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EFFECTS OF TREETHROW MICROTOPOGRAPHY ON THE CHARACTERISTICS AND GENESIS OF SPODOSOLS, MICHIGAN, USA

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Summary

This study examined the pedogenic effects of pit and mound microtopography, formed by tree uprooting, in a Spodosol (Haplorthods) landscape. Most soils in treethrow pits were Entic Haplorthods or Spodic Upidsamments whereas mound soils usually classified as Typic Udipsamments, suggesting that degree of profile development is: Undisturbed $\geq$ Pit $>$ Mound. Given that pit and mound soils are substantially younger than pedons on "undisturbed" sites, rates of pedogenesis are thought to be: Pit $>$ Undisturbed $>$ Mound. Strong pedogenesis in pits was explained by:

1. greater water contents in the upper sola, which may facilitate weathering processes,
2. thicker O horizons, which may lead to increased production of organic acids, and
3. greater insulation by thick litter and snow cover, which reduces the incidence of soil freezing.

In winter, mound soils may develop impermeable layers of concrete soil frost that impede infiltration of snowmelt waters, whereas pit soils remain unfrozen or acquire only a porous, granular frost layer. Thus, saturated flow of snowmelt within pits is relatively unrestricted, resulting in maximal leaching and profile differentiation.

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1 Introduction

The effect of relief on soil development has received considerable study; reviews are provided by RUHE (1969), GERRARD (1981), and BIRKELAND (1984). Many of these studies examine soil variability along a drainage sequence (e.g. DALSGAARD et al. 1981). At this scale, however, water table relations, aspect, erosion, microclimate, and variability in vegetation and lithology may introduce error into the state-factor equation (JENNY 1941). The present study focusses on microrelief as a pedogenic factor, in an attempt to minimize extraneous factors and effects.

Relatively few studies have focussed on the effects of microrelief on soil formation (e.g. LAG 1951, VENEMAN et al. 1984, ALEXANDER 1986, KNUTESON et al. 1989). Microtopography influences pedogenesis primarily through the redistribution of energy and materials, including water, litter, and snow. In this study I examined microrelief formed by the uprooting of trees, often called "pit/mound microtopography". The study of pit/mound microrelief allows for comparisons between pit, mound, and "control" or undisturbed pedons (VENEMAN et al. 1984, SCHAETZL et al. 1990).

Mounds are typically drier and less variable in temperature than pit sites (DWYER & MERRIAM 1981, BEATTY 1984, BEATTY & STONE 1986), and often have weak profile development (DENNY & GOODLETT 1956, SCHAETZL 1986, SCHAETZL et al. 1990). Overthickened, tongue-like E horizons are commonly observed beneath pits (LAG 1951, IVES et al. 1972, WANG et al. 1978). Organic (O) horizons tend to be overthickened in pits, primarily because of litter redistribution by wind and water (LUTZ 1940, LYFORD 1973, ARMSON & FESSENDEN 1973, SHUBAYEVA & KARPACHEVSKIY 1983, BEATTY & STONE 1986). These observations suggest that pits are commonly zones of stronger leaching than mounded sites (LUTZ 1940, IVES et al. 1972, VENEMAN et al. 1984).

This study examined:

1. the morphology of mound, pit, and undisturbed pedons,
2. the effect of pit/mound microtopography on soil water content and soil freezing,
3. the spatial and temporal variability of pedogenesis as indicated by cations of Fe, Al and H in soil solutions, and
4. the relationships between microtopography, soil frost, and infiltration, as they relate to pedogenesis.

2 Study area

The research was conducted in Baraga County, Michigan, USA (48°, 39′ N lat., 88°, 28′ W long.). Baraga County borders the southern shore of Lake Superior. Surficial sediments consist of glacial outwash, tills and glaciolacustrine sediments deposited approximately 11,000–10,000 BP (SAARNISTO 1974).

The climate is cool, humid continental. Snow cover is usually observed from late November through mid April; snowpack depths in excess of one meter are common. Locations near Lake Superior receive less snow than do sites inland, where orographic effects are evident. Early autumn snowfall coupled with thick litter accumulations on the soil surface can insulate the soil from cold temperatures that lead to deep freezing; soil frost is thus sporadic and thin. When snow cover is thin, however, soil frost is more pronounced.

Mixed deciduous and coniferous forest typifies this region, with *Tsuga canadensis, Acer saccharum, Tilia americana, Betula lutea,* and *Pinus strobis* trees being the most common species. Entic and Typic Haplorthods are the prevalent soil subgroups (SOIL SURVEY STAFF 1975). Udipsamments and Histosols occupy xeric and hydric sites, respectively.

3 Field and laboratory methods

Six pit/mound pairs in sandy, mixed, frigid Typic and Entic Haplorthod soils were excavated by digging trenches, approximately 0.7 m wide, parallel to the pit-mound axes. Three pedons were described and sampled (at pit center, mound crest, and in an undisturbed, or "control" pedon) in each trench. Laboratory analyses were performed on the air-

	Subgroup classification*	Pit	Mound	Undisturbed
			No. pedons	
Increasing Spodic Horizon Development ↓	Typic Udipsamments	1	4	
	Spodic Udipsamments	3	1	1
	Entic Haplorthods	2		3
	Typic Haplorthods		1	2

* Most pedons are in sandy, mixed, frigid families.
Classification follows the SOIL SURVEY STAFF (1975).

Tab. 1: *Field microtopography and soil genesis.*

dried, <2 mm size fraction. Particle size fractionation was by pipette. Soil pH was measured on 2:1 water:mineral soil mixtures (8:1 for O horizons). Organic carbon analyses were performed by acid digestion (ALLISON 1965), and Fe and Al extractions by sodium citrate-dithionite and sodium pyrophosphate (HOLMGREN 1967, USDA-SCS 1982). Modifications of the former method from that of HOLMGREN (1967) include:

1. use of 1 g Na-dithionite instead of 2 g;
2. use of 10 g Na-citrate instead of 20–25 g; and
3. centrifugation in preference to additions of Superfloc.

Fe and Al contents of the extracts were determined by atomic absorption spectrophotometry.

Contents of soil water were measured in the field, on two pit-mound-undisturbed pedon triplets, at 2–12 cm increments, during a dry period (Site #1) and 24 hours after a moderate rain (Site #2). Soil water was also collected in situ (samplers from Soilmoisture Equipment Corp., Santa Barbara, CA) during the spring snowmelt and summertime periods of 1986 and 1987 from O, A, E, Bs1, Bhs, Bsm, Bs2, and BC horizons of pit, mound, and undisturbed pedons. Field installation is described elsewhere (SCHAETZL & ISARD 1989). Sprinkling of deionized water onto the surface of several pedons was necessary on approximately 25% of the sites, during the 1986 summer sampling period. In all, 193 horizons in 84 pedons were sampled, lessening problems of pedon or site representativeness. Water samples were analyzed for pH, and for Fe and Al contents by atomic absorption spectrophotometry (1986 samples) and ICP spectrophotometry (1987 samples). Finally, general characteristics and spatial continuity of soil frost in the winter and sping of 1985–86 and 1986–87 were noted.

4 Results

4.1 Soil characteristics

Profile development, as indicated by the field observations, morphologic and chemical data (tab.1), and Soil Taxonomy (SOIL SURVEY STAFF 1975) is:

Horizon	Depth (cm)	Color*	pH (H_2O)	Org. Carbon %	Fe C-D	Al C-D	Fe Pyro	Al Pyro	Gravel	Sand**	Silt	Clay
					g kg^{-1}				%			
UNDISTURBED PEDON												
Oe	4–0	—	5.90	nd	—	—	—	—	—	—	—	—
A	0–9	N 2/0	5.67	7.1	3.3	0.5	0.5	0.4	0	69.2	26.5	4.3
E	9–19	5YR 5/2	4.71	0.4	3.3	0.2	0.2	0.2	0.7	86.0	12.8	1.2
Bs1	19–26	5YR 4/4	4.97	0.9	6.2	nd	2.5	3.2	3.7	89.4	9.6	1.0
Bs2	26–33	7.5YR 5/4	5.02	0.4	4.3	1.7	1.2	1.8	0.9	85.5	13.4	1.1
BC	33–54	7.5YR 6/4	4.91	0.4	4.3	1.6	1.4	2.3	0.4	84.7	14.5	0.9
Bs1'	54–74	7.5YR 5/6	5.23	0.4	5.4	2.8	0.8	1.8	0	90.7	9.0	0.3
Bs2'	74–104	7.5YR 4/6	5.49	0.1	1.9	nd	0.4	0.4	0	95.6	3.8	0.6
BC'	104–117	7.5YR 5/4	5.71	0	1.1	0.6	0.3	0.5	0	97.8	1.7	0.5
C	117–186+	7.5YR 6/2	5.70	0.1	0.7	0.4	0.2	0.5	0	97.8	1.7	0.5
PIT PEDON												
Oe	8–0	—	5.79	nd	—	—	—	—	—	—	—	—
A/Oa	0–10	N 2/0	4.83	nd	—	—	—	—	—	—	—	—
E	10–38	5YR 6/2	4.81	0.5	2.7	0.1	0.1	0.1	1.6	92.1	7.2	0.7
Bhs	38–55	2.5YR 3/4	5.16	0.7	4.2	1.7	1.5	1.2	0.1	94.7	5.3	0
Bs1	55–72	5YR 4/6	5.30	0.3	1.9	0.9	0.7	0.7	0	98.1	1.2	0.6
Bs2	72–94	5YR 5/6	5.52	0.2	2.0	0.1	0.3	0.6	0	98.3	1.3	0.4
Bs3	94–122	5YR 5/4	5.85	0.4	0.8	0.5	0.3	0.5	0	98.5	1.0	0.5
BC	122–135+	7.5YR 5/4	5.92	0	1.2	0.4	0.2	0.8	0	98.7	0.8	0.5
MOUND PEDON												
A/Oe	0–2	7.5YR 3/0	5.23	8.4	5.3	1.9	1.8	1.5	0	—	—	—
Bs1	2–46	5YR 4/6	5.00	0.5	6.3	2.5	1.6	1.9	0.1	90.2	5.6	4.3
Bs2	46–59	5YR 5/3	5.02	0.3	5.2	1.7	1.8	1.9	0.7	89.2	10.0	0.8
Bs3	59–88	5YR 4/6	5.15	0.3	4.0	nd	0.8	1.4	0.1	nd	nd	nd
BC	88–114	7.5YR 5/4	5.78	0.1	1.6	nd	0.4	0.8	0	98.0	1.5	0.6
C	114–151+	7.5YR 6/4	6.06	0	0.8	0.5	0.2	0.5	0	98.6	1.3	0.1

* Colors are for moist soil
** Typically, 75–90% of the sands are in the medium and fine size classes
nd = not determined

Tab. 2: *Selected physical and chemical soil properties of a pit, mound, and an undisturbed soil.*

Undisturbed ≥ Pit > Mound (see also SCHAETZL 1987).

Most pit soils were classified either as Entic Haplorthods or Spodic Udipsamments (tab.1). These soils were more deeply leached than mound soils, as evidenced by thicker E horizons that also had lower mean contents of Fe, Al, and organic carbon, and were generally higher in chroma (tabs.2 and 3). These pedons commonly exhibit deep (15–70+ cm) tongues of E horizon below overthickened O and A horizons (fig.1). Undisturbed sites show tongueing less frequently, and the tongues are usually much smaller. Bhs horizons, commonly observed below E horizon tongues, are commonly absent in many (adjacent) undisturbed soils. Undisturbed pedons were strong to intermediate with regard to most properties; most were in the Spodosol order.

Parameter	Units	Pit	Mound	Undisturbed
O Thickness	cm	12.9	3.6	3.4
E Thickness	cm	32.3	2.4	15.0
Depth to top of B*	cm	55.8	8.6	18.5
E Pyrophosphate Fe+Al	g kg^{-1}	0.2	0.6	0.5
E Organic Carbon	%	0.6	0.8	0.5
E Munsell color**		5YR 5/2	5YR 5/3	5YR 5/2
B Pyrophosphate Fe+Al	g kg^{-1}	2.8	3.0	5.6

* Depth from the soil surface to the top of the first pedogenic B horizon
** The most commonly observed Munsell color for the E horizon

Tab. 3: *Comparative soils data (mean values) from six trench sites.*

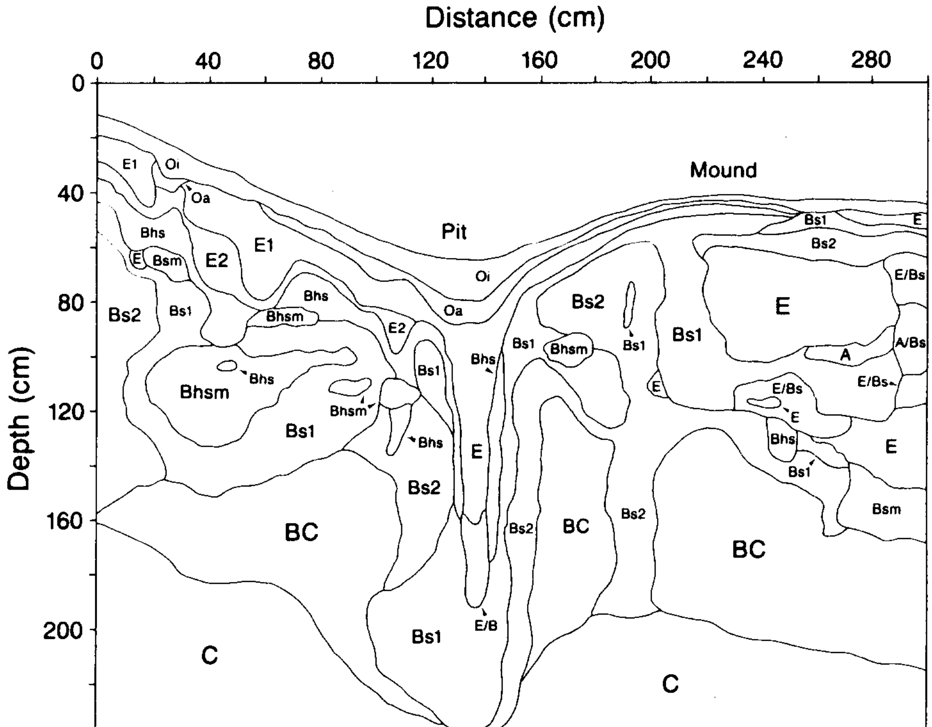

Fig. 1: *Cross section through a pit/mound pair, illustrating deep tongueing of the E horizon in the pit. Soil horizon clasts are mixed in the center of mound, and do not reflect post-uprooting pedogenesis..*

Mound soils ordinarily were Entisols, and unless they have low relief (generally implying greater age), have thin E and B horizons. Higher amounts of Fe and Al in B horizons of mounds than of pits (tab.2, 3) were inherited from the pre-uprooting soil and do not reflect contemporary pedogenesis.

4.2 Snow cover and soil frost

Snow cover, at near record depths for much of the winter of 1985–86, especially in November-December, was thinnest on mounds and thickest above pits. Layers (2–10 cm thickness) of impermeable, concrete frost (POST & DREIBELBIS 1942) were observed in the mineral soil of large mounds, usually where the snow depth was less than 30 cm. Pit and undisturbed soils were unfrozen in 1986.

During the snowmelt period, mounds became snow-free first, pits last. Concrete frost in mounds was retained for at least one week after the overlying snow cover had melted. Snowmelt waters thawed only a thin, surficial layer of soil in these mounds. Soils at pit and undisturbed sites were unfrozen and permeable during snowmelt in 1986.

The winter of 1986–87 had near record minimum amounts of snowfall. Frozen mineral soil horizons were common beneath thin snowpacks. By March, 1987, concrete frost had penetrated to >20 cm within mounds. O, A and upper E horizons of undisturbed soils had frozen, but only the E horizons contained concrete frost. Porous granular frost (POST & DREIBELBIS 1942) had formed in O and A horizons of undisturbed and pit soils; concrete frost was not observed.

4.3 Soil water content

Pit soils were wetter than mound or undisturbed soils during the warm season, near the surface (fig.2). Mound and undisturbed pedons were drier near the surface and showed little change in water content below about 25 cm. Within lower soil, water conditions were Pit = Undisturbed = Mound.

4.4 Soil solution analyses

Aluminum concentrations in soil water samples were generally 2–6 times greater than those of iron (figs.3, 4). Maximum concentrations of Fe and Al, as sampled during summers, occurred in O/A horizons (pits), in E horizons (undisturbed), and in upper B horizons (mounds). Maximum concentrations observed during snowmelt were in the upper B horizon for undisturbed and pit soils, and in the E horizons of mounds.

A nearly steady increase in pH with depth was observed for soil solutions of mound and undisturbed soils, collected during the summer period (fig.5); pit soil solutions were the most acidic. pH's of soil solutions collected during snowmelt were less predictable, but pit soils were commonly the most acidic at this time as well.

5 Discussion

SCHAETZL & FOLLMER (n.d.) provided evidence that most mounds in this area are less than 2500 radiocarbon years old. This finding, in conjunction other data (tabs.2, 3), implies that soils in pits have attained equal (sometimes greater) profile development than undisturbed pedons in a geologically short period of time, and that pedogenic pro-

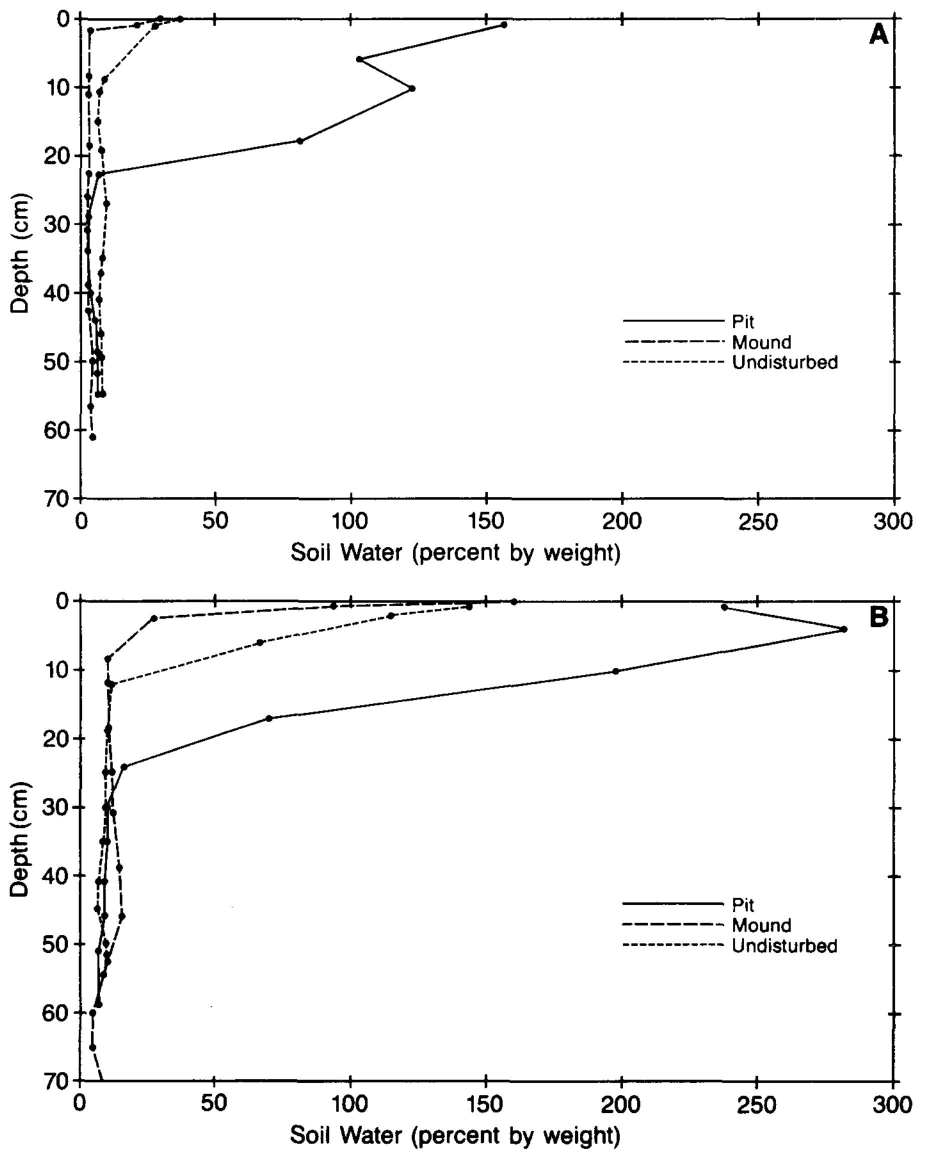

Fig. 2: *Upper: Soil water contents, determined gravimetrically, on a pit, mound, and undisturbed pedon during a dry period. Lower: Similar soil water contents, determined on a nearby mound/pit pair, 12 hours after a 27 mm rainfall event.*

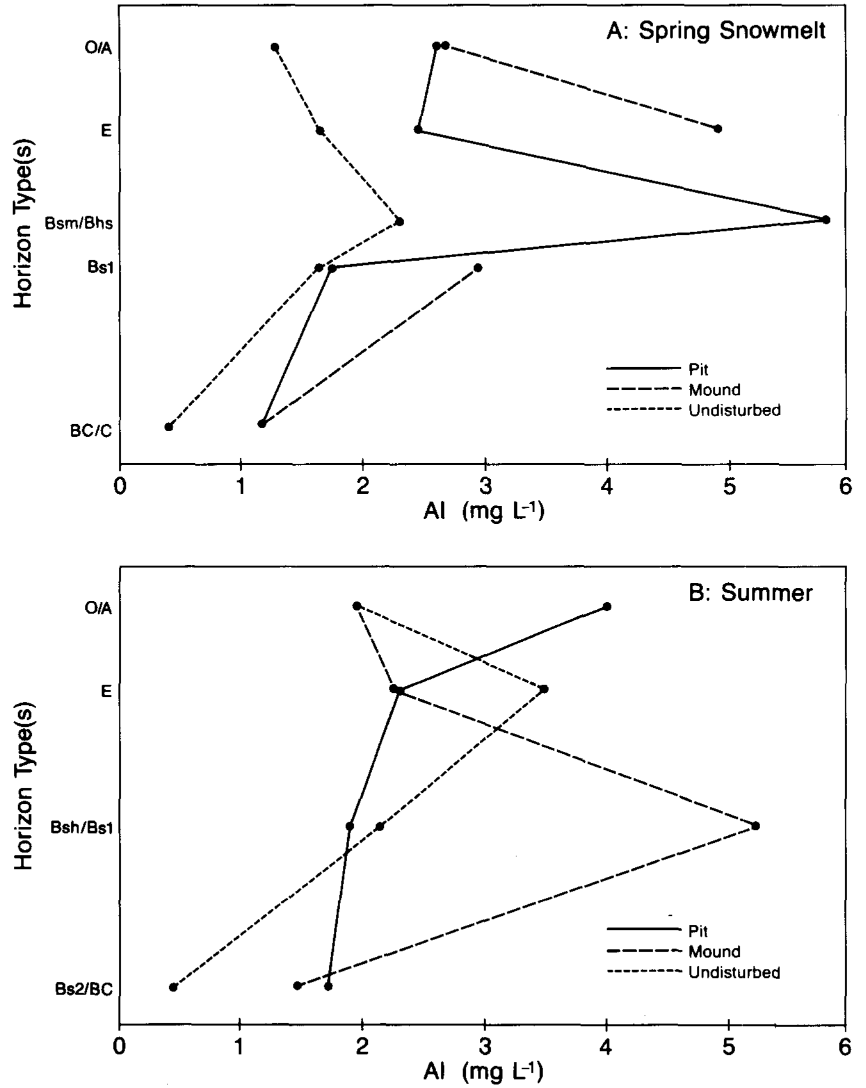

Fig. 3: *Aluminum contents of soil solutions (mean values) for pit, mound and undisturbed pedons. A. Spring snowmelt. B. Summer values.*

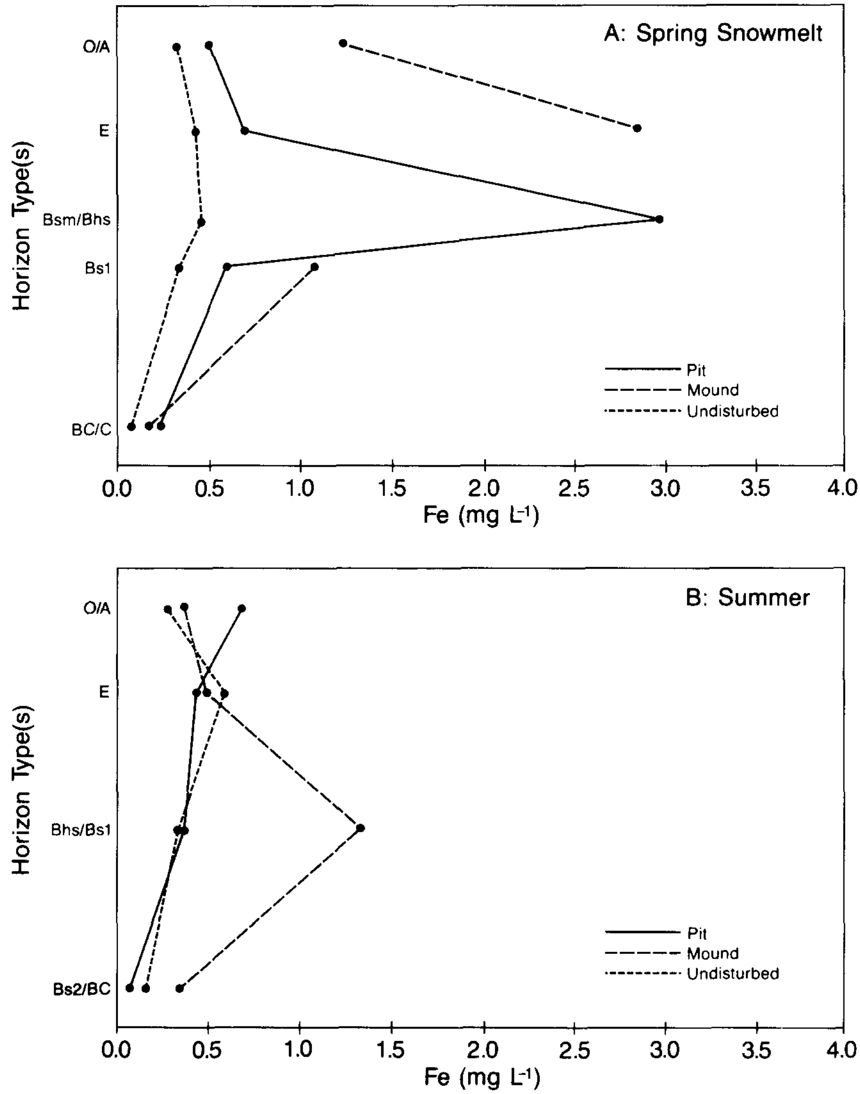

Fig. 4: *Iron contents of soil solutions (mean values) for pit, mound and undisturbed pedons. A. Spring snowmelt. B. Summer values.*

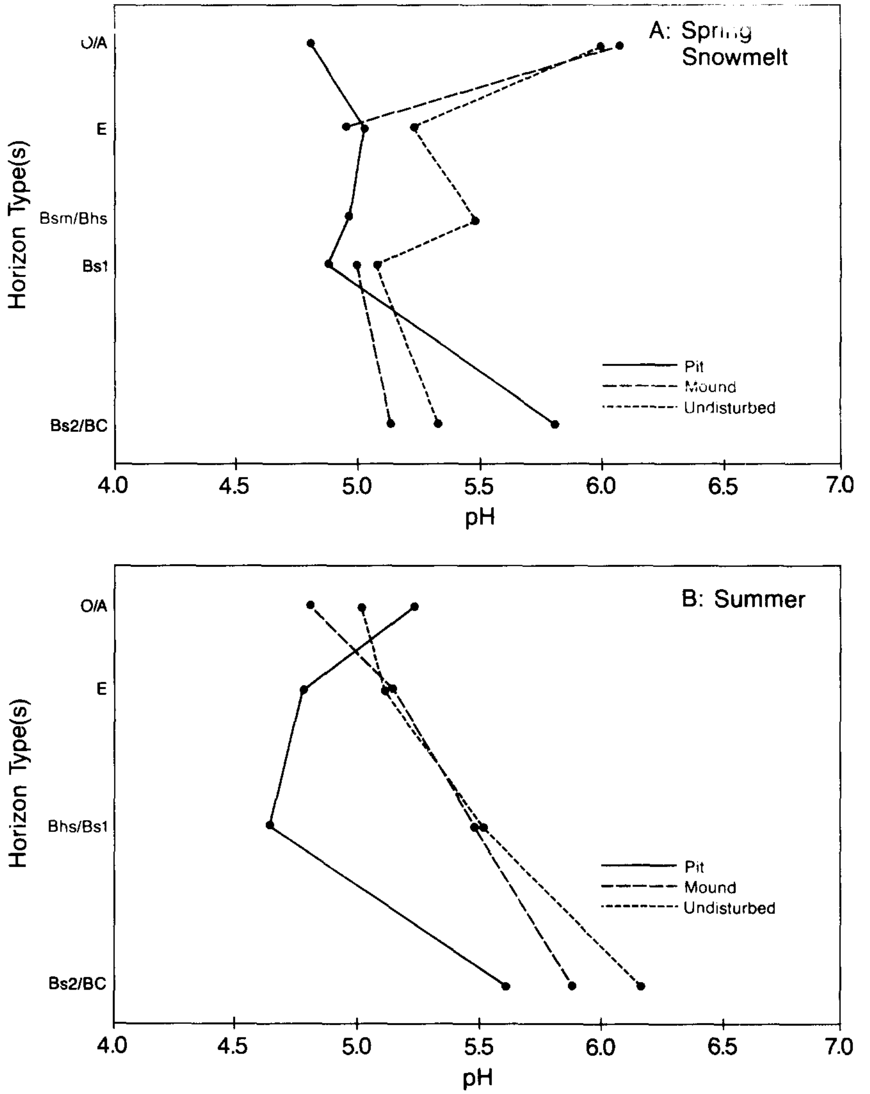

Fig. 5: *pH's of soil solutions (mean values) for pit, mound and undisturbed pedons. A. Spring snowmelt values. B. Summer values.*

cesses in pits may be operating at faster rates than on undisturbed sites. Thus, rates of pedogenesis appear to be: Pit > Undisturbed > Mound.

5.1 Pedogenesis during the warm season

Soils in this region have low water contents at many periods throughout the warm season, primarily because of the low water-holding capacities of the sandy soils, large amounts of water uptake by the forest, and the high capacity of the forest canopy and mor-like forest floor to intercept significant amounts of precipitation (ANDERSON et al. 1969, DWYER & MERRIAM 1981, SCHAETZL & ISARD 1989). Whereas deep horizons attain low water contents during dry climatic periods at all microtopographic sites (fig.2), water contents of O and A horizons during the warm season are: Pit > Undisturbed > Mound, due to high organic matter content that aids in water retention (see also BEATTY 1984, and BEATTY & STONE 1986). This relationship, observed by DWYER & MERRIAM (1981) as: Pit ≫ Level > Mound, is reflected by the density of fine roots within the upper sola (data not presented here). Mound soils have relatively few roots, whereas the root mat within the upper sola of pits is often very dense. Soil water is retained for longer periods of time in O and organic-rich A horizons (DWYER & MERRIAM 1981). Because O horizons are thickest in pits (tab.2) large amounts of water are retained there.

Between periods of deep wetting, summer soil solutions flow slowly due to low unsaturated hydraulic conductivities within sands (HILLEL 1982). Soil solutions thus remain in contact with the matrix for long periods of time. Long contact times have led, in most instances, to great similarity between soil solution and solid phase pH for the warm season (tab.2, fig.5), as the solid-solvent system approaches chemical equilibrium (TRUDGILL et al. 1983).

Retention of water in the mor-like litter of overthickened O horizons promotes decay of organic materials within, thereby releasing abundant acids. High concentrations of such acids could explain summer pH values below 5.5 in soil solutions from the upper sola of pits (MANLEY et al. 1987, Fig.5B). The acids are probably translocated into lower horizons only during major "flushing events" (snowmelt and large summer storms) (UGOLINI et al. 1982, STONER 1984). Thick O horizons in pits are thus viewed as organic acid "repositories".

O horizons in pits have a greater capacity to produce organic acids than do mound or undisturbed O horizons, because the former horizons are thicker and do not achieve similar levels of dryness. Pit and undisturbed pedons are highly anisotropic with regard to organic carbon, having abundant organic compounds in both A and B horizons, coupled with well-defined eluvial zones (tab.2). Organic carbon amounts within mound soils, however, are typically very low, and B horizons with illuvial OC are not observed (tab.2). These findings are suggestive of slower organic acid production and translocation within mound soils than in pits or on undisturbed sites.

The above findings agree with those of several other studies. DWYER & MERRIAM (1981) and SHUBAYEVA & KARPACHEVSKIY (1983) found that comparative rates of litter decomposition and humus formation were: Pit > Undisturbed > Mound, and attributed these differences to inequalities in soil water and temperature, since soil water is a major factor in the decomposition process (DE BOOIS 1974). Both VENEMAN et al. (1984) and IVES et al. (1972) concluded that increased pedogenesis in pits is primarily due to increased volume and acidity of leaches. The abundance of organic acids was ascribed to decomposition of thick litter layers. VENEMAN et al. (1984) thought that the increases in volume of leachate in pits were due to lateral flow within O horizons, whereas IVES et al. (1972) ascribed it to overland flow. Overland flow was not observed in the Baraga County study area, however, even during torrential rainstorms. Lack of runoff may be due to highly permeable sandy soils and porous litter mats.

Infiltration results in translocation of organo-metallic complexes and, ultimately, profile differentiation. Ion concentrations in soil solutions, being a function of additions (via weathering) minus losses (via translocation), is a means of estimating leaching intensity. High Fe and Al concentrations in the upper sola of pit and undisturbed soils were observed in summer (figs.3B 4B), suggesting that cations in solution may not be eluviating from these horizons, or that weathering rates and release of ions into solution exceed eluviation.

A possible explanation for the lack of eluviation is an inadequate number of deep percolation events, as much of the rainfall incident on the forest is intercepted by the coniferous canopy and retained in thick litter layers (WALSH & VOIGT 1977, DWYER & MERRIAM 1981, SCHAETZL & ISARD 1989). Whereas infrequent, heavy precipitation events may saturate the entire profile, many small to moderate precipitation events probably generate wetting fronts that only penetrate the forest floor or upper solum (ANDERSON et al. 1969). Successive (back-to-back) pulses of water through the soil are most effective at leaching organo-metallic compounds (STONER 1984); these seldom occur during summer because large rainfall events are isolated, both spatially and temporally (SCHAETZL & ISARD 1989). A second explanation for high Fe and Al concentrations in soil solutions of eluvial horizons may involve release of cations by weathering, accompanied by a lack of sufficient organic acids to complex the ions and render them mobile.

Fe and Al contents of **mound** soil solutions for summer show a peak in the B horizon, with low concentrations in eluvial horizons (figs.3B, 4B), indicating that eluviation is keeping pace with release of ions into the soil solution via weathering. The paucity of litter cover, the thinness of eluvial horizons, and comparative scarcity of roots within mounds probably allows more wetting fronts to penetrate the B horizons than in undisturbed and pit soils. In the latter, the depth to illuvial horizons is greater (tab.3); wetting fronts must first penetrate a thick litter layer containing may roots and an eluvial mineral horizon. Thus, more wetting fronts in undisturbed and pit soils probably terminate above or within eluvial layers, rendering them ineffective at translocation of organo-metallic complexes into the B horizon. Because mound soils are often dry and have relatively high pH's, comparatively slow weathering rates are also likely.

5.2 Pedogenesis during snowmelt

Soil frost has a pronounced effect on saturated flow, and hence pedogenesis, during spring snowmelt (BENOIT & BORNSTEIN 1970, PRICE & HENDRIE 1983). Observations indicate that the probability of a pedon freezing is: Mound > Undisturbed > Pit, because the two insulating agents, litter and snow cover (KIENHOLZ 1940, ANDERSON 1947), are cumulatively thickest above pits and thinnest on mounds (BEATTY 1984). Even if frozen, pit and undisturbed soils develop porous, granular frost layers, probably because of the inherent, low-density, soil structure. TRIMBLE et al. (1958) found that soil with granular frost was actually more permeable than unfrozen soil.

During most winters, mound soils commonly develop layers (0–30 cm) of concrete frost. The formation of **concrete** frost in sandy, otherwise porous soils is not uncommon (HELMREICH & CLARK 1962); surficial freezing initiates upward movement of substantial amounts of water via vapor flux, thereby adding volume to the frozen crust, filling in pore spaces, and "freeze-drying" the soil below (GARSTKA 1944, ANDERSON 1947). Meltwater cannot infiltrate through the impermeable, concretely-frozen surface. Snowmelt waters flow across the top of the frozen soil, however, and can subsequently thaw the uppermost few cm (HELMREICH & CLARK 1962). In most instances, concretely-frozen soil remains as an aquiclude below the thawed surface layer, and little or no vertical infiltration into the center of frozen mounds occurs.

In addition, many mounds become snow-free shortly after the snowmelt period begins, while pits still retain 10–40 cm of snow (BEATTY 1984). Thus, when mound soils become frost-free during latter phases of snowmelt, infiltration cannot occur due to lack of a water source. Pit and undisturbed soils therefore are leached by meltwater throughout the snowmelt period, whereas mounds may receive little or no water input. Even if pit soils did freeze, and the soils became impermeable, this situation would perch water above pit, which could then infiltrate into the pit soil at the onset of melting.

In winters with deep snow, frozen soil is rare and if present is only found as thin, discontinuous layers in mounds. In such years, infiltration potential into soils during snowmelt would be: Pit > Undisturbed > Mound, not because inhibition of infiltration by frost, but due to differential snow depths above the microtopographic sites.

Repeated freezing of upper horizons in mound soils (BEATTY & STONE 1986) may also act to destroy incipient E horizons and thus retard soil formation (GOODLETT 1954). These processes would be insignificant in pits, as the mineral soil rarely freezes to the depth of the E horizon.

Experimental evidence suggests that slow percolation (DAVIES 1971) and progressive leaching episodes (STONER 1984) are more effective at translocation of mobile complexes from eluvial zones than are similar amounts of infiltration that occur at widely disparate intervals. The former condition is attained during the snowmelt period (SCHAETZL & ISARD 1989). Low concentrations of Fe and Al in eluvial horizons of pit and undisturbed soils, coupled with high concentrations in upper B horizons (figs.3A, 4A) suggest that these soils are experiencing free leaching and translocation of organo-metallic complexes into the B horizon. The eluvial/illuvial relationship is best expressed in pit soils (figs.3A, 4A). Low pH values in the upper sola of pit soils (fig.5A), suggest that pit sites are also regions of strong organic acid production during snowmelt.

The data above indicate that the translocation of organo-metallic complexes from upper horizons (i.e., podzolization) may be more pronounced during snowmelt than the warm season. BRUCKERT (1970) found that at 0°C, where biological degradation is slow, transport of organo-metallic complexes involving small organic acids was more effective than at warmer temperatures.

Back-to-back pulses of meltwater could effectively leach organo-metallic complexes from E horizons into B horizons of pit and undisturbed soils. I suggest that this temporal and spatial disparity is the main difference among the genesis of pit, mound, and undisturbed soils. Except during the very deep wetting episodes, translocation of organo-metallic complexes in summer is inhibited by low concentrations of organic acids and high pH's. High concentrations of Fe and Al in mound E horizons support the contention that these horizons are minimally leached during snowmelt (figs.3A 4A).

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