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CHARACTERISTICS AND GENESIS OF SOME SUBALPINE PODZOLS (SPODOSOLS), BANFF NATIONAL PARK, ALBERTA

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ABSTRACT

Two well-drained pedons within the subalpine ecotone at Bow Pass, Banff National Park, have been markedly influenced in their development by the chemical and physical composition of the parent materials. Of particular importance has been the presence of a surficial aeolian deposit containing significant amounts of volcanic ash of unknown origin. The pedogenic degradation of the ash component under strongly acidic conditions results in the formation of Ae horizons with a characteristic clay mineral suite dominated by montmorillonite, and podzolic B horizons containing high concentrations of amorphous iron and aluminum oxides. Some of the extractable Fe and Al oxides present in the podzolic B horizons have been produced as a result of intensive weathering *in situ* rather than as a result of podzolization *sensu stricto*. An underlying calcareous till tends to restrict soil profile development such that the sola of the Podzols are shallow and largely confined to the surficial aeolian deposit.

INTRODUCTION

Podzols (Orthods and Humods),[1] Brunisols (Ochrepts and Umbrepts), Gleysols (Aquents and Aquepts), and Regosols (Orthents) have all been identified within the subalpine at Bow Pass, Banff National Park (Brewster, 1974). Many of the soils have complex morphologies which, together with the range of soil conditions, reflect the influence of environmental factors within the subalpine. Of these soils, those forming under freely drained conditions reveal most completely the full impact of the prevailing pedogenic processes, resulting in the formation of well-developed Podzols. This paper examines two well-drained soils within the Subalpine in this area and attempts to relate their morphology and genesis to both contemporary and past environmental conditions.

STUDY AREA

Bow Pass (50°42′N, 116°27′W) is a high subalpine pass located in the northwestern part of Banff National Park (Figure 1). The pass, at an elevation of 2608 m, lies just below the tree line at 2194 m. The subalpine here, as elsewhere, represents a tensional zone between the treeless alpine above, and the closed montane forest below (Löve, 1970, p. 69). Due to its relatively high elevation the pass experiences cool, short summers and long, cold winters. Although meteorological data for the whole area are sparse, it is nevertheless possible to generalize for the climate of the pass on the basis of data from adjacent stations at Banff (51°10′N, 115°34′W), Jasper (52°53′N, 118° 05′W), and Lake Louise (51°26′N, 116° 10′W).

The mean annual air temperature at the pass is approximately −0.5°C, with mean monthly air temperatures of −8.0°C in January and

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[1]The soils are classified according to The System of Soil Classification for Canada (Canada Soil Survey Committee, 1970); equivalent terms are from the U.S. soil taxonomy (Soil Survey Staff, 1960, 1974).
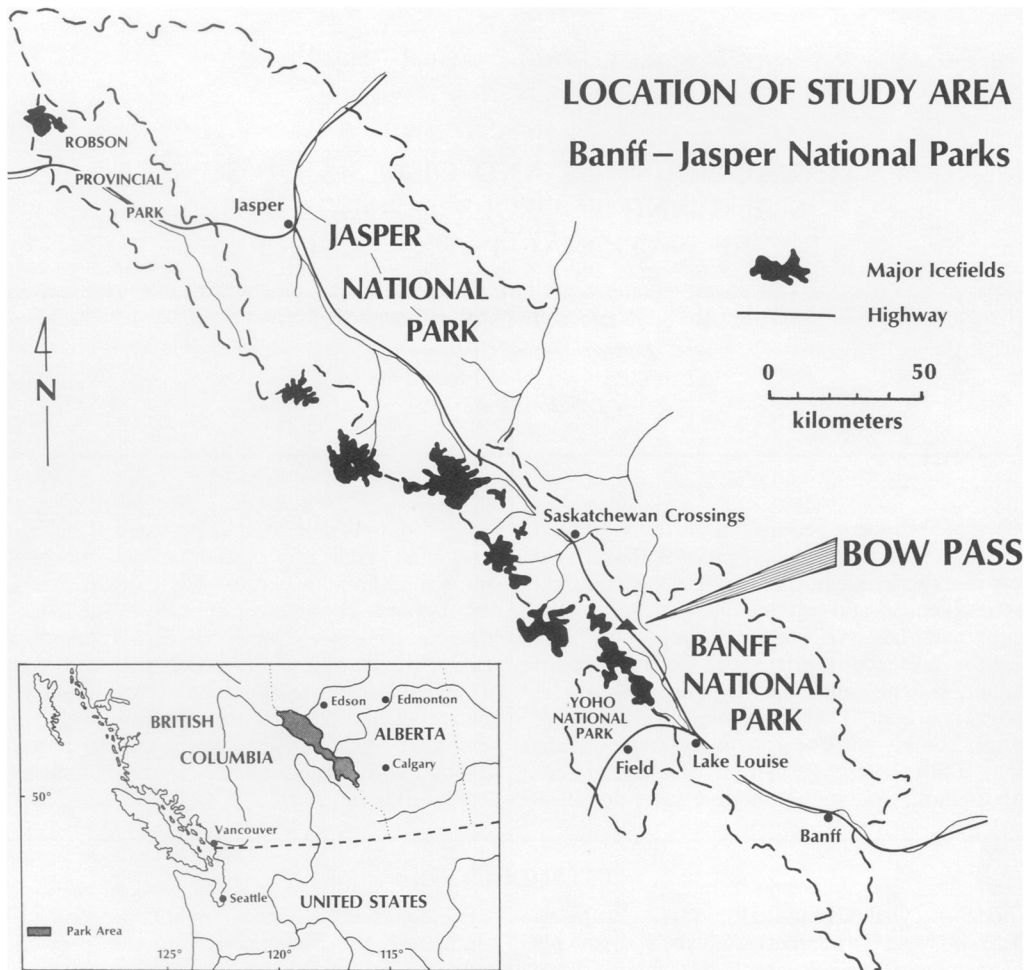
FIGURE 1. Location of the study.

12.0°C in August, the coldest and warmest months, respectively. Total annual precipitation amounts to approximately 80 cm, of which half falls as snow. Mean monthly air temperatures below 0°C occur for 5 months of the year and soil temperatures in the spring and early summer will probably remain relatively cooler than the corresponding mean air temperatures owing to the presence of a snow pack. During this period moisture would infiltrate through the frozen soil only with difficulty and in very limited amounts. During the spring snowmelt period the percolation of meltwater would effect a considerable transfer of heat to the underlying soil as well as possibly promoting a pronounced leaching regime. On the other hand, in spite of the relatively high precipitation values, part of the growing season at this elevation may experience drought conditions due to high potential evapotranspiration values (Bamberg and Major, 1968, p. 160).

The present vegetation at Bow Pass is only partially a reflection of the prevailing climatic conditions. The forest climax in this area comprises mostly Engelmann spruce (*Picea engelmannii*), with lesser amounts of alpine fir (*Abies lasiocarpa*) (Ogilvie, 1969, p. 30). However, due to the incidence of forest fires in the past, particularly in the last 185 years (Byrne, 1964, p. 87), lodgepole pine (*Pinus contorta*) is found in numbers equal to the spruce on the lower valley-side slopes. Snow avalanches originating above the tree line have locally cleared the trees on slopes within the subalpine zone as well as eroding and burying preexisting soils in these areas.

The main surficial deposit is a medium textured, calcareous till containing limestone and

dolomite clasts of Devonian and Mississippian age derived from the local bedrock (North and Henderson, 1954, p. 28). Deglaciation of the area is generally considered to have occurred approximately 10,000 years ago (Westgate and Dreimanis, 1967; Rutter, 1972). Since deglaciation extensive deposits of aeolian material have been laid down on top of the till in the pass. This deposit consists essentially of a 20- to 30-cm-thick layer of fine-grained, predominantly silt-sized material. Of particular significance is the fact that large amounts of volcanic ash have been incorporated within this aeolian material, either during deposition or as a result of subsequent incorporation by geomorphic and biologic processes.

Within Banff National Park volcanic ash from three separate eruptions has been identified (Westgate and Dreimanis, 1967). The oldest ash identified is Mazama, with an established age of 6600 years BP and originating from Mount Mazama in Oregon (Fryxell, 1965, p. 1288). More recent ashes compose the St. Helens "Y" ash with an age of approximately 3350 years BP and originating from Mount St. Helens in Washington (Crandell et al., 1962), and Bridge River ash from the southern Coast Mountains, British Columbia, with an approximate age of 2400 years BP (Nasmith et al., 1967, p. 169). Attempts at identifying a single source for the ash material incorporated within the aeolian deposit at the pass have so far proved unsuccessful and the possibility exists that the deposit contains an admixture of ashes of different ages and different orgins.

METHODS

Two well-drained soil pedons were sampled for this study. Samples from each major horizon of each pedon were subjected to physical and chemical laboratory analyses. Analyses were performed on air-dry soil that had been passed through a 2-mm sieve unless otherwise specified. All data are reported on an oven-dry weight basis and are the means of duplicate analyses. Particle size distributions were determined by the pipette method (Day, 1965, p. 552) on organic matter-free and carbonate-free samples using the Wentworth size scale (Wentworth, 1922). The sand sizes were fractionated by dry sieving and the fine clay fraction ($<0.5\mu$) was determined on an aliquot taken from the soil suspension after centrifugation (Jackson, 1956). Soil texture was determined in terms of the size criteria specified in *The System of Soil Classification for Canada* (Canada Soil Survey Committee, 1970) and required values were interpolated from the particle-size distribution curves.

Soil reaction was measured on a water-saturated soil paste and on a 1:2 soil to 0.01M $CaCl_2$ suspension using an Accumet pH meter and a combination glass electrode. Organic carbon was determined using a modified Walkley-Black (1934) technique and organic matter content obtained by applying the conventional "Van Bemmelen" constant (1.724) to the values obtained for organic carbon. Total nitrogen was measured by the semimicro-Kjeldahl method (Bremner, 1965, p. 1173). Cation exchange capacity was determined by the 1M sodium acetate method of Bower et al. (1952), and exchangeable cations were determined by atomic absorption spectrophotometry on a 1M neutral ammonium acetate extract (Heald, 1965, p.

999). Exchangeable hydrogen was measured in a 1M neutral ammonium acetate extract after the method of Yuan (1959). In samples containing carbonate contents in excess of 5%, exchangeable calcium and magnesium were determined in 1M sodium acetate extracts (Bower et al., 1952). Carbonate contents were measured by the Chittick gasometric technique (Dreimanis, 1962).

Dithionite-citrate-bicarbonate-extractable Fe and Al (Mehra and Jackson, 1960), acid ammonium oxalate-extractable Fe and Al (McKeague and Day, 1966), and sodium pyrophosphate-extractable Fe and Al (McKeague, 1967) were determined by atomic absorption spectrophotometry on soil ground to pass a 100-mesh sieve.

X-ray diffraction analyses were performed on the very fine sand fraction (125 to 63μ), the coarse silt fraction (63 to 31μ) and the clay fractions ($<2\mu$) using Ni-filtered $CuK\alpha$ radiation and a General Electric XRD-5 diffractometer with a scanning speed of $2°$ min^{-1}. For the analysis of the sand and silt fractions the mineral grains were mounted randomly on a glass slide using nail varnish as a mounting medium. Clay fractions ($<2\mu$) were obtained by centrifugation following sample pretreatments to remove organic matter, carbonates, and free iron oxides (Mehra and Jackson, 1960). Parallel oriented slides were prepared on porous ceramic plates from aliquots of the clay suspension following Mg and K saturation. Diffraction patterns were obtained for the following pretreatments: Mg saturated-air dried; Mg saturated-glycolated; K saturated-air dried, heated to $300°C$ and heated to $550°C$. The diffracto-

grams were interpreted according to standard methods in the literature (Jackson, 1956) and the clays were expressed as relative quantities as a function of diffraction peak intensity. Optical mineralogical analyses were also performed on the very fine sand fractions (125 to 63μ) following a citric acid pretreatment for the removal of free iron oxides. Two slides were prepared for each horizon sampled and 200 grain counts were carried out on each slide.

RESULTS AND DISCUSSION

The morphologies of the two pedons under consideration are described in Table 1. The first pedon, referred to as profile 1, was sampled at a level site located on the valley floor at an elevation of 2068 m. Vegetation at the site is dominated by *Picea engelmannii* and *Pinus contorta* with an understory comprising *Trollius albiflorus*, *Phyllodoce* spp. and *Cassiope tetragona*. The second pedon, profile 2, was sampled on a very gentle (2°) south aspect slope at an elevation of 2080 m. Vegetation at the site is dominated by *Picea engelmannii* and *Pinus contorta* with an understory comprising *Phyllodoce*

glanduliflora, *Trollius albiflorus*, and *Salix* spp.

One of the most striking morphological characteristics of the sola in the soils is the reddish brown color which contrasts strongly with the prevailing yellowish brown colors in the subsoil. This color development appears to be closely associated with the presence of the surficial aeolian deposit containing significant amounts of volcanic ash. Silt loam textures predominate in the sola but marked variations in particle size distributions (Table 2 and Figure 2) providing evidence of a pronounced lithological discontinuity at the base of the sola do not exist. This

TABLE 1

Soil profile descriptions

| Horizon	Depth (cm)	Description
Profile 1: Orthic Ferro-Humic Podzol		
L-F-H	6-0	Dark reddish brown (5YR 2.5/2 m) organic; fibrous turf; abundant, medium horizontal roots; abrupt, smooth boundary; 5 to 6 cm thick; extremely acid.
Ae	0-3	Light gray/gray (5YR 6/1 m) silt loam; weak, medium subangular blocky; friable; abrupt, smooth boundary; 2-3 cm thick; extremely acid.
Bhf	2-6	Dark reddish brown (2.5YR 2.5/4 m) silt loam; weak, medium subangular blocky; friable; 2% angular gravel; gradual, smooth boundary; 2 to 4 cm thick; extremely acid.
IICk$_1$	6-29	Yellowish brown (10 YR 5/8 m) gravelly loam; moderate, coarse subangular blocky; firm; very weakly effervescent; 15% angular cobbles; gradual, smooth boundary; 20 to 23 cm thick; extremely acid.
IICk$_2$	29-44+	Yellowish brown (10YR 5/4 m) gravelly loam; moderate, coarse subangular blocky; firm; strongly effervescent; 18% angular cobbles; mildly alkaline.
Profile 2: Orthic Humo-Ferric Podzol		
L-F-H	6-0	Black (5YR 2.5/1 m) organic; fibrous turf; abundant, medium horizontal roots; abrupt, smooth boundary; 5 to 6 cm thick; extremely acid.
Ae	0-4	Dark gray (2.5YR 4/0 m) silt loam; weak, fine subangular blocky; friable; abrupt, wavy boundary; 3 to 4 cm thick; very strongly acid. Overlain by a thin charcoal layer.
Bfh	3-7	Dark reddish brown (5YR 3/3 m) silt loam; weak, fine subangular blocky; friable; clear, wavy boundary; 3 to 4 cm thick; strongly acid.
IICk$_1$	6-13	Yellowish brown (10YR 5/4 m) silt loam; moderate, coarse subangular blocky; friable; very weakly effervescent; 2% subrounded cobbles; gradual, wavy boundary; 5 to 7 cm thick; medium acid.
IICk$_2$	13-34+	Yellowish brown (10YR 5/4 m) gravelly loam; moderate, coarse subangular blocky; firm; strongly effervescent; 18% angular cobbles; mildly alkaline.

TABLE 2

Selected physical and chemical data

Horizon	Sand 2 mm -63μ (%)	Silt 63-2μ (%)	Clay <2μ (%)	pH (H_2O)	pH (CaCl)	Exchangeable Cations (meq · $100g^{-1}$)					CEC (meq $100g^{-1}$)	Base Sat. (%)	Carb.[a] (%)	OC[a] (%)	N (%)	OC/N	OM[a] (%)
						Ca^{++}	Mg^{++}	Na^+	K^+	H^+							
Profile 1																	
L-H	13.2	74.9	11.9	4.4	4.0	5.00	5.00	.17	2.56	22.40	57.39	22.2		33.62	.97	34.51	57.80
Ae	25.7	53.8	20.6	4.0	3.4	.60	.43	.21	.14	15.85	18.70	7.4		1.76	.09	19.78	3.03
Bhf	35.0	46.7	18.2	4.2	3.7		.26	.14	.11	23.70	55.65	.9		8.43	.30	28.10	14.35
IICk$_1$				4.1	3.7		.16	.06	.06	13.00	11.52	2.4	.7	3.80	.09	44.50	6.55
IICk$_2$	38.2	37.4	24.4	7.3	6.9	5.82	2.74	.05	.09	5.09	22.17	39.2	28.5		.06		
Profile 2																	
L-H	11.0	71.2	17.8	4.4	4.1	6.35	8.33	.08	1.40	20.20	52.17	31.0		23.04	.60	38.40	39.72
Ae	21.2	62.9	15.8	4.9	4.6	4.95	6.00	.14	.24	11.95	27.39	41.4		2.15	.18	11.04	3.71
Bfh	28.7	55.8	15.5	5.3	5.1	4.35	4.04	.11	.15	12.40	47.74	18.1		3.98	.21	18.91	6.86
IICk$_1$				5.9	5.6	2.85	2.31	.03	.09	6.85	15.65	33.7	.6	.27	.07	3.38	.47
IICk$_2$	38.6	40.1	21.3	7.4	7.1	3.55	2.92	.01	.12		7.17	92.1	20.1	1.10	.07	17.46	1.90

[a]Carb.—total carbonates; OC—organic carbon; OM—organic matter.

would suggest that some mixing of the aeolian material and the till has taken place.

Mineralogically the surficial aeolian material and the underlying till are distinctly different. X-ray diffraction studies of the very fine sand fractions (125 to 63μ) and coarse silt fractions

PROFILE 1: ORTHIC FERRO - HUMIC PODZOL
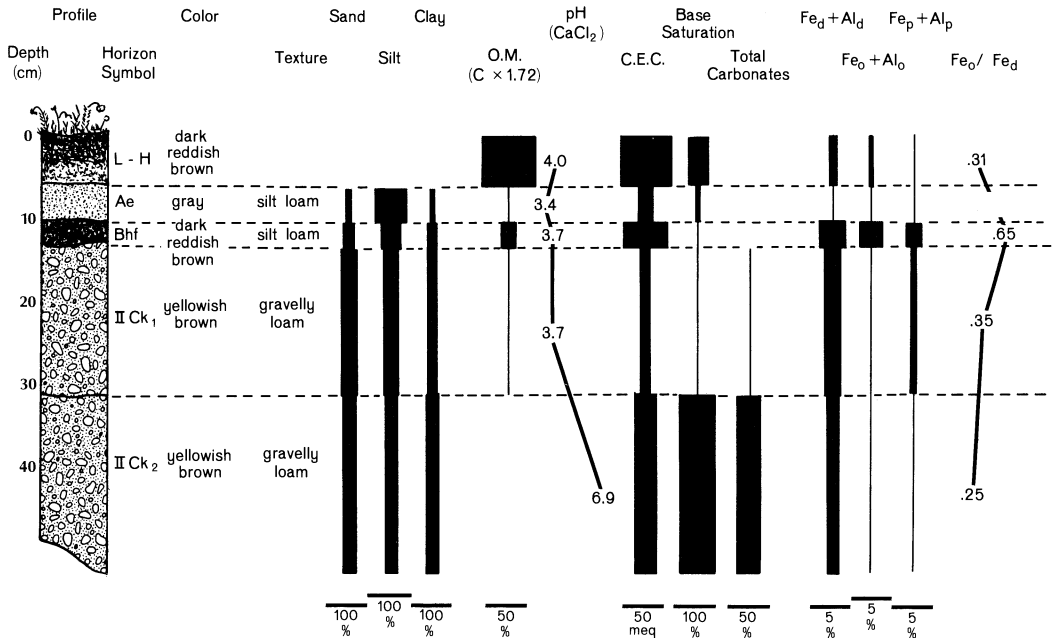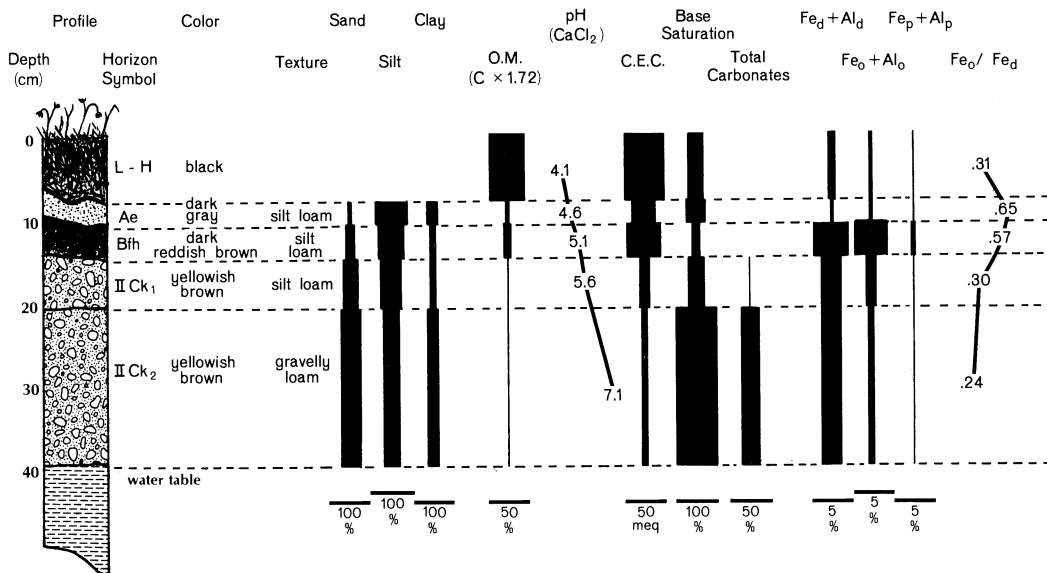

PROFILE 2: ORTHIC HUMO - FERRIC PODZOL

FIGURE 2. Selected physical and chemical characteristics of profiles 1 and 2.

(63 to 31μ) reveal that the aeolian material contains only a limited mineral suite with a predominance of quartz and plagioclase, with traces of mica, hornblende, and chlorite. The till, on the other hand, has a predominance of ankerite (iron-rich dolomite) and quartz, with subsidiary concentrations of plagioclase, orthoclase, muscovite, biotite, calcite, and chlorite. The presence of volcanic glass is not revealed in the X-ray diffraction traces owing to its amorphous nature, but it is revealed by petrographic analysis (Table 3). X-ray diffraction studies of the very fine sand and coarse silt fractions from the horizons of the two pedons under consideration revealed that, whereas there were significant concentrations of chlorite in the podzolic B horizons and in the underlying IICk horizons, there were only traces of this mineral present in the Ae horizons. Although the absence of chlorite within the very fine sand and coarse silt fractions of Ae horizons in Podzols may be due to its destruction by intense weathering, the extremely low concentrations of chlorite in the surface horizons of the present pedons is more probably a characteristic of the original aeolian deposit. X-ray diffraction analyses performed on reference samples of Bridge River ash, St. Helens "Y" ash, and Mazama ash provided by Dr. J. A. Westgate (University of Alberta) failed to reveal the presence of chlorite in any of these deposits. Silt- and sand-sized grains of chlorite present within the aeolian deposit are therefore believed to represent local contamination of the original volcanic ash by material derived from the regional till.

Owing to the presence of the ash certain difficulties are experienced in differentiating between the pedologic and the geologic contributions to horizonation within these soils. In terms of the overall profile development the high carbonate content of the till severely limits the depth of pedogenic activity. As a result, the profiles are relatively shallow and the sola are developed largely within the aeolian deposit. Both of the pedons show an extremely acid to very strongly acid reaction within the surface horizons (Table 2). The pH of the weathering environment in both the L-H and Ae horizons in these soils is within the range of solubility of aluminum and iron hydroxide complexes. Organic matter and nitrogen are concentrated in the surface horizons. The OC:N ratios for the L-H horizons are high, indicating a generally low degree of humification, a low level of microbial activity, and the accumulation of organic matter in response to the prevailing low soil temperatures. Organic carbon concentrations within the podzolic B horizons indicate that considerable organic matter translocation has taken place. The cation exchange capacity appears to be more a function of the organic matter content than clay distribution. The exchangeable cations in order of dominance are H^+, Ca^{++}, Mg^{++}, and Na^+, with H^+ decreasing in significance with depth.

The percentage base saturation and the distribution of cations in these soils reflect the inherent lithological differences in the parent materials, together with the effects of the degree of leaching, nutrient cycling by the vegetation, and the intensity of weathering. The distribution of clay within these soils suggests that very little if any clay translocation has taken place and that much of the clay distribution is related to the composition of the parent materials.

Probably the most significant feature of the

TABLE 3

Petrographic analysis of the very fine sand fractions (125-63μ)

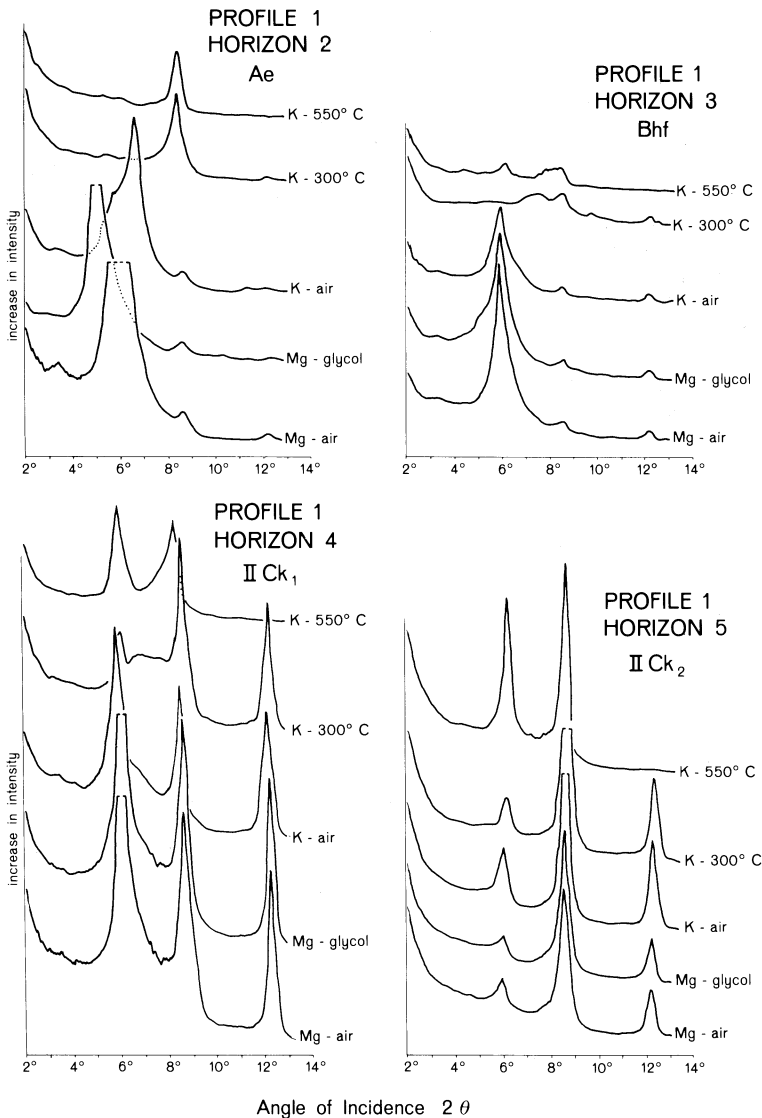| Horizon	Depth (cm)	Nonash fraction		Volcanic ash fraction	
		Opaque (%)	Nonopaque (%)	Volcanic ash (%)	Weathered ash (%)
Profile 1					
Ae	0-3	2	30	23	45
Bhf	2-6	5	50	30	15
IICk₁	6-29	4	93	2	1
IICk₂	29-44+	3	97	0	0
Profile 2					
Ae	0-4	3	27	16	54
Bfh	3-7	3	54	34	9
IICk₁	6-13	3	96	1	0
IICk₂	13-34+	3	97	0	0

FIGURE 3. X-ray diffraction patterns of oriented clays ($<2\mu$) from profile 1, an Orthic Ferro-Humic Podzol.

variations in clay mineralogy with depth revealed by the X-ray diffraction analyses is the marked concentration of expanding clays within the Ae horizons of these soils (Figures 3 and 4, and Table 4). The X-ray traces for the Ae horizons from both pedons, for example, reveal the presence of montmorillonite with a 14.7 Å Mg-saturated air-dried peak which expands to 16.9-17.3 Å when glycolated, and collapses to 13.1 Å when K-saturated and air dried, and to 10.4 Å when heated. Minor amounts of illite are also present as indicated by a poorly developed 10.2 Å peak, together with traces of an interstratified mineral and perhaps chlorite (Table 4).

The clay mineralogy of the podzolic B horizons in both pedons is dominated by chlorite, as characterized by a 14.2-14.5 Å peak when K-saturated and heated to 550°C. The destruction of the 7 Å peak at this temperature is a characteristic of iron chlorite (Martin, 1955, p. 128). Also present are minor amounts of illite and an interstratification possibly composed of chlorite and vermiculite. Analysis of the IICk horizons reveals that the dominant clay minerals are iron chlorite and illite (Table 4). Some vermiculite is again suggested by the existence of a 12.6 Å peak when K-saturated and heated to 300°C (Figure 3), although the mineral is poorly crys-
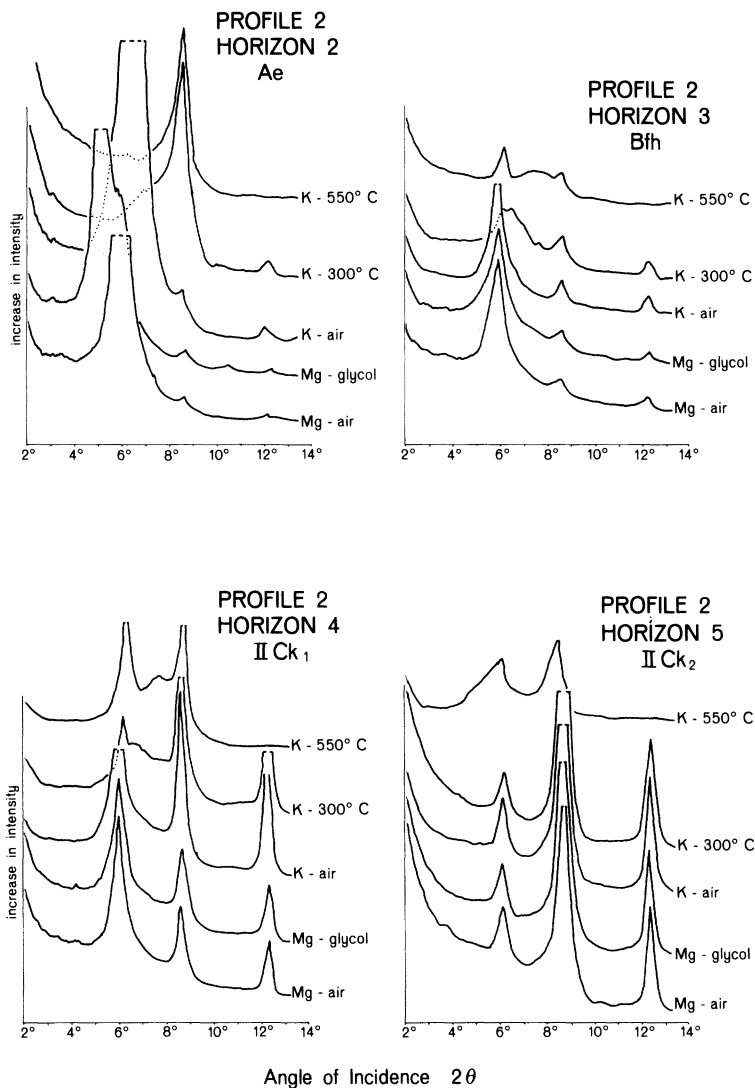
Figure 4. X-ray diffraction patterns of oriented clays ($<2\mu$) from profile 2, an Orthic Humo-Ferric Podzol.

tallized and may well be a chlorite-vermiculite interstratification. The estimation of kaolinite in the presence of iron chlorite by X-ray diffraction is extremely difficult owing to the fact that the 001 line for kaolinite and the 002 line for chlorite virtually coincide (Brown, 1961, p. 265).

The virtual absence of chlorite within the Ae horizons and its relative abundance within the podzolic B and IICk horizons in these subalpine soils supports similar observations for Podzols elsewhere in Canada (Brydon *et al.*, 1968, p. 42). However, in those cases it was assumed that soil development had occurred within a homogeneous parent material containing inherited chlorites. In the present case the pedons have

formed on heterogeneous parent materials of radically different lithologies and with only very minor concentrations of inherited chlorites occurring in the surficial deposit in which the Ae horizons have formed. In these pedons the distribution of chlorites with depth is not a function of weathering intensity but of parent material stratification.

The presence of abundant montmorillonite within the Ae horizons of these subalpine Podzols is in agreement with the opinion that the development of montmorillonite in the Ae horizon is a characteristic of Podzols in general (Brydon *et al.*, 1968, p. 47; Gjems, 1967, p. 385). The montmorillonite can originate in a number of ways. It is possible that the mineral

TABLE 4
Clay mineral associations as estimated from x-ray diffraction patterns[a]

Horizon	Depth (cm)	Montmorillonite	Chlorite (+Kaolinite)	Illite	Interstratified
Profile 1					
Ae	0-3	xxx	tr	x	tr
Bhf	2-6	—	xxx	x	x
IICk$_1$	6-29	—	xxx	xxx	x
IICk$_2$	29-44+	—	xx	xxx	—
Profile 2					
Ae	0-4	xxx	tr	x	tr
Bfh	3-7	—	xxx	x	x
IICk$_1$	6-13	—	xxx	xx	x
IICk$_2$	13-34+	—	xx	xxx	—

[a]Trace amount (tr); minor (x); moderate (xx); abundant (xxx). Dash (—) indicates not present.

might have been inherited with the original aeolian deposit, as has been suggested in the case of some Podzols in New York State (Coen and Arnold, 1972). However, its absence in the surface horizons of nonpodzolic soils in the Bow Pass area would appear to rule this possibility out. Another possibility is that the montmorillonite has formed as part of a mica (Ross and Mortland, 1966; p. 34) or chlorite (Gjems, 1967, p. 390) degradation sequence. The relatively small amount of both inherited mica and chlorite in the surficial aeolian deposit, however, suggests that these minerals are not a major source of expanding clay minerals, although chlorite does appear to form interstratified complexes. Similar results are reported by Pettapiece and Pawluk (1972, p. 518) for other soils derived partly from volcanic ash in the Canadian Rockies.

A more probable source for the well-organized montmorillonite is the volcanic ash itself. Information concerning the average glass compositions of the three ash types possibly present within the area (Westgate et al., 1970) indicates high original concentrations of the elements required for montmorillonite synthesis. Moreover, montmorillonite may readily form under conditions of drainage impedence controlled by topography, texture, or evaporation when the influx of mineral colloids and solutes in a basin analogue can result in the synthesis of montmorillonite (Jackson, 1965, p. 18). Within the subalpine at Bow Pass the intense hydrolysis of the ash possible under the strongly acidic conditions prevailing in the surface soil horizons and the retention of the basic cations under conditions of seasonal soil moisture deficit would both tend to favor the formation of montmorillonite.

An additional factor favoring the genesis of

montmorillonite in these soils may be the highly vesicular nature of the volcanic glass itself. Chichester (1967, p. 132) has postulated that there is a considerable retention of the soil solution by the internal capillary channels in the glass within those soils containing vesicular volcanic ash. The concentration of colloids of silica and alumina and of metallic cations would be expected to increase by mineral hydrolysis in this water held in the vesicles, just as it might under conditions of drainage impedence. It is therefore suggested that the formation of montmorillonite in the Ae horizons of these subalpine Podzols results largely from the further organization of amorphous weathering material derived as a result of the intense hydrolysis of the volcanic ash, and that this process is facilitated by the physical characteristics of the volcanic glass.

With this in mind, the nature and distribution of amorphous material may be expected to illuminate some of the possible processes of clay mineral genesis within these soils. The distribution of different forms of Fe and Al together with the various ratios have been used to indicate the mobilization and translocation of these elements in a variety of different soils (McKeague and Day, 1966; Blume and Schwertmann, 1969; Michalyna, 1971; Stonehouse and St. Arnaud, 1971; Singer and Ugolini, 1974).

Sodium dithionite-citrate bicarbonate removes finely crystalline hematite and goethite, amorphous Fe and Al oxides, together with organic-complexed Fe and Al from soils (Mehra and Jackson, 1960). Acid ammonium oxalate removes amorphous inorganic Fe and Al and organic-complexed Fe and Al (McKeague and Day, 1966), whereas sodium pyrophosphate removes only organic-complexed Fe and Al (McKeague, 1967). These three extraction proced-

TABLE 5
Selected Fe and Al fractions and ratios

Horizon	Sodium dithionite extraction (%)			Ammonium oxalate extraction (%)			Sodium pyrophosphate extraction (%)			Fe_d-Fe_o	Fe_o-Fe_p	Al_o-Al_p
	Fe_d	Al_d	Fe_d+Al_d	Fe_o	Al_o	Fe_o+Al_o	Fe_p	Al_p	Fe_p+Al_p			
Profile 1												
L-H	.70	.10	.80	.22	.06	.28	.07	.06	.13	.48	.15	
Ae	.34	.10	.44		.09	.09	.06	.08	.14	.34		.01
Bhf	2.00	1.50	3.50	1.30	2.50	3.80	.36	1.30	1.66	.70	.94	1.20
IICk$_1$	1.70	.30	2.00	.60	.25	.85	.27	.27	.54	1.10	.33	
IICk$_2$	1.70	.10	1.80	.42	.04	.46	.04	.06	.10	1.28	.38	
Profile 2												
L-H	.70	.10	.80	.22	.08	.30	.05	.06	.11	.48	.17	.02
Ae	.34	.10	.44	.22	.10	.33	.06	.10	.16	.12	.16	
Bfh	2.35	1.50	3.85	1.34	2.50	3.84	.27	.07	.34	1.01	1.07	2.43
IICk$_1$	2.30	.23	2.53	.70	.25	.95	.16	.10	.26	1.60	.54	.15
IICk$_2$	2.30	.10	2.40	.54	.04	.58	.06	.10	.16	1.76	.48	

ures thus allow for the differentiation of the three forms of Fe in soils, namely, hematite and goethite (dithionite-extractable Fe [Fe_d] minus oxalate-extractable Fe [Fe_o]); amorphous inorganic Fe (Fe_o minus pyrophosphate-extractable Fe [Fe_p]), and organic-complexed Fe (Fe_p). The results of these extraction procedures together with computed ratios are included in Tables 5 and 6 and in Figure 2.

Both of the pedons have relatively high concentrations of dithionite-extractable Fe and Al within the B horizons, with dithionite-extractable Fe remaining high with increasing depth. Dithionite-extractable Al, on the other hand, shows a marked decrease with increasing depth below the B horizons. Oxalate-extractable Fe and Al values are similarly high in the B horizons but both fractions then decrease in value with increasing depth. In both pedons oxalate-extractable Al exceeded dithionite-extractable Al within the B horizons. Similar results have been reported for Podzols elsewhere (McKeague and Day, 1966, p. 19). Pyrophosphate-extractable values indicate a concentration of organic-complexed Fe and Al within the B horizons in both pedons, although this concentration is comparatively small in the case of pedon 2. In both pedons hematite and geothite (Fe_d — Fe_o) (Table 5) show a progressive increase with depth. This is interpreted as being a function of the weathering of the iron-rich dolomite (ankerite) which is present in large concentrations in the calcareous till (IICk). Both amorphous Fe (Fe_o — Fe_p) and amorphous Al (Al_o — Al_p) show pronounced concentrations within the B horizons and in both instances the accumulation of amorphous Al is greater than that of amorphous Fe.

Blume and Schwertmann (1969) used the oxalate-extractable / dithionite-extractable Fe ratio as a measure of Fe activity. In both pedons presently under consideration the "active Fe ratio" (Fe_o/Fe_d) (Table 6 and Figure 2) shows an increase in the B horizons followed by a decrease with increasing depth. Such a decrease is indicative of the presence of crystalline Fe in the till. Also noticeable is the high value for this ratio in the Ae horizon in pedon 2 which indicates a concentration of amorphous Fe.

Another ratio used by Blume and Schwertmann (1969) was Fe_d/clay which, when constant with depth, was interpreted as indicating comigration of the two compounds. This ratio, when computed for the present pedons, reveals a marked increase in the B horizons when compared with the Ae horizons, followed by only a relatively slight decrease with increasing depth. This is interpreted as indicating a translocation of Fe rather than clay, together with a significant recrystallization of Fe within the underlying till (Table 6). The translocation of Al in these pedons is clearly indicated by the Al_o/clay ratio which shows a dramatic rise in the B horizons of both pedons (Table 6). However, the translocation of organic-complexed Al appears to be significant only in the case of pedon 1, as indicated by the constant Al_p values with increasing depth in pedon 2 (Table 5).

According to *The Soil Classification System for Canada* (Canada Soil Survey Committee, 1970) both of the pedons examined in this study would be classified as belonging to the Podzol Order. The criterion for the classification of a B horizon as a podzolic B horizon is an increase of 0.8% oxalate-extractable Fe plus Al in the B horizon over the IC horizon. With respect to the two

TABLE 6

Selected ratios

Horizon	Fe_o/Fe_d	Fe_d/clay	Al_o/clay	OC/Fe_p	OM/Fe_o
Profile 1					
L-H	.31			480.3	262.7
Ae		.03	.01	29.3	
Bhf	.65	.10	.12	23.4	3.8
IICk$_1$	.35	.09	.01	14.1	10.9
IICk$_2$	.25	.07			
Profile 2					
L-H	.31			460.8	180.6
Ae	.65	.02	.01	35.8	16.9
Bhf	.57	.15	.16	14.7	5.1
IICk$_1$	.30	.15	.02	1.7	0.7
IICk$_2$	.24	.11		18.3	3.5

subalpine pedons under consideration the heterogeneity of the parent materials, with the absence of pedogenically unaltered parent materials (IIC rather than IC), creates a major problem with respect to soil classification. The presence of the high concentrations of amorphous iron and aluminum in the B horizons and the existence of eluvial horizons permit these soils to be classified as Podzols. However, in both of the pedons there is a strong suggestion that some of the extractable Fe and Al oxides in the B horizons have been produced as a result of the intensive weathering *in situ* of both till and volcanic ash material rather than as a result of podzolization *sensu stricto* (Ponomareva, 1969, p. 259).

Recent recommendations for significant changes to the existing soil classification system in Canada (Canada Department of Agriculture, 1973) and the introduction of new criteria for the delimitation of podzolic B horizons go some way towards alleviating the problems associated with the classification of subalpine soils. With respect to the two pedons considered in this paper the recommended introduction of a minimum thickness criterion of 5 cm for podzolic B horizons would mean that neither of the pedons would be classified as Podzols. In any case, the introduction of the criterion that podzolic B horizons must contain at least 0.6% pyrophosphate-extractable Fe and Al would mean that only the B horizon in pedon 1 would qualify. Accordingly, both of the pedons would probably be classified as belonging to the Brunisol Order.

CONCLUSIONS

Pedogenesis within the subalpine ecotone at Bow Pass, Banff National Park, is markedly influenced by the physical and chemical composition of the parent materials. Of particular significance is the presence of a surficial aeolian deposit containing large amounts of vesicular volcanic glass of unknown origin. The ash component hydrolyzes rapidly under the strongly acidic conditions prevailing in the surface horizons, resulting in the production of considerable amounts of amorphous weathering products, especially aluminum. The physical and chemical characteristics of the ash, the annual soil hydrothermal regime, and the availability of a suitable chemical substrate result in the formation of montmorillonite as the dominant clay mineral within the Ae horizons.

The eluviation and subsequent illuviation of the amorphous weathering products in association with organic complexes at depth within the pedons leads to the development of podzolic B horizons, the clay mineralogy of which is dominated by chlorite and illite inherited from the regional till. The accumulation of extractable-Fe oxides within these podzolic B horizons is further facilitated by the *in situ* weathering of iron-rich dolomite present in considerable quantities within the till. The presence of the underlying calcareous till restricts soil development under conditions of relatively free drainage such that the sola are developed largely within the surficial aeolian deposit and are limited by the depth of this deposit.

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