FACTORS CONTROLLING DISTRIBUTION OF SELENIUM BY GEOMORPHIC AND PEDOLOGIC PROCESSES IN A SEMI-ARID ENVIRONMENT, LARAMIE BASIN, WYOMING[1]

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__Abstract:__ Selenium distribution was evaluated in nine pedons along a transect in the Laramie Basin, Wyoming. Soils of the study area formed from Tertiary-age parent materials in a semi-arid environment. In well-drained soils (seven of the pedons studied), Se distribution was a function of geomorphic process (landform), soil parent material, and pedogenic processes. In the two pedons affected by a high water table from a playa lake, Se distribution was altered as a result of the fluctuating water table. In soils on weathering limited slopes, soil Se content was controlled by soil parent material Se. On transport limited slopes, soils were aggrading; and soil Se content was controlled by Se content of soil parent material upslope from the site and by pedogenic processes (leaching). Distribution of both AB-DTPA extractable Se and total Se reflect the leaching regime in stable soils. AB-DTPA extractable Se reacted similarly to a semi-soluble salt in these soils (similar to exchangeable Na); total Se reacted similarly to a low-solubility salt, i.e. like calcium carbonate. Because of this, the relationship between toatl Se and AB-DPTA extractable Se at any particular depth in the soil was poor. Se in the two soils affected by a water table showed evidence of upward movement of Se from the water table and accumulation above the zone of flooding. While plants on the site are bio-cycling Se and some Se is probably being volatilized and lost; the Se content of the soils is predominately controlled by geomorphic relationships and by soil physical and chemical processes.

Additional Key words: Biogeochemical distribution of Selenium.

Introduction

The occurrence and pedogenic accumulation of selenium in soils is a complex question (Munshower and Prodgers, 1990). While describing seleniferous landscapes, early studies of selenium in vegetation on Wyoming rangelands noted a lack of direct correspondence between bedrock, soil and plant selenium contents (Byers et al., 1938; Beath et al., 1946). Recent research indicates that Se in the soil is relatively mobile in soils (Fisher et al, 1987), and tends to accumulate in the soil profile at a depth that is a function of the soil forming factors (Jenny, 1941). While soil genesis on stream terraces has been studied in some detail in semi arid environments, including Wyoming (Leopold and Miller, 1955, Reheis, 1984a, 1984b; Spackman and Munn, 1984; Reider et al., 1974), genetic relationships of soils on residual landscapes are less well documented (Yair, 1990; Palmquist, 1991). The present study was undertaken to evaluate the biogeochemical accumulation of selenium in soils along a transect on a residual landscape in a semi-arid environment, the Laramie Basin, Wyoming. These soils were derived from locally transported alluvium/ colluvium and are underlain by sedimentary sandstone and shale of Tertiary age.

Objectives of the study were three: 1. to determine if the distribution of Se in a semi-arid landscape was related to slope position and other topographic controls, 2. to determine if there was a relationship between AB-DTPA extractable Se and total Se content in these soils, and 3. to evaluate differences in Se accumulation by pedogenic horizon within a pedon and between pedons.

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Methods

The study site is 29 km. north of Laramie, Wyoming on the Harris Ranch. The landscape of the study area consists of Early Pleistocene and Tertiary surfaces, underlain by the Wind River formation, a 49 million year old variegated claystone and sandstone (Love and Christiansen, 1985). A 1.27 km long transect was established in July, 1989 which represented the major slope positions and landforms in the area. Elevation varied 52 m along the transect, following a steep slope from the terrace top down the scarp and gradually sloping to grade into a small playa lake. Nine pedons were sampled by genetic soil horizon along the transect. Pedons were sampled from backhoe pits to a depth of approximately 2 m. or to soft bedrock. In only one pit (pedon D) was the Cr horizon not exposed. After pit faces were freshened with a rock hammer, soil horizons were described using standard methodology (Soil Survey Staff, 1981) and classified in accordance with Soil Taxonomy (Soil Survey Staff, 1994).

A five-liter composite sample was taken from all sides of the pit to represent each horizon. In the laboratory, soils were air dried and ground to pass a 2 mm. sieve. Soil samples were analyzed for particle size (Soil Conservation Service, 1984) and for the following chemical characteristics: extractable cations (Thomas, 1982), electrical conductivity, soluble cations, pH and calcium carbonate equivalent (U.S. Soil Salinity Laboratory Staff, 1954), organic matter (Nelson and Sommers, 1982), cation exchange capacity (Chapman, 1965), total N (Jones, 1971), total Se following perchloric acid digestion (Kubota and Cary, 1982), AB-DTPA extractable Se (Soltanpour and Schwab, 1977), available P (Olsen and Sommers, 1982), and gypsum content (Nelson, 1982). Duplicate samples were analyzed from each horizon for all of the above attributes, and a laboratory reference soil was analyzed with each set of samples.

Results and Discussion

The landscape is represented by four distinct segments of the transect. The first segment is the terrace top (pedon A) where the soil has developed in early Quaternary/ Tertiary alluvium over Tertiary shale (Love and Christiansen, 1985). A soil wedge in this pedon is a relict permafrost feature (Mears, 1981; Munn and Spackman, 1991), indicating that the soil is older than the Pinedale (Wisconsin) glaciation. The second segment is the back slope, where the soil has weathered in a shale member of the Wind River formation (pedon B). The third segment is the footslope where the soils are formed in locally transported materials (pedons C, D, E, F and G). These pedons are not affected by a water table from the lake. Profiles C and D are underlain by sandstone; profiles E, F and G are underlain by shale. The fourth segment is the toeslope; these soils are affected by ground water around the periphery of the lake (pedons H and I). Both pedons are underlain by sandstone.

Average total Se content of the Cr horizons for the four profiles overlying sandstone was 1.18 ppm compared to 0.55 ppm for the Cr horizons of the four profiles overlying shale. Siegel (1979) gave a world-wide average of 0.5 ppm Se for shales and <0.01 ppm for sandstones. Naftz and Rice (1989) reported total Se values of 0.5 to 2.0 ppm for Early Tertiary sandstones associated with coal seams in the Powder River Basin. The Se values from the geologic materials along the transect are thus representative of shales world-wide and of Tertiary sandstones in Wyoming. The upper Wind River formation typically contains a tuff (Love and Christiansen, 1985) which may be the source of the Se.

Development of an argillic horizon above the permafrost relict soil wedge (Table 1) in pedon A suggests that the soil has been forming since at least Sangamon time (Munn and Spackman, 1991). This surface has apparently been protected from erosion for millennia by a surface lag of quartzite cobbles. These cobbles also act as markers of the lower boundary of reworked material in the pedons on the lower portions (segment 3 and 4) of the transect. The alluvium from which pedon A has developed has a higher Se content than the underlying shale (0.2 ppm). Total Se in the Bk1 horizon is the greatest concentration recorded in this study (5.7 ppm).

Pedon B, representing the backslope (segment 2 of the transect), had the least morphological development of all the soils sampled. Erosion has caused this soil to have the thinnest, weakest horizonation of those sampled. The parent material for this pedon was shale residuum. A few cobbles of quartzite have washed down onto the surface of this pedon from the terrace alluvium above. Total Se in the Cr horizon is 1.0 ppm and the soil weathering from the shale contained 0.5 ppm total Se.

Table 1. Selenium Transect Soil Morphological Data.

		Depth (cm) To:						
		Clay Films						
Pedon	Classification	Top	Bottom	$CaCO_3$	Gypsum	Se[1]	Mottles	Cr[3]
A	Ustic Calciargid	2	48	20	-----	48	-----	131
B	Typic Torriothent	4	19	-----	52	75	-----	75
C	Ustic Haplargid	8	55	-----	55	0	-----	171
D	Ustic Haplargid	4	80	36	159	4	-----	>185
E	Ustic Haplargid	11	188	132	-----	0	-----	232
F	Ustic Haplargid	40	54	5 (54)[2]	54	0	-----	159
G	Ustic Natrargid	4	90	18	56	0 (56)[2]	-----	157
H	Ustic Haplargid	6	48	21	48	0	164	203
I	Ustic Natrargid	9	57	30	30	57	0 (143)[2]	143

[1]Depth to an accumulation of Se, greater than the Cr horizon content.
[2]Profile contains two separate accumulations. Depth to top of second accumulation is in parentheses.
[3]Cr represents soft bedrock.

The remainder of the pedons along the transect have been built up by the accumulation of local alluvium/ colluvium from the slope above them. The Tertiary-age sandstone and shale bedrock underlying the floor of the basin have been extensively eroded except where protected by a Quaternary alluvial cap. Quartzite pebbles from the terrace alluvium serve as a convenient marker of the slope wash and separate it from the underlying residuum.

Pedon C was the first soil along the transect to be built up through the addition of materials eroding from the slope above. The subsoil of this pedon shows argillans on ped surfaces, which indicates that the site is relatively stable and that the rate of erosion onto this site, at present, must be relatively slow. This soil may have recieved a large addition of material from solifluction during the permafrost climatic cycle. The third, fourth and fifth horizons (2B horizons from 55 to 121cm) were formed in material derived from shale exposed on the slope above the site (Table 2). A zone of gypsum accumulation occured at a depth of 55 cm and there has been no carbonate accumulation in this soil. Total Se was high in the surface horizon (1.2 ppm); lower in the subsoil (0.1 to 0.3 ppm), and then increased with depth into the Cr horizon which was weathered from sandstone (1.8 ppm).

Pedon D was sampled at the base of the steep scarp. It has a thick profile and is the only pedon in which the underlying bedrock (sandstone) was below the sampling depth. Gypsum accumulation was at great depth (159cm) in this soil. This pedon and pedons C, E, F and G represent a balance between the accumulation of materials from upslope and surface erosion in the form of miniature scarps (dispersive erosion, Hopkins et al., 1991). The rate of this erosion has been slow enough that the distribution of organic matter is "normal" in all pedons of the transect. Coppinger et al. (1991) reported that erosion in a similar landscape was so slow that radioactive ^{137}Cs from nuclear test fallout was not useful in evaluating erosion. Total Se was lower in the upper horizons (0.1 to 0.7 ppm) than in the lowest horizon (By horizon) sampled (1.1 ppm).

Table 2. Selenium Transect Texture, Sodium Adsorption Ratio (SAR), Extractable Cations, Cation Exchange Capacity (CEC).

Horizon	Depth	Clay	Silt	Sand	SAR	Mg	Ca	K	Na	CEC
	inches	%				Cmole(+) kg^{-1}				
Pedon A.										
E	0 - 2	16.8	11.2	72.0	0.3	3.2	10.5	0.0	0.1	8.7
Bt	2 - 20	28.8	7.8	63.4	0.3	5.7	16.6	0.7	0.7	15.7
Btk	20 - 48	27.4	11.2	61.4	0.4	4.4	36.4	0.0	0.1	10.3
(wedge)		21.4	8.2	70.4	0.8	4.9	34.4	0.0	0.1	10.2
Bk1	48 - 95	21.4	8.2	70.4	2.3	7.9	35.8	0.0	0.8	9.0
(wedge)		20.0	7.9	72.1	3.8	6.7	32.4	0.2	0.8	9.0
Bk2	95 - 131	23.8	14.1	62.1	7.9	9.7	31.4	0.0	2.7	11.5
(wedge)		18.4	8.3	73.3	3.8	6.7	32.4	0.2	0.8	9.0
Cr	131 - 165+	55.0	35.9	9.1	4.3	15.6	41.5	0.3	5.6	23.9
Pedon B.										
E	0 - 4	48.6	33.2	18.2	1.6	8.9	29.4	0.3	0.8	21.6
Bt	4 - 19	55.0	34.2	10.8	5.4	14.4	36.8	0.3	3.5	26.4
Bw	19 - 52	50.2	34.5	16.3	6.5	10.9	23.7	0.3	4.7	33.0
By	52 - 75	49.4	36.4	14.2	7.9	11.3	25.8	0.4	5.0	20.7
Cr	75 - 96+	48.9	32.0	18.2	8.3	11.5	28.1	0.4	4.6	20.1
Pedon C										
E	0 - 8	26.3	29.2	44.5	1.7	3.9	11.4	0.3	0.8	11.5
Bt1	8 - 30	33.6	26.9	39.5	2.3	5.1	13.5	0.2	1.3	14.2
Bt2	30 - 55	35.5	23.0	41.5	6.4	4.2	17.1	0.4	2.3	12.8
2By1	55 - 90	51.4	33.8	14.8	12.5	19.3	67.2	0.4	9.6	22.4
2By2	90 - 122	46.2	41.1	12.7	18.4	16.9	19.9	0.3	11.9	20.0
2BC	122 - 171	46.4	34.6	19.0	18.3	13.6	23.5	0.0	12.5	18.2
3CR	171 - 210+	22.9	18.9	58.2	15.5	5.6	13.4	0.3	6.7	8.0

Table 2. Selenium Transect Texture, Sodium Adsorption Ratio (SAR), Extractable Cations, Cation Exchange Capacity (CEC). (Continued)

Horizon	Depth	Clay	Silt	Sand	SAR	Mg	Ca	K	Na	CEC
	inches	%				Cmole(+) kg^{-1}				
Pedon D.										
E	0 - 4	20.7	30.1	49.2	1.4	2.5	6.3	0.0	0.6	9.6
Bt1	4 - 36	39.3	24.4	36.3	5.9	6.5	16.4	0.0	1.7	14.9
Btk	36 - 45	45.7	25.3	29.0	5.6	7.0	21.7	0.0	2.4	20.4
B't2	45 - 80	42.6	27.4	30.0	6.7	6.9	16.7	0.0	3.0	19.2
2Bwl	80 - 107	26.9	23.6	49.5	7.7	4.4	10.2	0.0	2.0	12.4
2Bw2	107 - 159	19.2	18.0	62.8	11.2	3.4	7.3	0.0	1.9	9.3
3By	159 - 185+	35.7	28.7	35.6	8.2	6.0	15.0	0.0	3.2	14.4
Pedon E.										
E	0 - 11	17.9	21.5	60.6	0.4	3.1	7.4	0.0	0.3	9.4
Btl	11 - 45	22.0	15.0	63.0	0.9	3.8	8.6	0.0	0.4	10.2
Bt2	45 - 89	18.9	14.6	66.5	4.2	3.0	7.6	0.0	1.3	9.6
Bt3	89 - 132	28.5	23.9	47.6	10.4	4.6	10.5	0.0	2.5	11.8
Btk	132 - 188	30.6	32.8	36.6	10.3	4.6	13.4	0.0	2.4	14.1
Bk	188 - 232	34.9	19.8	45.3	10.9	5.1	28.2	0.0	3.6	14.2
2Cr	232 - 252+	42.7	41.8	15.5	13.2	1.3	6.8	0.0	1.0	18.3
Pedon F.										
E	0 - 5	18.8	27.3	53.9	6.6	0.7	3.8	0.0	0.4	10.5
Bw	5 - 32	22.7	23.7	53.6	4.4	4.1	26.2	0.0	1.6	12.0
E'b	32 - 40	13.7	21.8	65.5	16.8	2.5	6.6	0.0	2.0	7.3
Btb	40 - 54	25.1	17.8	57.1	26.0	5.0	6.6	0.3	6.4	12.3
Bkylb	54 - 101	24.8	24.7	50.5	29.0	8.1	39.4	0.0	12.1	13.9
Bky2b	101 - 116	29.8	19.2	51.0	20.8	8.3	42.4	0.3	9.7	15.1
Bkb	116 - 159	29.5	16.0	54.5	50.0	6.7	23.6	0.3	5.3	16.2
2Cr	159 - 194+	35.8	35.9	25.3	8.4	3.9	42.2	0.3	3.6	11.6

Table 2. Selenium Transect Texture, Sodium Adsorption Ratio (SAR), Extractable Cations, Cation Exchange Capacity (CEC). (Continued)

Horizon	Depth	Clay	Silt	Sand	SAR	Mg	Ca	K	Na	CEC
	inches	%				Cmole(+) kg^{-1}				
Pedon G.										
E	0 - 4	8.3	26.4	65.3	4.1	1.3	2.8	0.0	0.3	5.6
Bt	4 - 18	28.0	22.4	49.6	5.1	4.5	10.7	0.0	1.9	13.1
Btk	18 - 56	38.0	28.3	33.7	0.4	7.1	28.2	0.0	4.3	21.1
Btky	56 - 90	28.7	22.6	48.7	11.5	5.9	23.8	0.0	4.4	12.6
Bkyl	90 - 119	32.4	24.0	43.6	15.5	6.3	21.8	0.0	5.6	14.8
Bky2	119 - 157	31.5	20.7	47.8	14.5	6.1	40.9	0.0	5.6	13.9
2Cr	157 - 205+	31.3	20.7	48.0	13.7	4.5	44.7	0.0	5.4	11.2
Pedon H.										
E	0 - 6	22.7	18.1	59.2	2.8	5.3	16.3	0.0	1.0	10.9
Bt	6 - 2	31.1	17.4	51.5	0.9	6.3	21.6	0.2	0.4	12.6
Btk	21 - 48	31.9	18.2	49.9	2.1	6.6	25.6	0.0	0.7	13.3
Bky1	48 - 75	32.6	19.0	48.4	10.0	7.2	47.9	0.0	4.2	13.6
Bky2	75 - 125	34.9	26.2	40.5	14.2	6.6	95.5	0.0	5.5	14.3
Bky3	125 - 164	36.4	23.8	39.8	7.2	3.4	18.1	0.0	2.1	15.6
Bky4	164 - 203	28.4	17.2	54.4	3.3	4.6	13.0	0.0	1.0	12.9
2Cr	203 - 203+	13.3	11.1	7.5	2.3	4.6	8.4	0.0	0.6	10.5
Pedon I.										
Eg	0 - 9	10.2	17.6	72.2	1.5	2.3	6.1	0.8	0.3	8.5
Btg	9 - 30	23.4	19.2	57.4	3.7	6.5	12.0	1.0	0.9	15.3
Btky	30 - 57	34.3	19.3	46.4	25.3	7.6	45.3	0.3	12.1	16.1
Bky1	57 - 102	40.4	25.2	34.4	34.1	6.9	47.9	0.0	17.4	17.4
Bky2	102 - 143	37.0	18.2	44.8	60.0	4.0	23.1	0.0	9.0	13.9
Cg1	143 - 197	35.4	15.8	48.8	9.3	3.2	20.4	0.0	2.2	14.5
2Cg2	197 - 298+	17.1	22.0	60.9	43.5	2.1	11.9	0.0	0.7	10.1

Pedon E has a very thick argillic horizon (11 to 188 cm) and no gypsum accumulation. Carbonate accumulation in this soil occurs in the lower part of the argillic horizon (below 132 cm). This pedon was farther from the eroding scarp (where the shale contains gypsum) than pedon D, which may explain the absence of gypsum. Alternatively, gypsum may simply not be in equilibrium with the chemical environment in the Bk horizon because of bicarbonate anion control of the soil solution. Total Se was high in the surface (1.5 ppm) and decreased with depth to 0.2 ppm in the shale derived Cr horizon.

Morphology of pedon F demonstrates the mobility of gypsum in the soil environment. This soil was disturbed (buried) by soil material excavated from the adjacent irrigation ditch approximately 70 years ago. The upper 32 cm of the soil profile was formed in the excavated material; the horizons below 32 cm were the original soil which now contain salts and ions (gypsum and selenium) leached down from the new deposit. The soil is calcareous at a depth of 5 cm, indicating that rather limited leaching of carbonate from the "new" profile has occurred in the 70 years since construction of the ditch. A zone of gypsum accumulation begins at 54 cm in this pedon. A non-gypsiferous layer with an accumulation of secondary carbonate occurs below the By horizons (Bky1 and Bky2); this indicates that the profile did not contain gypsum in the upper horizons until after construction of the irrigation ditch. Total Se was high (3.1 ppm) in the upper part of the profile and much lower (0.6 ppm) in the underlying buried surface horizon. Total Se in the buried profile ranged from 0.5 to 1.6 ppm, while the Cr horizon which was derived from shale contained 0.6 ppm total Se.

Pedon G contains carbonate at 18 cm and gypsum at 56 cm. There seem to be two zones of concentration of each material within the profile. Quartzite gravels occur in this soil to a depth of 157 cm (the Cr contact) and the Bky2 horizon contains approximately 4 % gravel by volume. Sodium dominates the exchange complex of this soil (Natrargid). The The A and B horizons contain total Se concentrations of 0.2 to 1.2 ppm. The Cr horizon which was derived from shale contained < 0.1 ppm total Se.

Pedons H and I are on the toeslope and have been affected by a shallow water table from the nearby lake. As a result, these profiles have a greater content of organic materials, have an altered salt chemistry and have gleying. Pedon H contains carbonates beginning at a depth of 21 cm and a zone of gypsum accumulation which starts at 48 cm. This soil has a maximum total Se content of 2.6 ppm in the A and B horizons, compared to 0.7 ppm total Se in the Cr horizon which is formed from sandstone.

In pedon I, carbonate and gypsum accumulations both begin at about 30 cm. This reflects a longer time period with a high water table and reduced leaching within the profile. The soil material from the 2Cg horizon was gleyed at the time of sampling, but oxidized to an orange color very rapidly upon exposure to air. Total Se in the Cr horizon (derived from sandstone) was 1.1 ppm.; all soil horizons contained less total Se (0.3 to 1.0 ppm). Pedon I was classified as a Natrargid; its high Na content is probably a result of the water table influence. Pedon H has a high SAR in lower horizons in the profile (too deep to result in classification as a Natrargid) , and was classified as a Haplargid.

Accumulation of Materials

Selenium and Gypsum. Total Se was concentrated in two zones in most profiles (Table 3); the surface horizon and a subsoil layer beginning at some depth between 50 and 160 cm. The exception was pedon B, located on the eroding scarp, which has essentially the same Se content (0.6 ppm) throughout the solum. The AB-DTPA extractable Se was concentrated in the upper B horizon and in the shallowest subsoil layer where high total Se first occurs. This pattern of AB-DTPA extractable Se accumulation in the surface parallels the distribution of extractable Na. Total Se content seems to be related to the parent material of each horizon or group of horizons. For example, total Se content in the 55 to 121 cm zone in pedon C was similar to total Se content of the Cr horizon of Pedon B. The original surface of pedon F was buried when an irrigation ditch was constructed approximately 70 years ago. Here, AB-DTPA extractable Se distribution was similar to the other undisturbed soils, whereas the extractable Ca has not yet equilibrated in the profile since burial. The gypsum accumulation in this soil is prapparently related to the ditch construction as well (Btby, Bk1by and Bk2by horizons). The gypsum in this pedon occured at a shallow depth (40 cm) compared to the other pedons in footslope positions. In pedon D, the Bt horizon (Btk, 36 to 45 cm) has a

Table 3: Selenium Transect Soil Chemistry.

Horizon	Depth	pH	PO_4P	$CaCO_3$	Total N	Organic Matter	Gypsum	Electrical Conductivity	Total Se	AB-DTPA Se
	(cm)		mg kg^{-1}	---------------%	----------------	----------------	Cmole(+) kg^{-1}	DS m^{-1}	----------mg/kg	----------
Pedon A.										
E	0 - 2	7.2	8	0.6	0.13	3.3	...	0.6	0.8	0.015
Bt	2 - 20	7.1	2	0.2	0.07	1.3	...	0.5	1.2	0.027
Btk	20 - 48	7.9	2	17.3	0.10	1.6	...	0.5	1.6	0.009
(wedge)		8.2	2	6.0	0.05	0.7	...	0.4	5.7	0.019
Bk1	48 - 95	8.2	4	5.2	0.02	0.3	...	0.6	0.2	0.026
(wedge)		8.5	2	3.8	0.02	0.3	...	0.6	0.2	0.018
Bk2	95 - 131	8.0	3	2.5	0.02	0.1	0.2	4.5	1.9	0.024
(wedge)		8.6	2	1.9	0.02	0.2	...	1.0	2.3	0.016
Cr	131 - 165+	7.8	1	1.7	0.02	0.2	4.8	4.5	5.6	0.058
Pedon B.										
E	0 - 4	7.8	4	0.9	0.07	1.1	...	0.7	0.6	0.02
Bt	4 - 19	8.3	2	1.1	0.05	0.6	...	0.8	0.6	0.022
Bw	19 - 52	8.4	2	0.4	0.05	0.4	...	1.1	0.5	0.013
By	52 - 75	7.8	1	0.2	0.05	0.3	0.2	4.0	0.6	0.013
Cr	75 - 96+	7.6	2	0.1	0.05	0.2	1.2	4.5	1.0	0.027
Pedon C.										
C	0 - 8	6.3	9	0.0	0.12	2.6	...	0.9	1.2	0.027
Bt1	8 - 30	6.2	6	0.1	0.07	0.9	...	0.7	0.3	0.059
Bt2	30 - 55	7.2	2	0.1	0.05	0.5	...	3.4	0.3	0.053
By1	55 - 90	7.9	3	0.1	0.05	0.4	11.1	7.5	0.1	0.185
By2	90 - 122	7.8	4	0.1	0.05	0.2	0.9	7.8	1.0	0.078
BC	122 - 171	7.7	4	0.1	0.02	0.2	0.3	6.8	1.5	0.427
2Cr	171 - 210+	7.4	3	0.1	0.02	0.2	1.2	7.0	1.8	0.131

Table 3: Selenium Transect Soil Chemistry. (Continued)

Horizon	Depth	pH	PO_4P	$CaCO_3$	Total N	Organic Matter	Gypsum	Electrical Conductivity	Total Se	AB-DTPA Se
	(cm)		mg kg^{-1}	----------------%		----------------	Cmole(+) kg^{-}	DS m^{-1}	----------mg/kg	----------
Pedon D										
E	0 - 4	6.2	18	0.1	0.05	3.6	...	0.9	0.2	0.036
Bt1	4 - 36	6.4	6	0.1	0.10	1.4	...	1.3	0.7	0.050
Btk	36 - 45	7.5	5	0.4	0.10	1.3	...	1.9	0.2	0.074
B't2	45 - 80	7.7	25	0.1	0.07	1.0	...	1.8	0.1	0.136
2Bwl	80 - 107	7.0	13	0.1	0.05	0.4	...	1.4	0.3	0.043
2Bw2	107 - 159	6.7	5	0.1	0.02	0.3	...	2.0	0.2	0.096
3By	159 - 185+	7.2	3	0.1	0.02	0.3	...	2.1	1.1	0.101
Pedon E										
E	0 - 11	6.2	16	0.1	0.02	2.1	...	0.4	1.5	0.031
Bt1	11 - 45	6.1	8	0.1	0.05	1.1	...	0.4	1.4	0.041
Bt2	45 - 89	7.0	6	0.0	0.02	0.5	...	0.5	0.2	0.076
Bt3	89 - 132	7.7	4	0.1	0.02	0.5	...	1.8	0.2	0.031
Btk	132 - 188	8.0	7	0.4	0.02	0.4	...	1.4	0.7	0.073
Bk	188 - 232	8.0	4	2.3	0.02	0.4	...	1.9	0.8	0.050
2Cr	232 - 252+	7.8	4	0.9	0.02	0.3	...	1.9	0.2	0.052
Pedon F										
E	0 - 5	7.5	14	1.1	0.10	2.1	...	1.1	3.1	0.041
Bw	5 - 32	7.7	6	0.8	0.05	0.8	...	0.8	3.1	0.001
E'b	32 - 40	7.9	4	0.3	0.05	0.7	...	1.9	0.6	0.020
Btb	40 - 54	8.0	5	0.2	0.05	0.7	0.2	4.3	0.5	0.282
Bkylb	54 - 101	8.5	9	2.1	0.02	0.4	4.8	12.0	1.6	0.698
Bky2b	101 - 116	8.2	6	2.1	0.02	0.3	9.7	7.7	1.5	0.478
Bkb	116 - 159	7.9	4	1.6	0.01	0.4	0.2	5.5	0.6	0.084
2Cr	159 - 194+	7.8	2	0.3	0.01	0.3	9.7	5.0	0.7	0.081

Table 3: Selenium Transect Soil Chemistry. (Continued)

Horizon	Depth	pH	PO_4P	$CaCO_3$	Total N	Organic Matter	Gypsum	Electrical Conductivity	Total Se	AB-DTPA Se
	(cm)		mg kg^{-1}	---------------%		--------------	Cmole(+) kg	DS m^{-1}	---------mg/kg	---------
Pedon G										
E	0 - 4	6.3	8	0.2	0.07	2.5	...	1.0	0.7	0.009
Bt	4 - 18	6.8	8	0.1	0.05	1.5	...	1.1	0.2	0.022
Btk	18 - 56	8.1	10	0.9	0.03	1.1	...	2.8	0.2	0.117
Btky	56 - 90	7.8	16	0.3	0.02	0.6	4.0	6.5	0.7	0.443
Bky1	90 - 119	7.8	11	0.6	0.02	0.6	0.3	6.6	1.2	0.770
Bky2	119 - 157	8.0	4	1.8	0.02	0.5	4.0	6.5	0.5	0.543
2Cr	157 - 205+	7.9	2	0.6	0.02	0.4	8.5	6.3	0.1	0.214
Pedon H										
E	0 - 6	6.9	22	0.4	0.15	3.1	...	4.5	0.4	0.002
Bt	6 - 21	7.6	9	0.6	0.05	0.9	...	0.8	0.5	0.022
Btk	21 - 48	7.8	11	1.1	0.05	0.9	...	1.3	0.5	0.012
Bky1	48 - 75	7.9	8	0.7	0.02	0.6	8.3	5.0	0.2	0.062
Bky2	75 - 125	7.7	8	0.8	0.02	0.4	8.3	6.0	0.4	0.061
Bky3	125 - 164	7.7	5	0.7	0.02	0.3	0.2	2.2	2.6	0.000
Bky4	164 - 203	7.7	2	0.2	0.02	0.3	...	1.5	0.8	0.004
2Cr	203 - 230+	7.7	4	0.2	0.02	0.2	...	1.2	0.7	0.004
Pedon I.										
Eg	0 - 9	5.9	24	0.1	0.26	4.0	...	0.5	0.3	0.024
Btg	9 - 30	7.1	77	0.2	0.15	2.1	...	0.8	0.4	0.021
Btky	30 - 57	8.0	45	0.3	0.05	0.7	10.7	10.0	0.7	0.117
Bky1	57 - 102	8.1	12	0.7	0.02	0.6	5.5	10.0	1.0	0.181
Bky2	102 - 143	7.9	15	1.1	0.02	0.5	1.2	6.0	0.8	0.017
Cg1	143 - 197	7.9	10	1.1	0.01	0.4	...	1.4	0.2	0.018
2Cg2	197 - 298+	7.8	10	0.7	0.01	0.4	...	0.8	1.1	0.020

secondary accumulation of carbonate that occurred after the lower Bt horizon (45 to 80 cm) was in place. Gypsum accumulation in this soil occured at 159 cm. Se data from the periglacial wedge in pedon A illustrate the low mobility of Se in these soils. The highest total Se content in the wedge host soil was 5.7 ppm in the Bk1 horizon at a depth of 48 to 95 cm. The total Se content of the ground wedge at a depth of 95-131 cm was 5.6 ppm. A comparison of soil textures indicates that the host soil Bk1 horizon was the source of the wedge fill material. The total Se content has not changed to reflect soil depth in the 15 000 to 25 000 years since the last periglacial environment.

Selenium Accumulation Hypotheses. Two hypotheses might account for the bimodal distribution (with depth) of total Se observed in these soils: 1. deposition onto the surface of eroded soil material high in Se and 2. biological accumulation of Se and concentration in the soil surface tier by plants. If the surface Se content were a function of the recent deposition of eroded soil material onto the top of the pedons sampled, the total Se content in cummulative profiles should be more strongly related to soil texture (layer by layer) than to total Se of the underlying Cr horizons. This was observed. Additional support for this hypothesis was provided by pedon F, where the distribution of organic matter and nitrogen were what would be expected for an undisturbed soil, dispite the relatively short period of time since disturbance. If Se accumulator plants do indeed concentrate Se in the soil surface layer, as for example Greasewood (*Sarcobatus vermiculatus*) does with Na and hopsage (*Grayia spinosa*) does with K (Rickard, 1965), then Se distribution should parallel soil organic matter distribution (Abrams et al., 1990). The data for all of the pedons (except F) indicate that this was not the case. Selenium accumulator plants are known to give off volatile Se compounds under certain conditions (Lewis, 1976; Duckart et al., 1992) and plants as well as microbes (Frankenberger and Karlson, 1989) may act to decrease Se contents of soils over time. The high total Se in the upper 32 cm of pedon F is difficult to interpret. No horizon lower in the profile has an equivalently high total Se content. Texture of the material added to the top of the profile during construction of the ditch appears to have been similar to the subsoil material, but it contains somewhat less clay. Perhaps Se was concentrated on the spoil pile as sediment was dredged from the ditch during the few years of its operation. Only the subsoil of pedon A had a higher total Se content.

Organic Matter and Total N. The distribution of organic matter and total N was "normal" in all pedons, i.e. highest at or near the surface and a decreasing concentration with depth (Table 3). In pedon F, in which the original surface was buried, total N and organic matter have rather rapidly developed a "normal" distribution with soil depth. Extractable cations, soil color and morphology in the E'b horizon still reflect its original eluviated characteristics (Table 2).

Clay and Carbonate. All the soils along the transect, except pedon B, have argillic or natric horizons. Because most of the soils (pedons C through I) formed in materials eroded from higher on the slope, rather than from material similar to the underlying Cr horizons, the total amount of translocated clay in these pedons cannot be quantified. However, all of these soils show significant differences in clay content between their E and Bt horizons. The presence of an argillic horizon in pedon A, which was cross cut by the periglacial wedge, indicates that the soil at least predates the Wisconsin glaciation (> 140 000 years). The carbonate accumulation in pedon A (66 kg m^{-2} in the wedge soil and 98 kg m^{-2} in the wedge host) is comparable, although somewhat less, than the carbonate accumulation in Late-Wisconsin age soils in the Rawlins and Laramie areas (Munn and Spackman, 1991). Clay accumulation in this pedon (55 kg m^{-2}) was also less than that reported for the Late-Wisconsin soils in the Rawlins area, but greater than that in a similar soil near to Laramie (Spackman and Munn, 1991). Soils on the backslope portion of the transect are subject to rapid erosion at present because of the scant vegetative cover; it may have been even less stable during the periods when permafrost climates prevailed in the Laramie Basin.

Sodium. The soil on the toeslope that was most affected by the water table from the playa lake (pedon I) was classified as a Natrargid. The buried soil in pedon F was also classified as a Natrargid, as was pedon G, located below the old irrigation ditch. Other soils showed accumulation of sodium (SAR greater than 13) but the sodium accumulation occured too low in the profile to meet the criteria of a natric horizon (pedons C, G and H). The buried soil horizons in pedon F may be high in Na as a result of the burial of this pedon during construction of an irrigation ditch in the early 1920's. Water only flowed in the ditch for a few years before the attempt to establish irrigated farming was abandoned. However, water collects in the ditch during heavy precipitation events and during snow melt.

Soluble salts and gypsum were higher in pedon F than in adjacent pedons, and the secondary gypsum accumulation starts in the buried argillic horizon (Btby). Pedon G may have been affected by the ditch as well, even though it is 50 m below it. Pedons F and G were relatively shallow to the 2Cr horizon contact (<160 cm). The relatively shallow soil depth may explain the occurance of high SAR values in pedons F and G at shallower depths than in other profiles where the 2Cr horizons occured at depths of > 200 cm (Munn and Boehm, 1983).

Conclusions

The landscape has been continually modified by sheet erosion which forms minor terraces which advance up the slope. Below the eroding front, materials are deposited on the soil surface. Profile depths of up to 2 m have been built up in this way. Except for the backslope segment, this erosive process is slow and total selenium distribution in the soils is controlled by slope processes (parent material deposition). AB-DTPA extractable selenium, like sodium and gypsum, was found at depths in equilibrium with the modern hydrologic cycle in these soils. Selenium inherited from parent material persists for long periods (tens of thousands of years). Within a soil horizon, total Se and AB-DTPA extractable Se concentrations were not closely related. The data do not support the hypothosis that vegetation was responsible for accumulating selenium in this landscape.

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