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SOIL DEVELOPMENT ALONG TWO ALTITUDINAL TRANSECTS FROM NORTH-WEST TO SOUTH-EAST OF THE ISSYK-KUL LAKE (NORTHERN AND CENTRAL TJAN-ŠAN, KAZAKHSTAN-KYRGYZSTAN)

ABSTRACT: COMOLLI R., PREVITALI F. & ŠEFRNA L., *Soil development along two altitudinal transects from north-west to south-east of the Issyk-Kul Lake (Northern and Central Tjan-Šan, Kazakhstan-Kyrgyzstan)*. (IT ISSN 1724-4757, 2003).

In this work two altitudinal sequences, located in the northern and central mountain chain of Tjan-Šan, have been compared. The described areas are partially in Kazakhstan and partially in Kyrgyzstan. The main purpose of the surveys was to study the relations among soils, geomorphology, lithology and vegetation cover, to identify modern and past soil formation processes. For this reason, 12 soil sites among the most representative pedoenvironments recognized have been described, analysed and interpreted.

The survey showed that, even at very high elevations, pedological processes, similar to those responsible for the development of steppe chernozems, proved to be active. This is probably due also to the presence of aeolian silt covers, deposited in recent and in the past.

Moreover, even over the most acidic substrata and under the coniferous forest, we noticed the weakness of podzolization features. The process is retarded by abundance of bases within the parent material, and by their abundant release from vegetation.

KEY WORDS: Soils, Vegetation, Tjan-Šan (Kazakhstan-Kyrgyzstan).

RIASSUNTO: COMOLLI R., PREVITALI F. & ŠEFRNA L., *Distribuzione dei suoli lungo due transetti altitudinali da NO a SE del Lago Issyk-Kul (Tjan-Šan Settentrionale e Centrale, Kazakhstan-Kyrgyzstan)*. (IT ISSN 1724-4757, 2003).

Nel presente lavoro sono esaminate e poste a confronto due pedosequenze altitudinali, situate nella catena del Tjan-Šan settentrionale e centrale, nei territori del Kazakhstan e del Kyrgyzstan. Oggetto principale delle indagini è stato lo studio delle relazioni intercorrenti fra suoli, geomorfologia, litologia e coperture vegetali, con lo scopo di identificare i processi pedogenetici attivi e/o passati. Si sono scelti, quindi, 12 profili pedologici, rappresentativi dei principali pedoambienti riconosciuti, presentandone le descrizioni, le analisi e le relative interpretazioni.

Le indagini hanno evidenziato l'esistenza, anche a quote piuttosto elevate, di processi pedogenetici simili a quelli che controllano la formazione dei chernozems di steppa. Tali processi appaiono essere verosimilmente favoriti dalla presenza di coperture di limi eolici e dalle particolari condizioni climatiche. Le indagini hanno inoltre evidenziato il basso grado di intensità dei segni di podzolizzazione nei suoli, anche su substrati litologici acidi e sotto coperture di conifere. Tale processo pedogenetico sembra ritardato dalla relativa ricchezza in basi del materiale parentale e dal loro continuo rilascio da parte della vegetazione.

TERMINI CHIAVE: Suoli, Vegetazione, Tjan-Šan (Kazakhstan-Kyrgyzstan).

INTRODUCTION

The work deals with sequences of soils lying on the northern and southern slopes of the Hrebet Zailijskij Alatau range, on the northern slopes of the Hrebet Kjungej Ala-Too, and on the northern slopes of the Hrebet Terskej Alatau (fig. 1, fig. 2, and fig. 3). The examined area stretches along a NW-SE direction. It starts from the town of Alma-Ata, crosses the Zailijskij Alatau and the Kjungej Ala-Too mountain ranges, extends through the oriental shore of the Issyk-Kul Lake and the town of Prževal'sk (now called Karakol), and reaches the Terskej Alatau mountain range.

The soils and vegetation of these regions had been studied previously by Mamytov (1963, 1974), Samusenko & Kozhekov (1982), Assing (1986), Nasyrov & Sokolov (1988), Nasyrov & *alii* (1991), and Previtali & *alii* (1997).

These studies concern the vertical zonality of soils, their geographical distribution, the actual existence of podzols on acidic substrata and under spruce forest, the

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FIG. 1 - Map of the Issyk-Kul Lake region in Central Asia.

presence of loessic covers at high altitudes and their possible correlation with the development of chernozem-like soils. In particular, the discussion on cheluviation has been, and it is, very controversial. In 1909, Prasolov was the first one who excluded the presence of podzolic soils under the Tien-Shan spruce (Zonn, 1962). But later, other Authors, also due to the ambiguity the concept of «podzolization» had, believed that, under the same vegetation cover, was active such a process, responsible for the formation of the so-called cryo-podzols and crypto-podzols. But, under *Picea schrenkiana FISCH. et MEY.*, in different periods, numerous and very clashing typologies of soils have been reported: Mountain Forest-dark humiferous soils, Mountain Forest chernozem-like, Brown soils, Kastanozems, Cinnamonic soils, and Carbonate organic soils. All these soils are compatible with the spruce forest because of its drought-resistance and low moisture content of soils. The result is the development of chernozem-forest and mountain-forest dark-coloured dry-peaty soils, with properties similar to the chernozems (Matveev & Samusenko, 1967). In time, Rozanov (1958), Matveev & Samusenko (1967), Samusenko & Kozhekov (1982), Nasyrov & Sokolov (1988), and Previtali & *alii* (1997) supported the absence of podzolization processes in soils of Central Tjan Šan.

Some of the above mentioned issues have not as yet been solved. Therefore, during two following campaigns, some soils, landforms and vegetation have been investigated in the territory between Kazakhstan and Kyrgyzstan, in the central chains of Tjan-Šan, Northwest and East-South-East of the Issyk-Kul Lake. The purpose of this study was to examine the altitudinal zonality of soils and to clarify, as far as it is possible, the reason for persistence of chernozem-like soils at high elevation under coniferous forest. The results of the first campaign were presented in a previous work by Previtali & *alii* (1997).

MATERIALS AND METHODS

Two main rivers of the region, the Čilik and the Čong-Kemin, have their sources between the Zailijskij Alatau and the Kjungej Ala-Too ranges and flow respectively towards East and West (fig. 2).

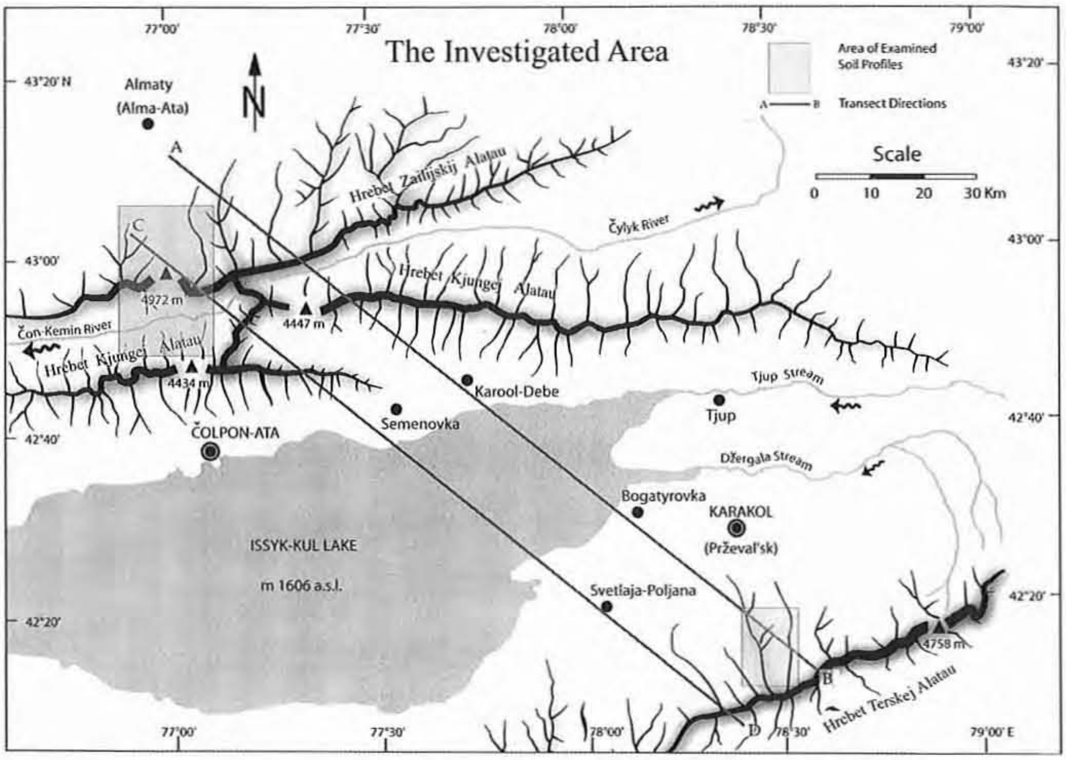
In this work, we refer to two different geographical districts, respectively located south of the town of Alma-Ata and south of Prževal'sk:

i – the Northern District (North of the Issyk-Kul Lake)
ii – the Eastern District (East of the Lake).

The soil transects stretch between latitudes 42°10'N and 43°10'N, and between longitudes 76°45'E and 78°32'E. The investigated sites are situated at altitudes ranging between m 2,000 and m 3,500.

We chose and presented 12 soil sites out of the many examined, as we believe they show, at best, the observed characteristics.

FIG. 2 - Main mountain ranges and rivers of the investigated area. A-B and C-D are the transect directions of the topographic profiles.



GEOLOGICAL AND GEOMORPHOLOGICAL OUTLINES

The Tjan-Šan mountain belt stretches out from West (the Syrdarja River basin) to East (the Gobi desert) for about 2,500 km, and from the northern Kazakh shield to the southern Tarim block it is about 600 km wide. This range is marked by several parallel mountain systems, roughly E-W oriented, with elevations frequently exceeding 5,000 m. At 2,000-3,000 m of altitude, some depressions separate the ridges (e.g., Alma-Atijnskoe Ozero). These depressions are covered by Late Pleistocene-Holocene glacial and fluvioglacial deposits and by Quaternary alluvial beds.

The regional deformations of the Tjan-Šan igneous and metamorphic formations date back mainly to Hercynian

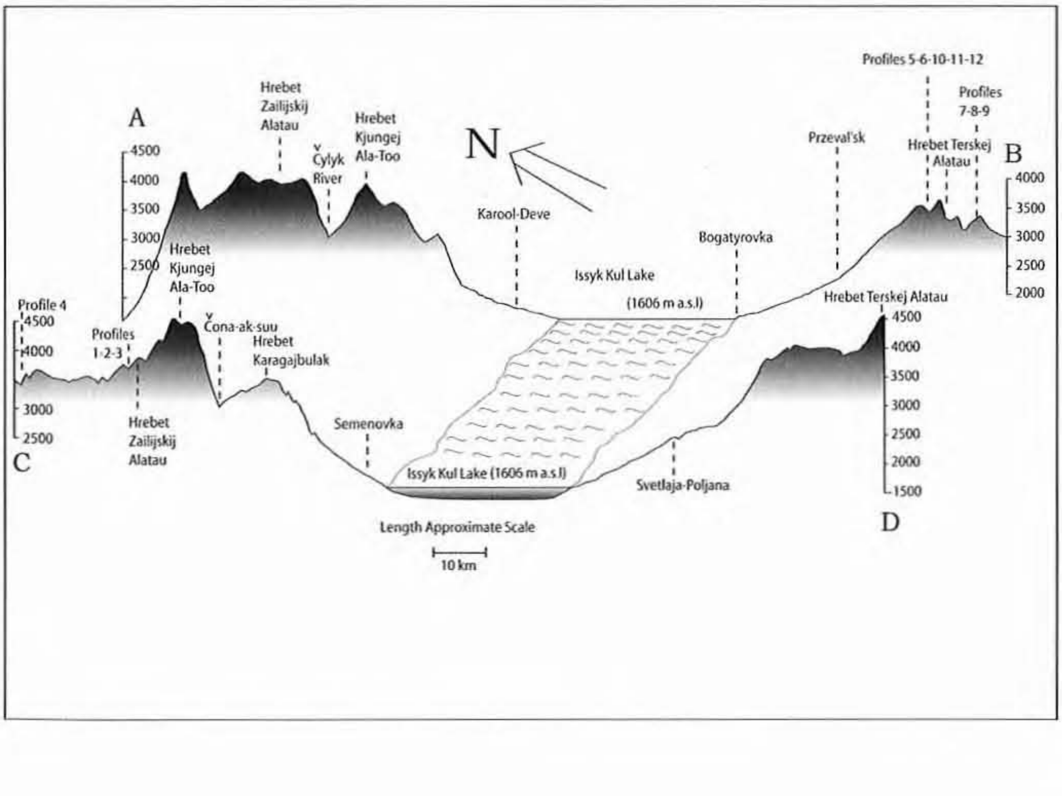


FIG. 3 - Cross sections: A-B and C-D showing the location of the soil profiles.

orogeny (middle Carboniferous-Permian) (Burtman, 1974; Tibaldi & *alii*, 1997).

During the Mesozoic, the range remained somewhat structurally stable. From the Oligocene on to the Quaternary, the Alpine orogenic cycle had a very strong morphotectonic influence. An intense seismicity and a strong uplifting of the range have favoured the remarkable mass wasting which characterises all the slopes. Together with deep torrential carving, the earthquakes are favouring the periodical occurrence of *mures* (debris flow), earthflows and debris avalanches.

During Early Pleistocene, glaciers reached 1,500-1,600 m a.s.l. Still during the last glaciation, the Tjan-Šan plateau was completely glacier-covered, the thickness of ice reaching 600-700 m (Kuhle, 1992), and the Equilibrium Line Altitude (ELA), today located at about 4,000 m a.s.l., dropped down at 3,000 m a.s.l. and even lower (Titkov, 1997). Today, sporadic permafrost has been recorded above 2,000 m a.s.l. (Aizen & *alii*, 1996).

Northern District

Alma-Ata hills, running along the northern fringe of the high Zailijskij Alatau mountains, are moulded in Quaternary deposits, mainly loessic and glaciofluvial. The loess mantle (fig. 4) has a thickness up to 20-30 m. The winds transporting the loess were prevalently northwesterly in the Pleistocene, and easterly in the recent Holocene (Schröder & Eidam, 2001). These deposits covered several and deep reverse faults. The first mountain relieves, southern of the town, are formed by Devonian granites and granodiorites (Ministry of Geology of SSSR, 1983; Abdulin & *alii*, 1984).

Further south; around the Alma-Atijnskoe Lake, Ordovician gabbros and norites aggregate to the above mentioned granites (Tibaldi & *alii*, 1997).

Crossed the drainage divide, in the Kyrgyz country, several great faults mark a sharp lithological change to metamorphic (phyllites, slates, greenschists, amphibolites) and sedimentary facies (mainly sandstones and conglomerates).

Eastern District

The town of Prževal'sk rests on Miocene-Pliocene sedimentary rocks, while, a short distance to the south, the hills are made of Oligocene-Miocene deposits. Due to a great compound of deep faults, the former formations are in spatial continuity, to the south, with Precambrian and Palaeozoic intrusive masses, represented by granodiorites, granites, and gabbros, locally with alternating metamorphic, extrusive igneous, and carbonate rocks.

CLIMATE

Air temperature regime

As the data in tab. 1 show, in the Northern District the average *temperature gradient*, between Alma-Ata and Alma-Atijnskoe Oz., is 0.47°C 100 m^{-1}, but rises to 0.71°C 100 m^{-1} in the summer months. More in particular, Aizen & *alii* (1996) measured, during summer, a minimum value of the gradient (0.22°C 100 m^{-1}) under the spruce forest (2,100÷2,750 m a.s.l.), and a maximum value (0.96°C 100 m^{-1}) under a mixed cover (fig. 5) of subalpine meadow and spruce forest (1,500÷2,100 m a.s.l.).

FIG. 4 - Chernozem developed on a loess layer (4 m thick) lying on glaciofluvial cobbles and boulders near Alma-Ata.

According to the data in tab. 2, in the Eastern District the average *summer temperature gradient* turns out to be 0.55 °C 100 m^{-1}, on the northern slopes of this mountain range, between Prževal'sk (1,770 m a.s.l.) and Karakol'skaja (3,100 m a.s.l.).

Precipitation regime

On the northern slopes of the Zailijskij Alatau range (Northern District), near 2,000 m, the annual variation of long-term mean precipitations is a function of altitude (tab. 3). At the upper elevations, an inversion gradient seems to occur.

If we merely take the summer months into consideration, the *precipitation gradient* turns to be more regular, with values around 8 mm 100 m^{-1}.

TABLE 1 - Mean monthly and annual air temperatures (°C) in the Zailijskij Alatau range (Northern District) (from Nasyrov & *alii*, 1991; Schröder & *alii*, 1996)

Locality	Station No.	Elevation (m a.s.l.)	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	*Mean annual*
Alma-Ata	1	825	-7.4	-5.5	1.7	10.4	16.6	20.7	23.0	22.3	16.8	9.2	1.4	-4.4	*8.7*
Talgar	2	1,015	-7.1	-5.5	1.4	9.1	15.1	19.8	21.3	20.2	14.9	7.4	1.3	-4.4	*7.8*
Medeo	3	1,713	-4.3	-3.3	0.7	6.4	11.7	15.9	18.0	17.5	12.5	6.5	1.8	-2.5	*6.7*
Alma-Atijnskoe Ozero	4	2,511	-9.7	-9.5	-5.1	0.3	5.4	9.1	10.5	10.5	6.5	1.3	-3.2	-7.7	*0.7*

Stations location. 1: Observatory. 2: 20 km east from Alma Ata. 3: 5 km south from Alma Ata. 4: 15 km south from Alma-Ata.

TABLE 2 - Mean monthly and annual air temperatures (°C) in the Terskej Alatau range (Southern District) (from Mamytov, 1963)

Locality	Station No.	Elevation (m a.s.l.)	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	*Mean annual*
Čolpon-Ata	5	1,640	-2.8	-2.0	1.5	7.1	11.5	15.1	16.9	16.7	13.0	7.6	2.6	-1.2	*7.2*
Prževal'sk	6	1,774	-6.1	-5.2	-0.2	6.9	11.4	14.8	16.4	16.0	12.0	6.1	-0.2	-4.3	*5.6*
Karakol'skaja	7	3,100	-19.1	-16.3	-8.2	-0.6	4.0	7.1	9.3	8.9	4.2	-2.6	-9.8	-17.3	*-3.4*
Tjan'-Šan'	8	3,672	-21.2	-19.5	-13.4	-7.0	-1.1	2.3	4.3	3.9	-0.5	-6.8	-14.3	-19.5	*-7.7*

Stations location. 5: Northern side of the Issyk-Kul Lake. 6: Suburbs of Prževal'sk. 7: 35 km south from Prževal'sk. 8: Kyrgyz unidentified station.

TABLE 3 - Mean monthly and annual precipitations (mm) in the Zailijskij Alatau range (Northern District) (from Nasyrov & *alii*, 1991; Schröder & *alii*, 1996)

Locality	Station No.	Elevation (m a.s.l.)	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	*Mean annual*
Alma-Ata	1	825	27	28	59	90	90	59	36	24	27	48	46	31	*565*
Talgar	2	1,015	20	25	63	90	115	79	41	25	37	35	44	32	*606*
Medeo	3	1,713	28	30	79	129	183	116	64	42	51	56	58	36	*872*
Alma-Atijnskoe Ozero	4	2,511	17	20	49	79	142	105	92	63	51	39	36	27	*720*

Stations location. 1: Observatory. 2: 20 km east from Alma Ata. 3: 5 km south from Alma Ata. 4: 15 km south from Alma-Ata.

In winter, this area is under the strong influence of the Siberian anticyclonic circulation, which decreases precipitation (Aizen & *alii*, 1995). After March, weak cyclonic activity and moderately cold air from the west, northwest and north, cause precipitations. The ratio, between warm season (May-September) and the annual precipitations, increases from the lowest to the highest station, going from 0.42 to 0.49, 0.52 and 0.63. Over about 2,000 m of altitude, the rainiest months are May, June and July. The *seasonal pattern of precipitations* is slightly different at different altitudes.

In the Terskej Alatau range (Eastern District), the precipitations are concentrated during the spring-summer (high-sun) season (tab. 4), under the clear influence of a semiarid and steppe climate. The *precipitations* are everywhere somewhat low, due to the action of the Siberian anticyclone, and seem to be weakly correlated with the altitudes, but they decrease over 2,000 m. The *seasonal pattern of precipitations* is very similar at different altitudes, with a unique maximum in June-July.

Since in both districts the main rain maxima occur in spring-summer, the temperatures in those seasons are relatively mitigated. Besides, the Eastern District shows a more marked character of continentality.

Soil temperature and moisture regimes

The soil temperature regimes (Soil Survey Staff, 1999), *frigid* and *cryic*, were estimated for soils not saturated with water during long times and covered, or lacking of, O horizons (tab. 5). The thermal conditions responsible for permafrost formation have been found above 4,000 m a.s.l. in the Northern District, and above 4,250 m in the Eastern District.

In the Northern District, the soil-water budget (fig. 6, a), which was determined using the Thornthwaite's method, underlines that, for a medium AWC (Available Water Capacity) of 75 mm, at the station of Alma-Atijnskoe Ozero (2,511 m a.s.l.), there is only a low-short water deficit.

In the Eastern District (fig. 6, b and c), on the contrary, the water deficit is very high: at Prževal'sk (1,774 m a.s.l.)

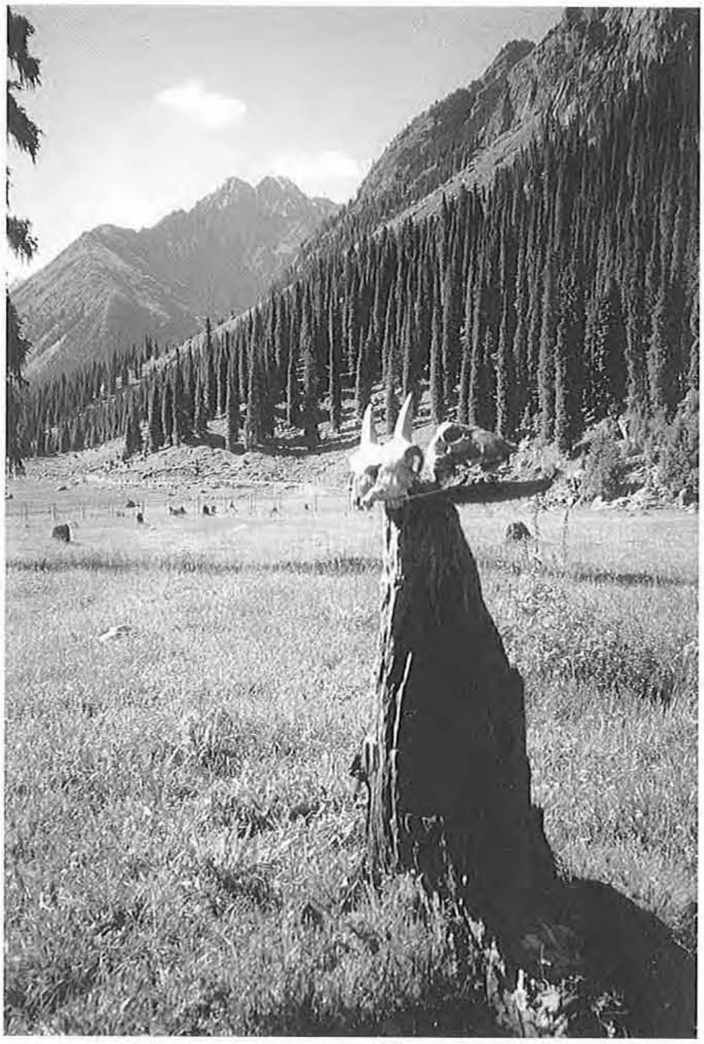


FIG. 5 - Subalpine meadow and spruce forest (*Picea schrenkiana FISCH. et MEY.*) in the Eastern District.

it is equal to 28% of precipitations, while at Karakol'skaja (3,100 m a.s.l.) it is even 97% of precipitations.

The soil moisture regime (Soil Survey Staff, 1999) in the Northern District was always *udic*, while in the Eastern it appeared to be *ustic* at Prževal'sk, probably *aridic* at Karakol'skaja.

VEGETATION VERTICAL ZONALITY

The upper limit of sparse vegetation and soil cover is 3,300-3,400 m a.s.l. (Mamytov, 1963; Nasyrov & Sokolov, 1988; Previtali & *alii*, 1997), reaching locally, on driest and warmest slopes, also 3,800 m. Over this altitude, there are bare rocks, detrital deposits and fans, moraines and glaciers. The line of the perennial snows is at 4,000÷5,000 m a.s.l., depending on slope orientations.

Above Alma-Ata (Medeo), in the Hrebet Zailijskij Alatau, the upper limit of the arboreal vegetation (*Picea schrenkiana FISCH. et MEY.*) is at about 2,700 m a.s.l. (locally up to 2,800 and 3,000 m a.s.l.) (Previtali & *alii*, 1997). On the northern slopes of the Hrebet Terskej Alatau, south of Prževal'sk, it rises up to 2,900÷3,000 m (Aizen & *alii*, 1996).

At high altitudes, there is a substantial similarity of the vertical succession of vegetation in the two Districts, with some altitudinal changes due to different slope aspects. From highest to lowest elevations, the glacio-nival, the subnival, the high alpine tundra, the alpine, and the subalpine stages follow one another. At lower altitudes, on the south-facing slopes of both the Districts, one can observe an increase of elevation of the mountain steppe stage.

In general, there is a strong development of cryohygrophile species on northern slopes, while the thermoxerophile species of the mountain steppe prevail on south

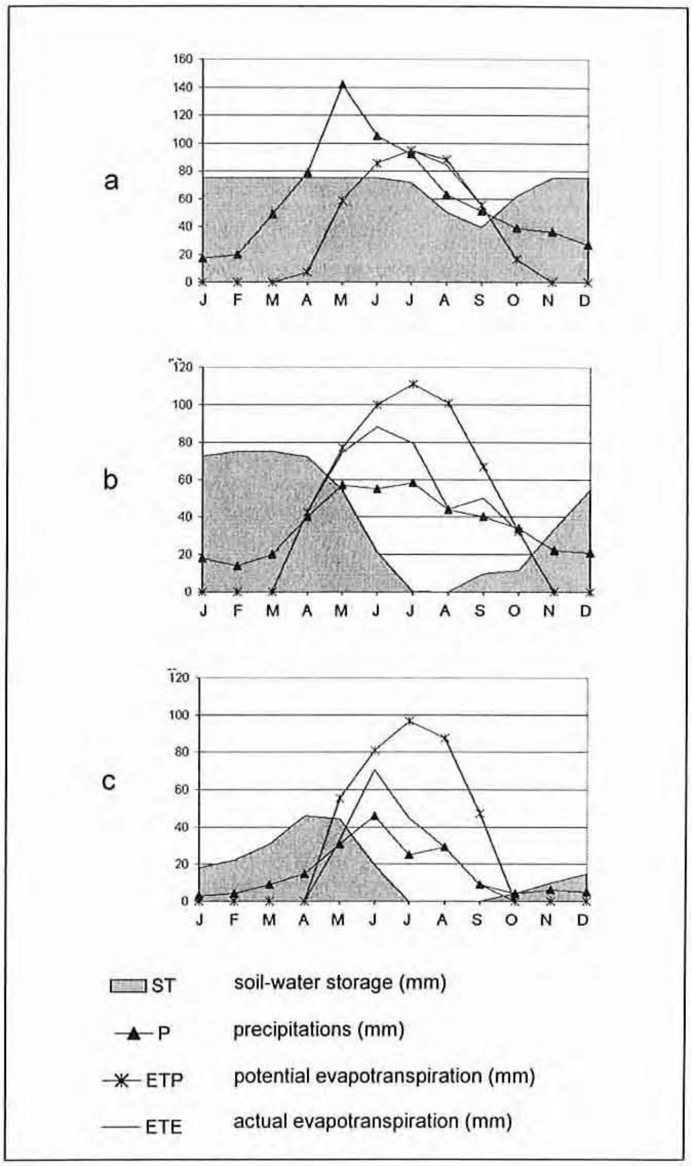


FIG. 6 - Soil-water budget for:
a) Alma-Atinskoe Ozero (2,511 m a.s.l.);
b) Prževal'sk (1,774 m a.s.l.);
c) Karakol'skaja (3,100 m a.s.l.).

TABLE 4 - Mean monthly and annual precipitations (mm) in the Terskej Alatau range (Southern District)

Locality	Station No.	Elevation (m a.s.l.)	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	*Mean annual*
Čolpon-Ata	5	1,640	10	8	18	14	25	30	45	33	25	24	8	10	*250*
Prževal'sk	6	1,774	18	14	20	40	57	55	58	44	40	34	22	21	*423*
Karakol'skaja	7	3,100	3	4	9	15	31	46	25	29	9	4	6	5	*186*
Tjan'-Šan'	8	3,672	5	5	12	23	40	58	57	49	22	10	7	7	*295*

Station locations. 5: Northern side of Issyk-Kul Lake. 6: Suburbs of Prževal'sk. 7: 35 km south from Prževal'sk. 8: Kyrgyz unidentified station.

TABLE 5 - Estimation of soil temperature regimes, on the basis of data from Nasyrov & *alii* (1991) and from Mamytov (1963), respectively for the Northern District and for the Eastern District

	Northern District (m a.s.l.)		Eastern District (m a.s.l.)	
	with O horizon	without O horizon	with O horizon	without O horizon
Frigid	< 2,750	< 1,800	< 2,900	< 1,800
Cryic	2,750-4,000	1,800-4,000	2,900-4,250	1,800-4,250

facing slopes. The northerly and westerly humid air masses heighten such distribution of the vegetation covers.

SOILS

The field description of the soil profiles and the site surface features were made according to FAO guidelines (FAO, 1990). Soil colours were noted according to the Munsell colour charts. The data from laboratory analyses were compared with field observations. The soils were classified according to the World Reference Base for Soil Resources (FAO, ISRIC & ISSS, 1994, 1998). In addition, we located the taxonomic correspondences with the Référentiel Pédologique (AFES-INRA, 1998) and the Legend of the Soil Map of the Kazakh SSR *(G.U.G.K., 1976).*

LABORATORY PROCEDURES

The analyses on soils were carried out according to the procedures of Ministero delle Politiche Agricole e Forestali (2000).

Bulk soil samples were air dried and sieved to remove coarse fragments (>2 mm). Soil particle-size classes included: coarse sand (2-0.1 mm), fine sand (0.1-0.05 mm), coarse silt (0.05-0.02 mm), fine silt (0.02-0.002), and clay (< 0.002 mm). Distribution was determined by the pipette method after dispersion with $(NaPO_3)_6$ (ISO 11277).

Soil pH was potentiometrically measured in a 1:2.5 soil-water suspension (ISO 10390).

Organic carbon was determined, in the Northern District soil samples, by Springler-Klee method (ISO 14235). The Walkley-Black procedure was followed for the samples of the Eastern District. In addition the furnace dry combustion was used for organic horizons.

Cation exchange capacity (CEC) and exchangeable bases were determined by $BaCl_2$-triethanolamine pH 8.2 method and atomic absorption spectrometry (ISO 11260).

Carbonates were determined by Dietrich-Frühling calcimeter (ISO 10693).

Total iron (Fe_t) was determined after HCl-HNO_3 digestion. Dithionite soluble Fe (Fe_d) and Al (Al_d) were extracted by the DCB method (Mehra & Jackson, 1960). The noncrystalline and poorly crystalline inorganic and the organic complexed iron (Fe_{ox}) and aluminium (Al_{ox}) were extracted by acid ammonium oxalate (Schwertmann, 1964). Pyrophosphate-extractable iron (Fe_p) and aluminium (Al_p) were extracted by McKeague & Schuppli (1982) methods. Both elements were determined by atomic absorption spectrometry.

RESULTS AND DISCUSSION

The geographical features of the investigated sites, and the morphological, chemical and textural properties of the soils are summarized in tab. 6. In this table is also reported the soil classification according to the World Reference Base for Soil Resources (FAO, ISRIC & ISSS, 1994, 1998).

In table 7 the soils are classified according to the *Référentiel Pédologique* (AFES-INRA, 1998), and the Legend of the *Soil Map of the Kazakh SSR* (G.U.G.K., 1976).

SOIL TEXTURAL PROPERTIES

Northern District

The silt loam textures are predominant, in agreement with the hypothesis of a frequent aeolian addition in this region. The *argillification index* (clay%/silt+sand%) is higher in the A horizons of No.1 and No.3 profiles, where it reaches the value of 0.32. But in the first profile this seems to be due to a former abundance of clay in the loamy diamicton material, while in the second one it is

TABLE 6 - Soil profiles location, classification and main characteristics

Profile Location Elevation Aspect Slope	*Soil type* (FAO, ISRIC & ISSS, 1994, 1998). Parent material	Horizon	Depth (cm)	Colour (moist)	pH (H_2O)	$CaCO_3$ (%)	Org. C (%)	Organic Matter (%)	CEC (cmol$^+$ kg^{-1} soil)	Base sat. (%)	Spodicity Index ($^1/_2Fe_{ox}$+ Al_{ox} (%))	Particle-size distribution (%)		
												Sand	Silt	Clay
					NORTHERN DISTRICT									
No. 1 Jugo-Zapadnoj Talgar stream 42°56'N 77°08'E 3,530 m SE 5%	*Cryic Leptosol.* Bouldery sandy loam moraine over crystalline schists.	Ah	0-30	10YR 3/4	5.2	0.0	6.1		44.4	54	0.44	26	50	24
		C	30-50	2.5Y 5/3										
		R	50-80+											
No. 2 Ak-Su stream 42°53'N 77°05'E 3,140 m E 3-4%	*Geli-Eutric Regosol.* Bouldery, pebbly and loamy diamicton over schist debris.	Ah	0-10	10YR 2/2	6.5	0.0	6.6		37.8	78	0.62	28	63	9
		BA	10-40	10YR 3/3	6.6	0.0	2.8		35.6	77	0.71	21	65	14
		C/R	40-50+											
No. 3 Čong-Kemin river42°54'N 77°03'E 2,980 m Level	*Haplic Phaeozem.* Alluvial deposit, buried by aeolian material.	A	0-20	10YR 3/2	6.0	0.0	3.8		47.0	64	0.75	19	57	24
		AC	20-60	10YR 3/3	6.4	0.0	1.2		39.1	66	0.62	26	59	15
		2C	60-80+											
No. 4 Prahodnaia stream 43°03'N 76°55'E 2,160 m W 80-100%	*Eutric Cambisol.* Magmatic debris and diamicton.	Oe	5-0	10YR 2/1										
		Ah	0-10/15	10YR 3/2	5.7	0.0	4.8		27.8	64	0.34	47	38	15
		BA	10/15-25/30	10YR 3/3	5.9	0.0	0.7		9.1	70	0.21	70	22	8
		C	25/30-50+			0.0								
					SOUTHERN DISTRICT									
No. 5 South of Prževal'sk, Karakol stream 42°19'N 78°26'E 2,755 m SE 80%	*Skeletic Phaeozem.* Granite and marble talus deposit.	Ah1	0-9	10YR 2/2	5.9	0.5	12.5		63.8	100	0.31	63	31	6
		Ah2	9-15	10YR 2/2	6.0	0.0	9.2		56.5	100	0.38	53	38	9
		2A	15-38	10YR 3/2	5.9	0.2	2.1		30.9	98	0.35	26	55	19
		2Bw	38-58	10YR4/3.5	5.8	0.7	0.6		19.6	100	0.20	59	29	12
		2CB	58-75+	10YR 5/3	6.3	0.9	0.4		20.8	100	0.17	39	43	18
No. 6 South of Prževal'sk, Karakol stream 42°19'N 78°27'E 2,850 m N 70%	*Episkeleti-Pachic Phaeozem (siltic).* Slate debris of alluvial fan, buried by aeolian silt.	Oi	0.5-0											
		Oe	0-3	10YR 3/2	5.5	0.6		65.3			0.27			
		Oa	3-6	10YR 2/2	5.4	1.4		50.3			0.42			
		Ah1	6-12	10YR 2/2	5.7	0.6	13.6		74.0	100	0.42	14	75	11
		2Ah2	12-40	10YR 3/2	6.5	0.9	6.6		50.4	100	0.25	50	45	5
		2AC	40-55	10YR 3/3	7.2	0.1	2.1		15.7	100				
		2C	55-75+	10YR 4/2										
No. 7 South of Prževal'sk, Kol-Ter stream 42°17'N 78°31'E 3,455 m NE 40%	*Mollihumic Leptosol.* Silty loam colluvial mudflow over solid granite, buried by aeolian silt.	Oi	0.5-0											
		Oa	0-2	10YR 2/2	5.8	0.8		51.2			0.27			
		Ah	2-4	10YR 3/3	5.5	0.0	8.0		41.1	100		33	62	5
		AB	4-24	10YR3.5/3	5.2	0.0	2.6		26.2	55	0.41	19	72	9
		2R	24-45+											
No. 8 South of Prževal'sk, Uyun-Ter stream 42°13'N 78°30'E 3,600 m SSE 10%	*Eutri-Skeletic Regosol.* Bouldery sandy loam ancient diamicton, buried by aeolian silt. (Figs. 7 and 8)	Oi	0.5-0											
		Oa	0-3	10YR 2/2	6.1	0.6		68.1			0.13			
		Ah	3-6	10YR2.5/2	5.7	0.0	13.4		67.5	100		62	36	2
		2A	6-9	10YR3/2	5.6	1.1	6.1		48.4	86	0.47	33	63	4
		3CB	9-20	1Y4/5	5.9	0.0	1.0		9.4	75	0.20	68	28	4
		3C	20-60+	2.5Y4.5/3	6.6	0.3	0.5		9.3	100	0.18	70	25	5
No. 9 South of Prževal'sk, Uyun-Ter stream 42°14'N 78°31'E 3,600 m NW 15%	*Eutri-Skeletic Regosol.* Recent bouldery diamicton. (Fig. 9)	Oi	0.5-0											
		Oa/Oe	0-2	10YR 2/2	5.7	0.0		47.2						
		A	2-6	10YR 3/3	5.1	0.3	5.6		29.9	83	0.34	63	34	3
		CA	6-19	2.5Y 4/4	5.6	1.0	1.8		9.4	65	0.14	72	25	3
		C	19-45+	5Y 4/1	5.9	0.0	0.4		5.6	100	0.09	76	20	4
N. 10 South of Prževal'sk, Karakol stream 42°19'N 78°29'E 2,450 m Level	*Humi-Gleyic Fluvisol (Endo-Skeletic, Eutric).* Alluvial deposits. (Fig. 10)	Ap	0-8	10YR 3/1	7.1	0.3	6.1		27.4	100				
		C	8-45	2.5Y 4/2	7.5	1.7	1.4		14.0	100	0.13	42	50	8
		Cg	45-55	5Y 4/1	7.2	1.2	1.2		10.4	100	0.07	29	66	5
		2Cg2	55-65+	10YR 4/5	7.2	0.1	0.4		7.8	100	0.18	43	51	6
No. 11 South of Prževal'sk, Karakol stream 42°19'N 78°28'E 2,470 m W 80%	*Skeleti-Humic Regosol (Eutric).* Crystalline schists and serpentinites talus deposit.	Oi	2-0											
		Oe	0-5	10YR 2/1	5.0	1.4		52.1			0.33			
		Ah	5-21	10YR 3/3	4.5	0.6	6.4		49.1	69	0.40	40	45	15
		CA	21-65+	2.5Y 4/4	5.8	0.0	1.5		17.6	78	0.15	62	25	13
No. 12 South of Prževal'sk, Karakol stream 42°19'N 78°27'E 2,695 m E 70%	*Eutri-Skeletic Cambisol.* Crystalline rocks talus deposit.	Oi	2-0											
		Oe	0-2	10YR 2/1	6.0	0.0		45.0						
		A	2-7	10YR 3/2	5.7	0.0	13.6		72.9	100	0.24	31	55	14
		AB	7-16	10YR 3/3	5.4	0.5	2.4		30.5	78	0.30	49	37	14
		Bw	16-60	10YR 4/4	5.8	0.2	2.1		33.7	100	0.37	45	40	15

TABLE 7 - Soil classification, according to: (a) *Référentiel Pédologique* (AFES-INRA, 1998); (b) Legend of the *Soil Map of the Kazakh SSR* (G.U.G.K., 1976)

PROFILE No. 1
(a) CRYOSOL MINÉRAL lithic, mesosaturated, gravelly loam, from recent moraine, with discontinuous dry permafrost, of subnival-rocky stage of alpine prairie.
(b) High Mountain Meadow Alpine soil.

PROFILE No. 2
(a) CRYOSOL MINÉRAL regosolic, mesosaturated, gravelly silt loam, from glacial drift, seasonally frozen, of mountain xerophile steppe-like meadow stage.
(b) Mountain Meadow Alpine soil.

PROFILE No. 3
(a) Quasi-PHAÉOSOL HAPLIQUE mesosaturated, silt loam, from aeolian silt and alluvial pebbles over bottom moraine, of alpine-subalpine subxerophile meadow stage.
(b) Mountain Meadow Alpine (Subalpine) soil.

PROFILE No. 4
(a) BRUNISOL MÉSOSATURÉ leptic, humiferous, mesosaturated, gravelly silt loam, from slope debris and morainic drift, of the upper forest (*Picea schrenkiana*) stage.
(b) Mountain Forest Dark Coloured soil.

PROFILE No. 5
(a) COLLUVIOSOL-PHAEOSOL dark, humiferous, saturated, sandy loam in surface and gravelly silt loam in depth, on talus midslope, from granite and marble debris, of transitional belt between the upper forest (*Picea schrenkiana*) and the lower subalpine stage of dense mesohygrophile alpine meadow.
(b) Meadow-chernozemic soil (?).

PROFILE No. 6
(a) COLLUVIOSOL chernic, humiferous, saturated, gravelly silt loam in surface and stony sandy loam in depth, on alluvial fan midslope, from aeolian silt over slate debris, of subalpine meadow stage.
(b) Meadow-chernozemic soil (?).

PROFILE No. 7
(a) COLLUVIOSOL humiferous, saturated in surface and mesosaturated in depth, silt loam, stony in depth, from aeolian material and colluvial mud-flow over solid granite, of alpine meadow stage.
(b) Mountain-meadow chernozem-like soil (?).

PROFILE No. 8
(a) RÉGOSOL eutric, resaturated at the surface and sub- and mesosaturated in depth, sandy and silt loam, cobbly and bouldery (granite), from aeolian silt over old moraine, of alpine meadow (subnival) stage.
(b) The cumulative character of the soil profile does not exactly allow the correlation with the main types of the G.U.G.K. classification.

PROFILE No. 9
(a) RÉGOSOL eutric, sub- and mesosaturated in surface and saturated in depth, cobbly sandy loam in surface and cobbly loamy sand in depth, from recent moraine, of alpine meadow (subnival) stage.
(b) The major soil grouping of Regosols does not appear in the G.U.G.K. and Stolbovoï's (2000) classifications.

PROFILE No. 10
(a) FLUVIOSOL BRUT humiferous, redoxic, saturated, silt loam, cobbly in depth, from alluvial deposits, of mountain-pastured meadow in the bottom of a valley.
(b) Alluvial neutral soil.

PROFILE No. 11
(a) COLLUVIOSOL humiferous, mesosaturated, gravelly loam in surface and cobbly sandy loam in depth, from crystalline schists and serpentinites, on a footslope of active talus, of mountain forest stage (*Picea schrenkiana*).
(b) Mountain Forest soil (?).

PROFILE No. 12
(a) BRUNISOL SATURÉ colluvial, humiferous, gravelly silt loam in surface and stony loam in depth, on a stable talus backslope, from crystalline rock debris, of the upper mountain forest (*Picea schrenkiana*) stage.
(b) Brownzems weakly unsaturated (with weak clay translocation).

probable that the loess-like parent material actually underwent a higher weathering.

The clay illuviation within the profiles seems to be absent or negligible, except possibly in profile No. 2.

The sum of very fine sand plus coarse and fine silt reaches the highest values in profile No. 3 (71.8% and 75.4%), implying a probable aeolian contribution.

Eastern District

Here, the soil textural classes are mainly sandy loam, as repeatedly reported in the world soils of the high-energy mountain environments. Such a datum, combined both to the low values of the *argillification index* and to the *horizonation degree*, confirms the low chemical weathering and the low intensity of the pedogenic processes. The high elevations, the cumulative characters and the relative young ages of the parent materials do not favour soil formation and evolution. The silt loam textures, prevailing in the present A horizons, as well as in the buried ones, suggest a frequent aeolian addition, except for profile No. 10, that has fluvial cumulative characters. Profile No. 7, apparently covered by loess-like cover, shows a low index of argillifi-

FIG. 7 - Eutri-Skeletic Regosol, developed from aeolian silt covering old diamicton, below alpine meadow of subnival stage (Profile No. 8; 3,600 m a.s.l., Uyun-Ter stream catchment, south of Prževal'sk). Marks at 10-cm intervals.

cation, indicating that the deposition of aeolian material has been a recent event (Schröder & Eidam, 2001).

The sum of very fine sand plus coarse and fine silt is more than 70% of the fine earth in surficial or buried horizons of profiles No. 6, No. 7, and No. 8. This index also seems to confirm some probable aeolian additions, which occurred in recent times. Regarding the aeolian additions, it is significant to compare the horizon textures, that are considered to show an aeolian silt input, to those of a typical carbonate loess ($CaCO_3$ 11.0%), located at 2000 m a.s.l., near the Karakol stream bridge. This loess is composed of 17.5% sand, 63.9% silt, and 18.6% clay, pointing out a strong textural similarity with the profiles that underwent a likely aeolian silt deposition.

In both Districts, it seems not possible to determine a correlation between the clay content and the elevation, as sometimes it has been found in similar environments (Bäumler & Zech, 1994).

SOIL CHEMICAL PROPERTIES

Northern District

The soil reactions range between strongly acid, with pH(H_2O) 5.2 (profile No. 1), and neutral, with pH(H_2O) 6.6, in the deepest horizon of profile No. 2.

All the soils show a high CEC, with average values around 34 cmol$^+$ kg^{-1}, except for the BA of profile No. 4. Such values are mainly related to a high content of organic matter. Exchangeable Ca^{2+} ranges between a maximum of 28 cmol$^+$ kg^{-1}, in Ah horizon of profile No.2, and a minimum of 5 cmol$^+$ kg^{-1} in BA horizon of profile No. 4. Mg^{++} varies between 3 cmol$^+$ kg^{-1} in A horizon of profile No.3, and 0.8 cmol$^+$ kg^{-1} in BA horizon of profile No. 4.

The soils appear to be constantly mesosaturated, reflecting the influences of limited leaching, due to relatively

FIG. 8 - Periglacial landscape surrounding the Regosol of Profile No. 8.

FIG. 9 - Regosol on recent diamicton (Profile No. 9; 3,600 m a.s.l., Uyun-Ter stream catchment, south of Prževal'sk). Marks at 10-cm intervals.

low rainfall (tab. 3), and lithology, also pointing out the role of vegetation in recycling the bases.

Eastern District

The soil pH ranges between very strongly acid, with pH(H_2O) 4.5 (profile No. 11), and neutral, with pH(H_2O) 7.2 (profile No. 6). The profile No. 10, which developed on alluvial materials, is a particular case, it shows values ranging from neutral to slightly alkaline in all the horizons. It has also the highest carbonate content, namely 1.7%. The total carbonates, everywhere very scarce, are, however, present, denoting a probable aeolian contribution and a certain release coming from some substrata.

The cation exchange capacity is rather high, with an average of about 32 cmol^{+} kg^{-1}, it correlates with the high contents in organic carbon. Ca^{2+} in the exchange complex ranges between a maximum of 114 cmol^{+} kg^{-1} (exchangeable and soluble) in A horizon of profile No. 12, and a minimum of 13 cmol^{+} kg^{-1} in AB horizon of profile No. 7. Mg^{++} varies between 5 cmol^{+} kg^{-1} in A horizon of profile No. 12 and 1 cmol^{+} kg^{-1} in A horizon of profile No. 10. The average base saturations are about 92% (subsaturated soils), with an intense base recharge due to the vegetation, and the low precipitations in this District (tab. 4).

On the whole, in both the two Districts, it can be noticed that the mean values of pH(H_2O), in the examined horizons, range around 5.8-6.0 (moderately acid), excluding profiles No. 3 and No. 10, where the alluvial origin of the parent material tends to influence the other soil forming factors. Such soil reactions do not favour the release of free Al ions. Exchangeable Ca is particularly abundant in soils of the Eastern District, due to a lesser climatic leaching in this area. The recharge of soil bases is ensured by the aeolian and plant inputs. It can be noticed, however, the particular tendency for desaturation in A horizons of Northern District soils, while Eastern District soils show constantly higher values of base saturation.

FIG. 10 - Humi-Gleyic Fluvisol on alluvial deposits along the Karakol stream (Profile No. 10; 2,450 m a.s.l.; south of Prževal'sk). Marks at 10-cm intervals.

SOIL ORGANIC MATTER

In the A horizons of the investigated areas the organic matter content ranges from moderate (2.4%) to very abundant (23.4%). Moreover, the content of organic carbon (weighted average over the upper 20 cm of the soil profile, excluded the organic O horizons) shows a fairly good correlation with the climatic parameters, mainly the mean annual and summer air temperatures (fig. 11).

The relation is defined by the equation:

$$\text{Org. C} = 2.386 - 3.199\ \text{T\_an} - 1.647\ \text{T\_est} - 0.376\ \text{T\_an}^{\wedge}2 + 0.19\ \text{T\_est}^{\wedge}2\ (R^2=0.71)$$

where Org. C is the organic carbon (%), T_an the mean annual air temperature in °C, T_est the mean summer air temperature in °C (mean of June, July, and August).

In addition, it can be notice that in similar soils it has been ascertained a strong prevalence of the humic acids on fulvic acids (Previtali & *alii*, 1997), as expected for the melanization process. The multiple linear regression (fig. 12) among CEC, OM and textures makes it possible to estimate that the CEC value of organic matters is on the average (about 234 $\text{cmol}^+\ \text{kg}^{-1}$), while the average of the clays is high (98 $\text{cmol}^+\ \text{kg}^{-1}$) and the one of silt is moderate (20 $\text{cmol}^+\ \text{kg}^{-1}$). It may hence be inferred that the clays are active, presumably of smectitic type (Baize, 1988).

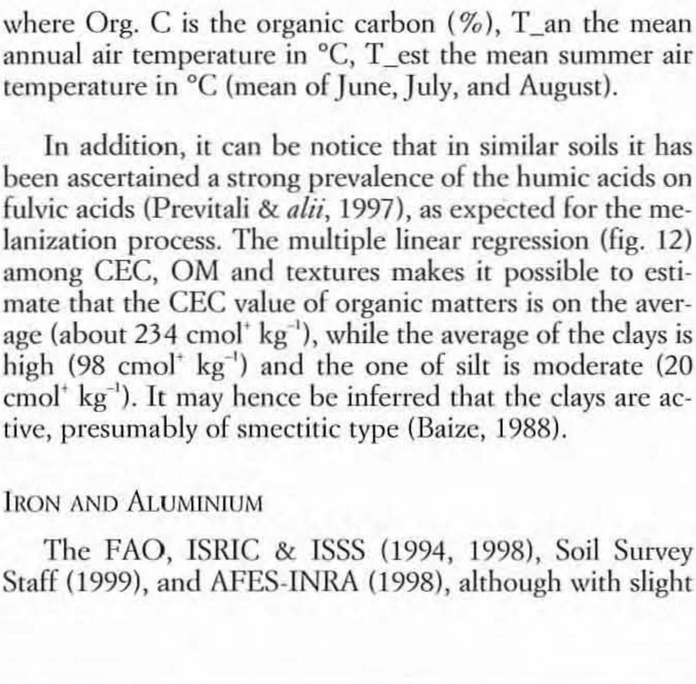


FIG. 11 - Organic carbon measured (actual) and estimated (predicted) on the basis of the annual and summer temperature.

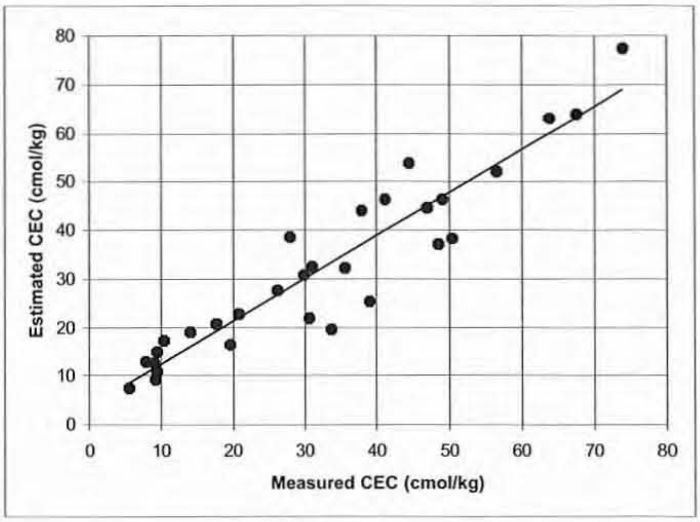


FIG. 12 - Measured and estimated CEC as function of organic matter, clay and silt for mineral horizons (r^2=0.88).

IRON AND ALUMINIUM

The FAO, ISRIC & ISSS (1994, 1998), Soil Survey Staff (1999), and AFES-INRA (1998), although with slight differences, found the diagnostic criteria for identification of the podzolic/spodic features and horizons, on different chemical and morphological characters, among which are fundamental the contents in Al_{ox} and Fe_{ox} (*Spodicity Index*). Only in the horizons of soil profiles No. 2 and 3 in the Northern District the Spodicity Index turned out to exceed the 0.50%, diagnostic threshold for the spodic horizon or materials (Soil Survey Staff, 1999). In this District, the rainfall, the annual temperatures, the acidic mineralogical composition of most parent rocks, and the altitudes, seem to be environmental factors favourable for the development of the podzolization process. Therefore in all soil samples were measured also Fe_d, Al_d, Fe_p and Al_p. But the ratios Fe_p+Al_p/Fe_d+Al_d and Fe_p+Al_p/clay (Soil Survey Staff, 1990) resulted to be lower by 0.50 and 0.20, respectively. Nevertheless, to better checking the existence of any podzolization process, firstly the temperatures and the precipitations were estimated for each investigated site, on the basis of the regression equations between the climatic parameters and the elevation. Then the Spodicity Index was calculated on the basis of summer temperatures and precipitations. This index has shown a positive correlation with the temperatures and the precipitations (fig. 13).

The obtained equation was:

$$\text{Spodicity Index} = -1.593 + 0.0129\ \text{P\_est} - 0.0000245\ \text{P\_est}^{\wedge}2 + 0.179\ \text{T\_est} - 0.0126\ \text{T\_est}^{\wedge}2\ (R^2=0.84)$$

where P_est = average summer precipitations in mm (the sum of June, July, and August); T_est = average summer temperatures in °C (mean of June, July, and August).

In general, soils belonging to Eastern District show values of the Spodicity Index even lower than previous ones and only in profile No. 12, under spruce, we can find in the B horizon the evidence of a weak illuvial process.

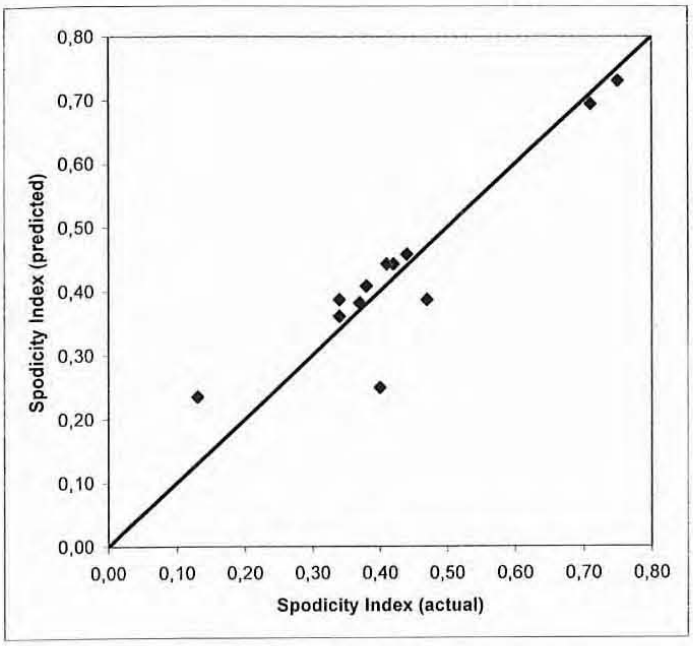


FIG. 13 - The *Spodicity Index* measured (actual) and estimated (predicted) on the basis of summer temperatures and precipitations, in the two Districts. The reported values are the highest measured in the whole soil profile.

Checking the existence of any podzolization process, in both soil Districts, led us to conclude that the deep horizons do not meet the diagnostic requirements of the different taxonomic systems for a typical spodic (podzolic) B horizon. Moreover, in none of the examined sites was noticed the presence of albic E horizons. In conclusion, the presence of typical spodic horizons can be excluded, but not the occurrence of the segregation of Al and Fe and their mobilization in amorphous organic complexes, that is the so-called cryptopodzolization (Blaser & *alii*, 1997). Moreover, although a fair accumulation of Fe_2O_3 in the litters has been found, the abundance in alkaline earths seems to obstruct the podzolization. Zonn (1962), in particular, underlined how the great quantity of Ca^{2+} in spruce plant tissues, and the consequent abundance in topsoil (even stronger than in more humid areas of the melanization), hinders the podzolization process. Moreover, the same Author has noticed how, even in Bulgaria and Eastern Tibet under Picea forests soils do not show podzolization features.

CONCLUSIONS

The research carried out has confirmed, first of all, the absence of the diagnostic horizons characteristic of a complete *podzolization process*, although the composition of parent materials and the climate conditions could have led to postulate the opposite. The considerable abundance in Ca and, subordinately, in Mg in the exchange complex, and, even if modest, the presence of $CaCO_3$, in the soils, especially in the Eastern District, appeared to be the main inhibitor-factors for the podzolization process. Such elements are mainly of aeolian contribution, deposited during the Holocene and Pleistocene time, as evidenced by the frequent loess-like covers that have been found up to altitudes of 3,600 m a.s.l. Moreover, both the spruce and the steppe vegetation favour an accumulation of bases within the soil profile, so that the values of pH, especially in the Eastern District, are frequently neutral. The sporadic presences of crystalline limestones do not explain, in fact, the wide distribution of Ca^{2+} within the exchange complex of soils.

Besides, the percentage base saturation is everywhere high and the soils, mesosaturated in the Northern District, become subsaturated and even saturated in the Eastern District, where the climatic leaching notably decreases.

The presence of phaeozems and chernozem-like soils (melanization process) was, then, confirmed at very high altitudes. This is due both to the existence of steppe conditions and to the presence of loess covers up to 3,600 m a.s.l. The melanization is favoured both by the abundance of al-

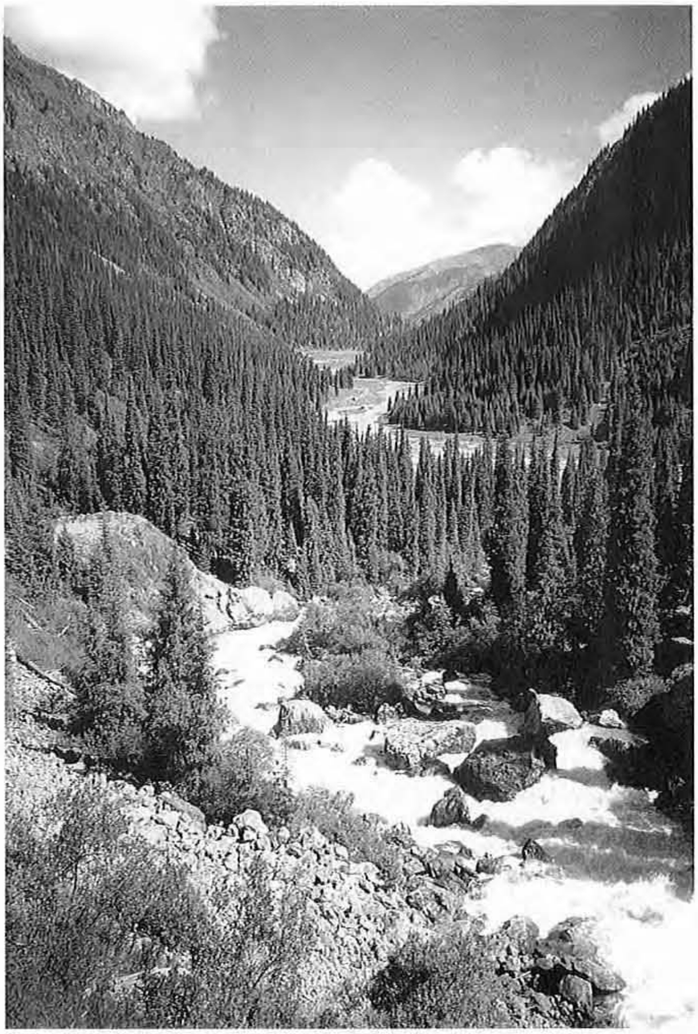


FIG. 14 - Steep slopes and stoniness cause the rejuvenation (haploidization) of soil profiles.

kaline earths and organic matter, and by the existence of a local steppe-like vegetation. Some of these soils, especially at the lowest elevations, have relict characters that seem to be inherited by dominant steppe palaeoclimates (Holocene warmer phases and pre-Holocene interglacial periods), which favoured the formation of chernozemic humus.

Moreover, it is quite difficult to recognize a regular vertical zonality of soils, since a considerable variety of geomorphic processes have contributed in addition to the soil forming processes, such as climate, vegetation, parent material and time. The relief factor (fig. 14) tends to cause the rejuvenation of soil profiles, which results into the so-called haploidization (Buol & *alii*, 1973), while the podzolization and the melanization contend for the control of the pedogenic processes.

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