Mineralogy and genesis of selected soils and their implications for forest management in central and northeastern British Columbia

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Arocena, J. M. and Sanborn, P. 1999. **Mineralogy and genesis of selected soils and their implications for forest management in central and northeastern British Columbia**. Can. J. Soil Sci. **79**: 571–592. Soil properties in central and northeastern British Columbia are strongly influenced by parent materials because of geologically young till, glaciolacustrine, and glaciofluvial deposits. We examined pedogenesis on various parent materials to support studies of long-term forest productivity. We sampled nine pedons developed on till (Bobtail, Lucille Mountain, Skulow Lake, Log Lake, Topley, and Kiskatinaw), glaciofluvial (Bowron), and glaciolacustrine (Aleza Lake 1, 2) deposits. The Skulow Lake pedon is distinctive in the occurrence of talc, while the Lucille Mountain pedon has the only clay fraction in which kaolinite is absent. Other pedons on till contain mica, kaolinite, chlorite, smectite, and vermiculite. The Bowron pedon has mica, kaolinite, and chlorite, while the Aleza Lake pedons have mica, kaolinite, chlorite, and 2:1 expanding minerals. In pedons with low amount of 2:1 expanding clays in the C horizon, mica and chlorite appear to degrade into 2:1 expanding clays, while in pedons with C horizons containing 2:1 expanding clays, mica and chlorite seem stable and the formation of hydroxy-interlayered clays is the predominant process. Podzolization and lessivage are major pedogenic processes, while redoximorphic processes are observed in some pedons with illuvial Bt horizons. Significant soil compaction hazards are presented by the medium and fine soil surface textures. Although clay-rich Bt horizons may benefit soil nutrient regimes, conservation of nutrient-rich forest floors is important, given the low S contents in mineral soils. High contents of feldspars in these soils provide a large reserve of nutrients such as Ca and K.

Key words: Clay minerals, parent material, podzolization, lessivage

Arocena, J. M. et Sanborn, P. 1999. **Minéralogie et genèse de certains sols et leur signification pour l'aménagement des forêts du centre et du nord-est de la Colombie-Britannique**. Can. J. Soil Sci. **79**: 571–592. Les propriétés des sols du centre et du nord-est de la Colombie-Britannique sont fortement tributaires du matériel parental en raison de la jeunesse généalogique du till glaciaire et des dépôts glacio-lacustres et fluvio-glaciaires. Nous avons examiné la pédogenèse de divers matériels parentaux dans le cadre d'études sur la productivité à long terme de la forêt. Étaient examinés par échantillonnage, neuf pédons formés sur till (Bobtail, Lucille Mountain, Skulow Lake, Log Lake, Topley et Kiskatinaw), sur dépôts fluvio-glaciaires (Bowron) et glacio-lacustres (Aleza Lake 1 et 2). Le pédon de Skulow Lake se distingue par la présence de talc, alors que la fraction argileuse du sol de Lucille Mountain est la seule à ne pas contenir de kaolinite. Les autres pédons formés sur till contiennent du mica, de la kaolinite, de la chlorite, de la smectite et de la vermiculite. Le pédon de Bowron contient du mica, de la kaolinite et de la chlorite, tandis que les pédons de Aleza Lake contiennent, en plus des trois mentionnés, des minéraux gonflants 2:1. Dans les pédons révélant peu ou pas d'argiles gonflantes 2:1 dans l'horizon C, il semble que la présence de ces argiles dans les horizons A et B résulte de la dégradation du mica et de chlorite. En revanche, dans les sols contenant des proportions importantes d'argiles gonflantes 2:1 dans l'horizon C, le mica et la chlorite paraissent stables, le processus dominant étant la formation d'argiles hydroxy-interstratifiées. La podzolisation et le lessivage constituent les principaux processus pédogénétiques, bien que l'intervention de réactions rédoxymorphes ait été constatés dans certains sols à horizon Bt illuvial. Les sols à surface de texture fine et moyenne comportaient des risques importants de compaction. Bien que les horizons Bt riches en argile peuvent profiter à la fertilité du sol, la conservation d'horizons organiques forestiers riches en matière nutritive devient un objectif important vu la faible teneur en S du sol minéral. Les fortes concentrations de feldspaths dans ces sols constituent une réserve importante d'éléments nutritifs comme Ca et K.

Mots clés: Minéraux argileux, matériel d'origine, podzolisation, lessivage

Parent material influences soil properties such as texture, clay mineralogy, and chemical composition (Buol et al. 1989). This influence is particularly strong in the geologically young landscapes of central and northeastern British Columbia, where repeated Quaternary glaciations have deposited soil parent materials, which have undergone relatively limited weathering and pedogenesis.

These Quaternary glaciations have obscured the influence of local bedrock by creating surficial deposits originating from a wide area, with a corresponding diversity of lithology. For example, in northeastern BC, Catto (1991) noted that the mineralogical composition of till parent materials reflected not only the local Cretaceous sedimentary bedrock, but also lithologies derived from the Cordillera to the west and the Canadian Shield to the east. In the central interior plateau, the Late Wisconsinan Fraser glaciation involved ice movements that came predominantly eastward from the Coast Mountains and westward from the Cariboo

Table 1. Description of study sites

Site	Location	Elevation (m)	Parent material	Bedrock geology[z]	Biogeoclimatic zone (subzone)[y]	Dominant tree species[x] (site index)[w]	Research project[v] (reference)
Bobtail	53°40′N 123°39′W	1030	Till	Granodiorite, quartz diorite, quartz monzonite	Sub-Boreal Spruce (SBSdw3)	Pl (18-19)	E.P. 1185 (Sanborn et al. 1997)
Lucille Mountain	53°16′N 120°14′W	1500	Till	Phyllite, schist	Engelmann Spruce-Subalpine Fir (ESSFmm)	Sx (15), Bs	E.P. 1119 (Jull et al. 1996)
Log Lake	54°21′N 122°37′W	780	Till	Basalt, sediments, Gneiss	Sub-Boreal Spruce (SBSwk1)	Sx (18.5), Fd (19.2), Pl, Bs, Ep	E.P. 1148 (Holcomb 1996)
Skulow Lake	52°20′N 121°55′W	1050	Till	Basalt, sediments	Sub-Boreal Spruce (SBSdw2)	Pl (17.9), Sx, Fd	E.P. 1148 (Holcomb 1996)
Topley	54°37′N 126°18′W	1100	Till	Andesite, basalt	Sub-Boreal Spruce (SBSmc1)	Sx (16.1), Pl (15.7), Bs	E.P. 1148 (Holcomb 1996)
Kiskatinaw	55°58′N 120°28′W	720	Till (with fluvial veneer)	Sandstone, shale	Boreal White & Black Spruce (BWBSmw1)	At (18), Sw	E.P. 1148 (Holcomb 1996)
Bowron	53°34′N 122°47′W	910	Glaciofluvial	Basalt, sediments	Sub-Boreal Spruce (SBSwk1)	Pl (23), Sx, Hw	E.P. 886.13 (Brockley 1992)
Aleza Lake 1 and 2	54°5′N 122°5′W	700	Glaciolacustrine	(unspecified: deep Quaternary deposits)	Sub-Boreal Spruce (SBSwk1)	Sx (20-24), Bs, Fd, Ep	(Jull, 1992; Lawrie et al. 1996)

[z] As interpreted from generalized map by Tipper et al. (1974)

[y] Terminology after Meidinger and Pojar (1991)

[x] Tree species codes: At, trembling aspen *(Populus tremuloides)*; Bs, subalpine fir *(Abies lasiocarpa)*; Ep, paper birch *(Betula papyrifera)*; Fd, interior Douglas fir *(Pseudotsuga menziessi* var. *glauca)*; Hw, western hemlock *(Tsuga heterophylla)*; Pl, lodgepole pine *(Pinus contorta* var. *latifolia)*; Sx, hybrid white spruce *(Picea glauca* × *engelmannii)*; Sw, white spruce *(Picea glauca)*.

[w] Site index (m at 50 yr breast height (1.3 m) age) estimated or obtained from: Nigh (1997), Bobtail & Bowron; Site Productivity Working Group (1997), Lucille Mountain; Trowbridge *et al.* (1996), Log Lake, Skulow Lake & Topley; BC Ministry of Forests unpublished data, Kiskatinaw & Aleza Lake.

[v] BC Ministry of Forests Experimental Project (EP) number provided, where applicable.

Mountains (Tipper 1971; Clague 1988). The resulting glacial deposits reflect this extensive source area, with a composition drawn from fine-textured volcanic and coarse-textured intrusive rocks in the west, and minor fine-textured metasedimentary and metavolcanic rocks from the east (Lord and Mackintosh 1982; Clague 1987, 1988). Till parent materials are generally medium to moderately coarse textured in the central interior (Lord and Mackintosh 1982; Dawson 1989), but are medium to finer-textured east of the Rocky Mountains in northeastern BC (Lord and Green 1986).

During deglaciation, extensive ice-dammed lakes occupied major valleys such as those of the Fraser River and its tributaries, resulting in thick glaciolacustrine deposits of silty and clayey sediments (Tipper 1971). Associated glacial meltwater channels accumulated much coarser-textured glaciofluvial deposits (sands, gravels).

Only limited information is available on the mineralogical composition of soil parent materials in this region. The earliest publication (Floate 1966) addressed only the mineralogy of soils derived from glaciolacustrine deposits, and reported clay assemblages dominated by mica, chlorite, montmorillonoid (smectitic), vermiculite, mixed layer clays, quartz, feldspars, and amphibole with variations in mineral composition observed between basins. More recently, similar results were reported by Luttmerding (1992) for the glaciolacustrine-derived Pineview soil association near Prince George. Kodama (1979) reported the presence of chlorite, mica and smectite in the western Cordilleran region, and smectite, mica and kaolinite in the interior Cordillera. We are not aware of any publications on the clay and sand fraction mineralogy of soils derived from till and glaciofluvial parent materials in central and northeastern BC.

Such information is important, not only for the study of pedogenesis, but also because of the practical implications of mineralogy for nutrient cycling and forest productivity. This region supports a significant forest industry, and a better understanding of soil mineralogy and its role on site productivity is part of the knowledge essential for long-term, sustainable forest management.

The objectives of this paper are: (1) to examine the physical, chemical and mineralogical composition of representative soils developed from till, glaciofluvial, and glaciolacustrine parent materials in central and northeastern interior BC, (2) to discuss the major pedogenic processes involved in the formation of these soils, emphasizing mineral transformations, and (3) to consider the implications of these soil properties and processes for forest management.

MATERIALS AND METHODS

Description of the Study Areas, Sample Collection and Preparation

To ensure that these findings contribute to the basic inventory of soil data relevant to forest productivity in BC, we chose well-characterized study sites linked to active installations of the Research Program of the BC Ministry of Forests. The location, elevation, biogeoclimatic zone and

Table 2. Physical and chemical properties of selected pedons in central and northeastern British Columbia

Parent Material Site/Horizon/ Depth (cm)	Sand	Clay	Total C	Total N	pH H_2O	pH $CaCl_2$	Avail. P	Tot S	K	Ca	Mg	Na	CEC
	(g kg^{-1})						(mg kg^{-1})		(cmol$_c$ kg^{-1})				
Till													
Bobtail – Brunisolic Gray Luvisol													
LF (4–0)	ND	ND	504.8	10.4	4.2	3.6	64.6	1270	0.86	22.11	5.86	0.65	31.73
Ahe (0–5)	553	70	15.3	0.8	4.7	4.0	85.6	37	0.10	1.84	0.80	0.08	4.47
Bf (5–12)	457	121	13.0	1.0	5.0	4.4	88.7	58	0.14	3.02	1.14	0.08	5.28
Bm (12–48)	631	59	2.5	0.4	5.7	4.9	16.0	28	0.09	2.70	1.53	0.13	4.63
Bt (48–80)	467	200	2.7	0.4	6.5	5.8	1.3	29	0.26	7.63	5.61	0.23	13.77
BCk (80–90)	458	176	1.5	0.3	7.1	6.4	1.4	24	0.18	6.84	5.25	0.19	12.50
Ck (90–115+)	461	190	2.4	0.2	8.1	7.7	0.0	47	0.17	7.46	4.80	0.24	12.67
Lucille Mountain – Orthic Humo-Ferric Podzol													
LF (3–0)	ND	ND	515.9	18.6	3.7	3.2	75.6	1711	2.44	9.08	5.35	0.49	20.33
Ae (0–4)	388	45	9.7	0.9	3.8	3.1	2.5	27	0.05	0.24	0.21	0.04	3.66
Bf1 (4–11)	438	44	19.1	1.2	4.2	3.6	8.7	108	0.05	0.26	0.16	0.05	3.72
Bf2 (11–25)	399	41	10.2	0.9	4.5	3.9	2.3	54	0.02	0.12	0.05	0.04	1.56
Bf3 (25–60)	389	81	6.6	0.7	4.6	4.1	3.5	54	0.02	0.06	0.02	0.03	0.85
BC (60–100)	574	45	2.7	0.4	5.0	4.4	9.5	33	0.05	0.15	0.07	0.06	0.69
C (100–120+)	513	63	1.8	0.4	5.0	4.5	21.9	13	0.03	0.06	0.02	0.08	0.35
Log Lake – Gleyed Humo-Ferric Podzol													
LF (4–0)	ND	ND	550.2	15.3	5.1	4.7	47.4	1261	2.55	52.26	5.89	0.69	63.57
Ahe (0–9)	513	58	11.0	0.9	4.5	3.9	40.2	49	0.13	2.25	0.37	0.10	4.38
Bf (9–27)	398	172	8.5	0.7	5.2	4.4	39.8	50	0.16	0.97	0.24	0.09	2.16
Bfj (27–45)	437	180	3.4	0.6	5.1	4.2	25.4	26	0.07	0.63	0.24	0.11	1.83
Bmgj (45–70)	414	179	2.4	0.6	5.1	4.3	18.7	32	0.10	2.34	0.91	0.14	4.21
Cg (70–100+)	402	213	1.7	0.6	5.6	4.8	16.9	31	0.09	5.18	1.71	0.15	7.32
Skulow Lake – Brunisolic Gray Luvisol													
LF (2.5–0)	ND	ND	345.6	9.3	4.3	4.0	132.2	385	2.20	19.60	8.57	0.63	32.79
Ahe (0–2)	456	91	27.4	1.2	4.9	4.4	18.9	81	0.15	5.72	3.77	0.09	10.32
Ae (2–11)	460	103	11.1	0.8	5.1	4.5	28.4	36	0.07	3.81	3.62	0.13	8.26
Bm (11–21)	454	222	7.0	0.7	6.4	6.0	0.3	46	0.11	8.15	8.60	0.11	17.05
Bt1 (21–48)	426	312	6.6	0.5	7.1	6.8	0.0	31	0.18	12.32	12.29	0.11	24.93
Bt2 (48–68)	450	249	5.4	0.6	7.0	6.6	0.2	14	0.15	9.64	8.59	0.13	18.52
BCk (68–99)	516	192	9.7	0.5	8.1	7.7	0.0	8	0.09	7.62	4.08	0.09	11.87
IICk (99–105+)	768	81	2.4	0.2	8.1	7.6	0.0	16	0.06	5.92	2.82	0.09	8.89
Topley – Orthic Luvic Gleysol													
LF (5–0)	ND	ND	442.5	12.4	4.9	4.4	44.6	725	0.88	35.47	8.23	0.71	48.02
Ahegj (0–5)	485	172	22.0	1.0	5.2	4.7	5.4	32	0.20	6.73	2.09	0.13	9.88
Aeg (5–36)	473	160	7.7	0.7	5.9	5.5	2.3	45	0.13	5.10	1.88	0.12	7.62
Btg (36–78)	412	249	3.2	0.6	6.7	6.1	0.2	25	0.16	8.59	3.10	0.19	12.12
Cg (78–110+)	422	248	2.4	0.4	7.5	6.9	0.0	52	0.16	8.99	2.97	0.20	12.35
Kiskatinaw – Humic Luvic Gleysol													
LF (9–3)	ND	ND	552.7	17.3	6.0	5.7	86.4	1508	3.44	80.88	15.93	0.81	101.36
H (3–0)	ND	ND	386.2	17.4	5.8	5.4	43.7	1252	2.11	57.44	12.09	0.63	72.54
Ah (0–12)	80	335	32.2	2.7	6.2	5.9	87.4	194	0.87	17.30	5.22	0.11	23.54
Aeg (12–28)	172	86	4.3	0.6	5.6	5.1	12.6	37	0.21	2.35	1.05	0.06	3.72
IIBtg (28–52)	165	589	9.4	1.4	5.7	5.3	7.8	106	0.29	12.88	9.78	0.21	23.23
IIBCk (52–80)	134	535	12.0	1.2	7.5	7.3	2.5	218	0.21	17.69	9.26	0.29	27.47
IICk (80–105+)	145	443	12.0	1.2	7.9	7.7	0.0	273	0.21	12.00	8.21	0.42	20.85
Glaciofluvial													
Bowron – Eluviated Dystric Brunisol													
LF (2–0)	ND	ND	320.7	6.4	4.2	3.6	32.7	318	0.64	7.84	1.15	0.55	13.75
Ae (0–5)	730	32	6.1	0.3	4.2	3.4	3.5	27	0.03	1.09	0.33	0.05	3.52
Bf (5–12)	811	57	8.9	0.7	4.8	4.4	51.5	71	0.03	0.28	0.05	0.10	1.05
Bfj (12–27)	912	18	3.9	0.5	5.5	5.0	58.1	37	0.01	0.21	0.02	0.10	0.39
Bm (27–60)	928	15	4.5	0.6	5.7	5.0	32.9	28	0.02	0.46	0.03	0.09	0.64
BC (60–100)	963	3	1.4	0.3	6.0	5.1	12.8	23	0.03	0.71	0.09	0.05	0.90
C (100–125+)	973	6	1.3	0.1	5.8	5.0	17.9	29	0.02	0.39	0.05	0.04	0.53

Continued

Table 2. Continued

Parent Material Site/Horizon/ Depth (cm)	Sand	Clay	Total C	Total N	pH H_2O	pH $CaCl_2$	Avail. P	Tot S	K	Ca	Mg	Na	CEC
	(g kg^{-1})						(mg kg^{-1})		(cmol$_c$ kg^{-1})				
						Glaciolacustrine							
Aleza Lake 1 – Orthic Luvic Gleysol													
LF (4.5–0)	ND	ND	425.3	13.7	ND	ND	137.8	1006	2.62	48.23	7.66	0.60	61.44
Ahe (0–10)	162	502	21.7	1.9	4.6	4.0	19.6	66	0.37	7.61	5.50	0.19	16.77
Btg (10–37)	43	795	7.2	1.3	5.0	4.5	4.6	59	0.37	13.92	14.98	0.34	30.35
BCg (37–57)	55	745	4.6	1.0	6.8	6.4	0.0	57	0.32	14.30	14.69	0.44	29.78
Ckg (57–105+)	24	818	3.7	0.7	7.8	7.5	0.2	51	0.39	14.75	13.95	0.35	29.43
Aleza Lake 2 – Orthic Humo-Ferric Podzol													
LF (5–0)	ND	ND	445.0	14.0	4.9	4.6	90.7	1044	2.83	42.35	4.77	0.63	53.08
Ahe (0–5)	145	111	22.9	1.9	4.5	3.8	31.9	1000	0.11	4.49	0.84	0.12	8.85
Bf (5–16)	179	143	13.8	1.1	5.1	4.3	32.0	64	0.05	2.82	0.62	0.10	5.01
BC (16–45)	64	146	3.8	0.7	5.6	5.0	4.3	37	0.10	8.18	3.26	0.20	11.80
C (45–105+)	52	177	3.0	0.6	5.8	5.2	5.3	31	0.13	10.40	4.27	0.21	15.05

subzone, parent material, bedrock geology and forest stand composition for each site are summarized in Table 1. Forest productivity was assessed by site index (SI_{50}) – the average height of suitable trees of a given species at 50 yr breast height (1.3 m) age (Table 1). Where site-specific data were not available, SI_{50} was estimated using either the growth intercept method (Nigh 1997) or the ecologically based tables provided by the Site Productivity Working Group (1997).

Six pedons developed on till (Bobtail, Lucille Mountain, Log Lake, Skulow Lake, Topley, and Kiskatinaw), one pedon formed on glaciofluvial deposits (Bowron), and two pedons developed on glaciolacustrine parent material (Aleza Lake 1 and Aleza Lake 2) were studied. At each site, we dug a representative soil pit measuring at least 1 m wide × 1 m long × 1 m deep and described the morphology of the pedon using the criteria in the Canadian System of Soil Classification (Soil Classification Working Group 1998). We collected samples representing each genetic mineral soil horizon as well as the L, F and H layers. The soil samples were air-dried and passed through a 2mm sieve prior to particle size separation, chemical and mineralogical analyses.

Particle Size Analysis and Separation

Particle size analysis was conducted on <2-mm air-dried samples with the pipette method (Kalra and Maynard 1991). Separation of clay, silt and sand was done after ultrasonic dispersion for 6 min at 400 W. Samples from Bf horizons were pretreated with dithionite-citrate-bicarbonate (Mehra and Jackson 1960) to remove the cementing effects of iron oxides and to ensure proper dispersion. We did not use H_2O_2 pre-treatment to remove organic matter because the soil samples contained less than 5% organic matter (Kalra and Maynard 1991). Clays were separated from sand and silt through successive dispersion and gravity sedimentation following the principles of Stoke's Law (Kalra and Maynard 1991). Clay samples were then saturated with Ca and K for mineralogical analyses. The sand fraction from each sample was separated from the silt fraction by wet sieving on a 53-µm sieve.

Chemical Analyses

Soil pH in H_2O and 0.01 M $CaCl_2$ was determined from 1:2 soil to solution ratio using an electronic pH meter. For C and N analyses, the mineral soil and L, F and H samples were ground to pass 100-mesh sieve and analyzed using a Carlo Erba NA1500 Elemental Analyzer where atropine was used for standard calibration. Exchangeable **cations and the cation exchange capacity** (**CEC**) was determined using the $BaCl_2$ method (Hendershot et al. 1993). Selective extraction of Fe and Al from the soil was conducted using pyrophosphate-, acid ammonium oxalate-, and dithionite-citrate extractants following the methods outlined in Page et al. (1982), and Kalra and Maynard (1991). Other chemical analyses conducted on the samples were available phosphorus using the Bray P1-method (Kalra and Maynard 1991) and total sulphur by Leco S Analyzer. Total elemental analysis of clay and sand fractions was conducted on microwave digested samples using inductively coupled plasma-atomic emission spectroscopy and reference soil samples from the Canadian Certified Reference Materials Project (CCRMP) identified as SO-2 and SO-3 were used as internal standards.

Mineralogical Analysis and Parent Material Uniformity

Clay mineral identification was conducted on Ca- and K-saturated slides, prepared by the paste method (Theisen and Harward 1962), by **X-ray diffraction** (**XRD**) analysis. Potassium-saturated clays were scanned from 3 to 36°2Θ in the K-0% **relative humidity** (**RH**) treatment, and from 3 to 19°2Θ in 54% RH, K-300 and K-550°C treatments. Calcium-saturated clays were scanned from 3 to 36°2Θ in the Ca-54% RH treatment, and from 3 to 19°2Θ after ethylene glycol (Ca-EG) and glycerol (Ca-Gly) solvations.

Kaolinite and chlorite were recognized by the reflections at 0.71 nm and 1.4 nm, respectively, that were not affected by various RH and solvation treatments. In addition, kaolinite in the presence of chlorite was identified by the doublet reflections at 0.357 nm and 0.354 nm as suggested by Bradley (cited in Barnhisel and Bertsch 1989). Mica was

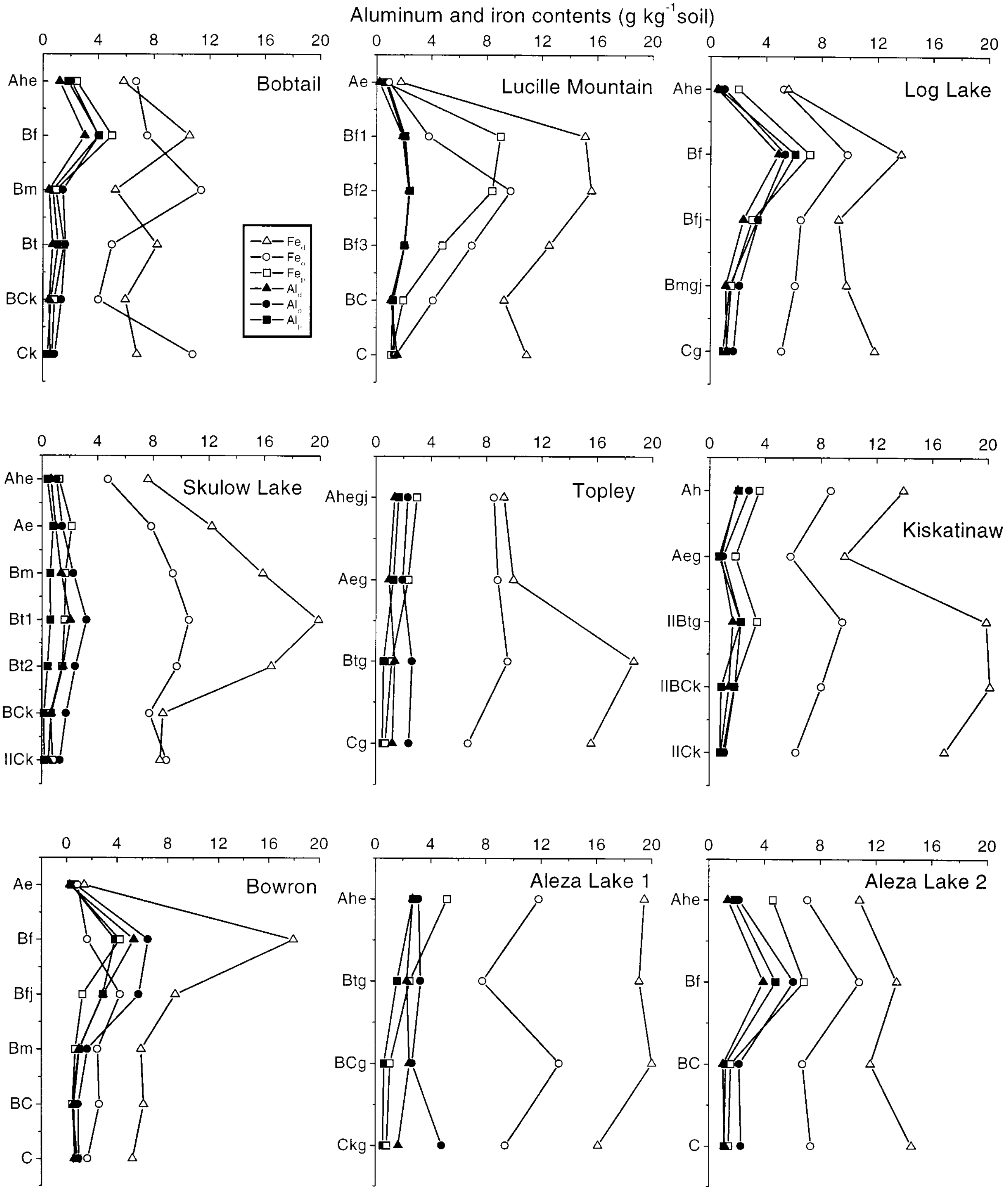


Fig. 1. Distribution of dithionite-citrate-extractable (Fe_d, Al_d), acid ammonium oxalate-extractable (Fe_o, Al_o) and pyrophosphate-extractable iron and aluminum (Fe_p, Al_p) within selected pedons in central and northeastern British Columbia.

identified from the 1.0 nm reflection in all XRD treatments. Low-charge swelling clay (smectite) was recognized by the 1.7 nm reflection from the Ca-Gly and Ca-EG treatments. The presence of high-charge clay (vermiculite) was based on 1.7 nm reflection in Ca-EG treatment and on its absence in Ca-Gly treatment. Identification of talc was based on reflections at 0.92–0.94 and 0.312 nm that were stable in all the treatments.

We estimated the amounts of mica (muscovite) from the total K content and chlorite from total Mg content in the clay fraction. The estimates were based on the general chemical compositions, $K(Si_3Al)Al_2O_{10}(OH)_2$ for muscovite (Fanning et al. 1989), and $(Mg, Fe, Al)_6(SiAl)_4O_{10}(OH)_8$ for chlorite (JCPDS Card # 7-78). In cases where talc and chlorite were present in the same sample, the amount of Mg allocated to chlorite was proportional to the XRD intensities of 1.4 nm and 0.94 nm in K-0% RH treatment. Estimates of talc were based on the amount of Mg in the clay fraction and the formula $Si_4Mg_3O_{10}(OH)_2$ for talc (McBride 1994). The amount of 2:1 expandable clays (vermiculite and smectite) was estimated from CEC_{Ca} and CEC_K of the clay fraction following the guidelines of Alexiades and Jackson (1965). The CEC_{Ca} was measured from the amount of Ca replaced by $MgCl_2$, while CEC_K was determined from the amount of K displaced by 1.0 M NH_4Cl after overnight heating of the K-saturated clay at 110°C. Kaolinite content was estimated from a modified procedure of Warren et al. (1990). We subtracted the area under 0.712 nm peak in K-550°C treatment from the area of the same XRD reflection in Ca-54% RH treatment.

X-ray diffraction analysis of the sand fractions was determined on samples back-packed in an aluminum sample holder against a filter paper to minimize preferred orientation. The powder mount was scanned from 3 to 90°2Θ at ambient condition. Identification of the minerals in the sand fraction was based on the following criteria: (1) quartz , 0.425, 0.334, 0.245, 0.228 and 0.182 nm reflections; (2) feldspars, 0.635, 0.404–0.420, 0.315–0.325 nm reflections; (3) amphiboles, 0.826, 0.324, 0.304 and 0.270 nm reflections. We estimated the amounts of feldspars (albite, anorthite and orthoclase) from the total contents of K, Na, and Ca in the sand fraction.

We also estimated the amounts of secondary minerals in the soil samples. The amount of allophane was calculated from the contents of Si extracted by acid ammonium oxalate (Si_o) multiplied by a factor determined from the amount of Al extracted by pyrophosphate (Al_p) and acid ammonium oxalate (Al_o) following the formula $(Al_o\text{-}Al_p)/Si_o$ (Parfitt 1990). Relative amounts of less-ordered Fe oxides was estimated from the amounts of Fe extracted in acid ammonium oxalate (Fe_o) and dithionite-citrate (Fe_d) using the ratio $Fe_o{:}Fe_d$ (Schulze 1981; De Geyter et al. 1982).

Parent Material Uniformity

Parent material uniformity in each pedon was evaluated by using the χ^2 goodness-of-fit test calculated from the contents of sand fraction and albite, anorthite and orthoclase in the sand fraction. This uniformity index was used because of the abundance of feldspars in the sand fraction and the immobility of sand relative to the clay fraction. To calculate χ^2 goodness-of-fit test value, the contents of sand, and albite, anorthite and orthoclase in the sand fraction of each horizon (observed values) were compared to C horizons (expected values) with degrees of freedom equals three. Except for Ae horizons (due to negative enrichment of sand), a χ^2 goodness-of-fit test value with $P > 0.05$ means similar parent material at 95% confidence interval. Statistical analysis was conducted using Statistica™, version 5 (StatSoft, Inc. 1995).

RESULTS

Soil Physical and Chemical Properties

Most pedons that developed on till parent materials (Bobtail, Lucille Mountain, Log Lake, Skulow Lake and Topley) have forest floors less than 5 cm thick, Ae horizons less than 10 cm thick and B horizons extending to about 80 cm depth from the mineral surface (Table 2). Kiskatinaw has 12-cm LF and H layers, Ah and Aeg horizons with combined thickness of 28 cm, and B horizons extending to 80 cm depth. Clay content ranges from 41 g kg^{-1} soil in the Bf2 horizons of the Lucille Mountain pedon to 589 g kg^{-1} soil in the IIBtg horizon of the Kiskatinaw pedon. The Bobtail, Skulow Lake and Topley pedons have clay accumulation in Bt horizons. For the five central interior till-derived soils (Bobtail, Lucille Mountain, Log Lake, Skulow Lake and Topley), solum sand contents range from 388 to 631 g kg^{-1} soil. In the Kiskatinaw pedon, sand contents range from 80 g kg^{-1} soil in the Ah horizon to 172 g kg^{-1} soil in the Aeg horizon. In the forest floor, total C contents range from 345 g kg^{-1} in the Skulow Lake pedon to 553 g kg^{-1} in the LF layers of Kiskatinaw and Log Lake pedons, while total N contents range from 9.3 g kg^{-1} in the Skulow Lake pedon to 18.6 g kg^{-1} in the Lucille Mountain pedon. From the data in Table 2, the calculated C:N ratio in the forest floor layers varies from 28 (Lucille Mountain) to 51 (Bobtail) while C:N ratio for mineral horizons ranges from 7 to 22 in A horizons and from 6 to 13 in B horizons. Soil pH ($CaCl_2$) increases with depth and ranges from 3.1 to 5.9 in the A horizons and from 4.5 to 7.7 in the C horizon (Table 2). Soil pH ($CaCl_2$) in the forest floor ranges from 3.2 (Lucille Mountain) to 5.7 (Kiskatinaw). Except for the Bobtail pedon, Bray P-1 content in the forest floors is greater than in the mineral horizon (Table 2). Available Bray P-1 content varies from 2.5 (Lucille Mountain) to 87.4 mg kg^{-1} soil (Kiskatinaw) in the A horizons, and from <1.0 mg kg^{-1} soil (Skulow Lake) to 89 mg kg^{-1} soil (Bobtail) in the B horizons. Total S ranges from 385 (Skulow Lake) to 1711 mg kg^{-1} soil (Lucille Mountain) in the forest floor. Total S contents in mineral horizons of the till-derived soils range from 27 mg kg^{-1} soil in the Ae horizon from Lucille Mountain to 273 mg kg^{-1} soil in the IICk horizon from Kiskatinaw. Almost all of the Kiskatinaw mineral horizons have consistently higher total S concentrations than those from all other sites.

In the pedon that developed from glaciofluvial parent material (Bowron), the forest floor is 2 cm thick, reflecting recent disturbance by logging and prescribed fire, the Ae horizon is 5 cm thick and the B horizon extends down to a

Table 3. Probability (*P*) values of χ^2 tests and estimates of the amount of different feldspars minerals (% weight of total sand fraction) in the sand fraction of selected pedons developed from three major types of parent materials in central and northeastern British Columbia

Parent material/ location	P^z of χ^2	Albite	Anorthite	Orthoclase
		(% weight of total sand fraction)		
			Till	
Bobtail				
Ahe	0.000	3	0	1
Bf	0.190	7	5	3
Bm	0.010^{*}	8	5	5
Bt	0.220	8	5	5
BCk	0.180	7	5	5
Ck		9	12	4
Lucille Mountain				
Ae	0.220	10	0	10
Bf1	0.490	8	0	6
Bf2	0.170	10	0	11
Bf3	0.290	9	0	8
BC	0.710	11	1	9
C		12	0	7
Log Lake				
Ahe	0.370	9	3	5
Bf	1.000	8	3	5
Bfj	0.830	7	2	5
Bmgj	0.910	10	3	5
Cg		8	3	5
Skulow Lake				
Ahe	0.000	16	9	6
Ae	0.003	20	11	6
Bm	0.003	18	12	6
Bt1	0.002	20	16	6
Bt2	0.004	17	16	6
BCk	0.020	16	13	5
IICk		18	16	6
Topley				
Ahegj	0.650	27	5	9
Aeg	0.650	29	6	9
Btg	0.920	30	7	9
Cg		30	9	9
Kiskatinaw				
Ah	0.004	5	1	5
Aeg	0.009	7	2	6
IIBtg	0.650	2	5	16
IIBCk	0.005	3	11	22
IICk		3	4	20
			Glaciofluvial	
Bowron				
Ae	0.110	26	12	15
Bf	0.350	24	10	12
Bfj	0.900	26	13	13
Bm	0.950	25	13	14
BC	0.910	27	14	14
C		25	12	14
			Glaciolacustrine^y	
Aleza Lake 1				
Aleza Lake 2				
Ahe	0.000	16	7	9
Bf	0.000	23	8	11
BC	0.860	20	6	11
C		19	8	11

[z] Probability of χ^2 values (df = 3) comparing the amount of sand and feldspars between each horizon and the C horizon in each pedon.
[y] No data available due to insufficient sample for Aleza Lake 1.

depth of 60 cm from the mineral surface (Table 2). The soil is sandy throughout the profile with sand content ranging from 730 to 973 g kg^{-1} soil. Clay shows maximum accumulation in the Bf horizon (Table 2). The C:N ratio is highest at 50 in the LF layers and decreases with depth to 5 in BC horizon. Soil pH increases from 3.6 in the Ae horizon to 5.1 in the C horizon. Extractable P and total S increase with depth from the Ae horizon, reaching maxima in the B horizons and decreasing in the C horizon.

Pedons formed on glaciolacustrine parent materials (Aleza Lake 1 and Aleza Lake 2) have Ahe horizons of 10 and 5 cm thickness, respectively (Table 2). The Aleza Lake 1 pedon has a 27-cm thick Btg horizon while the Aleza Lake 2 pedon has 11-cm thick Bf horizon. Clay content ranges from 502 to 818 g kg^{-1} soil with a maximum in the Ckg horizon in the Aleza Lake 1 pedon, but is almost uniform throughout (111 to 177 g kg^{-1} soil) the Aleza Lake 2 pedon (Table 2). In the Aleza Lake 1 pedon, clay content increases from Ahe to Btg and Ckg horizons. The C:N ratios are 31 in the forest floors and less than 12 in the mineral horizons. Soil pH ($CaCl_2$) in the Aleza Lake 1 pedon ranges from 4.0 in Ahe horizon to 7.5 in Ckg horizon while the Aleza Lake 2 pedon pH ranges from 3.8 in the Ahe horizon to 5.0 in BC horizon. Extractable P and total S contents decrease from forest floors to C horizons in both Aleza Lake pedons.

Except for the Skulow Lake pedon, relative amounts of exchangeable cations follow the order Ca > Mg > K ~ Na (Table 2). Generally, in all soils, the amounts of Fe_d are higher compared Fe_p and Fe_o. Both Fe_p and Al_p have maximum contents in the Bf horizons (Fig. 1).

Mineralogical Properties of Soils

Soil minerals identified in pedons that developed on till are shown in Figs 2, 3, 4, 5, 6a, and 7, and Table 3. The clay fractions of soils developed from till contain mainly the following phyllosilicates: mica, kaolinite, chlorite, smectite and vermiculite. Talc is present in the clay fraction of the Skulow Lake pedon. Non-phyllosilicate minerals in the clay fractions include hornblende, feldspars and quartz. For the Lucille Mountain pedon, XRD and CEC analyses indicated that the clay fraction in the C horizon is composed mainly of mica and chlorite (Figs 2 and 3). The chlorite content decreases from 200 g kg^{-1} clay in the C horizon to 100 g kg^{-1} clay in Ae horizon, while the amount of mica reaches a maximum of 650 g kg^{-1} clay in the Ae horizon and a minimum of 400–450 g kg^{-1} clay in the Bf horizons (Fig. 3). The 2:1 expanding clays (vermiculite and smectite) are present in Ae and Bf1 horizons. In Fig. 2, the absence of the XRD diffraction doublet at 0.354 and 0.357 nm in the Ca 54% RH and K 0% RH treatments and the increase in the intensity of 1.4 nm diffraction peak in the K 550°C heat treatment indicate the absence of kaolinite (Barnhisel and Bertsch 1989). In the Kiskatinaw pedon, XRD reflections indicated the presence of mica and kaolinite in the IICk horizon with minor amounts of chlorite and 2:1 expanding clays while the Ah horizon contains mica, 2:1 expanding clays, kaolinite and chlorite (Fig. 4). The clay fractions from the Skulow Lake pedon have chlorite, talc, kaolinite, 2:1 expanding clays and mica (Fig. 3 and Fig. 5). The amounts of chlorite

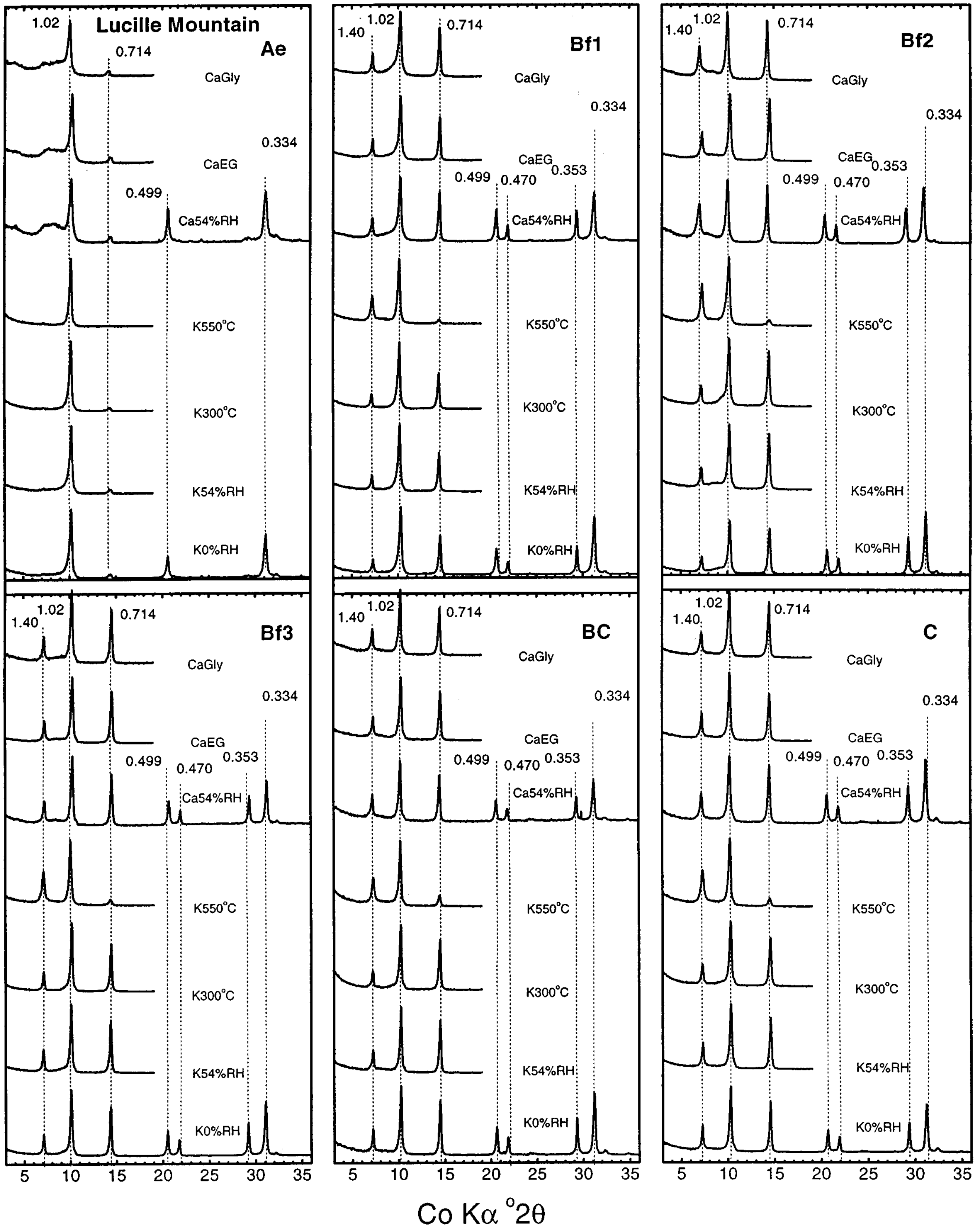
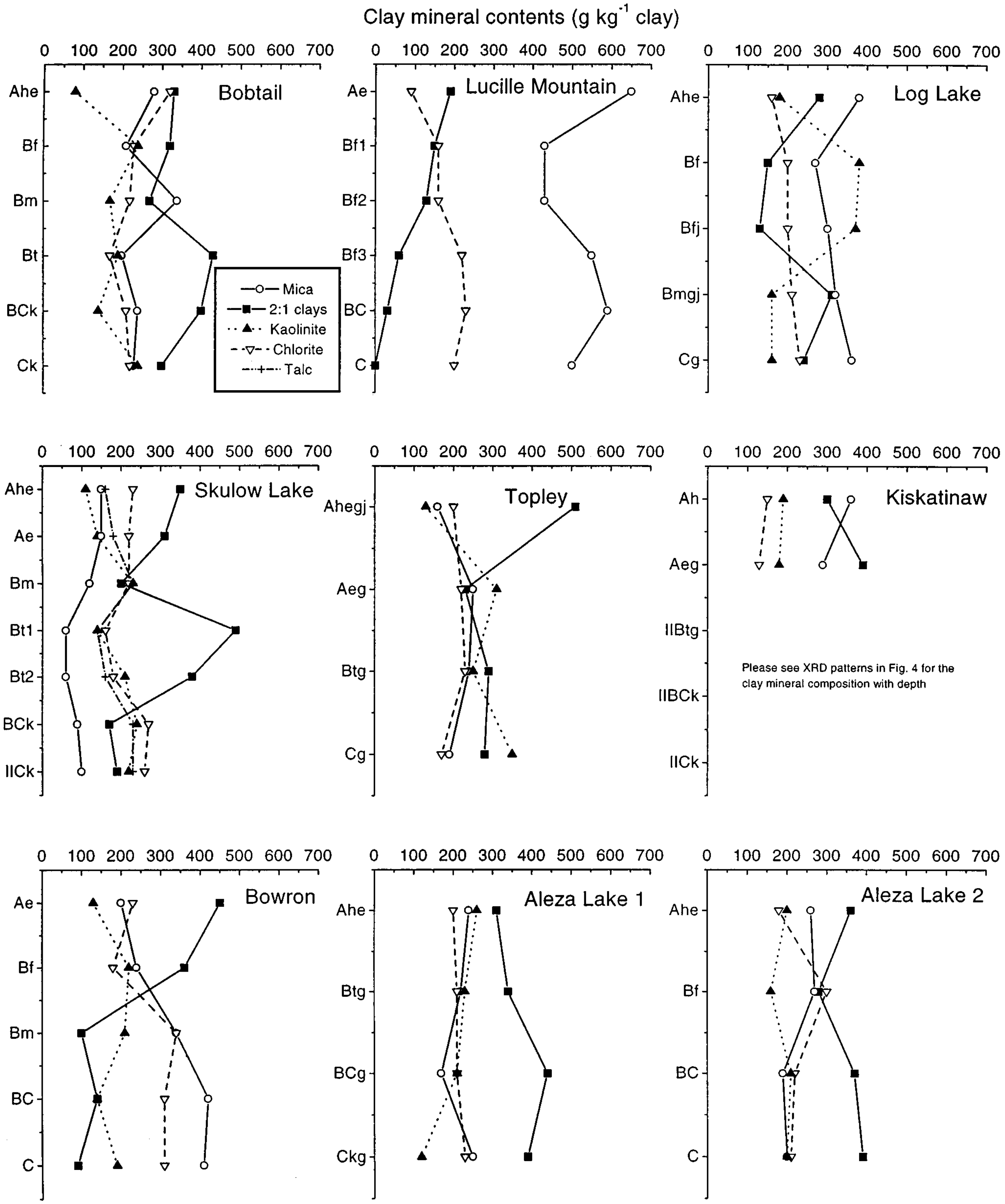


Fig. 2. X-ray diffraction patterns for the clay fractions of Lucille Mountain pedon. Treatment designations refers to various K and Ca saturation, ethylene (EG) and glycerol (Gly) solvations, heat treatment and RH. Spacings are shown in nanometers.



Please see XRD patterns in Fig. 4 for the clay mineral composition with depth

Fig. 3. Distribution of mica, kaolinite, chlorite, 2:1 expanding clays and talc various phyllosilicates within selected pedons in central and northeastern British Columbia.

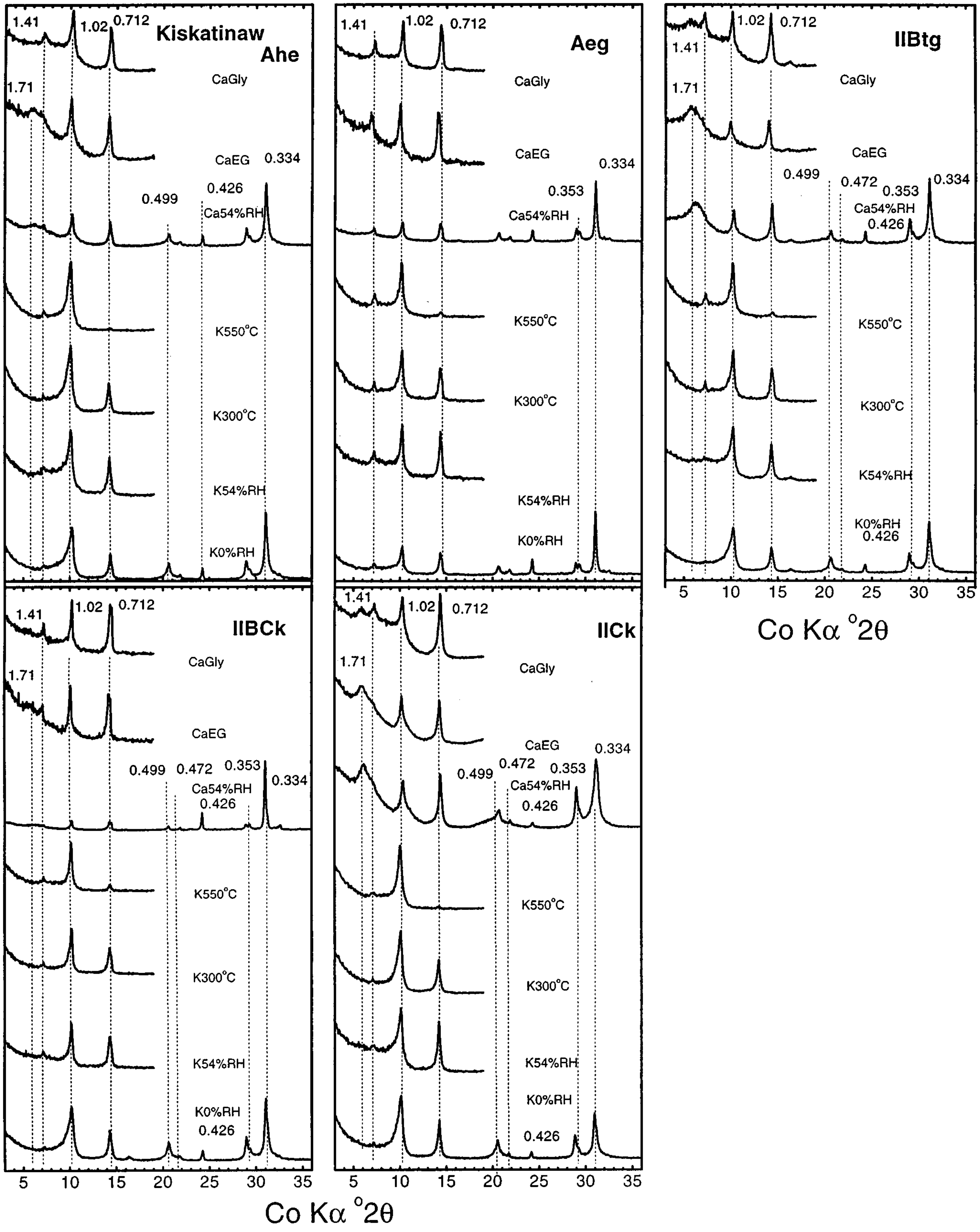


Fig. 4. X-ray diffraction patterns for the clay fractions of the Kiskatinaw pedon. Treatment designations refers to various K and Ca saturation, ethylene glycol (EG) and glycerol (Gly) solvations, heat treatment and RH. Spacings are shown in nanometers.

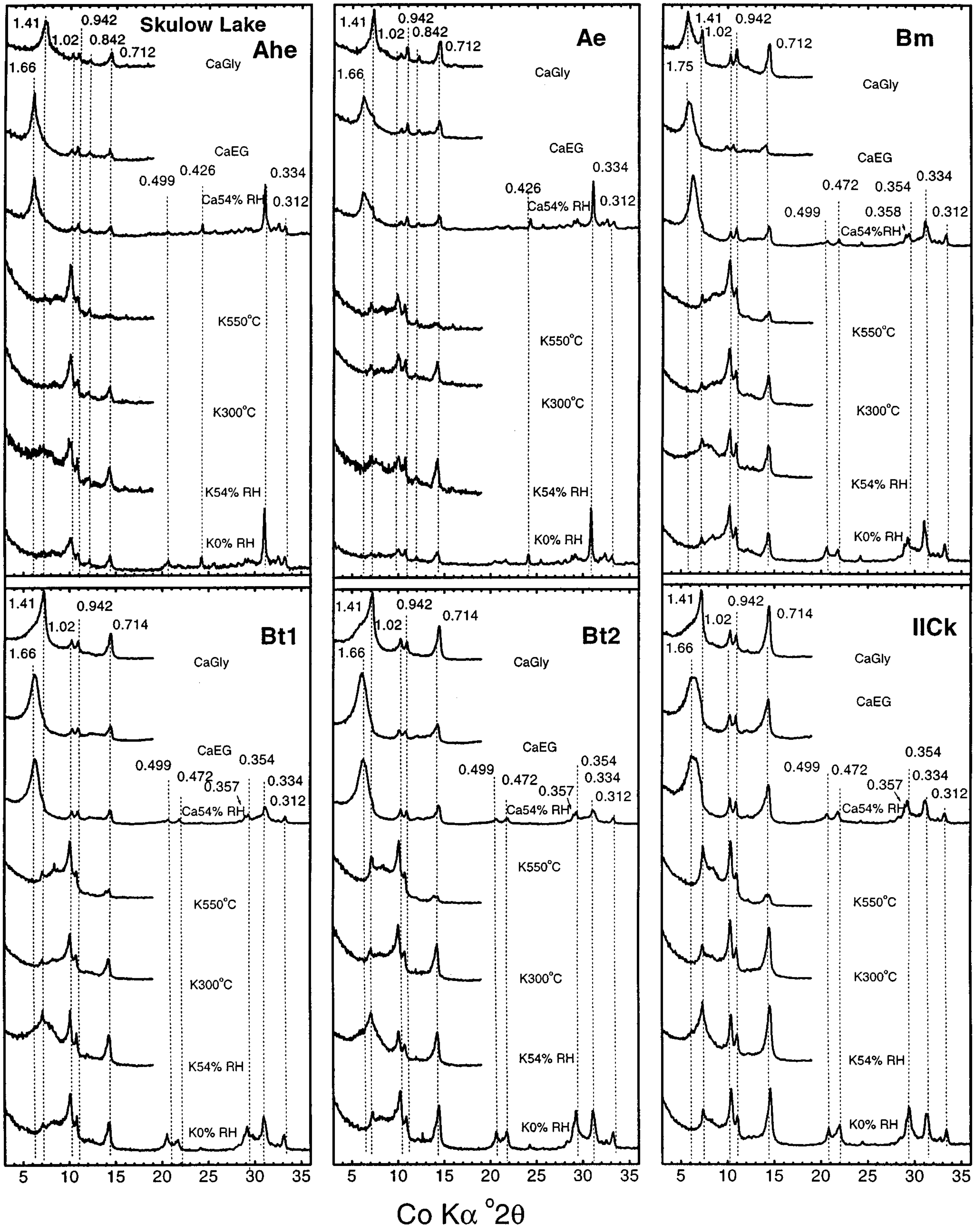


Fig. 5. X-ray diffraction patterns for the clay fractions of the Skulow Lake pedon. Treatment designations refers to various K and Ca saturation, ethylene glycol (EG) and glycerol (Gly) solvations, heat treatment and RH. Spacings are shown in nanometers.

and mica seem to remain relatively constant throughout the profile while kaolinite decreases from 220 g kg^{-1} clay in the IICk horizon to 110 g kg^{-1} clay in the Ae horizon (Fig. 3). The amount of talc decreases slightly from 230 g kg^{-1} clay in the IICk horizon to 160 g kg^{-1} clay in the Ae horizon. Vermiculite or high-charged smectite is present in the Bm horizon as shown by the XRD reflection at 1.65 nm in the Ca-EG treatment and 1.42 nm reflection in the Ca-Gly treatment, while smectite is present in the Bt and IICk horizons (Fig. 5). In Fig. 5, the broad XRD reflections at around 1.20 nm for all K-treated clays indicate the presence of a hydroxy-interlayered clay mineral in the Skulow Lake pedon.

In the Bobtail, Log Lake, and Topley pedons, the major components of the clay fractions are 2:1 expanding clays, mica, chlorite and kaolinite (Fig. 3). The relative amounts of chlorite and mica in these soils appear unchanged from C to A horizons. Kaolinite is least abundant in the A horizon and, except in the Topley pedon, 2:1 expanding clays are generally most abundant in the B horizons. The XRD reflections for all K-saturated samples (data not shown) for the A and B horizons in these pedons show a consistent hump between 1.20 and 1.40 nm for all the K-saturated samples indicative of hydroxy-interlayered clay mineral.

Generally, the XRD patterns of sand fractions from the C horizon of soils derived from till parent materials show the presence of quartz, feldspars, traces of hornblende, chlorite and mica (Fig. 6a). Table 3 shows the uniformity with depth in the amount of albite, anorthite and orthoclase in all but the pedon from the Kiskatinaw site. Kiskatinaw has a higher content of orthoclase in the IIBtg, IIBCk and IICk horizons compared to Ah and Aeg horizons.

In the till-derived soils, the allophane content reaches maximum values in the B horizons, except in the Log Lake pedon (Fig. 7). The highest Fe_o:Fe_d ratio for each pedon is observed in the B horizons of the Bobtail, Lucille Mountain, Skulow Lake and Topley pedons and in the A horizons of the Log Lake and Kiskatinaw pedons (Fig. 7).

Soil minerals present in the Bowron pedon that developed on glaciofluvial parent material are shown in Figs. 3, 6b, 7, and 8, and Table 3. The clay fractions have decreasing amounts of mica, chlorite and kaolinite from the C horizon to the Ae horizon. In addition, the Ae and Bf horizons have 2:1 expanding clays and traces of feldspars, hornblende and quartz. The sand fractions consist predominantly of quartz and feldspars with minor amounts of chlorite and hornblende (Fig. 6b). The relative contents of the different feldspars follow the order albite > anorthite ≈ orthoclase and do not vary within the soil profile (Table 3). The allophane content reaches a maximum in the Bf and Bfj horizons and then decreases with depth (Fig. 7). The lowest Fe_o:Fe_d ratio is in the Bf horizon while the maximum ratio is observed in the overlying Ae horizon.

Soil mineralogy of pedons that developed on glaciolacustrine parent materials is given in Figs 3, 6b, 7, and 9, and Table 3. The clay mineralogy of the Aleza Lake 1 and 2 pedons is relatively uniform with depth, and dominated by 2:1 expanding clays, mica, kaolinite, and chlorite (Fig. 3). Vermiculite or high-charged smectite in the Ae horizon is indicated by a diffraction peak round 1.66 nm in Ca-EG but not in Ca-Gly treatment (Fig. 9). In Ahe and B horizons, the hump around 1.29 nm for K-0% RH, K-54% RH, K-300°C and K-550°C indicates the presence of an interlayered clay mineral. Other minerals present in the clay fraction are traces of hornblende, feldspars and quartz. The XRD patterns of the sand fraction from the C horizons of the Aleza Lake 1 and Aleza Lake 2 pedons show the predominance of quartz and feldspars with traces of hornblende, chlorite and mica (Fig. 6b). Table 3 shows the uniform amounts of various types of feldspars throughout the profile of Aleza Lake 2. The amount of allophane increases with depth in the two pedons. The Fe_o:Fe_d ratio reaches maximum values in the Bf horizon of Aleza Lake 2 and in the BCg horizon of Aleza Lake 1 (Fig 7).

Forest Productivity

No single tree species occurred at all sites, making comparisons of productivity based on site index difficult (Table 1). For the most widely distributed species, hybrid white spruce, estimated SI_{50} ranged from 15 m at the high-elevation Lucille Mountain site (Engelmann Spruce – Subalpine Fir zone), to 20-24 m at Aleza Lake (Sub-Boreal Spruce zone). At the latter, soils with lower clay content and Podzolic rather than Luvisolic morphologies are associated with the higher end of the site index range (M. Jull, Univ. Northern B.C., personal communication). Although restricted to those sites in the Sub-Boreal, lodgepole pine displays a similar range in SI_{50} values, from 15.7 m (Skulow Lake) to 23 m (Bowron).

DISCUSSION

Parent Material Uniformity and Nature of Till Materials

Except for the Kiskatinaw and Skulow Lake pedons, all pedons in this study have uniform parent material throughout the profile as shown by the probability ($P > 0.050$) of the χ^2 goodness-of-fit test values calculated from the contents of albite, anorthite and orthoclase in the sand fraction (Table 3). The lithological discontinuity between the Aeg and IICk horizons in the Kiskatinaw pedon is indicated by the χ^2 goodness-of-fit test value with $P < 0.009$. In the Skulow Lake pedon, the discontinuity is indicated by the χ^2 goodness-of-fit test value less than 0.05 for all the horizons overlying the IICk horizon. In the Bobtail pedon, the χ^2 goodness-of-fit test value ($P < 0.010$) between the Bm and Ck horizons suggests a discontinuity in the pedon that was not evident in the field. The significant value ($P < 0.000$) of the χ^2 goodness-of-fit test between the Ahe and C horizons in this pedon could also be attributed to a high degree of feldspar weathering in the Ahe horizon. This may also be true for the χ^2 goodness-of-fit test in the Ahe and Bf horizons compared to the C horizon in the Aleza Lake 2 pedon (Table 3).

Mineralogical analysis of the clay and the sand fractions of the C horizons show the diversity of till composition in central and northeastern BC. For example, talc is present only in the Skulow Lake C horizon, the Lucille Mountain C horizon has undetectable amounts of kaolinite (Fig. 2), and albite is considerably more abundant in the Topley pedon

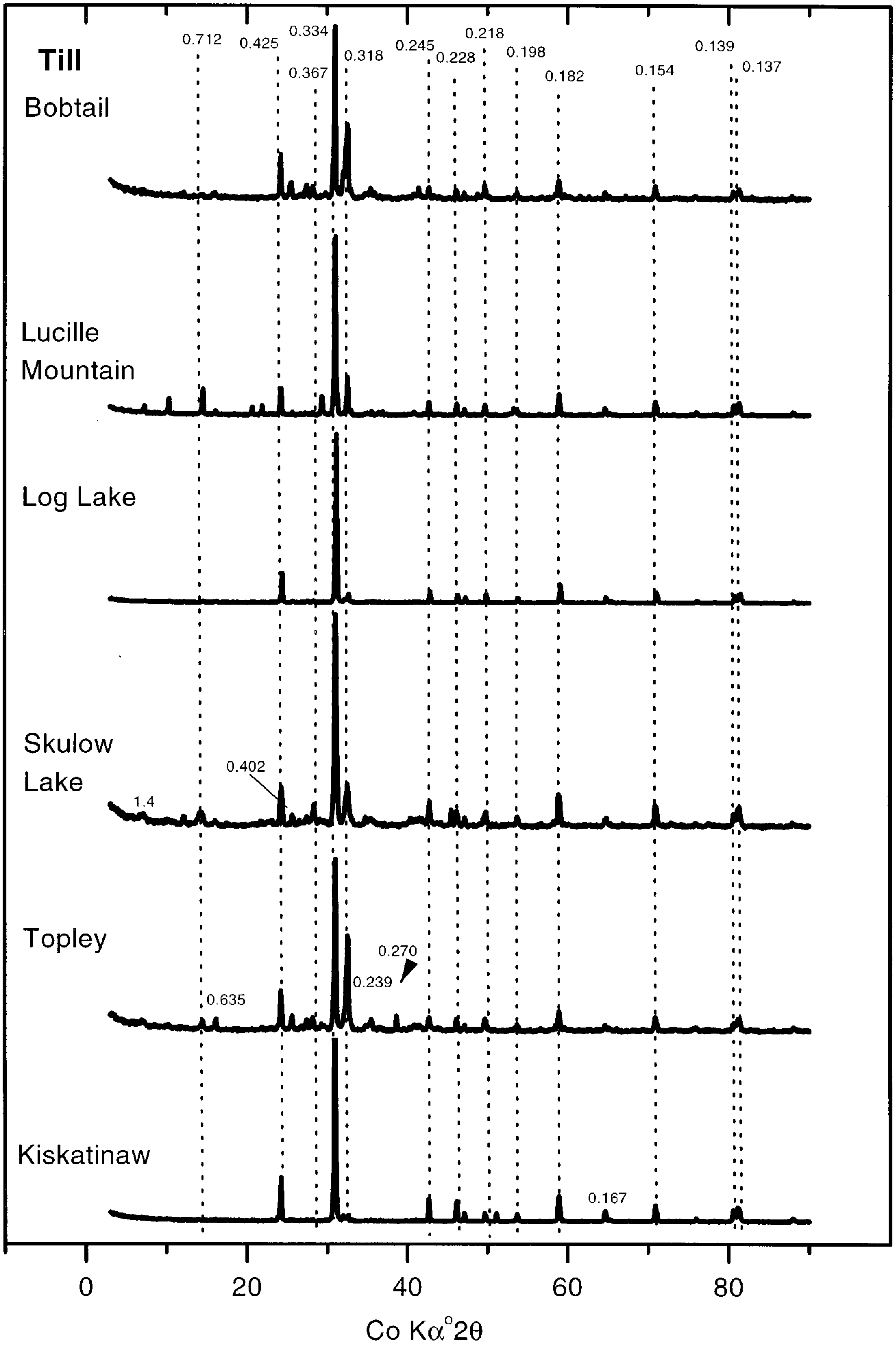


Fig. 6a. X-ray diffraction patterns for the sand fraction from till parent materials. Spacings are shown in nanometers.

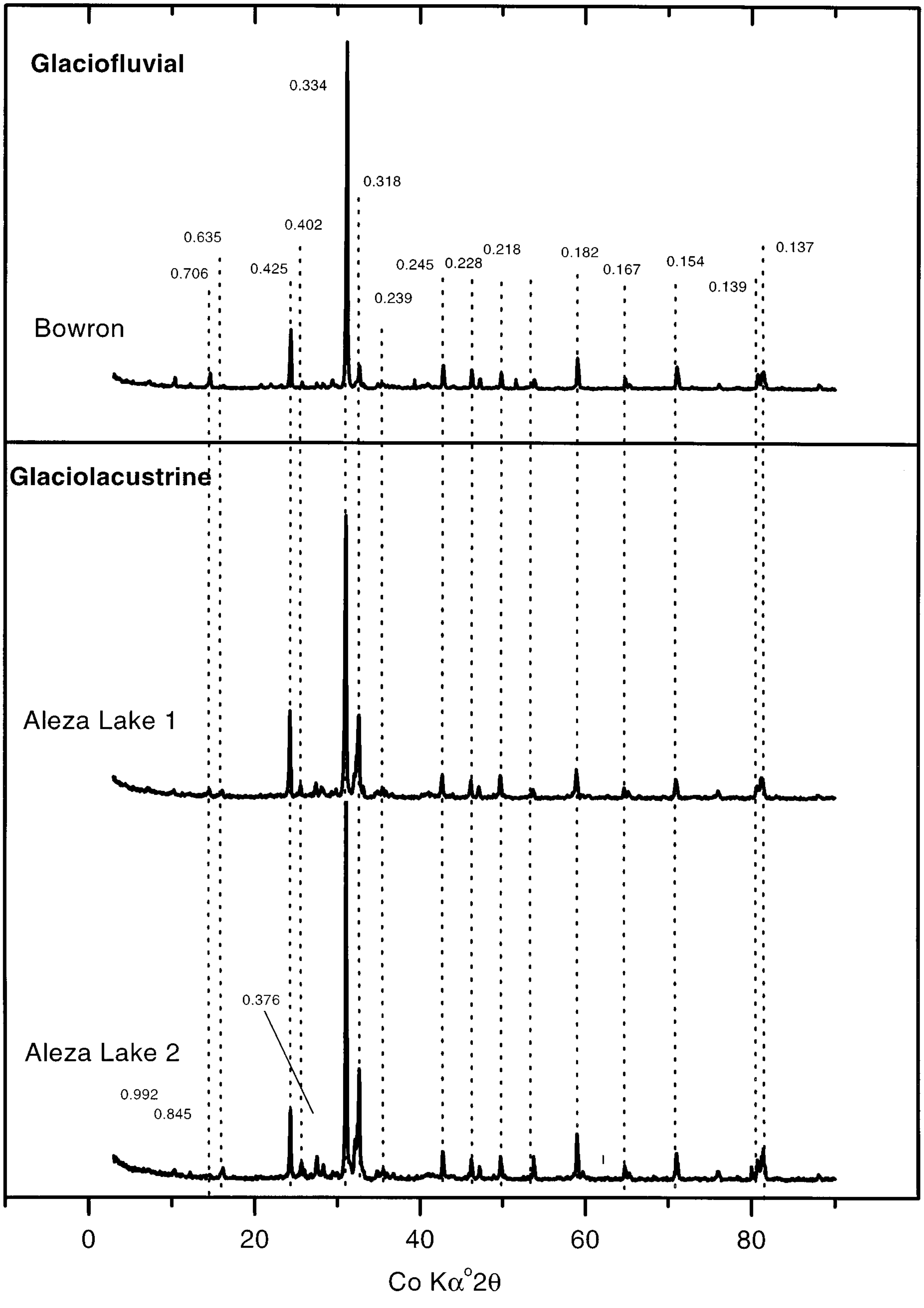


Fig. 6b. X-ray diffraction patterns for the sand fraction from glaciofluvial and glaciolacustrine materials. Spacings are shown in nanometers.

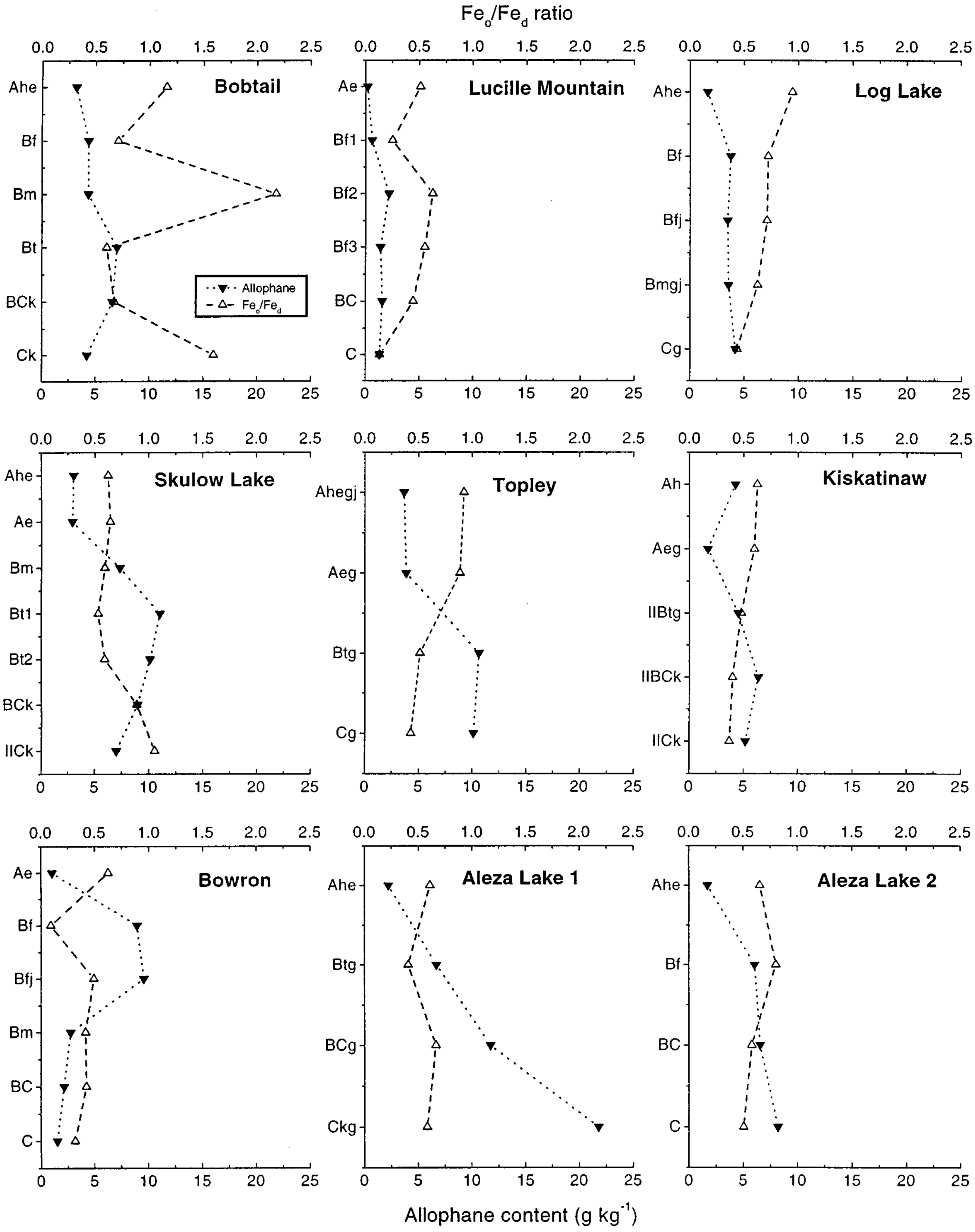


Fig. 7. Distribution of allophane and Fe$_o$/Fe$_d$ ratio within selected pedons in central and northeastern British Columbia.

(Table 3). In the BC central interior, such differences in parent material mineralogy reflect the varied bedrock lithology, combined with complex interactions of east- and westward-flowing glaciers between 10 and 20 ka BP. Diversity in soil minerals in the western and interior Cordillera has also been reported in an earlier review (Kodama 1979).

Mineral Transformation

Mica and Chlorite

We observed two main pathways for mica and chlorite transformation in soils from central and northeastern BC regardless of the type of soil parent material. One of the pathways operates in soils containing mica and chlorite and with little or no (<100 g kg^{-1}) 2:1 expanding clays (smectite and vermiculite) in the C horizon (e.g. Lucille Mountain). The decreased amount of mica and chlorite in the C horizons and the increased contents of 2:1 expanding clays in the Ae horizons from the Lucille Mountain (till) and Bowron (glaciofluvial) pedons suggest the transformation of mica and chlorite into 2:1 expanding clays. This type of mineral transformation is commonly observed in Podzolic soils (e.g. Adams and Kassim 1983; Righi and Lorphelin 1986; De Coninck et al. 1987; Arocena et al. 1994). Organic acids in the forest floor of the Podzolic soils are recognized as the driving force in the process (Ugolini et al. 1988). Weathering processes involve the removal of K^+ from the mica structure, especially along the particle edges and cleavage planes (Scott and Amonette 1988; Fanning et al. 1989), and the removal of Mg-hydroxide from chlorite **(**Rabenhorst et al. 1982**)**.

The second pathway is observed in soils with mica, chlorite and >100 g kg^{-1} clay 2:1 expanding clays in the C horizon (Bobtail, Log Lake, Topley, and Aleza Lake 1 and 2). The proportions of mica, chlorite and 2:1 expanding clays vary little within these pedons, suggesting no or minimal transformation of mica and chlorite into 2:1 expanding clays. Lång and Stevens (1996) attributed a similar trend in mica content in Podzolic soils developed on till parent materials in Sweden to continuous replenishment of clay-sized mica from large mica grains and sericitized feldspars. In the A and B horizons of these soils, there seems to be a formation of interlayered clay minerals as exemplified by the diffraction hump at around 1.29 nm in clays subjected to K 54% RH, K 300°C and K 550°C treatments (Fig.8). Interlayered minerals generally arise from the irregular transformation of micaceous and chloritic minerals as well as the incorporation of an octahedral layer within the 2:1 structure of some expanding clays (Kodama 1979; Barnhisel and Bertsch 1989). The latter is probably the dominant process in these interior B.C. pedons because of their nearly uniform contents of mica and chlorite. Lång and Stevens (1996) attributed the formation of interlayered clay in the Ae horizon to the incorporation of Al-hydroxide in the interlayer of vermiculite caused by the low pH ($CaCl_2$) (~pH 3.5) in the Ae horizon. The high amounts of Al and Fe released at low pH can be incorporated in the interlayer of 2:1 clays to form hydroxy-interlayered 2:1 clay (Farmer et al. 1985; Ghabru et al. 1990). The incorporation of Al into hydroxy-Al interlayers is claimed to provide a sink for Al released by weathering of alumino-silicate minerals (Dahlgren et al. 1997). This may also account for the lower concentration of extractable Al and Fe. Incomplete removal of the OH-sheet from chlorite has also been postulated as a possible pathway in the formation of hydroxy-interlayered 2:1 clay (Adams and Kassim 1983). In the Skulow Lake pedon, the preferential transport of the higher-charged and finer clays during illuviation, may result in the high proportion of 2:1 expanding clays in the Bt horizons.

Kaolinite and Talc

Kaolinite is detectable in all but the Lucille Mountain pedon. In the other pedons, the amount of kaolinite varies very little with depth, indicating its relative stability in these soil environments. Similar results were reported by Arocena et al. (1994) for Podzolic-like soils in Alberta. Minor differences in the amount of kaolinite between A and B horizons (e.g. Bowron) could be attributed to physical translocation of clay into the B horizon.

The presence of talc $[(Si_8Mg_6)O_{20}(OH)_4]$ is restricted to the Skulow Lake pedon. Talc content in the Ae horizon is slightly less than in the C horizon in this pedon, indicating minimal alterations, probably due to its low surface charge. Talc might have originated from the basaltic bedrock in the Skulow Lake area because talc had been observed as alteration products in Mg-rich environments (Zelazny and White 1989).

Non-phyllosilicate and Secondary Minerals

Quartz, feldspars (albite, anorthite and orthoclase) and amphiboles are the dominant non-phyllosilicate minerals in these pedons (Fig. 6a and Fig. 6b). Except for the Ahe horizon of the Bobtail pedon, there seems to be no reduction in the amount of feldspars from the parent material to the Ae or Ahe horizons. In the Ahe horizon of the Bobtail pedon, anorthite seems to break down completely, and albite to some extent. This could be attributed to the high acidity (pH 3.6 in $CaCl_2$) of the forest floor. The elements released from the weathering of these feldspars, particularly Al, may contribute to the formation of interlayered 2:1 minerals.

The accumulation of allophane in the B horizons (Bf, Bm and Bt) is consistent with earlier reports on Podzolic, volcanic and young soils (e.g., Farmer et al. 1985; Parfitt and Kimble 1989; Parfitt 1990). Allophane could form from the reaction of silicic acid and hydroxy-aluminum cations released from the congruent weathering of minerals in the overlying Ae horizon (Dahlgren and Ugolini 1989; Parfitt and Kimble 1989; Arocena et al. 1994). Except for the Bowron and Skulow Lake pedons, the highest value of Fe_o:Fe_d ratio in each pedon is in the B horizon suggesting accumulation of less-ordered Fe oxides such as ferrihydrite (Schulze 1981; De Geyter et al. 1982). Ferrihydrite is considered to be a precursor to highly ordered Fe oxides such as goethite (Schwertmann and Taylor 1989)

Soil Formation

Podzolization and lessivage are the major soil-forming processes in these pedons. Podzolization consists of the movement of organic matter, Fe, Al (and Si) with or without organic matter (De Coninck 1980; Farmer et al. 1985; Evans and Mokma 1996) and is expressed in the formation of Bf horizons in the Bobtail, Lucille Mountain, Log Lake, Bowron, and Aleza Lake 2 pedons, as shown by maxima of Fe_p and Al_p. The Fe_p is normally indicates the amount of Fe accumulated in the form of Fe-humus complexes (Dahlgren et al. 1997). In these pedons, decomposition products of coniferous litter in the forest floor acidify the A horizon and promote the rapid breakdown of mica and chlorite to release Fe and Al in solution (Farmer et al. 1985; Ugolini et al. 1987; Arocena et al. 1994). Mica and chlorite weathering in Ae horizons is more pronounced in soils where 2:1 expanding clays are absent or scarce (< 100 g kg^{-1}) in the parent material, such as in the Lucille Mountain and Bowron pedons. In the Bobtail and Log Lake pedons, Fe and Al in the Bf horizons might have come from the breakdown of Fe-containing minerals such as hornblende and lithogenic Fe oxides, and perhaps from the slight weathering of mica and chlorite. In such soils, fulvic acid produced in the forest floor forms may be forming organo-metal complexes with Fe and Al released from the breakdown of mica and chlorite. In the Skulow Lake, Topley, Kiskatinaw, and Aleza Lake 1 pedons, clay contents show maximum accumulation in the Bt horizon, indicative of clay illuviation. In the latter three pedons, impeded drainage induced by the accumulation of clay in the Btg horizons has resulted in the formation of Luvic Gleysols. In the Bobtail pedon, the occurrence of both podzolization and lessivage results in the development of a Brunisolic Gray Luvisol, a “bisequum” pedon. In other pedons, the relative importance of these processes appears to be controlled by parent material texture, with podzolization predominating in sandy materials (Bowron) and lessivage in clay-rich materials (Aleza Lake 1).

Redoximorphic processes associated with impeded drainage results in the formation of mottles in the Log Lake, Topley, Kiskatinaw, and Aleza Lake 1 pedons. The formation of Aeg and IIBtg in the Kiskatinaw pedon is probably due to an intermittent perched water table induced by the inferred low hydraulic conductivity of the IIBtg and IIBCk horizons.

Implications for Forest Management

Both inherited and pedogenic soil characteristics have major implications for forest management practices at these sites. Interpretations of site index data in relation to these properties are more difficult, due to the substantial range in climatic conditions over such a large study area.

The predominantly medium and fine textures in the uppermost 30 cm of most of these pedons result in high or very high hazard ratings for soil compaction and puddling (Ministry of Forests 1995). This degree of sensitivity dictates that harvesting and mechanical site preparation should occur under either dry summer or frozen winter conditions in order to prevent soil compaction and resulting loss of site productivity. Aspen is an important part of the forest resource in northeastern BC, and it regenerates prolifically from its shallow root systems. This process is vulnerable to compaction by harvesting equipment, particularly under moist summer conditions on fine-textured soils. Studies in progress at the Kiskatinaw site since 1995 have observed marked reductions in the abundance and vigour of aspen suckers after even moderate degrees of soil compaction (R. Kabzems, personal communication), consistent with findings elsewhere in North America (Shepperd 1993).

Strongly developed Bt horizons may restrict the depth of root penetration, potentially limiting access to moisture and nutrients deeper in the soil profile. This may account for the higher SI_{50} values associated with an absence of Bt horizons, as in the Bowron and Aleza Lake 2 pedons, compared with Aleza Lake 1 (Table 1). Soil morphologies with strongly developed Bt horizons also increase the risk that surface soil displacement during forestry operations will damage site productivity by exposing materials that are less favourable rooting media. As a result, soil rehabilitation studies in central BC have found that recovery of displaced surface mineral soil horizons assists in restoring productivity to landings and other access structures constructed on Luvisolic and related soils (Sanborn et al. 1999a). The high proportion of 2:1 expanding clays in some Bt horizons may help promote recovery from soil compaction through the shrink-swell activity of these minerals, as suggested by recent observations of soil rehabilitation treatments at the Aleza Lake Research Forest (Sanborn et al. 1999b).

The much higher contents of total N, S and extractable P in surface organic horizons relative to most mineral horizons justify the need to avoid excessive displacement of forest floors during harvesting and site preparation. The low concentrations of total S in mineral soils at all of the central BC sites are consistent with emerging evidence for widespread S deficiencies in conifer plantations in that region (Brockley 1996).

Empirical schemes for classifying forest site nutrient status, such as those developed by Klinka and co-workers (e.g. Courtin et al. 1988; Klinka et al. 1994), often include exchangeable base content as a differentiating characteristic. As a result, such classifications tend to assign higher relative nutrient status to fine-textured soils, reflecting their higher CEC. However, in youthful glaciated landscapes such as BC, soils exhibit only a moderate degree of mineral transformation, so the presence of primary minerals in most particle size fractions must also be considered in assessing long-term nutrient status. For example, the feldspars usually comprised ~200 g kg^{-1} of the sand fractions in this study, and also could be detected in some clay fractions, providing a substantial reservoir of essential cations (Ca^{2+}, K^{+}). Such potentially large long-term supplies of nutrients provide a buffer against depletion by forest biomass harvesting. However, the rates of nutrient release by chemical weathering are poorly documented (Zabowski 1990), so caution is still advisable when considering practices such as whole-tree harvesting, which accelerate nutrient removals from managed forest sites (Kimmins 1997).

CONCLUSION

The six till parent materials examined in this study display considerable mineralogical diversity. Talc occurs in the Skulow Lake pedon, kaolinite is undetectable in the Lucille Mountain pedon, while albite is more abundant at Topley

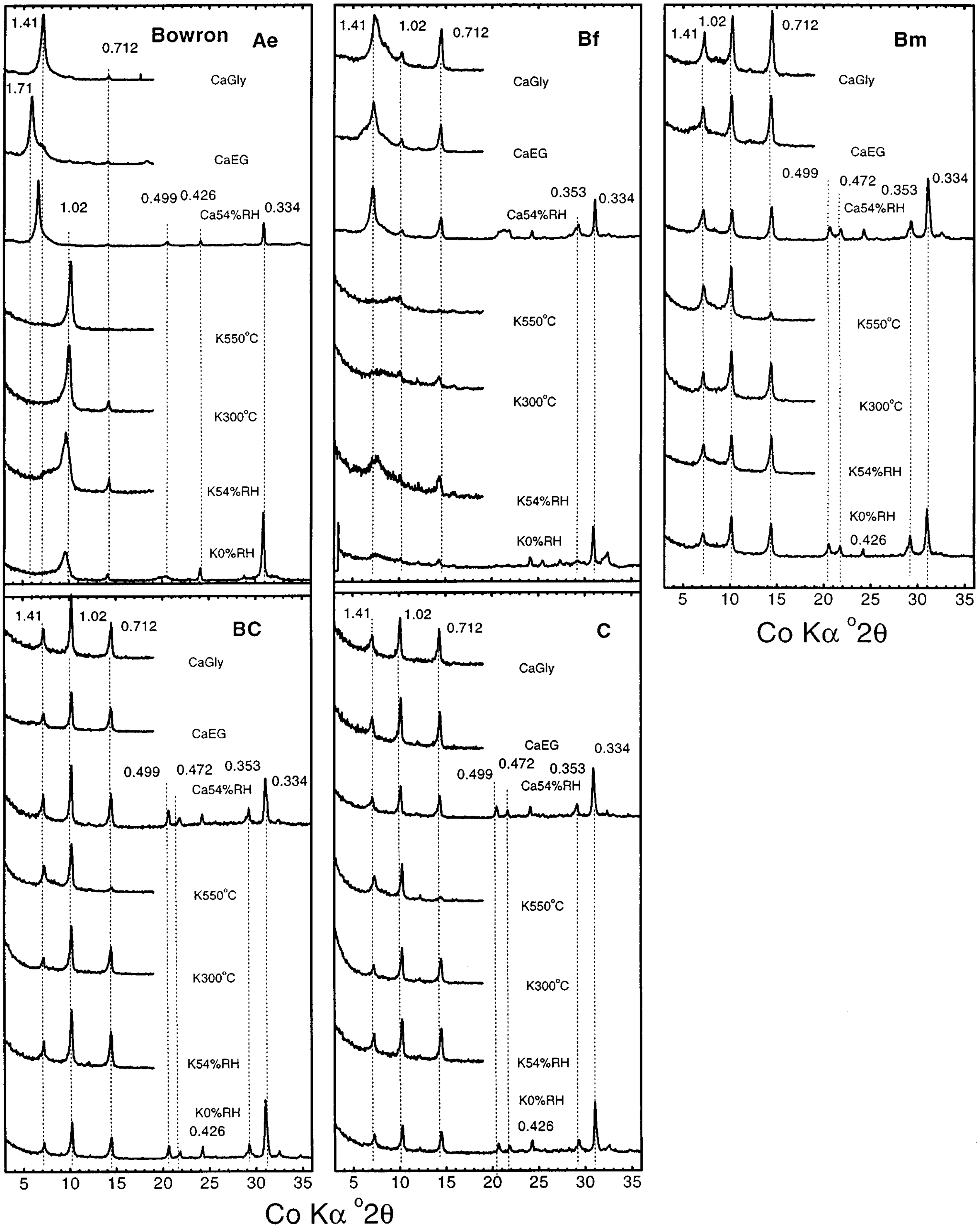


Fig. 8. X-ray diffraction patterns for the clay fractions of the Bowron pedon. Treatment designations refers to various K and Ca saturation, ethylene glycol (EG) and glycerol (Gly) solvations, heat treatment and RH. Spacings are shown in nanometers.

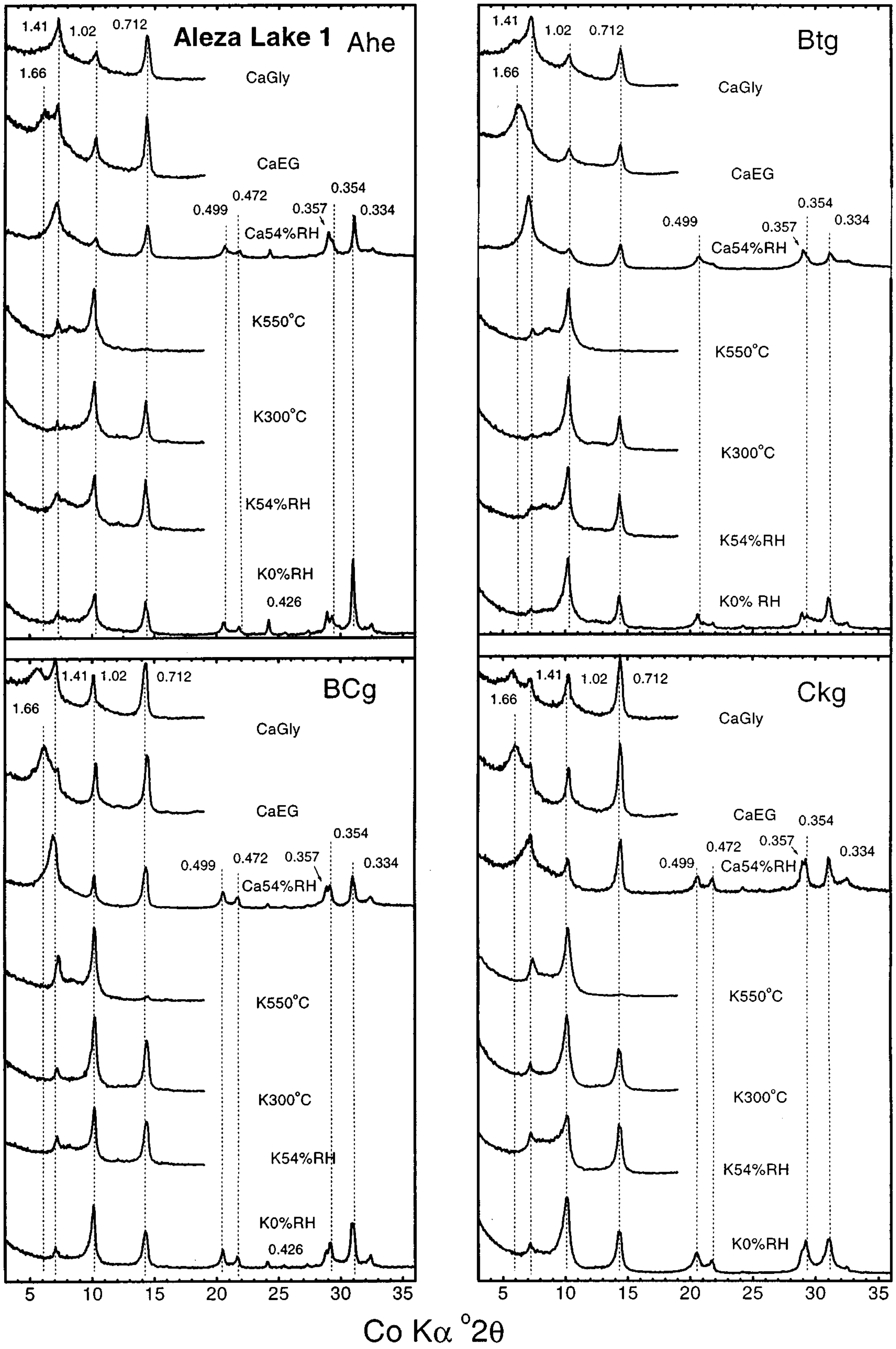


Fig. 9. X-ray diffraction patterns for the clay fractions of the Aleza Lake 1 pedon. Treatment designations refers to various K and Ca saturation, ethylene glycol (EG) and glycerol (Gly) solvations, heat treatment and RH. Spacings are shown in nanometers.

than in the other till-derived pedons. This diversity reflects the interaction of bedrock lithology with complex patterns of glacial transport and deposition. Although the glaciolacustrine and glaciofluvial materials did not differ greatly in mineralogy, only three pedons were examined and it is likely that further investigations of these parent materials would encounter additional diversity across central and northeastern BC.

The transformation of mica and chlorite seems to be dependent on the presence of 2:1 expanding clays in the C horizon. In soils without 2:1 expanding clays in C horizons, mica and chlorite appeared to degrade into 2:1 expanding clays in the A and B horizons (e.g. Lucille Mountain). In soils with 2:1 expanding clays in the C horizon, mica and chlorite appeared to be stable and there seems to be a formation of hydroxy-interlayered clays (e.g. Bobtail). Allophane and secondary Fe oxides (mainly ferrihydrite) also form in the B horizons. Acidity produced through the decomposition of organic matter in the forest floor is considered to be a driving force in mineral weathering. Kaolinite appears to be stable in these pedons.

Weathering of mica and chlorite lead to the formation of Bf horizons through the process of podzolization. Lessivage is another major soil-forming process, and accumulation of clay in Bt horizon can impede drainage and result in the formation of Luvic Gleysols.

Forest management practices must avoid the significant soil compaction on the predominantly medium and fine soil textures. Although strongly developed Bt horizons in Gray Luvisols and Luvic Gleysols may benefit soil nutrient regimes through their high CEC, exposure of these horizons and excessive displacement of nutrient-rich forest floors by forestry practices should be avoided. Mineral soil total S concentrations were consistently low in pedons from the BC central interior, supporting other evidence for S deficiencies in forests of that region. Weatherable minerals, such as feldspars, are still abundant in these moderately developed soils, providing a large potential source of slowly available C and K, but caution is still warranted when considering practices such as whole-tree harvesting, which accelerate nutrient removal.

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