. 71-78

Northern Tian-Shan paleosoil sedimentary sequences as a record of major climatic events in the last 30,000 years

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ABSTRACT

Specific features of the polygenetic mountain soils of northern Tian-Shan (Kyrgystan) are due to the action of present-day and relict soil processes that varied in age and intensity. These properties can be used as indicators of paleoclimatic changes. Diagnosis of ancient pedogenesis was based on criteria with the longest response time, namely soil morphology, humus characteristics, isotope composition of humus and carbonates, and the soil age. Results indicate a glacial climate with mean annual temperature about -25° C during the late Pleistocene, a dry and cold climate during the early Holocene, warm and dry conditions of soil formation in the middle Holocene, and a humid climate of the late Holocene.

Key words: paleoclimatic changes, mountain soils, organic matter, Kyrgystan, Holocene.

RESUMEN

Las características específicas de los suelos poligenéticos de montaña, del norte de Tian-Shan (Kyrgystan), son debidas a la acción de procesos pedogenéticos actuales y relictos que variaron en edad e intensidad. Estas propiedades pueden usarse como indicadores de cambios paleoclimáticos. El diagnóstico de la pedogénesis antigua se basó en criterios con el más largo tiempo de respuesta, es decir, la morfología del suelo, las características del humus, la composición isotópica de humus y carbonatos y la edad del suelo. Los resultados indican un clima glacial con temperatura media anual de aproximadamente -25° C, durante el Pleistoceno tardío, un clima seco y frío durante el Holoceno temprano, condiciones calientes y secas de formación del suelo en el Holoceno medio y clima húmedo en el Holoceno tardío.

Palabras clave: cambios paleoclimáticos, suelos de montaña, materia orgánica, Kyrgystan, Holoceno.

INTRODUCTION

Global warming and impending sea-level rise have attracted increasing interest in regional climate changes during the Pleistocene and Holocene and in the methods of their investigation. While many global change studies are based on geomorphology, lichenometry, dendrochronology and pollen analysis, soil properties also record environmental and paleoclimatic ñhanges over periods of 10–10^6 years (Ostroumov, 1988). In spite of this, only a few investigations of soil development as an indicator of the Pleistocene and Holocene climatic and landscape evolution exist in Kyrgystan (Dergacheva and Zykina, 1988; Mahaney *et al.*, 1996; Zech *et al.*, 1996; Kovaleva and Evdokimova, 1997).

The soil cover of the extensive territory of Tian-Shan

(Kyrgystan) is represented by polygenetic Holocene soils along with soils buried by late Pleistocene and Holocene loess. Specific features of these soils are due to the action of elementary modern and relict soil processes, whose age and intensity varied under the influence of glacier movements and climatic fluctuations. Thus, the analysis of soil properties could help to elucidate conditions of soil formation during the late Pleistocene and Holocene.

This paper presents soil morphological descriptions combined with chemical properties of humus and radiocarbon dating, as well as records of ^{13}C/^{12}C ratios of soil organic matter and carbonates to reconstruct changes in climate and paleoenvironments during the Pleistocene and Holocene in the high mountains of Asia, focusing on the Kirgizskiy Range in Kyrgystan.

STUDY SITES

A soil chrono-climosequence was studied in the central part of Kirgizskiy Range (at the longitude of the city Bishkek, 74° 42′ E ; Figure 1) at elevations between 1,800 and 3,400 m a.s.l. on an interfluve between the Alamedin and Ala-Archa Rivers. The interfluve is the highest part of the Kirgizskiy Range that was glaciated by the Shopokov Glacier. The highest peak is West Alamedin, which reaches 4,895 m a.s.l. (Figure 2). Because of its orientation and marginal position within the mountain system of central Asia, the Kirgizskiy Range receives considerable precipitation from northern cyclones, the majority of which (60 %) falls in May to June, while summer and autumn are mostly hot and dry.

Data from the geobotanical-meteorological stations in the studied river basin are given in the Table 1 (Lebedeva, 1984). The studied valley contains typical glacial features including U-shaped cross-sections, cirques, moraines, and glaciofluvial sediments. Bedrock is comprised of limestone, diorite, porphyrite, and metamorphic rocks.

This study examined 40 soil profiles, representing the change of soil types from the foothills to the top slope of the Tatyr, Chon-Kurchak, Kurchak-Tor valleys. The profiles were grouped into three genetically similar units based on soil profile morphology. The groups are:

1) The older members of the chronosequence developed on the lowest frontal moraines of the Last Glacial Maximum (LGM) (as established by Maksimov, 1980) at altitudes of 1,900–2,100 m (Table 2). These soils are full-Holocene mountain Chernozem (Russian Soil Classification, 1997) or Chernozems Haplic (FAO, 1998) profiles with the following horizonation: A-AB-B-BC1-C1-Bb1-C2-C3-Bb2-C4-Bb$_3$. Vegetation cover is herbage-estragon (*Festuca valesiaca, Artemisia dracunculus, Poa relaxa, Stipa capillata, Phlomis oreophila*, *Elytrigia repens*) meadow-steppe. Soil texture is strongly affected by aeolian silt additions, similar to descriptions from other mountain ranges of Asia (Zech *et al.*, 2000). The aeolian additions have

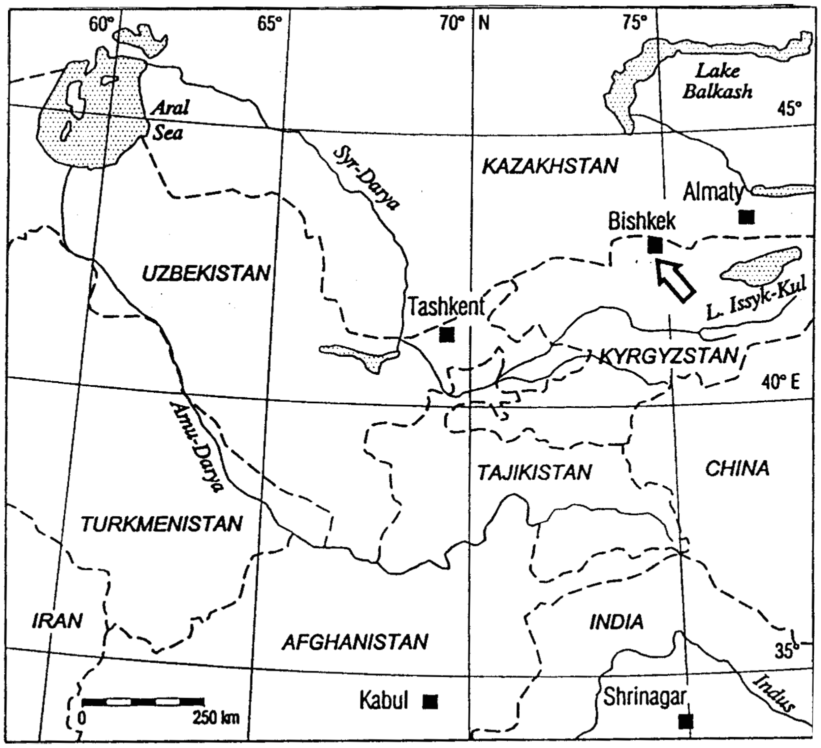

Figure 1. Location map of Kyrgyzstan/Bishkek.

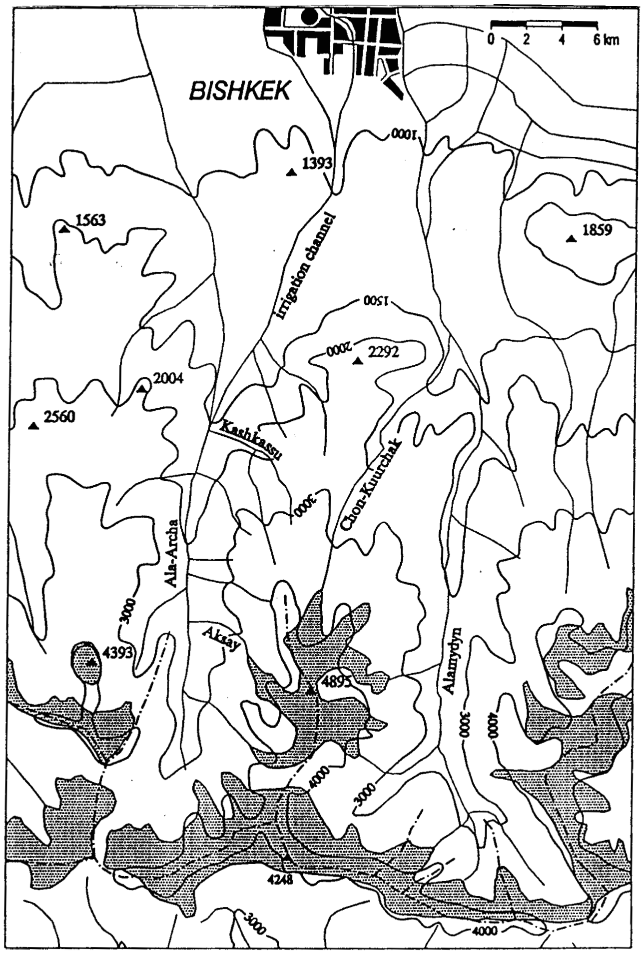

Figure 2. The research area in the Kyrgyz Range.

resulted in burial of soil horizons (*e.g.*, Bb_1, Bb_2, Bb_3 horizons above).

2) Upvalley moraines are present at 2,100, 2,350, 2,450 and 2,600 m a.s.l. These moraines characterize Late Glacial ice advances, as shown by Heuberger and Sgibnev (1998) and Maksimov (1980). These soils are full-Holocene polygenetic soils that have buried A and B horizons. The soils can be classified as Leptosols Mollic (FAO, 1998) or Chernozem-like soils (Russian Soil Classification, 1997) with A-Ab-AB-B-Bt-C1-Bb1-C2-Bb2-C3 horizonation. Vegetation is a prairie-grass-herbage meadow steppe (*Brachypodium pinnatum, Helictotrichon schellianum, Phleum phleoides, Campanula glomerata, Galium septentrionale, Rananculus polyanthemus*) and dry subalpine meadows (*Phlomis oreophila, Aegopodium alpestre, Alchemilla retropilosa, Dichodon cerastoides, Ligularia thomsonii, Brachypodium pinnatum, Poa angustifolia, Dactylis glomerata, Geranium regelii, Alopecurus pratensis*) (Kovaleva, 1989).

3) Monogenetic incomplete Holocene soils, developed on the frontal moraines with large porphyrite and granite–diorite boulders, occur at altitudes of 3,100 m. These soils are in the initial stages of their formation and are classified as alpine-meadow soil-rankers (Leptosols Umbric according FAO, 1998), with A-AC-C horizonation. Vegetation is cobresia meadow including *Kobresia humulis, Alchemilla retropilosa, Allium atrosanguineum, Astragalus alpinus, Potentilla nivea, Carex stenocarpa.*

METHODS

All samples were collected from soil pits and were air dried, sieved (<2 mm), and ground prior to chemical analysis. Macro-, meso-, and micromorphological descriptions were made for all studied profiles. Total C and N, as well as organic C (C_{org}) were analyzed by dry combustion with a Carlo Erba ANA 1500 C/N/S Analyzer. Group and fractional composition of humus was analyzed by the Tyurin method (Orlov, 1990). The optical properties of humic and fulvic acids were measured in an alkaline extract with a CF-18 spectrophotometer, and the coefficient

Table 1. Selected meteorological data of the studied area.

Altitude (m a.s.l.); soil type	**Annual precipitation (mm)**	**Annual July temperature (ºC)**	**Years of observation**
1,900; Chernozem	520	+18	1968–1989
2,400; Chernozem-like soils	593	+11	1969–1989
3,000; alpine soils	700	+ 5	1969–1989

of extinction, color coefficient, and humification indexes were determined. These analyses are defined as follows (Orlov, 1990): (1) coefficient of extinction, E, is the optical density of the solution when the λ= 465 nm, the concentration of humic acids is 0.001 %, and the cuvette length is 1 cm; (2) color coefficient $Q = D_{465}/D_{650}$, where D is the optical density at 465 and 620 nm wavelength; (3) humification index = ($E \times \%C_{\text{humic acids}} / \%C_{\text{total}}$). Other analyses included pH and content of calcium and magnesium carbonates after Khitrov (1984).

Radiocarbon analyses of extractable humic acids were carried out at the geochemical laboratory of the Institute of Geography, Russian Academy of Sciences. I also used radiocarbon data obtained by Maksimov (1980) and Pomortsev (1980) for soils studied at Leningrad University.

The $^{13}C/^{12}C$ ($\delta^{13}C$) ratio was measured on a Finnigan MAT 251 mass spectrometer with PDB as reference and average precision less than 0.1 ‰ at the Soil Science Institute of Bayreuth University, Germany. Interpretation of organic carbon stable isotope ratio ($\delta^{13}C$) values is based on the model of Francey and Farquhar (1982), using the correlation between $\delta^{13}C$ values in humus and CO_2 concentrations in atmosphere, and the model of Ryskov *et al.* (1996) using the distribution of theoretical and experimental values of $\delta^{13}C$ for carbonates under different temperature. Values of $\delta^{13}C$ in carbonate and humus have been under examination for loess and soils to clarify the type of vegetation and conditions promoting carbonate precipitation. Results are shown in Tables 3 and 4.

RESULTS AND DISCUSSION

Soil morphology and radiocarbon age

The morphology of the soil profiles studied demonstrates that all Holocene polygenetic Chernozem-like soils (Leptosols Mollic) are clearly differentiated by color, structure, and texture. The boundaries between horizons are often smooth. A typical profile of a polygenetic Holocene Leptosols Mollic includes the following horizons:

1. Dark-brown crumb-structure A horizon, leached of carbonates, with large amount of roots, smooth boundaries, and an average depth of 35 cm. The radiocarbon age of this horizon in profile 22 is 3,010±90 years BP (Table 4).

2. Black buried horizon of the humus profile of a previous stage of soil formation. A thick humus horizon of a relict soil or its lower part (Ah+AB) remained as the second humus horizon at a depth 35–60 cm; it has a residual granular structure and provides evidence for a warmer and wetter period than at present, with high plant biomass production. Its radiocarbon age is 5,560±120 ^{14}C years BP. According to Solomina and Kamnianski (1998), favorable climatic conditions occurred during the middle Holocene and terminated around 3,500–4,200 years BP. According to Maksimov (1980), the age of this horizon in the Chernozem-like soil is 6,440 (at altitude 2,450 m) and 7,130 (at altitude 2,350 m) ^{14}C years BP. Moreover, these radiocarbon dates correspond to the age determinations obtained by Zech *et al.* (2000) in the western Tian-Shan, Gasse *et al.* (1996) and Yan *et al.* (1999) in Tibet, and Alexandrovskiy (1988) in the northwestern Caucasus and Eastern Europe. I conclude that the climatic changes in the middle and late Holocene seem to coincide in these regions. Simultaneous changes of climate and the accumulation of loess sediments on the surface of terra-rossa in valleys of northern Tian-Shan during the early and middle Holocene warm and dry climate created conditions for the development of the mountain Chernozem Haplic.

3. Lower brown B and textural Bt horizons with a pronounced boundary recognized by color and texture and corresponding to the upper boundary of effervescence; the Bt horizon has a strong, subangular-blocky structure with humic-clay films and crusts on ped surfaces. Micromorphological investigations of this horizon found strongly ferruginated anisotropic clay coatings, with 5 to 10 laminae in them (Kovaleva, 1996). The occurrence of clay coatings in this zone shows the limits of modern illuvial processes, which are a result of the specific climate regime in the vertical belt studied. Sixty percent of the annual precipitation falls during one month and intensively penetrates the soil profile. The geochemical barrier for percolating humic-clay solutions in the lower part of these profiles is a calcareous loess horizon.

4. Loess-like loam contains buried Pleistocene soils (Bb) transitioning to the highly weathered and rubefied metamorphic bedrock. According to Zech *et al.* (2000), the radiocarbon age of such soils (Bb2 and Bb3 horizons) in loess of northwestern Tian-Shan is 15,930±460 and 24,300±1,160 years BP. Zech *et al.* (2000) assume that the latter paleosol developed during a warmer interstadial that, they postulate, is correlated with oxygen isotope stage 3,

Table 2. Basic information about soils developed on terminal moraines at the Chon-Kyrchak valley, Kirgizskiy Range, Kirgystan.

Profile No.	**Location**	**Altitude (m a.s.l.)**	**Classification (FAO, 1998)**
8	Crest of LGM moraine, lower Chon-Kyrchak valley, nature-reserve plot of Biology Institute of Kirgyzian Academy of Science	1,900	Chernozems Haplic
12	Upper slope of Late Glacial Moraine, Central Hayfield of "Alamedin" farm	2,100	Leptosols Mollic
22	Crest of Late Glacial Moraine, control (hayed once a year) plot of Biology Institute of Kirgyzian Academy of Science	2,350	Leptosols Mollic
29	Crest of Late Glacial Moraine, nature-reserve plot of Biology Institute of Kirgyzian Academy of Science	2,450	Leptosols Mollic
38	Crest of Little Ice Age Moraine close to the mouth of Schopocov glacier, left side	3,100	Leptosols Umbric

between the Sartan (Late Valdai, isotope stage 2) and Zyryanka (Early Valdai, isope stage 4) ice advances. Beginning with the Sartan glaciation about 24,000 years BP, solifluction debris and Shopocov till began to cover the paleosol.

Organic matter characteristics

Along with data on the morphological differentiation of profiles, the system of indicative characteristics of organic matter elaborated by Dergacheva and Zykina (1988) was used for the diagnostics of ancient pedogenesis.

Monogenetic full-Holocene soils are not clearly differentiated in terms of humus properties (Table 3). Their profile can only be subdivided into upper and lower parts, which are assessed as recent and early Holocene, respectively. The criteria to subdivide the profile are the values of the color coefficient ($Q>4$ and $3<Q<4$), the coefficient of extinction (0.08 and 0.19), and the degree of humification (3.40 and 9.86). This subdivision is in agreement with the climate of the modern meadow steppe and the effect of the early and middle Holocene xerothermic period on the formation of ancient Chernozems.

The profiles of the Holocene polygenetic soils that formed on the moraines of the Shopocov glacier during the last 10,000–13,000 years are clearly differentiated in terms of humus properties. The upper A horizons have mean values of the humification index, as well as values of the color coefficient (Q) >4. Moreover, the humus type is humic-fulvic in the A horizon. Very high values of the humification index, high values of the coefficient of extinction, and the spectral curve slope with color coefficient $3<Q<4$ are intrinsic to the Ab and AB horizons. The latter is indicative of a more complex structure of humic acids rich in benzoid compounds typical of mountain Chernozem profiles. In addition, the Ab horizon has the following relict characteristics: high values of the Cha/Cfa ratio, humus with the predominance of humic acids bound to Ca, along with a darker color and well expressed granular structure (as distinct from A horizon). Thus, humus composition in the horizons below the A is identical to that of the mountain Chernozems, reflecting a previous stage of Chernozem soil development. This all indicates dry conditions of soil formation existing in the area of Chernozem soils before the climatic changes that occurred between the middle and late Holocene.

At the same time, A horizons forming under modern bioclimatic conditions differ appreciably from the underlying horizons with respect to the condensation of aromatic nucleus which are closer to typical alpine soils. Thus, late Holocene climatic changes toward cooler and wetter caused the formation of a new subalpine soil type on the profile of mountain Chernozem in the zone from the lower boundary of the LGM (2,100 m) to the alpine belt (3,000 m). Low values of the humification index and the coefficient of extinction are characteristic of the B and Bt horizons.

Soil in initial stages of formation at the altitude above 3,100 m are characterized by high humus content (up to 15%), humate-fulvate-type humus, low value of the extinction coefficient (0.06), and considerable green humic acids content, all of which indicate a humid and cold climate of the alpine zone during, at least, the last 100–200 years. The radiocarbon date of the A horizon in the alpine soil is 109±1.47 years BP. These soils correspond with glacial advances during the so-called "Little Ace Age" with a maximum advance at about 1850 AC in the Alpine zone (Zech *et al.*, 1996).

Palaeolandscape evolution history

The $^{13}C/^{12}C$ ratio in carbonates and humus has been examinated in loess and soils in order to clarify the type of vegetation and conditions promoting carbonates formation. Based on the radiocarbon chronology and $\delta^{13}C$ data of the buried soils the following major climatic events can be reconstructed:

1) $\delta^{13}C$ values of -4 to -5‰ from carbonate in the C2 and C3 horizons of the mountain Chernozem (on the LGM moraine) characterized the glacial climate with a mean

Table 3. Chemical characteristics of soils.

Soil (profile)	**Horizon**	**Depth (cm)**	**pH**	**N (%)**	**C_{org} (%)**	**C_{CaCO_3} (%)**	**$\frac{C}{N}$**	**$\frac{Cha}{Cfa}$**	**E**	**Humification index**
Cherno-Zem Haplic (No. 8)	A	0–12	7.80	0.48	4.53	0	10	2.2	0.09	3.40
		12–18	7.86	0.40	3.89	2.60	10	3.1	0.08	4.64
		18–38	7.96	0.49	4.29	2.82	9	2.1	0.14	7.26
		38–44	7.98	0.31	3.05	3.76	10	1.4	0.19	9.86
	AB	44–53	8.00	0.28	2.62	4.48	10	1.6	0.12	5.63
	B	53–73	8.10	0.23	2.43	5.11	11	1.2	0.15	6.85
	BC_1	73–83	8.16	0.14	3.39	11.52	24			
	Bb_1	83–101	8.28	0	1.15	10.07	1			
	C_2	101–114	8.37	0	0.78	7.67				
	C_3	114–126	8.40	0	0.41	8.53				
	Bb_2	126–157	8.40	0	0.67	8.01				
	C_4	157–187	8.48	0	0.24	4.36				
	Bb_3	187–200	8.52	0	0.42	4.65				
Leptosols Mollic (No. 12)	A	0–5	6.30	1.08	10.5	0	9	1.5	0.08	2.17
		5–20	6.00	0.88	7.92	0	9	0.4	0.11	1.90
	Ab	20–33	6.45	0.66	5.87	0	9	1.8	0.17	1.85
		33–47	7.23	0.35	3.39	0	10	2.1	0.24	7.40
	AB	47–58	7.90	0.19	1.74	0.28	9	1.5	0.23	10.88
	B	58–78	7.90	0.16	1.68	3.15	11	1.1	0.14	6.12
	Bt	78–87	8.00	0.11	1.23	5.50	11	0.4	0.05	0.48
	C_1	87–110	8.50	0.09	0.48	7.84	16			
	Bb_1	110–125	8.50	0.06	0.55	19.55	17			
	C_2	125–135	8.48	0.03	0.36	7.80	12			
	C_3	135–165	8.57	0.04	0.81	7.54	20			
	Bb_2	165–200	8.60	0	0.50	8.04				
Leptosols Mollic (No. 22)	A	0–4	6.50	1.50	11.6	0	10	1.0	0.14	3.29
		4–35	6.92	0.61	6.00	0	9	2.5	0.17	9.03
	Ab	35–50	6.25	0.21	5.22	0.19	10	1.7	0.07	3.66
	AB	50–67	6.53	0.13	2.05	0.26	9	1.2	0.06	2.55
	B	67–87	7.80	0.12	1.17	10.86	8	1.3	0.08	4.11
	Bt	87–97	7.91	0.14	1.00	17.41	9			
	C_1	97–110	8.44	0	1.23	11.94				
	Bb_1	110–120	8.58	0	0.70	8.00				
	C_2	120–160	8.90	0	0.34	9.30				
Leptosols Mollic (No. 29)	A	0–14	6.34	1.12	11.6	0	10	1.6	0.09	4.29
		14–23	6.54	0.71	7.26	0	10	1.3	0.13	3.49
	Ab	23–37	7.04	0.29	2.91	0	10	1.7	0.13	4.55
	AB	37–50	8.71	0.17	1.80	0	11	2.8	0.18	11.67
	B	50–73	8.04	0.04	1.31	2.16	33	0.5	0.01	0.26
	Bt	73–85	8.68	0.10	1.07	11.52	11	0.3	0.03	0.35
	C_1	85–100	8.76	0.04	0.62	11.09	16	0.8	0.01	0.37
	Bb_1	100–130	5.12	0.03	0.45	9.11	15			
	C_2	130–150	5.70	0.03	0.66	9.27	22			
Leptosols Umbric (No. 38)	A	0–5	5.25	0.39	9.11	0	23	1.3	0.06	0
		5–10	4.85	0.82	9.09	0	11	0.9	0.06	11.9
	AC	10–35	4.96	0.08	0.71	0	9	0.9	0.09	8.0
		35–50	5.00	0.73	1.09	0	2	0.8	0.05	12.8

annual temperature about -25° C, according to the model of Ryskov *et al.* (1996). Unfortunately, no organic material was found for radiocarbon dating. I assume, based on the works of Zech *et al.* (2000), that the age is greater than 24–25 kyr BP.

2) On the basis of $\delta^{13}C$ values between -8 and -10‰, a cold and dry climatic period with mean annual temperature about 0º C, with little alpine desert vegetation and slightly weathered interstadial soils can be reconstructed. This period likely corresponds to the North Atlantic 2 Heinrich event (Williams *et al.*, 1998). A similar horizon is described by Zech *et al.* (2000) in western Tian-Shan (24,300±1,160 years BP), as well as by Yan *et al.* (1999) in Tibet (25,910±400 years BP).

Table 4. Isotope composition of carbonate and humus carbon in soils of Kirgizskiy Ridge.

Soil **Altitude (a.s.l.)**	**Horizon**	**Depth (cm)**	**Radiocarbon age* (years BP)**	**δ^{13}C humus (‰)**	**δ^{13}C carbonates (‰)**
Chernozem	A	12–18		-25.50	
Haplic (No. 8)		38–44		-25.22	
1,800 m	B	56–76		-25.03	
		76–83		-14.91	
	BC1	83–101		-12.30	-10.07
	C1	101–114		-9.00	-7.68
	C2	114–126		-9.59	-8.53
	Bb_1	126–157		-9.41	-8.01
	C3	157–187		-5.09	-4.36
	Bb_2	187–200	> 24,000	-5.59	-4.65
Leptosols Mollic	A	0–12		-25.34	
(No. 12)	Ab	37–50		-25.39	
2,100 m	B	80–95		-19.37	
	C1	100–110		-8.32	-7.84
	Bb_1	110–125	14,030 ± 880	-24.41	-19.55
	C2	125–135		-8.53	-7.80
	C3	135–165		-8.62	-7.54
	Bb_2	165–200		-9.11	-8.04
Leptosols Mollic	A	4–35	3,010 ± 90	-24.91	
(No. 22)	Ab	35–50	5,560 ± 120	-25.25	
2,350 m	B	87–97	7,130 ± 610	-28.80	-11.94
	C	97–110		-10.58	-8.00
	Bb	110–120	10,100 ± 564	-10.36	-9.30
Leptosols Mollic	A	0–14		-26.01	
(No. 29)		23–37		-25.43	
2,450 m	Ab	37–50	6,440 ± 180	-25.32	
	BC	73–83		-21.01	-11.52
	Bb_1	83–100	9,130 ± 640	-11.12	-10.09
	C1	100–130		-10.19	-9.11
	Bb_2	130-150		-10.62	-9.27
Leptosols Umbric	A	3–10	109 ± 47	-24.18	
(No. 38)	AC	10–35		-24.21	
3,100 m	C	35–50		-23.89	

* Maksimov (1980); Pomortsev (1980); Kovaleva and Evdokimova (1997).

3) According to δ^{13}C in the B_{1b} horizon (-24.41 ‰) of a Chernozem-like soil, the warm period is reconstructed at about 14,030±880 yr BP (date from Pomortsev, 1980) with C-3 type of vegetation. It conforms to the North Atlantic 1 Heinrich event. Similar findings were reported from Western Tian-Shan (Zech *et al.*, 2000) and in China (Yan *et al.*, 1999).

4) Cold and dry climate with temperatures about 0ºC and CAM-type photosynthesis (δ^{13}C in the C1 horizon: -7 to -10 ‰) predominated probably in the early Holocene at about 10,100±564 and 9,130±640 yr BP (date from Pomortsev, 1980).

5) At 8–6 kyr BP, I reconstruct a warm and dry period with mean annual temperature about +15º C, when peats spread out in the piedmonts and lowlands due to glacial melting. Meadows with C-3 type of plants developed, based on δ^{13}C values ranging from –19 to –29 ‰. The age of B horizons at altitudes of 2,350 and 2,450 m is 7,130 and 6,440 ^{14}C yr BP respectively (dates from Maksimov, 1980).

6) The Holocene climatic optimum had a warm and dry climate, with air temperatures higher than present, a C-3 type of vegetation on the Chernozem soils in the valleys can be reconstructed at 6–4 kyr BP. The age of the Ab horizon, as described above, is 5,560±90 years BP.

7) Modern subalpine and alpine vegetation and Chernozem-like soils below 3,000 m, and subalpine soils at altitude above 3,000 m began to develop at 4–3 kyr BP, and a trend towards increasing humidity has taken place ever since (δ^{13}C: -28 ‰). The age of the present-day A horizon is 3,010±90 years BP in Chernozem-like soils and 109±47 years BP in alpine soil. Similar findings were reported by Savoscul and Solomina (1996) from Western Tian-Shan (2,850±110 yr BP and 910±40 yr BP).

Thus, Holocene climatic changes in the mountain regions of Tian-Shan (Kyrgystan) seem to coincide with changes in Tibet, Eastern Europe, and northwestern Caucasus, and correspond to global climate changes. But, these changes were probably less intensive in Central Asia than it in the other regions.

CONCLUSIONS

1) The genetic pattern of Chernozem-like soils of Northern Tian-Shan is determined by a combination of two types of soil formation processes: present-day sub-alpine meadow with mor humus formation and Al-Fe-humus illuviation and paleochernozem with mull humus formation.

2) Since soil evolution is determined by a trend in the landscape development, soils studied indicate cold and dry climate in the late Pleistocene and early Holocene, warm and dry conditions of soil formation in the middle Holocene, and a moderate climate in the late-Holocene.

3) Holocene climatic changes in the Northern Tian-Shan seem to coincide with those of Western and Inner Tian-Shan, Tibet, Eastern Europe, northwestern Caucasus, and correspond to global climate changes, but have lower intensity.

ACKNOWLEDGEMENTS

This work was made in the Soil Science Institute of the Bayreuth University, Germany, under the guidance of Prof. W. Zech and Dr. B. Glaser, with support of a DAAD scholarship.

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Manuscript received: October 20, 2002
Corrected manuscript received: January 23, 2003
Manuscript accepted: July 13, 2003