Micromorphological and ^{13}C NMR characterization of a Humic, Lignic, and Histic Folisol from British Columbia

C. A. Fox[1], C. M. Preston[2], and C. A. Fyfe[3]

[1]*Centre for Land and Biological Resources Research, Research Branch, Agriculture and Agri-Food Canada, Ottawa, Ontario, Canada K1A 0C6;* [2]*Pacific Forestry Centre, Natural Resources Canada, 506 West Burnside Road, Victoria, British Columbia, Canada V8Z 1M5; and* [3]*Department of Chemistry, University of British Columbia, Vancouver, British Columbia, Canada V6T 1W5.* *Contribution no. 92-211[1], received 16 February 1993, accepted 31 August 1993.*

Fox, C. A., Preston, C. M. and Fyfe, C. A. 1994. **Micromorphological and ^{13}C NMR characterization of a Humic, Lignic, and Histic Folisol from British Columbia.** Can. J. Soil Sci. **74:** 1–15. The thick folic (mainly upland forest) materials (>40 cm of accumulated organic material) that occur in the Coastal Western Hemlock Biogeoclimatic Zone in British Columbia have not been described with regard to the spatial interrelationships of the soil constituents in context with the chemical composition of the different horizons. Micromorphological assessment and solid-state ^{13}C NMR were used to characterize the accumulated folic materials from a Lignic Folisol (northern Vancouver Island), Histic Folisol (Prince Rupert, BC) and a Humic Folisol (Queen Charlotte Islands, BC). Micromorphology provided information on the spatial relationships of the soil constituents and ^{13}C NMR provided data on the chemical components of the folic materials. Soil faunal activity, primarily from mites, was the dominant soil-forming process observed in the organic horizons of the Folisols, being especially prominent in the Lignic Folisol with the breakdown of woody materials. Solid state ^{13}C CPMAS NMR spectra facilitated distinguishing three main types of horizons: (1) Horizons derived from accumulated residues (L, Fr, and Hr) showing higher carbohydrate-like C and *O*-alkyl C values and lower total aromatics; (2) Horizons with advanced decomposition (Hr2, Oh1, and Hd) which were higher in alkyl C; and (3) Horizons derived from ligneous material (Fw and Hdw) where carbohydrate-like C was less than total aromatic C. Implications for adequate nutrient content and forest growth were inferred from the observed micromorphology and chemical composition of the folic materials.

Key words: Folisol, forest soils, micromorphology, ^{13}C NMR, faunal activity

Fox, C. A., Preston, C. M. et Fyfe, C. A. 1994. **Caractérisation selon la micromorphologie et selon la RMN du ^{13}C de folisols humiques, ligniques et histiques de Colombie-Britannique.** Can. J. Soil Sci. **74:** 1–15. Les épais matériaux foliques, sutout sous forêt de bas plateau, (>40 cm de m.o. accumulée) qu'on trouve dans la zone biogéoclimatique côtière de la pruche de l'ouest en Colombie-Britannique n'ont pas été décrits quant aux interrelations spatiales des composants du sol relativement à la composition chimique des divers horizons. L'évaluation micromorphologique et la RMN (non destructive) du ^{13}C ont servi à caractériser les matériaux foliques accumulés dans un folisol lignique (nord de l'île de Vancouver), dans un folisol histique (Prince Rupert) et dans un folisol humique (Iles de la Reine Chalotte). La micromorphologie apportait des lumières sur les relations spatiales des composants du sol, et la RMN du ^{13}C sur la composition chimique des matiériaux foliques. L'activité faunique du sol, principalement des acariens, était le processus pédogénétique dominant dans les horizons organiques des folisols et était particulièrement en évidence dans le folisol lignique, à juger par la décomposition des matières ligneuses. Les spectres de la RMN du ^{13}C avec rotation à l'angle magique et polarisation croisée (CPMAS) ont facilité la séparation des trois principaux types d'horizons: (1) horizons dérivés de résidus accumulés (L, Fr et Hr) manifestant des valeurs plus élevées pour le C de type glucidique et le C *O*-alkylique et des valeurs moins hautes pour les composants aromatiques totaux; (2) horizons présentant un taux avancé de décomposition (Hr2, Oh1 et Hd) et plus riches en C alkylique; et (3) horizons dérivés des matières ligneuses (Fw et Rdw dans lesquels le C glucidique était moins important que les composés aromatiques. La signification de ces données pour la fertilité du sol et pour la croissance forestière est déduite à partir des observations micromorphologiques et de la composition des matières foliques.

Mots clés: Folisol, sol forestier, micromorphologie, RMN du ^{13}C, activité faunique

Within the cool, moist, humid forest ecosystems, such as found within the Coastal Western Hemlock Biogeoclimatic Subzone (CWHvm) of British Columbia and Vancouver Island (Pojar et al. 1987), biomass production typically exceeds decomposition. Podzolic soils with thick (10–25 cm) accumulations of forest materials (referred to as folic materials) occur frequently together with occurrences of Folisols having organic material accumulations greater than 40 cm. Trowbridge et al. (1985) point out that the roots of the trees and undergrowth, most biological activity, and land management are related to the surface horizons of the thick folic accumulations rather than the mineral soil that may be present below. Folic materials consist of accumulations of leaves, cones, twigs, branches, and mosses and are designated as L, F, and H horizons depending on the overall field assessment of the state of decomposition. The L horizons are relatively fresh material, F horizon materials show little to moderate decomposition and H horizon materials are well decomposed.

Fox (1985) related the spatial distribution of the folic materials to the topographic relationship of the landscape,

the amount of ligneous material incorporated in the soil (usually from a major tree-fall event having occurred in the past), and the amount of accumulated plant residues. Fox (1985) and Fox et al. (1987) suggested that the organic accumulations observed in the Folisols may have been relatively undisturbed for approximately 400–2000 yr depending on the tree-fall history.

The old-growth coastal rainforests of British Columbia have historically provided an important source of timber. At present, strategies are being developed to preserve the rich biodiversity of the old-growth coastal rainforests, while at the same time managing a portion of the land base for recreation, wildlife, and sustainable production of timber and other forest products. Problems have been encountered in maintaining growth rates of seedlings on cutovers previously occupied by the old-growth phase of western red cedar (*Thuja plicata* D. Don) and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.). On these sites on northern Vancouver Island, the planted seedlings initially grow well but become chlorotic and stagnant after 5–8 yr, coincident with reinvasion of the ericaceous shrub salal (*Gaultheria shallon* Pursh.) (Messier and Kimmins 1991). Rates of nutrient mineralization are also low in litter and humus from the old-growth sites (Prescott et al. 1993). Site treatments such as fertilization or site preparation by slashburning, cultivation, and herbicides have not given consistently satisfactory improvement in productivity (Weetman et al. 1989). While the most obvious examples of this problem have been encountered so far for northern Vancouver Island, it is anticipated that similar situations may occur over large areas of young second-growth forest in this biogeoclimatic zone. There is some urgency, therefore, for characterizing the organic accumulations within this ecosystem, so that appropriate site rehabilitation and long-term management strategies can be developed.

Solid-state ^{13}C nuclear magnetic resonance spectroscopy with magic-angle spinning and cross polarization (CPMAS NMR) has recently been used to characterize directly the organic components of forest litter and humus layers (Hempfling et al. 1987; Kögel et al. 1988; Kögel-Knabner et al. 1988; Zech et al. 1987, 1990). These studies have focused on the thin accumulations of organic humus material over mineral soils. ^{13}C NMR has also been used to characterize the thick humus horizons of old-growth sites of northern Vancouver Island (deMontigny et al. 1993), and to assess changes in organic components during decomposition of fallen logs of Douglas-fir (*Pseudotsuga Menziesii* (Mirb.) Franco), western hemlock and western red cedar in old-growth forests of the Pacific northwest (Preston et al. 1990).

Bullock (1973), Lee (1983), Fox (1985), and Bouma et al. (1990) provided reviews of micromorphological research on organic soils. The concepts (Brewer 1976; Bullock et al. 1985) and procedures (Murphy 1986) of soil micromorphology provide a means for evaluating both the spatial relationships of the soil constituents (mineral, organic and biological components) and their changes in distribution, as well as assessing the effect of various soil processes on the soil constituents themselves. Chemical and physical analyses obtained from disturbed samples do not provide any information about the spatial interrelationships of the soil constituents. Consequently, micromorphological assessment can place the chemical and physical data in context of the soil as it existed in the field at the time of sampling.

The thick folic materials (>40 cm) of the different subgroups of the Folisol great group of the Organic soil order (Agriculture Canada Expert Committee on Soil Survey (ACECSS) 1987) have not been described with regard to the spatial interrelationships of the soil constituents in context with the chemical composition of the different horizons. This paper will report on the micromorphology of the folic materials of a selected Humic, Lignic and Histic Folisol in the Coastal Western Hemlock Zone from British Columbia as well as characterize the chemical composition of the organic horizons with ^{13}C CPMAS NMR. The chemical composition of the folic materials of each horizon will be assessed in terms of the spatial arrangement of the soil constituents to understand better the soil processes within the thick organic accumulations and to consider possible relationships of these processes to forest growth.

MATERIALS AND METHODS

Site Location

The Folisol sites chosen for this study are located within the Coastal Western Hemlock Biogeoclimatic Zone as described by Pojar et al. (1987). The Folisol great group as defined in the Canadian system of soil classification (ACECSS 1987) are organic soils composed of upland organic (folic) materials, generally of forest origin, that are thicker than 40 cm or at least 10 cm thick if lying over bedrock or fragmental material. The specific classification criteria of the four subgroups, the Hemic, Humic, Lignic and Histic Folisol are defined in ACECSS (1987). The rationale for the soil classification of the Folisols, the field macromorphology, and chemical characteristics are described in Trowbridge et al. (1985), Fox (1985) and Fox et al. (1987). The horizon designations are after concepts in ACECSS (1987) and the proposal for lower case designations for F and H horizons outlined in Fox (1985). Terminology for soil field description is after Klinka et al. (1981) and Day (1983).

The Humic, Lignic and Histic Folisol (Table 1) with accumulations of folic materials of 82, 70 and 52 cm, respectively, were selected from a total sample set of 12 sites [Humic Folisol (seven sites); Lignic Folisol (three sites); Histic Folisol (two sites)] as being representative of old-growth forest sites. Additional information on the chemical and physical data of the sampled sites, including the selected sites for this study, are presented in Fox (1985), Trowbridge et al. (1985) and Fox et al. (1987). The sites were located under mature-stage secondary growth forest cover consisting primarily of western hemlock and amabalis fir with an understory of various mosses and small hemlock trees with *Vaccinium* often occurring on decomposing logs. Mature western red cedar that escaped logging as well as remnants of large stumps logged in the past (1800's) occurred occasionally. The Histic Folisol was sampled adjacent to a mature western red cedar. All three sites showed evidence for past tree-fall events such as uprooting and randomly strewn decomposing logs now entirely covered with mosses.

Table 1. Brief description of site characteristics of organic horizons for selected Folisols[z]

Horizon	Depth (cm)	pH[y]	Color[x]	Description
Humic Folisol: Located near the Kundis River, Graham Is., Queen Charlotte Islands [53° 39′29″ N. Lat., 132° 7′42″ W. Long.].				
Fr	0–8	3.9	5YR 3/2 m (Dark reddish brown)	Fibrous; moderate noncompact matted; abundant very fine to fine roots; few random fungi.
Hr1	8–20	2.9	5YR 2.5/2 m (Dark reddish brown)	Fibrous; moderate noncompact matted; abundant very fine to medium roots.
Hr2	20–64	2.7	5YR 2.5/1.5 m (Black - Dk red brown)	Fibrous; weak granular; abundant very fine to very coarse roots.
Hd	64–82	3.3	10YR 2.5/1 m (Black)	Massive; greasy; few very fine to medium roots.
Lignic Folisol: Located near Port Alice turn-off on northern Vancouver Island [50° 36′16″ N. Lat., 127° 18′23″ W. Long.].				
L	0–1	4.4	5YR 2.5/1.5 m (Black - Dk red brown)	Acerose; moderately fibered; very few, very fine roots.
Fq	1–5	3.3	5YR 3/1 m (Very dark gray)	Felty; moderate, noncompact matted; abundant, very fine to fine roots; abundant fungi in discontinuous matted bands.
Hr	5–10	3.0	2.5YR 2.5/2 m (Very dusky red)	Fibrous; strongly compact matted; abundant very fine to fine roots; plentiful fungi.
Fw	10–17	2.9	5.0YR 2.5/2 m (Dark reddish brown)	Ligneous; moderately layered; plentiful medium to coarse roots.
Hdw	17–68	2.6	2.5YR 2.5/2 m (Very dusky red)	Ligneous; greasy; weak granular; abundant fine roots upper part, lower (51–60 cm) plentiful medium to coarse roots.
Ho	68–70	2.9	5YR 2.5/1 m (Black)	Amorphous, greasy; massive; plentiful roots.
Histic Folisol: Located near Prince Rupert, British Columbia [54° 13′50″ N. Lat., 130° 4′52″ W. Long.].				
Fr	0–3	4.5	5YR 2.5/2 m (Dark reddish brown)	Fibrous; weak noncompact matted; loose; common very fine to medium roots; few fauna, common fungi.
Hr1	3–20	3.0	2.5YR 2.5/2 m (Very dusky red)	Weak noncompact matted to fine granular; friable, very fine to very coarse roots.
Hr2	20–52	2.8	2.5YR 2.5/2 m (Very dusky red)	Moderate blocky, nonsticky, firm, greasy; plentiful fine to coarse roots, wood.
Oh1	52–82	2.8	5YR 2.5/1 m (Black)	Sedimentary-amorphous peat; massive; greasy.
Oco	82–99	3.0	5YR 3/3 m (Dark reddish brown)	Sedge-sedimentary peat; massive; greasy; few rootlets.
Oh2	99–151	3.5	5YR 3/2 m (Dark reddish brown)	Moss-sedge-sedimentary peat; massive; greasy; few rootlets.

[z] Adapted from Fox et al. (1987).
[y] pH in 1:2 0.01 M $CaCl_2$.
[x] Munsell Soil Color charts.

Micromorphology

The Hemic and Histic Folisol were sampled in September 1983 and the Lignic Folisol in June 1983 and again in August 1984. Samples for micromorphological analyses were taken where possible either from the mid-point of each soil horizon as described in the field (Fox et al. 1987) or, in some cases, where extremely thick horizons occurred as in the Lignic Folisols, samples were taken at successive depths within the individual horizons. Horizons too thin or consisting of intact wood were not sampled. Sample container size was 6.5 cm wide × 8.5 cm long × 5 cm deep. Samples were kept in a cold room at 4°C until prepared for impregnation with polyester resin which was completed within 1 yr of sampling. From each sample, two thin sections (2 × 4 cm) were prepared following methodology (84–047) outlined in Sheldrick (1984). The soil arrangements observed in the thin sections were described according to terminology defined in Brewer (1976) and Fox (1984). The morphology of the Histic Folisol (horizons Hr1 and Hr2) is also very briefly referred to by Bouma et al. (1990). A Leitz Ortholux IIPol-BK microscope was used with observations at magnifications ranging from 10 to 125×. The micromorphological descriptions are based on a qualitative measure of frequency of occurrence of the observed features as follows: Very rare (isolated occurrence); Rare (very hard to find, but can be located); Occasional (few occurrences); Common (very easily found, but not abundant); Frequent (numerous); Very frequent (extremely abundant).

NMR Spectroscopy

Samples for chemical analyses were taken in the field from about the mid-portion of each horizon. Samples were stored in a cold room at 4°C. Subsamples were removed, air dried, and ground to pass through a 35-mesh (< 0.50-mm) sieve. To take advantage of limited time availability of the NMR spectrometer, one replicate of the 35-mesh material was analyzed.

Solid-state ^{13}C CPMAS NMR spectra of the dry, powdered samples were obtained at 22.6 MHz on a Bruker CXP-100 spectrometer with a home-built, double-tuned single coil probe with an external lock and an Andrew-Beams type spinner. The sample holders were made of Kel-F with an internal volume of approximately 450 μL and were spun with air at 3 kHz. Spectra were obtained with 1 ms contact time, 1 s recycle delay, and 30 000–100 000 transients, and processed with 40 Hz linebroadening. Chemical shifts are reported as parts per million (ppm) relative to tetramethylsilane (TMS) at 0 ppm.

Spectra were divided into chemical shift regions according to chemical types of carbon and will be referred to as follows: (A) alkyl 0–50 ppm; (B) methoxyl 50–62 ppm; (C) *O*-alkyl 62–95 ppm; (D) di-*O*-alkyl and aromatic 95–140 ppm; (E) phenolic 140–160 ppm; (F) carboxyl 160–190 ppm; and (G) aldehyde and ketone 190–220 ppm. Areas of the chemical shift regions were measured by cutting and weighing and were expressed as percentages of total spectral area ("relative areas"). These data were used to derive two other parameters, "carbohydrate-like C" and "total aromatic C", as described in Preston et al. (1987), Cheshire et al. (1992) and Preston et al. (1989). In this procedure, all of the *O*- and di-*O*-alkyl C intensity [area C + area D] is treated as though arising from six-carbon sugars, so that "carbohydrate-like C" can be estimated as 1.2 (area C). The contribution of aromatic carbon in area D (95–140 ppm) is then defined as [(area D) – (0.2 area C)], and "total aromatic C" as [(area D – 0.2 area C) + (area E)].

To evaluate the decomposition of the organic materials, the following ratios were calculated from the relative areas of the chemical shift regions:

1. [(Area A)/(Area C)]: a ratio relating the more resistant long-chain aliphatic material (alkyl) to easily decomposable carbohydrate (i.e., polysaccharide) type material (*O*-alkyl); and,
2. [Σ(Areas A,B,C,F,G)/Σ(Areas D,E)]: a ratio relating aliphatic material to aromatic materials primarily phenol and lignin groups that represent carbohydrate-depleted residues.

RESULTS AND DISCUSSION

General Observations from Micromorphology and ^{13}C NMR Spectra

The morphology of the folic materials of the Humic, Lignic, and Histic Folisols is dominated by the effect of faunal activity. Throughout the thick organic accumulations for all three sites (Tables 2–4), micromorphological evidence was especially frequent for oribatid mites with respect to the occurrence of fecal material and the attack on organic residues (Figs. 1 and 2). In general, the granular structure observed in the horizons has resulted from faunal activity with fungi often binding together the plant residues, organic fine materials and fecal material. These observations for faunal activity support the research on fauna distributions reported by Battigelli (1992) that in the hemlock-amabalis fir ecosystem microarthropods were observed to depths of 80–90 cm. Most organisms were found in the upper F horizons and in order of decreasing dominance were Nematoda, Acari (in toto), Collembola (in toto), and Copepoda.

The spectra for the folic materials (Figs. 3–5) show characteristic peaks at the following chemical shifts: $-CH_2-$ in long alkyl chains at 30 ppm; $-OCH_3$ at 56 ppm; *O*-alkyl C including those in carbohydrates at 73 ppm; di-*O*-alkyl C including the anomeric C of carbohydrates at 104 ppm; phenolic C at 145–150 ppm; carboxyl C at 173 ppm, and a weak region of intensity due to carbonyl C around 200 ppm. Peak maxima or shoulders occur at approximately 130 and 115 ppm in the aromatic region. The spectra are not well-resolved due to the complex nature of the samples, and peak maxima may vary by ± 1 ppm. Spectra of the different horizons generally have similar features, but differ in relative areas among the chemical-shift regions, as shown in Table 5.

The folic materials show distinctive NMR spectra as a reflection of their organic constituents; three main types of folic materials can be characterized:

A. Horizons which are derived mainly from residues that show higher carbohydrate-like C and *O*-alkyl C values and lower total aromatics. These horizons are Fr, Hr1

Table 2. Micromorphological features of the Humic Folisol (Graham Island)

Horizon	Depth (cm)	Soil material arrangement[z]	Soil material features[y]
Fr	0–8	Not sampled	
Hrl	8–20	*Overall:* Soil matrix is very porous; consists of organic fine material of residues and fecal material dominantly mite derived (Fig. 1A). *Basic RDP:* Phyto-humigranic *Fabric zone symbol:* [Ga Pp Mg Mag]	*Fecal material:* Mite origin — 1. Ellipsoidal units 80×200 μm which form granular structure, are dark reddish brown, mainly amorphous, but, contain plant cells and fungi. 2. Ellipsoidal units 40×100 μm, completely amorphous, light yellow brown, associated with the interior of plant fragments. *Plant material:* Root tissues: Common to frequent, 240–400 μm, moderate decomposition, commonly with mycorrhizal mantles which have strong decomposition. Leaf tissues: Rare, strong decomposition, major portions of interior tissues removed by fauna. *Fungi:* Frequent fragments throughout the organic fine material.
Hr2	20–64	*Overall:* Very porous soil matrix consisting primarily of abundant fecal material, residues, and root sections (Fig. 1B). Increased decomposition, organic material and fungal hyphae than observed in Hr1. *Basic RDP:* Phyto-humigranic *Fabric zone symbol:* [Ga Pp Mag Ma Mg]	*Fecal material:* Dominantly of mite origin and observed as follows: 1. Elliptical units, diameter 120 μm by 220–230 μm long, consist of amorphous material with fungal fragments and plant tissue cells, very abundant throughout and usually occur in clusters. 2. Individual elliptical units 70–100 μm long × 40–60 μm diameter, include amorphous organic material plus well decomposed cell tissues, observed within plant tissues. Irregular, granular units up to 60 μm diameter (probably enchytraeids) associated with leaf fragments, occur as clusters within organic fine material, composed of fungal fragments, plant tissues, highly decomposed and amorphous material. *Plant material:* Root tissues: frequent, diameters 240–400 μm, randomly distributed, frequent mycorrhizal mantles. *Fungi:* Very frequent throughout.
Hd	64–82	*Overall:* Dense soil matrix (Fig. 1C) showing complex arrangement of amorphous material, faunal material, mineral particles, root sections, and wood fragments. *Basic RDP:* Meta-mullgranoidic/mullgranoidic-porphyroskelic//porphyroskelic. *Fabric zone symbol:* [Mam Mg Ga Pp] [Mamp]	*Fecal material:* The massive appearing as well as the densely packed amorphous material has fabric zones with weak expression of granular structure that was derived from faunal activity. *Plant material:* Root sections are common but tend to be clustered; show minor to extreme decomposition; occasional mycorrhizal mantles occur on roots with diameters 320–400 μm and as fragments in the soil matrix. Occasional ghosts of plant (root) tissues occur and are often filled with fauna-reworked organic fine material and fecal material. Rare to occasional wood tissues; extreme decomposition. *Fungi:* Common to occasional throughout; often in greater abundance in association with root sections and fecal material. Occasional clusters of fungal sclerotia (diam. 320–1600 μm) with occasional fragments in the soil matrix. *Mineral material:* Mineral grains < 10–50 μm dominate throughout; occasional clustering of grains 80–160 μm.

[z] Soil material arrangement described at 25 × magnification after Brewer (1976) re: Basic related distribution pattern [Basic RDP] and Fox (1984) re: Fabric Zone Symbol.
[y] Soil material features described at magnifications ranging from 10 to 125×.

and Hr2 (Humic Folisol); L, Fq and Hr (Lignic Folisol) and Fr and Hr1 (Histic Folisol) which have relative areas of carbohydrate-like C values greater than 31% and *O*-alkyl C greater than 27% (Table 5).

B. Horizons with advanced decomposition were distinguished by increased alkyl C content which likely derived from accumulation of microbial biomass. These horizons are Hr2, and Oh1 of the Histic Folisol, and the Hd horizon of the Humic Folisol.

C. Horizons which are ligneous in character, where carbohydrate-like C is less than total aromatic C, for example, the Fw and Hdw of the Lignic Folisol.

The general features of the spectra are similar to those widely reported for forest litter and humus layers (deMontigny et al. 1993; Hempfling et al. 1987; Kögel et al. 1988; Kögel-Knabner et al. 1988; Zech et al. 1987, 1990), and peats (Preston et al. 1987, 1989; Nordén et al. 1992). For this reason, the individual spectra and peak assignments (Figs. 3–5) will not be discussed in any detail, but will focus on differences within and between profiles with special attention directed towards horizons containing ligneous materials.

Humic Folisol

In the Humic Folisol (Table 2), decomposition of the organic materials increases in intensity with depth and the entire soil pedon has been affected by soil fauna.

The NMR spectra for the Humic Folisol (Fig. 3) show very little difference between the Hr1 and Hr2 horizons despite differences observed in the morphology with regard to decomposition of the residues. In the Hr1 horizon, overall, the soil matrix (Fig. 1A) consists of organic fine materials, fecal material and comminuted plant residues, with root tissues commonly having mycorrhizal mantles. The Hr2 horizon is very similar to the Hr1 horizon but shows more

Table 3. Micromorphological features of the Lignic Folisol (Vancouver Island)

Horizon	Depth (cm)	Soil material arrangement[z]	Soil material features[y]
L	0–1	*Overall:* Very porous soil matrix (Fig. 2A) dominated by layered plant residues (leaf, root, stem tissues) that are interspersed with finer organic material composed of fecal material, comminuted plant materials and amorphous materials (unrecognizable as to origin). *Basic RDP:* Phytogranic/mullgranoidic-porphyroskelic *Fabric zone symbol:* [Pp Ga Mag]	*Fecal material:* The fine organic material consists of fecal material 80–100 μm which is very frequently coalesced together to form aggregates and bridges (Fig. 2B) between fragments. Rare occurrence of leaf fragments with fecal material (mites) 50×100 μm. *Plant material:* Frequent root cross-sections (200–680 μm, mainly 320 μm) show weak to moderate decomposition and occasionally have mycorrhizal mantles. Leaf fragments, conifer needles show moderately strong to extreme decomposition often with evidence of faunal activity. Occasional moss fragments observed at the surface show little to no decomposition of tissues. *Fungi:* Fungal hyphae are present as mycorrhizal mantles, as fungal masses (i.e. lichen or basidiomycete), are very frequent throughout the organic fine material, and provide stabilization for aggregates of the finer materials.
Fq	1–5	*Overall:* Fungal masses (Fig. 2C) predominate throughout the soil fabric, with interlayering of leaf/plant fragments, fecal pellets, comminuted residues and root sections. *Basic RDP:* Humi-phytogranic/phytogranic. *Fabric zone symbol:* [Pp Ma Ga Gap Mag]	*Fecal material:* 1. Occasional reddish yellow brown ellipsoidal units 60×110 μm and amorphous material having bow-like fabric arrangement are associated entirely with the interior of the leaf fragments. 2. The organic fine material of the soil matrix consists of comminuted residues that have been organized into irregular and ellipsoidal units by faunal activity, widths and lengths vary, 80–120 μm; soil material consists of fragmented tissues, fecal material together with abundant fungal hyphae which often binds the units together into aggregations. 3. Rare rectangular shaped units, 320 μm wide × 480–600 μm long composed of extremely decomposed cells/fragments of plant material. Fungal hyphae have entered from the soil matrix. 4. Rare to occasional ellipsoidal units 140×220 μm, reddish brown, composed of fungal hyphae and amorphous material which are clustered in the soil matrix. *Plant material:* Leaf fragments exhibit strong to extreme decomposition with most showing evidence of mite activity with the removal of interior parenchyma cells and tissues. Root sections (majority range from 160 to 400 μm in diameter, dominantly 320 μm) occur very frequently, show minor to moderate decomposition, and frequently have mycorrhizal mantles. *Fungi:* Dominant, observed as masses or binding material into aggregates.
Hr	5–10	*Overall:* The soil matrix is a mixture of root sections and organic fine material that is composed primarily of fecal material and comminuted residues with a weak expression of interlayering of plant remains (Fig. 2D). *Basic RDP:* Humi-phytogranic/ humigranoidic/ humigranoidic-porphyroskelic. *Fabric zone symbol:* [Pp Ga Gap Mg] [Pp Mag]	*Fecal material:* Evidence for faunal activity dominates in the soil matrix as individual units, clusters, and aggregations (by fungal hyphae) with comminuted residues. Fecal material associated with leaf tissues occurs as follows: 1. Released into the soil matrix from the interior of leaf tissues are frequent to common, dark reddish brown, amorphous, ellipsoidal units 110 μm (w) × 260 μm (l); 2. Occasionally enclosed within the leaf tissue, reddish yellow brown, ellipsoidal units, 64 × 128 μm and 30 × 50 μm, are primarily amorphous but also contain plant cells and fungal hyphae; 3. Rare occurrences of massive amorphous material (faunal derived) filling interior of leaf tissues. *Plant material:* Root sections, dominant diameters 200–400 μm, are frequently moderately strongly decomposed with occasional sections showing extreme decomposition. Frequent mycorrhizal mantles. Wood fragments show extreme decomposition, are bright reddish-yellow; frequently below the epidermal layer, the highly decomposed cell tissues separate and become an integral part of the soil material. *Fungi:* Frequent throughout soil matrix, binds fecal material together often into aggregates; in association with root tissues, mycorrhizal mantles.
Fw	10–17	Not sampled	
Hdw	17–68	*Overall:* Soil fabric is characterized by a dominance of faunal activity (Figs. 2E to 2G) and biological decomposition of wood material. *Basic RDP:* Metagranic-metagranoidic/ porphyroskelic/ granoidic-porphyroskelic. *Fabric zone symbol:* [Mg Mag Pp Ga]	*Fecal material:* The soil material consists of reddish yellow-brown discrete units of faunal material (i.e., ellipsoidal units 80–100 μm × 120–180 μm, circular units 50 μm, probably mite origin) that are frequently coalesced together to form amorphous masses (Fig. 2F) that still retain a weak expression of the outlines of individual units. *Plant material:* Root sections 200–400 μm are common; moderate to moderately strong decomposition with the outer epidermal layer showing extreme decomposition of the cell tissues (Fig. 2G). Remaining wood fragments show extensive faunal activity, primarily by mites (Fig. 2E) as well as intrusion by fungal hyphae. *Fungi:* In close association with mycorrhizal mantles on root tissues; extremely abundant as fungal fragments within the amorphous masses.
Ho	68–70	*Overall:* Soil matrix consists of very frequently occurring mineral material in organic fine material (Fig. 2H). *Basic RDP:* Humigranoidic porphyroskelic *Fabric zone symbol:* [Mg Pm Pp] [Mg]	*Fecal material:* The organic fine material is faunal in origin, tends to have uniform shape, size, spherical 30–128 μm units. *Plant material:* Occasional root tissues; tend to be clustered; 250–800 μm in width; moderate to moderately strong decomposition. Occasional mycorrhizal mantle and/or outer epidermal layer occurs as fragments in the groundmass, dark blackish red to black, 80–480 μm in length. *Fungi:* Fungal hyphae fragments occur commonly in the soil matrix. Rare fungal sclerotia 800 μm width. *Mineral Material:* Very frequently occurring mineral grains < 10–120 μm and commonly occurring mineral fragments 200–800 μm.

[z] Soil material arrangement described at 25× magnification after Brewer (1976) re: Basic Related Distribution Pattern [Basic RDP] and Fox (1984) re: Fabric Zone Symbol.

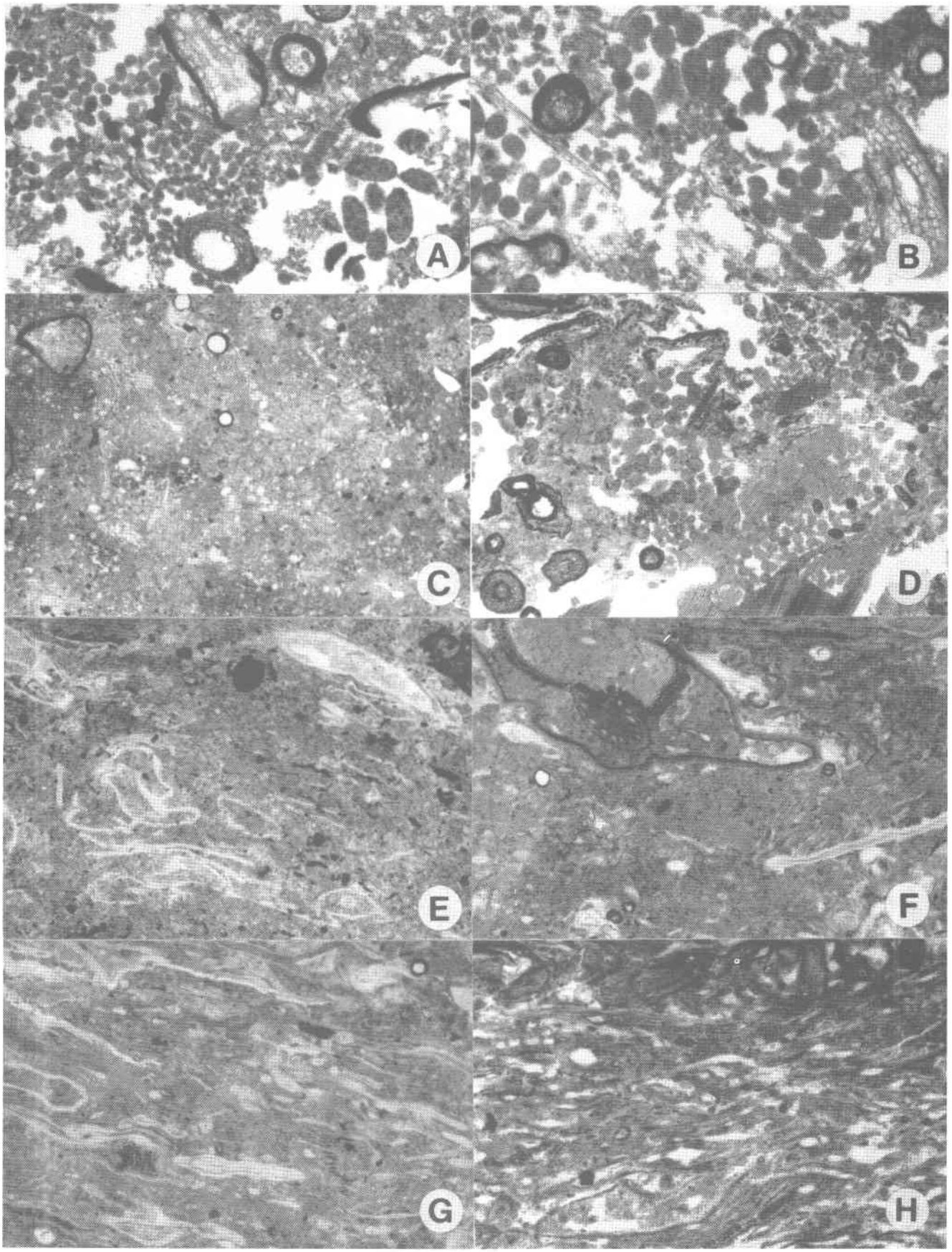
[y] Soil material features described after Brewer (1976) at magnifications ranging from 10 to 125×.

Table 4. Micromorphological features of the Histic Folisol (Prince Rupert area)

Horizon	Depth (cm)	Soil material arrangement[z]	Soil material features[y]
Fr	0–3	Not sampled	
Hr1	3–20	*Overall:* The soil morphology (Fig. 1D) consists of closely packed granular units and plant particles which form massive-appearing fabric; granular units coalesced at contact points, and zones with clusters of distinct fecal pellets. *Basic RDP:* Phytogranic/humigranoidic/humigranoidic-porphyroskelic. *Fabric zone symbol:* [Mg Pp Gap Ga] [Gap Pp] [Ma Ga Pp]	*Fecal material:* The soil morphology is dominated by granular units derived from faunal activity; the size range varies 40–500 μm, mainly 100–200 μm. Very frequent clusters of intact pellets (80 × 200 μm); also in association with massive appearing amorphous material that appears to be a reworking of material already subjected to faunal activity; primarily mites. Ligneous fragments show extensive faunal activity (i.e., portions excavated by mites). Rare to occasional root cross-sections contain fecal material (40 μm × 80 μm); occasionally as a result of complete decomposition and break-up of the epidermal layer, fecal pellets are released into the groundmass material. *Plant material:* Root sections are very frequent, dominantly 140–320 μm; epidermal layers moderately strong to extreme decomposition; interior cell structures moderate to moderately strong decomposition. *Fungi:* Abundant fungal hyphae occur within the granular units as fungal fragments (most prevalent in units 150–230 μm) and/or as fungal filaments surrounding the granular units. Occasional mycorrhizal mantles occur on root sections with greater frequency of fungi in adjacent soil material.
Hr2	20–52	*Overall:* The soil matrix is dominated by a massive appearing amorphous groundmass. *Basic RDP:* Humi-porphyroskelic. *Fabric zone symbol:* [Ma Pp]	*Fecal material:* Rare occurrences of roots with interiors often occupied by both fecal material 30–40 μm diameter × 50 μm length, and very fine matrix material. *Plant material:* Characteristic features of the fabric are "ghosts" of plant tissues particularly the epidermal layer; the interiors are filled either with amorphous matrix material or remnants of epidermal and interior cell structures that appear almost transparent (Fig. 1E). *Fungi:* Fungal hyphae are distributed throughout the amorphous material. Frequent occurrences of circular fungal bodies, dominantly 50–100 μm diameter; occasionally broken apart; rare large (1 mm) sclerotia intact; occasional mycorrhizal mantles remain. *Mineral material:* Fine silt size (10–60 μm); distributed randomly throughout the soil matrix.
Oh1	52–82	*Overall:* Soil morphology consists of extremely well-decomposed plant material, unrecognizable re origin; but retains weak to moderate horizontal layering. *Basic RDP:* Humi-porphyroskelic. *Fabric zone symbol:* [Ma Mg Pp]	*Fecal material:* None observed. *Plant material:* Remnants of epidermal layers of plant tissues (appear transparent) occur frequently within the dense soil matrix. The interiors are associated with well decomposed amorphous material (reddish-orange) (Fig. 1F). *Fungi:* Fungal bodies (sclerotia) 20–150 μm are extremely frequent, dominantly 50–100 μm, randomly distributed throughout but tend to follow the horizontal layering of plant material, rare sclerotia 1400 μm in diameter.
Oco	82–99	*Overall:* Dense soil matrix of well-decomposed amorphous material with abundant stem tissues of horizontally aligned mosses and sedges (Fig. 1G). Fabric zones occur where plant material (dominant length 2–6 mm) shows compression and twisting. The amorphous material forms fine material with weak granular morphology between stems of organic fragments as well as infillings in the interiors of plant fragments with colloidal, even-coloured amorphous material. *Basic RDP:* Humi-granoidic porphyroskelic/humiporphyroskelic. *Fabric zone symbol:* [Ma Mg Pp]	*Fecal material:* Very rare occurrences of fecal material, circular 40–50 μm. *Plant material:* Horizontal alignment with zones showing compression. Rare occurrence of leaf tissues; highly decomposed. Pore space in the dense soil material is associated directly with the organic fragments. *Fungi:* Fungal hyphae are common to occasional and occur throughout the amorphous soil matrix. *Mineral material:* Rare; rare to very few diatoms.
Oh2	99–151	*Overall:* Well-decomposed organic matrix, with inclusions of plant material dominated by moss fragments. There is a dominant horizontal alignment of the abundant plant material (Fig. 1H) with amorphous material between the plant fragments showing weak granular morphology. *Basic RDP:* Humi-porphyroskelic *Fabric zone symbol:* [Map Mg Pp]	*Fecal material:* Rare evidence of fecal material, circular units 30–50 μm, associated with very decomposed organic fragments. Well decomposed fragments with internal portions filled with amorphous material suggestive of faunal activity. *Plant material:* Portions of fragment remnants contain reddish-yellow gel-like organic material. *Fungi:* Fungal hyphae are common in the amorphous matrix. *Mineral material:* Mineral grains (10–160 μm mainly <60 μm) are common to frequent, random throughout but with tendency towards clustering.

[z] Soil material arrangement described at 25× magnification after Brewer (1976) re: Basic Related Distribution Pattern [Basic RDP] and Fox (1984) re: Fabric Zone Symbol.

[y] Soil material features described after Brewer (1976) at magnifications ranging from 10 to 125×.



advanced decomposition and greater proportion of finer organic material as well as greater frequency of fungal hyphae. Evidence of faunal activity (Fig. 1B) is frequent in the form of fecal material and comminuted organic plant residues. Compared with the Fr horizon, the Hr1 and Hr2 horizons are lower in alkyl C, and higher in total aromatics which is consistent with increased decomposition of the materials. The spectra for the Hr1 and Fr horizons indicate the presence of tannins with a peak at 144 ppm ± 1 ppm as interpreted by deMontigny et al. (1993) and Preston and Sayer (1992). In the Hr1 horizon, micromorphological evidence of leaf and root materials with strong decomposition, and frequent occurrences of fungi in the organic fine materials may strengthen this observation of the presence of tannins.

The spectrum (Fig. 3) of the Hd horizon is quite different. There is about a twofold increase in the relative area of the alkyl C region when compared with the Hr1 and Hr2 horizon (Table 5). Alkyl C reflects the more resistant organic compounds such as long-chain aliphatics. This difference is also noted in the ratio of alkyl C to *O*-alkyl C of 1.77 and the ratio of aliphatics (regions A–G) to aromatics (regions D and E) of 3.35. Increasing alkyl C intensity with decomposition has been observed in peats (Preston et al. 1987, 1989; Nordén et al. 1992) and forest litter and humus (Hempfling et al. 1987; Kögel-Knabner et al. 1988; Zech et al. 1987, 1990) similar to the levels seen in the Hr2, Oco and Oh2 of the Histic Folisol, but the Hd horizon in this Humic Folisol appears to be an extreme case. The morphology of the Hd horizon (Table 2) has a dense closely packed soil matrix of amorphous organic material (Fig. 1C) where extreme decomposition and reworking of the plant materials has occurred and only the extremely resistant plant fragments are observed. In specific fabric zones, there remains a weak expression of granular units which were faunal derived. Fungal hyphae are frequent throughout the Hd horizon and are associated with root sections, mycorrhizal mantles, and aggregations of faunal material. With both the micromorphological and NMR observations, substantial decomposition of this horizon has occurred probably from biological processes resulting in the accumulation of the more resistant organic compounds with lower amounts of aromatics.

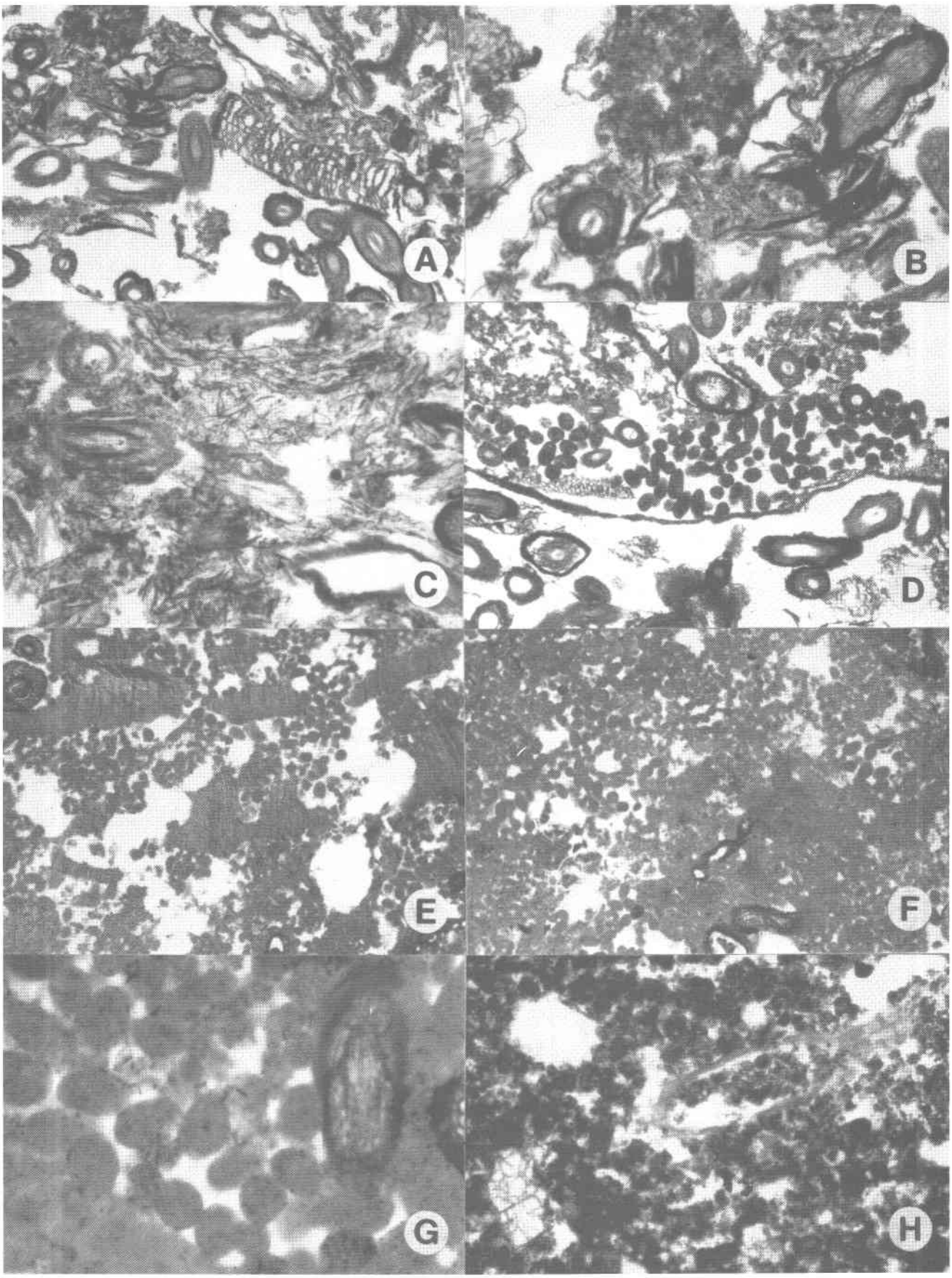
Fig. 1. A. The morphology consists of organic fine material and fabric zones of fecal material, primarily mites. Dark outer regions on root material are mycorrhizal mantles. Taken from the Hr1 horizon of the Humic Folisol. Frame length 2.15 mm. Plane polarized light (PPL). B. Extremely porous morphology with fecal material (mites) in close association with plant tissues. Note mycorrhizal mantles on root tissues. Taken from the Hr2 horizon of the Humic Folisol. Frame length 2.15 mm (PPL). C. The morphology is dominated by massive-appearing amorphous (unrecognizable) material. Root tissues with only the mycorrhizal mantle remaining can be seen in the upper left of the photo. Taken from the Hd horizon of the Humic Folisol. Frame length 4.25 mm (PPL). D. A complex morphology results from close packing of fecal material, amorphous material derived from faunal activity, plant fragments, and root tissues. Taken from the Histic Folisol in the Hr1 horizon. Frame length 4.0 mm (PPL). E. Epidermal layers appear almost transparent in a massive-appearing fabric of organic materials. There is a moderate horizontal trend of interlayering of the plant tissues. The round feature in the upper part of the photo is fungal material (specifically sclerotia). Taken from the Histic Folisol in the Hr2 horizon. Frame length 4.25 mm (PPL). F. The soil fabric is massive appearing with weak horizontal layering and consists of well-decomposed organic material with remnants of more resistant plant tissues. Taken from the Histic Folisol in the Oh1 horizon. Frame length is 4.0 mm (PPL). G. The soil morphology shows strong layering of the plant tissues with fine amorphous organic material. Taken from the Histic Folisol in the Oco horizon. Frame length is 4.25 mm (PPL). H. Horizontal layering of the well-decomposed plant material dominates the soil fabric. Taken from the Histic Folisol in the Oh2 horizon. Frame length is 4.0 mm (PPL).

Lignic Folisol

The Lignic Folisol (Table 3) is characterized by layered plant residues and fecal material interspersed with fine organic materials in the L horizon (Figs. 2A and 2B); the dominance of fungal masses in the Fq horizon (Fig. 2C); the abundant evidence of faunal activity throughout the H horizons (Fig. 2D–H), and the strong decomposition of wood materials in the Hdw horizon by fauna and biological components (Fig. 2E–G). Fecal material forms the dominant component of the soil morphology in the Hr, Hdw, and Ho horizons. In the Hr horizon (Fig. 2D), the fecal material is in association with various plant residues. In the Hdw horizon, the faunal material is directly associated with wood. In the Ho horizon (Fig. 2H), very fine, very humified organic material has penetrated the upper layer of the underlying mineral material; the morphology of this organic fine material is suggestive of fecal material. In the Fq, Hr, and Hdw horizons, mycorrhizal mantles on root sections are frequent. In the Hdw horizon, fungal hyphae in the soil matrix are in close association with the mycorrhizal mantles.

The NMR spectra for the L, Fq, and Hr horizons are similar to each other (Fig. 4) with respect to the overall organic composition but with the Fq horizon showing slightly increased levels of alkyl C (Table 5). The increase in alkyl C in the Fq may have been the result of the extremely abundant presence of fungal hyphae and fungal mats probably contributing to the breakdown of the organic residues. The ratios of alkyl C to *O*-alkyl and of aliphatics to aromatics also suggest very similar chemical composition for the L and Hr horizons. Increased decomposition is indicated with depth by the progressive decrease in the relative areas of carbohydrate-like C from 35 to 31. This is supported by the morphology observed in the L, Fq, and Hr horizons. With depth, there is increased intensity of decomposition of the plant residues and dominating effect of faunal activity on the folic materials.

The spectra for the Fw and Hdw horizons (Fig. 4) are similar to those observed for decomposed wood (Preston et al. 1990). Whereas the ^{13}C NMR spectrum of fresh wood is dominated by signals due to cellulose, with increasing decomposition of the brown-rot type, the relative contribution of cellulose and hemicellulose decreases, and that of lignin increases (Hatcher 1987; Preston et al. 1990). In the Hdw horizon (Table 5), the total aromatics are 43% compared with carbohydrate-like C at 18%; whereas, in the Fw horizon,



the relative areas are almost the same. The phenolic, aromatic and methoxyl peaks of the Hdw horizon become more prominent from the Fw to Hdw horizons as the relative area at 73 and 104 ppm decreases. The sharp phenolic signal is characteristic of guaiacyl lignin; this region becomes more complex with increasing contributions from syringyl and phenylpropane units, as well as from tannins. Fresh wood also has very little aliphatic or carboxyl intensity; these increase with decomposition due to lignin oxidation and the build-up of microbial biomass. Suberin from roots running through the woody horizon would also contribute to increasing intensity in these regions (Beudert et al. 1989). In the field, plentiful medium to coarse roots were observed in the Fw horizon and the lower portion of the Hdw horizon and abundant fine roots in the upper Hdw horizon (Table 1). The Fw horizon in the field consisted of intact recognizable wood structure. In contrast, the Hdw horizon, although identified as being derived from ligneous materials, was greasy in consistency with a weak granular structure indicating from the field structure a very advanced stage of decomposition. For the Hdw horizon, the micromorphology supports this observation with evidence of extreme decomposition of root material, extensive faunal activity of remaining wood fragments as well as fungal hyphae penetration of the amorphous material.

The spectrum of the Ho horizon with 27% C and 2.9% total iron was broad and distinct peaks could not be distinguished for evaluation of the chemical shift regions and thus was not included in Fig. 4.

Fig. 2. A. Plant materials, root tissues, comminuted fine material, and aggregates of organic material (upper left) form an extremely porous morphology. Taken from the L/upper Fq horizon of the Lignic Folisol. Frame length 4.25 mm (PPL). B. Closer view of aggregates of organic material (See upper left of Fig. 2A) showing association with fungal hyphae (black filaments) and root tissues with mycorrhizal tissues. Taken from L/upper Fq horizon of the Lignic Folisol. Frame length 2.15 mm (PPL). C. Fungal masses predominate (upper right) interspersed between root tissues with moderate decomposition. From the Fq horizon of the Lignic Folisol. Frame length 2.15 mm (PPL). D. Total removal of plant tissues by mite activity as evidenced by fecal material and minor remnants. Root tissues are very frequent often with mycorrhizal mantles. Note interlayering of plant fragments, fecal material and organic fine material. Taken from Hr horizon of the Lignic Folisol. Frame length 4.25 mm (PPL). E. The wood tissues have been almost completely removed by mites producing an extremely porous soil fabric. In bottom right, fecal material forms amorphous masses. In upper left, root tissues show minor decomposition. Taken from the Lignic Folisol in the Hdw horizon at 34–40 cm depth. Frame length is 4.25 mm (PPL). F. The morphology is dominated by fecal material both as individual units and zones of amorphous masses. Taken from the Lignic Folisol in the Hdw horizon at 34–40 cm depth. Frame length is 4.25 mm (PPL). G. Closer view of fecal material and amorphous masses shown in Fig. 2F. Black speckled appearance in fecal material is from fragments of fungal hyphae. Root tissue shows moderate decomposition and evidence of mycorrhizal mantles. Taken from the Lignic Folisol in the Hdw horizon at 34–40 cm depth. Frame length is 1.0 mm (PPL). H. Fine organic material tends to be aggregated. Note mineral grains on upper and lower left of photo as well as remnants of root tissue on upper right. Taken from Lignic Folisol in the Ho horizon. Frame length is 1.0 mm (PPL).

Histic Folisol

The Histic Folisol has developed as the result of a change from a saturated (wetland) to unsaturated environment (forest, upland). Fox et al. (1987) reported a radiocarbon date of 1930±350 y B.P. for this soil from wood sampled at the interface between the unsaturated and saturated environments as designated by the change in composition of plant residues from wetland to folic (forest) materials. This site has been fairly stable since then to allow for the thick accumulation of folic materials.

The NMR spectra for the Fr and Hr1 horizons (Fig. 5) are similar to each other, with only a small decrease in carbohydrate-like C, and increase in total aromatic C with depth (Table 5). The Hr1 horizon (Table 4) is characterized by granular morphology (Fig. 1D) that has resulted from faunal activity; there are frequent root sections that show moderate to extreme decomposition. There is a large increase in alkyl C observed in the Hr2 horizon (Table 5) and a

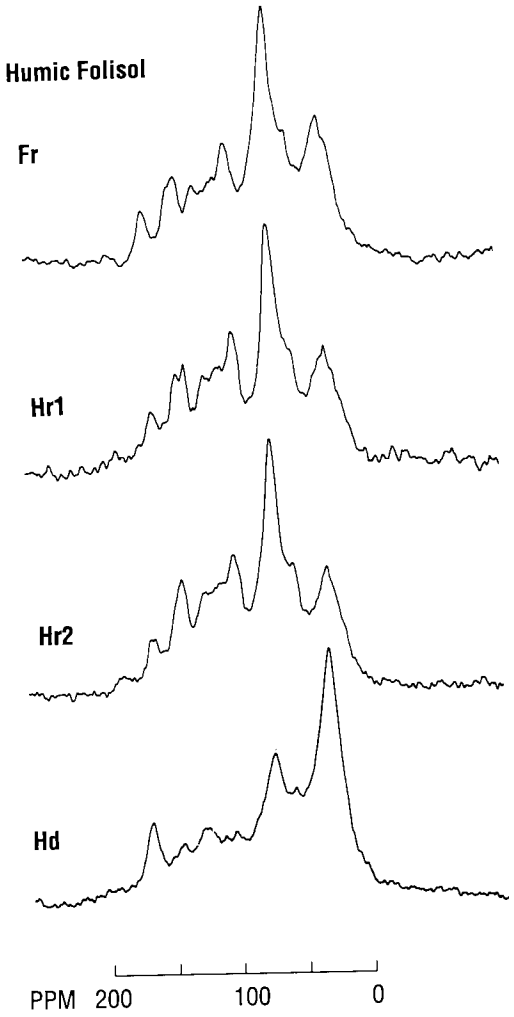


Fig. 3. Solid-state ^{13}C CPMAS NMR spectra of the folic materials of the Humic Folisol.

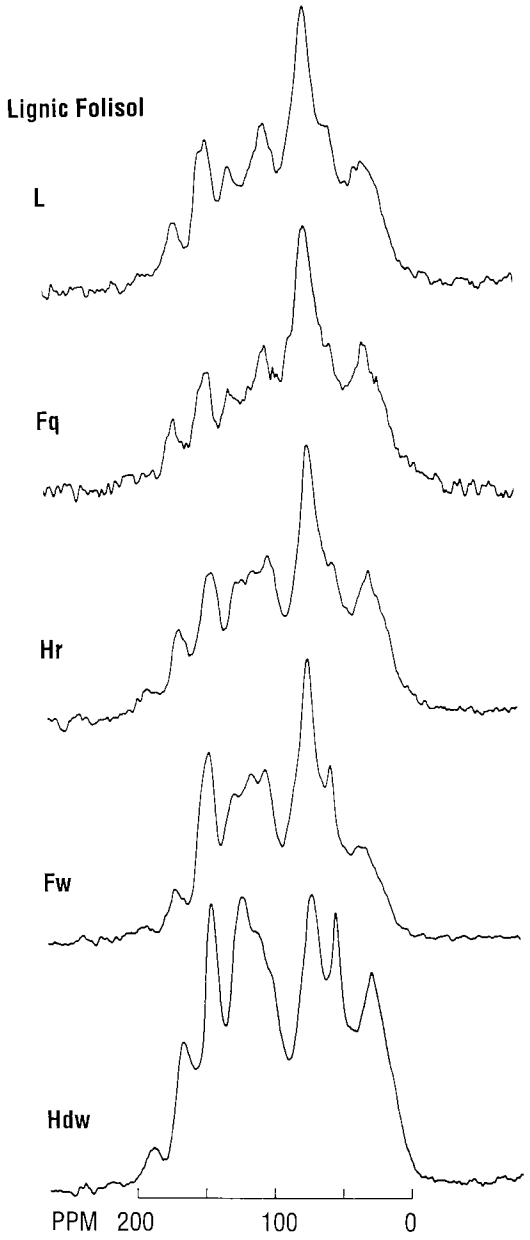


Fig. 4. Solid-state ^{13}C CPMAS NMR spectra of the folic materials of the Lignic Folisol.

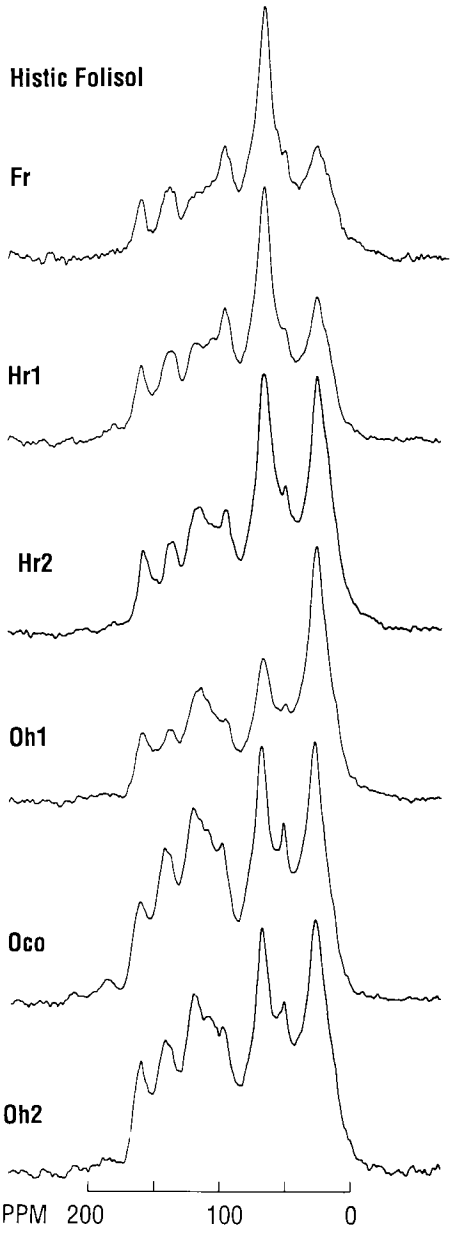


Fig. 5. Solid-state ^{13}C CPMAS NMR spectra of the folic materials of the Histic Folisol.

further increase to Oh1 suggesting increased occurrence of more resistant organic compounds. The morphology of the Hr2 horizon is extremely decomposed with a massive-appearing soil matrix that retains evidence of plant residues (Fig. 1G) which show weak horizontal alignment, faunal attack within root sections, and frequent occurrences of fungal hyphae.

The Hr2 horizon is probably transitional between the unsaturated environment of accumulation of folic materials and the dominantly saturated environment of the Oh1 horizon. The fecal material, fungal bodies and mycorrhizal mantles observed in the Hr2 are indicative of an unsaturated environment as discussed by Bouma et al. (1990). The Oh1, Oco, and Oh2 horizons (Fig. 1F–H) represent primarily a saturated environment that is characterized by prominent horizontal alignment of the peat materials. Unsaturated periods may have occurred as evidenced by the frequent fungal material. The soil matrix is well to extremely decomposed in these horizons. The relative areas of the alkyl C for the Oco and Oh2 horizons are similar (Table 5) but lower than those for the Hr2 and Oh1 horizons. The Oco and Oh2 horizons differ also in being higher in total aromatic C. This and the relatively well-resolved methoxyl signal (Fig. 5) suggests probable lignin content. The morphology of the Oco

Table 5. Solid state ^{13}C NMR data for selected Humic, Lignic and Histic Folisol

	Relative Areas (% of total intensity) of chemical shift regions							Calculated values			
Horizon	(A) Alkyl [0–50][z]	(B) O-Me [50–62]	(C) *O*-alkyl [62–95]	(D) Di-*O*-Alk. + Arom. [95–140]	(E) Phenolic [140–160]	(F) Carboxyl [160–190]	(G) Carbonyl [190–220]	"Carb.-like" (%)	"Total arom" (%)	(A):(C)	Σ(A,B,C,F,G) / Σ(D,E)
Humic Folisol											
Fr	27	8	29	23	8	4	1	35	25	0.93	2.23
Hr1	20	7	28	26	10	7	2	34	31	0.71	1.78
Hr2	21	8	28	27	10	5	1	34	31	0.75	1.70
Hd	39	7	22	17	6	7	2	27	18	1.77	3.35
Lignic Folisol											
L	19	8	30	26	11	5	1	35	32	0.63	1.70
Fq	23	8	28	24	10	5	2	33	28	0.82	1.94
Hr	20	7	27	26	11	7	2	31	32	0.74	1.70
Fw	14	8	28	31	14	4	1	34	39	0.50	1.22
Hdw	19	10	15	33	13	8	2	18	43	1.27	1.17
Histic Folisol											
Fr	23	8	31	23	8	6	1	38	25	0.74	2.23
Hr1	22	7	27	26	9	7	2	32	29	0.81	1.86
Hr2	31	7	24	24	7	6	1	29	16	1.29	2.23
Oh1	37	6	18	24	7	7	1	22	27	2.06	2.23
Oco	25	7	20	28	11	7	2	25	35	1.25	1.56
Oh2	21	7	24	29	11	7	1	28	35	0.88	1.50

[z]Values in brackets refer to ppm range of the chemical shift region designated as regions A–G.

and Oh2 horizons consists of well decomposed amorphous material with inclusions of plant material dominated by moss fragments.

CONCLUSIONS

Implications for Forest Growth

With increasing decomposition it was observed, in general, that there was a decrease in carbohydrate-like C and an increase in alkyl C. This increase in alkyl C may have important implications with respect to the growth of plants in the Folisols. Lipids, a component of the alkyl C fraction, have been reported (Dinel et al. 1992) to have an inhibitory effect on the germination, initial growth, dry matter yield, and hydraulic properties of the soil. For the Folisols, the potential is high for lipids. Dinel et al. (1990) reported that lipids (long-chain aliphatic carbon) result from partially decomposed and undecomposed plants and animals, and that they are affected by the pH of the soil and the state of saturation. Preston et al. (1987) also noted increased concentrations of long-chain aliphatic carbons in saturated organic layers. The Folisols have cool soil temperatures, are moist but are not saturated for most of the year, and are extremely acidic with pH values (Table 1) of less than 4.5 and often less than 3.0 (Fox et al. 1987); these soil conditions would inhibit decomposition of the organic materials as well as affect the penetration of new roots. Further research is needed to determine if the alkyl C component of the organic material may be contributing to the suppressed growth of new seedlings in the thick accumulations of folic materials.

Implications for Adequate Nutrient Content

The lignin content of the organic horizons is important with respect to the amount of nitrogen and phosphorus that may become available for plant growth. Berg and McClaugherty (1989) observed that a net release of nitrogen and phosphorus was related to the onset of decomposition and disappearance of acid-insoluble organic substances such as lignin. In this study, for the Hdw horizon of the Lignic Folisol, the NMR spectra indicated high total aromatics (i.e., lignin and phenols) and the morphology consisted almost entirely of fecal material; this horizon made up 51 cm or 72.8% of the accumulated folic materials. For the Folisols, further research is needed to assess the precise contribution of the abundant faunal activity to the release of available nutrients resulting from the fragmentation of the organic matter as well as understand the factors that control lignin degradation and nitrogen mineralization (Melillo et al. 1989; Taylor et al. 1989).

Faunal activity has resulted in a tremendous contribution to the structure of these soils and physical break-up of the folic materials. While some horizons now consist almost entirely of fecal material, the NMR spectra do not differ greatly from those of weakly decomposed plant inputs. Using scanning and transmission electron microscopy, Lee and Foster (1991) found that plant tissue sometimes underwent little modification by passage through the gut. Because of the similarity of the original organic inputs to the horizons and the abundant faunal activity with depth as observed by Battigelli (1992), it is suggested that where the NMR spectra show little variation chemically between the horizons that the faunal activity may have had an homogenization effect on the folic materials.

Prescott et al. (1993) have observed that on old growth forest sites in the Coastal Western Hemlock Biogeoclimatic Zone (located near the Lignic Folisol site in this study) there were lower concentrations of total and extractable N and P in some organic layers. The question yet to be answered is

whether, following the ingestion of the organic residues by the soil fauna, only the insoluble and acid resistant components of the organic material remain, and consequently, produce a state of organic material where the release of nitrogen and phosphorus may be minimal, and thus provide inadequate nutrients for plant growth.

In addition, the role of the soil environment such as the extreme acidity, cool temperatures and moist conditions must be considered in terms of the decomposition of the folic materials with respect to the carbon, nitrogen, and phosphorus dynamics, the presence of available macro- and micronutrients, the activity of mycorrhizal fungi and the capability of roots for uptake of necessary plant nutrients.

Agriculture Canada Expert Committee on Soil Survey. 1987. The Canadian system of soil classification. 2nd ed. Agriculture Canada, Ottawa, On. Publ. 1646, 164 pp.

Battigelli, J.P. 1992. Soil fauna communities in Cedar-Hemlock- and Hemlock-Amabalis Fir forest types on Northern Vancouver Island, British Columbia. MSc. thesis. Department of Soil Science, University of British Columbia, Vancouver, BC. 84 pp.

Berg, B., McClaugherty, C. 1989. Nitrogen and phosphorus release from decomposing litter in relation to the disappearance of lignin. Can. J. Bot. **67**: 1148–1156.

Beudert, G., Kögel-Knabner, I. and Zech, W. 1989. Micromorphological, wet-chemical and ^{13}C NMR spectroscopic characterization of density fractionated forest soils. Sci. Total Environ. **81/81:** 401–408.

Bouma, J., Fox, C. A. and Miedema, R. 1990. Micromorphology of hydromorphic soils: Applications for soil genesis and land evaluation. Pages 257–278 *in* L. A. Douglas, ed. Soil micromorphology: A basic and applied science. Proceedings of the VIIIth International Working Meeting of Soil Micromorphology, San Antonio, Texas — July 1988. Developments in Soil Science 19. Elsevier, New York, NY.

Brewer, R. 1976. Fabric and mineral analysis of soils. Robert E. Krieger Publ. Co., Huntington, NY.

Bullock, P. 1973. The micromorphology of soil organic matter — A synthesis of recent research. Pages 49–66 *in* G. K. Rutherford, ed. Soil microscopy. Proceedings of the Fourth International Working-Meeting on Soil Micromorphology, Department of Geography, Queen's University, Kingston, Ontario. August 27–31, 1973. The Limestone Press, Kingston, ON.

Bullock, P., Fedoroff, N., Jongerius, A., Stoops, G. and Tursina, T. 1985. Handbook for soil thin section description. Waine Res. Pub., Wolverhampton, U.K. 152 pp.

Cheshire, M. V., Russell, J. D., Fraser, A. R., Bracewell, J. M., Robertson, G. W., Benzing-Purdie, L. M., Ratcliffe, C. I., Ripmeester, J. A. and Goodman, B. A. 1992. Nature of soil carbohydrate and its association with soil humic substances. J. Soil Sci. **43**: 359–373.

Day, J. H. (ed.) 1983. Manual for describing soils in the field. 1982 rev. ed. Expert Committee on Soil Survey. LRRI No. 82–52, Research Branch, Agriculture Canada, Ottawa, ON. 97 pp.

deMontigny, L. E., Preston, C. M., Hatcher, P. G. and Kögel-Knabner, I. 1993. Comparison of humus horizons from two ecosystem phases on Northern Vancouver Island using ^{13}C CPMAS NMR spectroscopy and CuO oxidation. Can. J. Soil Sci. **73**: 9–25.

Dinel, H., Lévesque, M. and Jambu, P. 1992. Effects of long-chain aliphatic compounds on the germination and initial growth of corn, radish and spinach seedlings, and on hydrological properties of a sand growth medium. Can. J. Soil Sci. **72**: 107–112.

Dinel, H., Schnitzer, M. and Mehuys, G. R. 1990. Soil lipids: Origin, nature, content, decomposition, and effect on soil physical properties. Pages 397–427 *in* J. M. Bollag and G. Stotzky, eds. Soil biochemistry. Vol. 6. Marcel Dekker, Inc., New York, NY.

Fox, C. A. 1984. A morphometric system for describing the micromorphology of organic soils and organic layers. Can. J. Soil Sci. **64**: 495–503.

Fox, C. A. 1985. Characteristics of the Folisolic soils of British Columbia. Pages 205–232 *in* J. A. Shields and D. J. Kroetsch, eds. Expert Committee on Soil Survey, Proc. of the Sixth Annual Meeting, Guelph, ON., November 26–30, 1984. Research Branch, Agriculture Canada, Ottawa, ON.

Fox, C. A., Trowbridge, R. and Tarnocai, C. 1987. Classification, macromorphology and chemical characteristics of Folisols from British Columbia. Can. J. Soil Sci. **67**: 765–778.

Hatcher, P. G. 1987. Chemical structural studies of natural lignin by dipolar dephasing solid-state ^{13}C nuclear magnetic resonance. Org. Geochem. **11**: 31–39.

Hempfling, R., Ziegler, F., Zech, W. and Schulten, H.-R. 1987. Litter decomposition and humification in acidic forest soils studied by chemical degradation, IR and NMR spectroscopy and pyrolysis field ionization mass spectrometry. Z. Pflanzenernaehr. Bodenk. **150**: 179–186.

Klinka, K., Green, R. N., Trowbridge, R. L. and Lowe, L. E. 1981. Taxonomic classification of humus forms in ecosystems of British Columbia, First Approximation. Land Management Report ISSN 0702-9861; No. 8. Information Services Branch, Ministry of Forests, Victoria, BC. 54 pp.

Kögel, I., Hempfling, R., Zech, W., Hatcher, P. G. and Schulten, H. -R. 1988. Chemical composition of the organic matter in forest soils: 1. Forest litter. Soil Sci. **146**: 124–136.

Kögel-Knabner, I., Zech, W. and Hatcher, P. G. 1988. Chemical composition of the organic matter in forest soils: the humus layer. Z. Pflanzenernaehr. Bodenk. **151**: 331–340.

Lee, G. B. 1983. The micromorphology of peat. Pages 485–501 *in* P. Bullock and C. P. Murphy, eds. Soil micromorphology. Vol. 2. Soil genesis. Proc. 6th Int. Work. Meet. Soil Micromorphology. London. 17–21 Aug. 1981. A B Academic Publishers, Berkhamsted, U.K.

Lee, K. E. and Foster, R. C. 1991. Soil fauna and soil structure. Aust. J. Soil Res. **29**: 745–775.

Melillo, J. M., Aber, J. D., Linkins, A. E., Ricca, A. Fry, B. and Nadelhoffer, K. J. 1989. Carbon and nitrogen dynamics along the decay continum: Plant litter to soil organic matter. Plant Soil **115**: 189–198.

Messier, C. and Kimmons, J. P. 1991. Above- and below-ground vegetation recovery in recently clearcut and burned sites dominated by *Gaultheria shallon* in coastal British Columbia. For. Ecol. Manage. **46**: 275–294.

Murphy, C. P. 1986. Thin section preparation of soils and sediments. A B Academic Publishers, Berkhamsted, U.K. 149 pp.

Nordén, B., Bohlin, E., Nilsson, M., Albano, A. and Rockner, C. 1992. Characterization of particle size fractions of peat. An integrated biological, chemical, and spectroscopic approach. Soil Sci. **153**: 382–396.

Pojar, J., Klinka, K. and Meidinger, D. U. 1987. Biogeoclimatic ecosystem classification in British Columbia. For. Ecol. Manage. **22**: 119–154.

Prescott, C. E., McDonald, M. A. and Weetman, G. F. 1993. Availability of N and P in the forest floors of adjacent stands of western cedar-western hemlock and western hemlock-amabalis fir on northern Vancouver Island. Can. J. For. Res. **23**: 605–610.

Preston, C. M. and Sayer, B. G. 1992. What's in a nutshell: an investigation of structure by carbon-13 cross-polarization magic-angle spinning nuclear magnetic resonance spectroscopy. J. Agric. Food Chem. **40**: 206–210.

Preston, C. M., Shipitalo, S. -E., Dudley, R. L., Fyfe, C. A., Mathur, S. P. and Lévesque, M. 1987. Comparison of ^{13}C CPMAS NMR and chemical techniques for measuring the degree of decomposition in virgin and cultivated peat profiles. Can. J. Soil Sci. **67**: 187–198.

Preston, C. M., Axelson, D. E., Lévesque, M., Mathur, S. P., Dinel, H. and Dudley, R. L. 1989. Carbon-13 NMR and chemical characterization of particle-size separates of peats differing in degree of decomposition. Org. Geochem. **14**: 393–403.

Preston, C. M., Sollins, P. and Sayer, B. G. 1990. Changes in organic components for fallen logs in old-growth Douglas-fir forests monitored by ^{13}C nuclear magnetic resonance spectroscopy. Can. J. For. Res. **20**: 1382–1391.

Sheldrick, B. H. (ed.) 1984. Analytical methods manual 1984. LRRI Contribution No. 84-30. Research Branch, Agriculture Canada, Ottawa, ON.

Taylor, B. R., Parkinson, D. and Parsons, W. F. J. 1989. Nitrogen and lignin content as predictors of litter decay rates: A microcosm test. Ecology **70**: 97–104.

Trowbridge, R., Luttmerding, H. and Tarnocai, C. 1985. Report on Folisolic soil classification in Canada. Pages 180–204 *in* J. A. Shields and D. J. Kroetsch, eds. Expert Committee on Soil Survey, Proc. of the Sixth Annual Meeting, Guelph, ON. November 26–30, 1984. Research Branch, Agriculture Canada, Ottawa, ON.

Weetman, G. F., Fournier, R., Barker, J. and Schnorbus-Panozzo, E. 1989. Foliar analysis and response of fertilized chlorotic western hemlock and western red cedar reproduction on salal-dominated cedar-hemlock cutovers on Vancouver Island. Can. J. For. Res. **19**: 1512–1520.

Zech, W., Johansson, M. -B., Haumaier, L. and Malcolm, R. L. 1987. CPMAS ^{13}C NMR and IR spectra of spruce and pine litter and of the Klason lignin fraction at different stages of decomposition. Z. Pflanzenernaehr. Bodenk. **150**: 262–265.

Zech, W., Hempfling, R., Haumaier, L., Schulten, H. -R. and Haider, K. 1990. Humification in subalpine Rendzinas: chemical analyses, IR and ^{13}C NMR spectroscopy and pyrolysis-field ionization mass spectrometry. Geoderma **47**: 123–138.