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Longevity of treethrow microtopography: implications for mass wasting

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ABSTRACT

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This study examines and compares methods of dating pit/mound microtopography formed by tree uprooting, and provides ^{14}C evidence for the longevity of these landforms. Microtopography can often by dated by reference to known meteorological phenomena, or within certain age constraints, by dendrochronologic means. We used ^{14}C analysis of buried wood and charcoal in treethrow mounds in Michigan and Wisconsin, U.S.A. to arrive at estimates of the geochronometric ages of treethrow mounds. Results indicate that mounds in these areas often persist for more than 1000 years, which are two to five times longer than published estimates by less reliable methods. The longevity of treethrow mounds in these regions is ascribed to (1) sandy, porous soils which minimize runoff, (2) a continuous mat of forest litter and vegetation cover, (3) surface concentrations of gravel which may act as an "armor", (4) large initial size of the features, and (5) soil freezing. Implications are that rates of mass movement due to uprooting may be substantially less than studies from other regions suggest.

Introduction

Floralturbation is the mixing of soil by the action of plants (Johnson et al., 1987; Schaetzl et al., 1989a, 1990). Uprooting is the most obvious type of floralturbation in forested areas. The roots of an uprooted tree tear up masses of soil (Fig. 1) which later often deteriorate into a microtopography of pits and mounds (Lutz and Griswold, 1939; Cline and Spurr, 1942; Stephens, 1956; Rozmakhov et al., 1963; Brewer and Merritt, 1978; Coutts, 1983). Pit/mound microtopography in most forests ranges from strikingly visual examples (Fig. 2) to those far more subtle. The scale and geomorphic importance of uprooting is made evident by the fact that forests cover one third of the earth's land surface (Leith, 1975). Pit/mound microtopography also has a pronounced impact upon soil development (Veneman et al., 1984; Beatty and Stone, 1986; Schaetzl, 1989) and vegetation patterns (Beatty, 1984; Schaetzl et al., 1989b).

Although the formative processes of pit/mound microtopography have been examined (Lutz, 1940; Schaetzl, 1986), the rates of degradation of these landforms are unclear. Except for cases of extremely rapid erosion of pit/mound microtopography in tropical regions (Putz, 1983), the maximal ages of these features have only been crudely estimated. This research establishes the ages of several pit/mound landforms in two geographically separate areas in the Great Lakes region, U.S.A., by *radiometric means*, and examines the importance of uprooting on rates of mass wasting.

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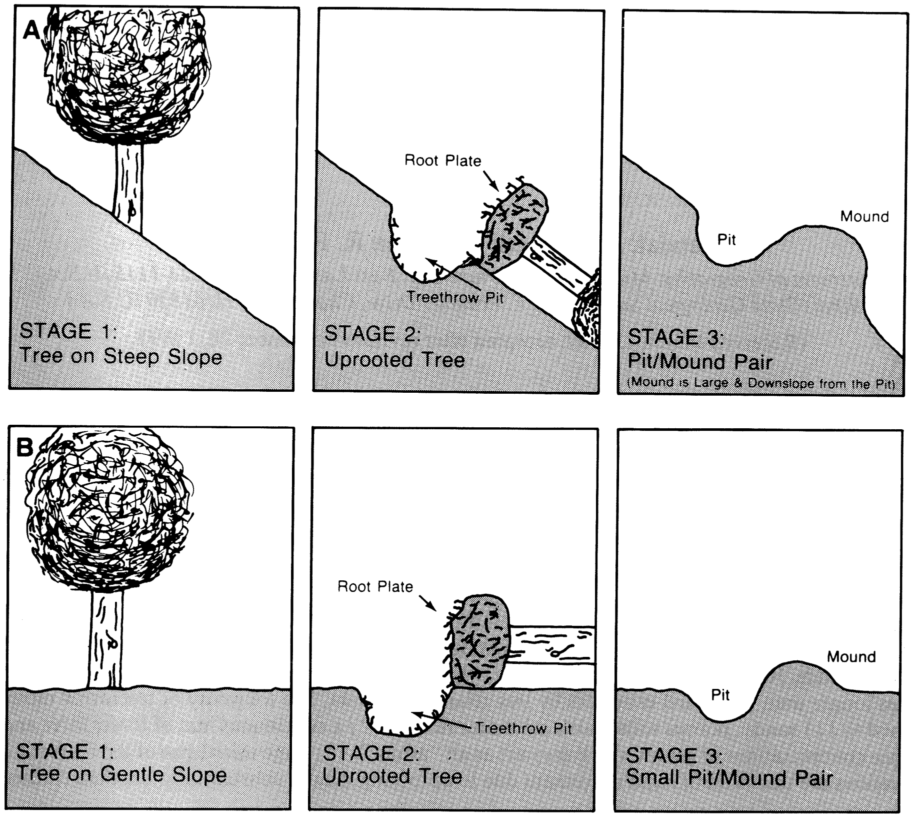

Fig. 1. The uprooting process, demonstrating the formation of a pit/mound pair by soil slump off the root plate, and the resulting mixed horizons within the mound.

Fig. 2. Pit/mound pair in the study area. The shovel is 95 cm long.

Background

Treethrow pits are usually filled in faster than mounds are eroded (Goodlett, 1954), due to washing in of sediment from the root plate (and later, the mound) and from surrounding undisturbed pedons (Putz, 1983). Where root plates are thin, as in the uprooting of shallowly rooted trees, the end result is a very shallow, broad pit and a linear-shaped mound (Beatty and Stone, 1986). These types of pits are easily obscured by surficial processes and may be overlooked by researchers, perhaps explaining why reported densities are routinely higher for mounds than for pits (Lyford and MacLean, 1966; Beatty and Stone, 1986). In the present article we will concentrate our efforts on the longevities of *mounds*.

To estimate the age of a treethrow mound, one must determine the date of the uprooting event. The latter determinations are usually based upon one or more lines of evidence: (1) connections between uprooting events and specific meteorologic events, (2) historical accounts, (3) principles of dendrochronology, forest ecology and succession, (4) mound morphology, (5) development of mound and pit soils, and (6) radiometric dating of organic materials within or beneath the mound.

Tornado, hurricane, or even volcanic events have been used to date assemblages of mounds. Generally, this method is used when pit/mound pairs of uniform size and orientation dominate a landscape, with the assumption that the majority of the mounds were formed synchronously (Schaetzl et al., 1989b). As an example, evidence of large hurricanes that uprooted millions of hectares of trees in New England in 1635, 1815, and 1938 is still widespread (Spurr, 1956).

U.S. Federal Land Survey records, early geology surveys (Irving, 1880; Van Hise, 1904), and journals of explorers (Goodlett, 1954) provide historical records of large-scale uprooting sites. Maps provided by early surveyors have been used to locate extensive tracts of treethrow (Stearns, 1949; Lindsey, 1972).

Reconstruction methods employing principles of forest ecology and dendrochronology are often used to date treethrow events. Large-scale treefalls, especially when followed by fire, often result in relatively even-aged successional forests (Cline and Spurr, 1942; Jones, 1945; Oliver and Stephens, 1977; Shubayeva and Karpachevskiy, 1983). Dendrochronological ages of the oldest trees in these stands can provide a minimum age for the uprooting event. Obviously, this method has limitations: (1) the time elapsed since uprooting may be longer than the age of the oldest trees in the region; (2) standing, remnant trees may be accidentally dated and their ages taken as a surrogate for time since the major uprooting event.

Uprootings of individual trees can be dated by several methods. A single treefall creates an opening in the forest canopy, which may be quickly filled by pioneer seedlings (Foster and Reiners, 1986; Schaetzl et al., 1989b). Dendrochronological dating of these trees can be used to date the uprooting event (Goodlett, 1954). Increased light on the forest floor may also stimulate increased growth ("release"; see Henry and Swan, 1974) in suppressed understory saplings and surrounding trees (Thompson, 1980). Because many plants utilize fallen, rotting tree trunks as seedbeds (Bormann et al., 1970; McFee and Stone, 1966; Handel, 1978), dendrochronologic dating of trees that germinate on the fallen, decaying trunk of a tree can provide yet another minimum age estimate for an uprooting event. Zeide (1981) determined the ages of treethrow mounds by dating *Betula lutea* trees that had germinated on the mineral soil of the newly formed mound. Foster and Reiners (1986, p. 111) discussed other ecologic means by which uprooting can be dated.

The above methods have timespan limitations; accurate estimation of mound ages beyond 200 to 300 years must generally be accomplished by other means. Relative age estimation of these older mounds is often based on examination of soil horizonation or mound

TABLE 1

Published estimates of pit/mound ages

Location	Age range	Line(s) of evidence	Reference
Massachusetts	14– 500+	Meteorologic[a]; dendro[b]	Stephens (1956)
Massachusetts	18– 456+	Meteorologic; dendro	Oliver and Stephens (1977)
Massachusetts	<500	Meteorologic; dendro	Veneman et al. (1984)
Pennsylvania	60– 300	Dendro; mound morphology[c]	Denny and Goodlett (1956)
Pennsylvania	200– 300	Soil and mound morphology; dendro	Goodlett (1954)
New Hampshire	80– 300	Dendro	Lutz (1940)
Michigan	150–2420	Dendro; radiocarbon[d]	Present study
New York	250– 350	Buried wood[e]; soil chemistry[f]	Stone (1975), Beatty and Stone (1986)
New York	200– 500	Soil morphology; mound morphology[g]	Denny and Goodlett (1968)
Oregon	150	Dendro; buried wood[h]	Swanson et al. (1982)
New Brunswick	250–1000	Soil morphology[i]	Lyford and MacLean (1966)
New Zealand	300– 400	Mound morphology	Burns (1981)
Panama	5– 10	Process measurement[j]	Putz (1983)
Siberia	60– 400+	Buried wood[k]; forest ecology[l]	Shubayeva and Karpachevskiy (1983)

[a] Based on historical evidence and dates of major tornadoes and/or hurricanes that passed through the region. Generally, this evidence is used when numerous mound/pit pairs are present which appear to have similar orientation and age.

[b] Dendrochronological counts from trees growing either on the treethrow mounds or on the downed and decaying tree trunk, both of which provide a minimum age for the mound.

[c] Based on morphology of mounds and pits (e.g., size and slope), and relating to estimated rates of downwastage.

[d] Based on radiocarbon dating of charcoal buried within the mound core.

[e] Based on the absence of decaying wood fragments in mounds, and the presence of only charcoal. This follows the study of McFee and Stone (1966), who examined the longevity of wood fragments in soils.

[f] Based on the presence of bits of "calcined soil" in mounds, and the gradational characteristics of other soil properties with depth, suggestive of several centuries of post-uprooting soil development.

[g] Evidence not explicitly stated, but presumed to be based on soil and mound morphology.

[h] Based on the stage of decay of residual organic matter and wood in the mounds (the specific location of the organic materials is not stated).

[i] Based on relation between internal horizonation and known rates of pedogenesis.

[j] Based on rates of pit infilling, measured on stakes driven into the bottom of newly formed pits. Monitoring spanned 12 months, in 32 pits.

[k] Based on the decayed condition of resinous wood buried within the mound, after the method of Skvortsova (1979).

[l] Based on the forest ecology of *Pinus sibirica*. The species exists in coeval populations, where a mature and dying cohort will uproot nearly en masse. The mounds are dated by knowing the age of the succeeding trees. This method has the inaccuracy of (1) not providing for multiple generations after the treethrow events, and (2) assuming that most of the mounds are from one cohort.

morphology. Accurate knowledge of soil development rates is required in the former method. Because of the dramatic effects of microtopography on soil genesis (Veneman et al., 1984; Schaetzl, 1989), and fragmentary knowledge about rates of mound erosion, stability, and longevity, neither method is very accurate.

Table 1 lists reported estimates of mound ages. It is noteworthy that the shortest "lifespan" of pit/mound microtopography actually measured is 5–10 years (Putz, 1983), and the oldest age estimate is 1000 years (Lyford and MacLean, 1966). Most mound ages are estimated to be ≤500 years. We used radiometric methods to date wood and charcoal buried within mounds. Although mounds with buried organic materials have been previously documented (Goodlett, 1954; Denny and Goodlett, 1956, 1968; Stephens, 1956; Troedsson and Lyford, 1973; Stone, 1975; Shubayeva and Karpachevskiy, 1983; Beke and McKeague, 1984; Veneman et al., 1984), this study may be the first to present ^{14}C dates on such materials.

Study area and methods

One of two study areas is in Baraga County, northern Michigan, U.S.A. Here, treethrow mounds are common, especially on steep slopes ($>35\%$). The largest (by volume) mounds, and those with the greatest pit-to-mound vertical relief (up to 75 cm), are on steep slopes. On nearly level uplands, mounds are uncommon and pit/mound relief is seldom greater than 25 cm. Most mounds are covered by thin layers of raw and partially decomposed forest litter, in places reaching 10 cm in thickness.

Soils in the region are Haplorthods (Podzols), composed typically of 93–99% sand, 1–4% silt and 0–2% clay, with medium and fine sands dominating. The parent material is glacial outwash draping tills of Wisconsin age (approximately 11,000 to 10,100 B.P.; Saarnisto, 1974). The study area is located in a stand of *Tilia canadensis, Pinus strobus*, and *Betula allegheniensis* that has been minimally disturbed by selective cutting of some of the *Pinus* spp.

A second study area is in Kettle Moraine State Park, Fon Du Lac County, southeastern Wisconsin, U.S.A. Soils here are gravelly sands and loamy sands; on steep slopes they are even more gravelly. Vegetation consists of second-growth deciduous forest (*Quercus–Acer*). This site was chosen because it had numerous mounds in gravelly outwash, and because its inclusion allowed for a more geographically diverse data set.

Field investigation revealed layers (1–20 cm thick) of competent angular fragments of charcoal and wood, up to 20 mm in size, within treethrow mounds on steep slopes ($>30\%$) in both study areas. These layers usually overlie the former (now buried) soil surface (Fig. 3). The pedostratigraphic position of this layer suggests that it was formed as soil slumped off the root plate (Schaetzl, 1986). The wood and charcoal from within five treethrow mounds in Michigan and one in Wisconsin was dated by the ^{14}C method.

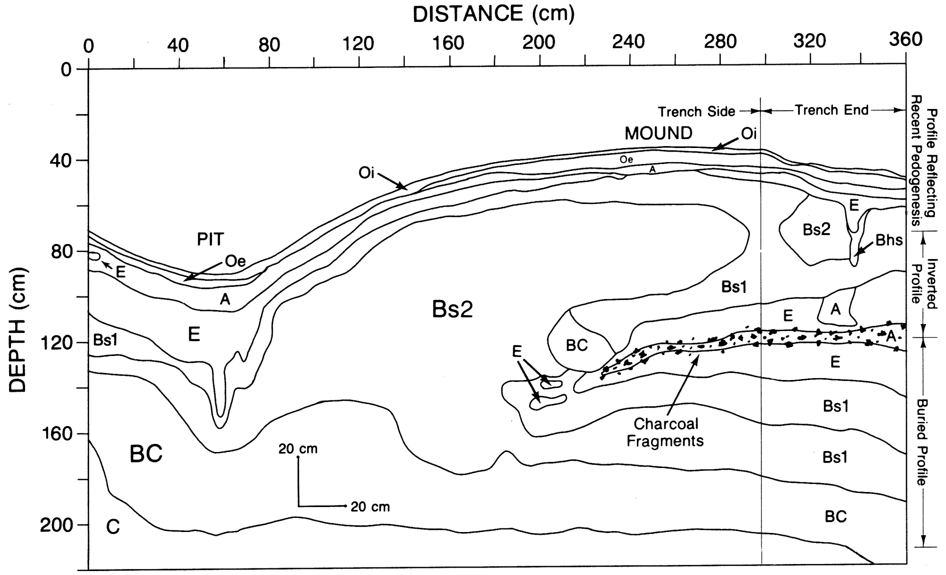

Fig. 3. Cross-section through a pit/mound pair (mound #2), which exhibits profile overturning, or inversion. The location of wood and charcoal fragments, dated by the ^{14}C method, is noted. (Modified from Schaetzl, 1987.)

TABLE 2

^{14}C ages of wood and charcoal in treethrow mounds

Mound no.[a]	Age (RCYBP)	ISGS No.[b]	Slope[c] (%)	Relief[d] (cm)
1	960± 80	1525	40	27
2	2010± 70	1462	35	54
3 (surface, 0 cm)	380± 70	1761	58	26
3 (at depth, 25 cm)	300± 70	1503	58	26
3 (at depth, 35 cm)	360± 70	1760	58	26
4	530± 70	1524	34	45
5	2420± 70	1782	25	26
6	590±100	1781	30	25

[a] Mound #6 is located in southeastern Wisconsin; all others are in northern Michigan.
[b] Illinois State Geological Survey radiocarbon lab sample number.
[c] Local slope at the site of the pit/mound pair.
[d] Vertical distance between mound crest and pit center.

Results

The ^{14}C ages of some dated mounds within the two study areas (Table 2) exceeded other reported estimates for mound age or longevity (Table 1). Indeed, one such landform has retained its integrity for 2420 years, despite being formed from sandy, noncoherent materials.

Radiocarbon dating of charcoal from the mound surface (mound #3, 0 cm) and within the core (mound #3, at depth) indicated little or no contamination due to proximity to the atmosphere (Table 2). The similarity in age among the surficial and buried samples implies that the micro-environment of deposition does not affect the ^{14}C age of carbonaceous material.

Theoretical considerations in mound longevity

Because the ^{14}C dates (Table 2) represent the number of radiocarbon years since the wood was living meristematic tissue, outer tree rings will date younger than inner rings. If the buried wood used to derive the ^{14}C date came from the outer rings, the date will closely approximate the uprooting event. Charcoal or wood from the core of the tree, however, will erroneously date older than the uprooting event. Given that the oldest trees in the region are 200+ years old, the dates in Table 2 should be viewed as maximal dates. The elapsed time between uprooting and mound formation (the time necessary for soil to slump off the root plate) must also be considered in estimates of mound longevity. Based on observations in Michigan and Wisconsin, we estimate this timespan to be 5–10 years. The ages in Table 2 may therefore be older than the mounds by possibly 5–10 years, because they date the death of the tree (the uprooting event) and not mound inception per se. Nonetheless, this last error type contributes significantly less than do, for example, error estimates on the radiocarbon dates.

Explanation of mean and maximum mound ages involves processes or origination and erosion. Theoretically, the density (D) of pit/mound pairs can be viewed as the result of two opposing processes: uprooting (origination, U), and downwasting (erosion, E), operating through time (t). Then,

$$D=f(\mathrm{d}U/\mathrm{d}t,\ \mathrm{d}E/\mathrm{d}T)$$

where $\mathrm{d}U/\mathrm{d}t$ is the rate of mound formation, and $\mathrm{d}E/\mathrm{d}t$ is the rate of downwasting. A dynamic steady state is described for the system when $DU/\mathrm{d}t=DE/\mathrm{d}t$ (Putz, 1983). When $\mathrm{d}U/\mathrm{d}t>\mathrm{d}E/\mathrm{d}t$, mound density will increase if most uprooting takes place on previously undisturbed sites, but if most trees are growing on already existing mounds (as in poorly drained soils), additional uprooting will not necessarily lead to increased mound densities. In the latter situation, uprooting may act only to form more complex microtopography and internal mound horizonation when existing mounds are again pedoturbated by uprooting. If mound erosion rates exceed those of uprooting ($\mathrm{d}U/\mathrm{d}t<\mathrm{d}E/\mathrm{d}t$), microtopographic irregularities will become diminished.

The rate of uprooting ($\mathrm{d}U/\mathrm{d}t$) is dependent upon several factors. In general, physical or chemical soil impediments that inhibit deep rooting (fragipans, shallow bedrock, a high water table) make trees more susceptible to uprooting (Lutz, 1940, 1960; Cline and Spurr, 1942; Mueller and Cline, 1959; Rozmakhov et al., 1963). Trees on wet or organic soils are shallowly rooted, and thus more likely to be uprooted than those on better drained soils (Mueller and Cline, 1959; Karpachevskiy et al., 1968). Nielsen (1963) listed twelve factors that influence the density and size of treethrow mounds in an area; examples are solum depth, root architecture, slope, vegetational history, and soil texture (see also Coutts, 1983 and Schaetzl et al., 1989a).

Mound lowering and erosion (dE) processes primarily include erosion by wind and water, frost heave, soil settling, creep, burrowing of animals, and decomposition of organic material (Zeide, 1981; Beatty and Stone, 1986). Denny and Goodlett (1968) concluded that erosion rates were a function of exposure, slope, and nature of the material. Zeide (1981) suggested that rates of mound erosion were largely a function of mound height; Rozmakhov et al. (1963) stressed soil wetness. In the tropics, Putz (1983) found that rapid rates of mound erosion were due to torrential rains on bare soil. We suggest that the rate of downwasting of root plates and mounds is a function of:

(1) Soil texture, including coarse fragment content.
(2) Soil permeability, porosity, and natural drainage.
(3) Size and strength of soil aggregates.
(4) Macro- and microclimate.
(5) Coverage of litter and growing vegetation above the mound.
(6) Initial root plate or mound size.
(7) Faunal activity.
(8) Surface wash and runoff processes.
(9) Fire history.
(10) Time since uprooting (age).

We find no reason to suspect that uprooting rates (dU/dt) are any greater here than elsewhere. At the Michigan study area, dU/dt values may even be lower than some "regional mean"; large tree sizes suggest that uprooting has been infrequent for the last few centuries. Observations indicate that more trees are broken off partially up the trunk than are uprooted, and protection of mounds from erosion cannot be ascribed to the presence of large trees growing on mound crests, as has been suggested elsewhere (Goodlett, 1954).

The relatively great longevities of mounds in the two study areas may be due, first, to low dE/dt values. We suggest that low rates of mound downwasting are, first, related to the sandy, porous soils and their thick litter and vegetation cover. Sandy soils allow for rapid infiltration of rainfall, minimizing runoff. Erosion is also slowed by a protective cover of litter or vegetation (Putz, 1983). Additionally, mounds on steep slopes are protected from overland flow by the upslope pit, which intercepts this type of runoff. Coarse fragments within and on top of the soil may also aid in reducing dE/dt. This type of mound preservation ("armoring" see Beatty and Stone 1986), was not observed at the Michigan study area. At the Wisconsin study area, however, it may have accounted for the increased mound longevities.

Mound longevity is enhanced by large initial size. Small mounds appear to be more easily eroded, such that they are only briefly recognizable as a microtopographic high; large mounds and deep pits require more time for levelling. Therefore, factors which interact to form microtopography of greater initial relief will indirectly act to increase its longevity.

The process of soil profile inversion or overturning by treethrow is not uncommon to steep slopes in the study areas (Schaetzl, 1986). This process leads to the formation of larger mounds and deeper pits than simple erosion of root plates on more gentle slopes, where much of the material falls or washes back into the pits. Soil profile inversion by uprooting is envisaged as occurring by: (1) uprooting on steep ($>30\%$) slopes, wherein the tree falls down-

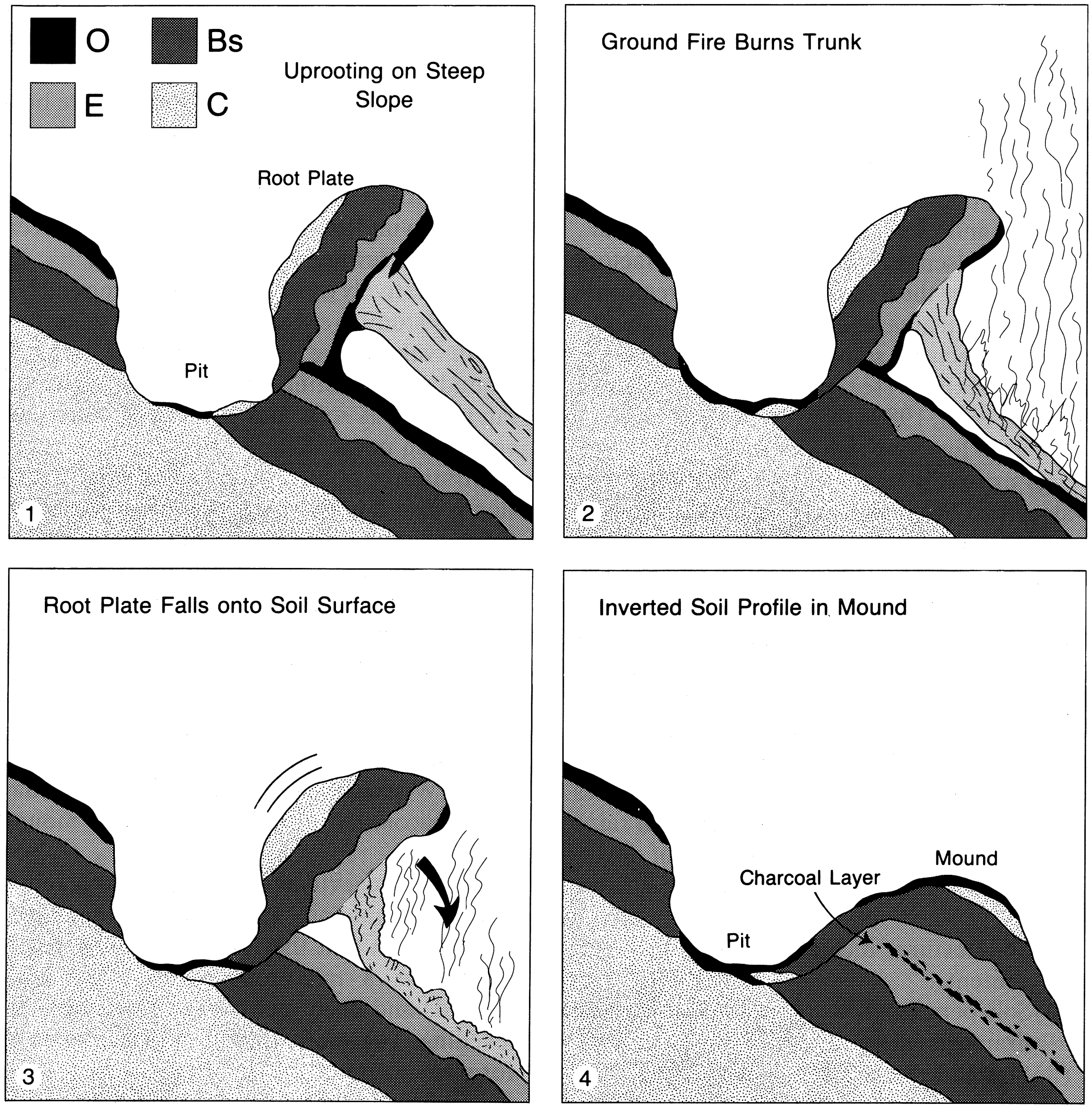

Fig. 4. Diagrammatic representation of uprooting on a steep slope, leading to profile inversion. Fire, subsequent to the uprooting event, is necessary for this process to occur.

slope (Cremeans and Kalisz, 1988), (2) subsequent burning of the trunk and bracket roots, and (3) collapse of the root/soil mass onto the soil, producing a sequence of inverted soil horizons in the mound (Schaetzl, 1986). A charcoal layer often marks the contact between the undisturbed (buried) soil and the inverted soil (Fig. 4). Profile inversion on steep slopes leads to maximal pit/mound relief because the overturning process forms mounds that are downslope from pits, minimizing the amount of soil which could wash back into the pit and thus fill it. Areas that do not ordinarily experience this type of overturning may have lower mean pit/

mound relief and shorter "mound crest-to-pit center" distances, even on steep slopes.

Mound longevity may also be promoted by soil freezing. The probability and frequency of soil freezing is greatest in mounds and least in pits, primarily being controlled by differential thicknesses of litter and snow cover (Hart et al., 1962; Schaetzl, 1989). During snowmelt, frozen soil in mounds may inhibit erosion (Denny and Goodlett, 1956, p. 65). Repeated freeze–thaw cycles in mounds may also indirectly aid in their preservation by maintaining high soil permeabilities and low bulk densities (Goodlett, 1954, p. 80; Denny and Goodlett, 1956, p. 654), thereby reducing runoff and lowering dE/dt.

Mass wasting implications

Three studies have estimated the amount of downslope movement initiated by uprooting (Denny and Goodlett, 1956; Burns, 1981; Mills, 1984). These researchers estimated the mean volume and number of treethrow pits across a study area, and then assumed that this volume represents half the net downslope movement (i.e., 50% of the soil in the mound will eventually waste back into the pit). Calculation of total pit (or mound) volume per unit area produces a mean "thickness" of a soil layer, across the study area, displaced by an instantaneous uprooting event. Also calculated was the amount of soil moved downslope by uprooting, both due to one event and over a 1000 year period. The latter calculation is made possible by assuming a recurrence interval (RI) between uprooting events, and multiplying the "thickness displaced" data by 1000/RI. Our findings suggest that the uprooting recurrence intervals employed by others (Denny and Goodlett: 200 yr, Burns: 100–280 yr, Mills: 50 yr) may be too short, and therefore the total amount and distance of soil moved downslope over a 1000 year period may have been overestimated.

Summary

We have demonstrated that high mound densities do not imply rapid rates of formation, or that all or most pedons in a forest are disturbed by treefall several times per millenia. Rather, we suggest that uprooting processes on steep slopes can produce large mounds that retain their integrity for hundreds or perhaps thousands of years, leading to relatively low rates of downslope movement. Uprooting on gentle slopes may actually lead to only small amounts of lateral transport of soil material. The direction of fall on such slopes is not a function of slope, but rather of predominant wind direction. In general, only haphazard redistribution and mixing occurs, with some net transport in a downwind, not downslope direction. Therefore, we conclude that tree uprooting has been overemphasized as a mass wasting process vector, at least in northern Michigan and Wisconsin.

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