COMPLETE SOIL PROFILE INVERSION BY TREE UPROOTING

Randall J. Schaetzl
Department of Geography
Michigan State University
East Lansing, MI 48823

Abstract: Treethrow pits and mounds in sandy Spodosols were examined to determine their internal soil horizonation. Treethrow mounds were found to contain either (1) nearly intact, yet inverted soil profiles above otherwise undisturbed soil horizon sequences, or (2) more typical mixed and random horizonation. Soil profile inversion, emphasized here for the first time, is initiated by treethrow on steep slopes which produces overhanging root plates. Subsequent fire burns the trunk, eliminating all support and allowing the plate to overturn. Charcoal within buried A horizons of mounds supports this hypothesis. On gentle slopes, soil slumps off a more vertically-inclined root mass, resulting in a haphazard arrangement of horizons. This arrangement occurs regardless of the presence or absence of fire, and results in the typical contorted horizonation often reported for treethrow mounds. [Key words: Spodosols, treethrow, pedoturbation, fire, Michigan.]

INTRODUCTION

Uprooting of trees is a natural process in all forests. Wind is the most common forcing agent for treethrow, although snow and ice may also topple trees (Rozmakhov, Serova, and Yurkina, 1963). The upthrown root mass or plate may be of considerable size, resulting in the displacement of large quantities of soil material. Brewer and Merritt (1978) reported an average of 11.9 m^2 of soil surface disturbed at the base of windthrown trees. The depth of soil disturbance, although dependent upon rooting characteristics, may be a meter or more for large trees (Lutz, 1940). A pit commonly marks the former position of the roots. After some time, the roots which bind the soil decay or are otherwise destroyed, allowing the soil to slump off and form a soil mound. The result is a pit/mound pair where once there was a tree.

Treethrow is common to all forests. Falinski (1978), for example, reported that between 200 and 450 tree trunks/100 ha accumulate each year in the Bialowieza National Park in Poland. Secondary evidence of the widespread occurrence of uprooting comes from the numerous reports of pit/mound topography (Denny and Goodlett, 1956; Thompson, 1980).

The process of uprooting often contorts and mixes soil horizons, as well as acting to move large quantities of material through mass wastage. For example, Denny and Goodlett (1956) stated that treethrow, not soil creep, is the most important factor in downslope movement of overburden on forested slopes. Soil which slumps off root plates is reported to create irregular patches of mixed and discontinuous horizons in the mound (Lutz, 1940; Troedsson and Lyford, 1973). Lutz and Griswold (1939) note that changes in soil morphology

Physical Geography, 1986, 7, 2, pp. 181–189.

due to uprooting may be expressed in many ways which do not fit any single pattern.

This research documents examples of two distinct types of mounds, and explains their formation and occurrence. The two subsets of mound types are: (1) those which contain the typical, or more common, mixed horizonation pattern, and (2) mounds where intact, overturned soil profiles are found. Previous studies which noted examples of fold-over or inverted horizonation in mounds (Lutz and Griswold, 1939; Veneman, Jacke, and Bodine, 1984) differ from the present study in three respects: (1) their primary purpose was not to investigate complete fold-over morphology or related processes, (2) diagrams of mound morphology show considerable mixed horizonation and less complete overturning than is reported here, and (3) the mechanism invoked for the release of soil from the root plate in prior studies was normal root decay, not fire as is now suggested. This paper emphasizes the formation and significance of mounds with inverted soil horizonation, and compares their formation to more typical mounds where horizonation is mixed.

STUDY AREA AND SOILS

The study area is located in the Upper Peninsula of Michigan, south of Lake Superior (Fig. 1). The region has undergone repeated glaciation, with the last advance occurring in Late Wisconsinan times (Bryson and Wendland, 1967).

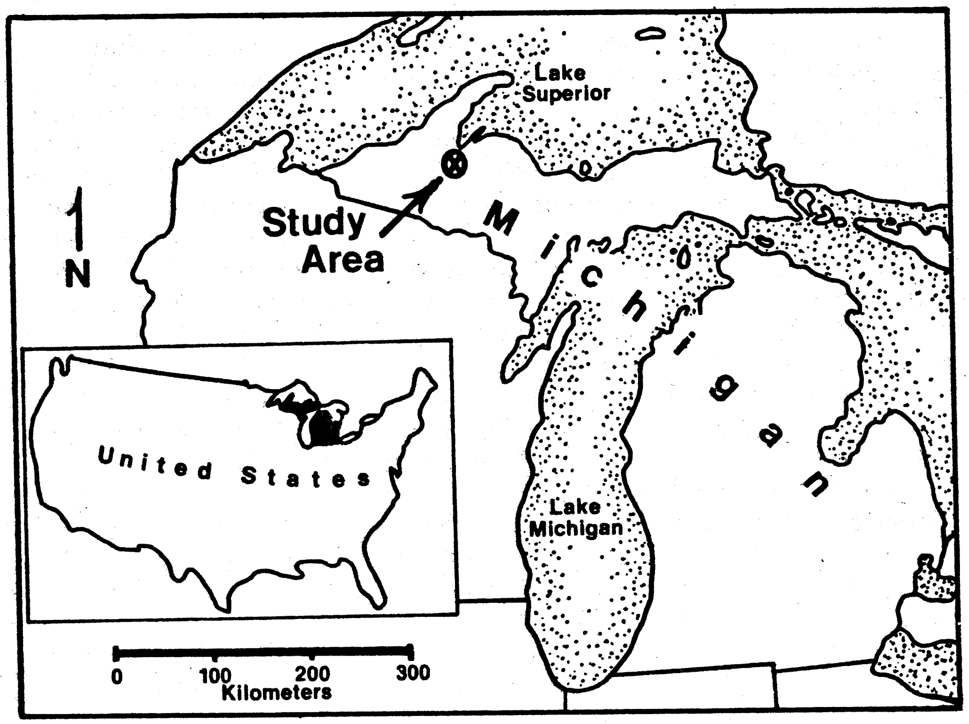

Fig. 1. Study area location.

Steep-sided moraines with slopes approaching 30° occur near broad, sandy outwash plains. A thin cap of eolian sand or silt commonly covers the glacial deposits. Over 90% of the region is forested, with sugar maple (*Acer saccharum*) and hemlock (*Tsuga canadensis*) being the principal forest species.

The soils of the region range from sandy to loamy textures, as both the tills and outwash are derived from local Precambrian sandstone (Jacobsville) bedrock. Spodosols dominate the landscape. A typical soil profile is given below. This soil (Wallace sand; sandy, mixed, frigid, ortstein, Typic Haplorthod) is formed in outwash sand which contains virtually no coarse fragments (>2 mm). Colors are for moist soil. The nomenclature follows that of the Soil Survey Staff (1975).

Oi	5-2 cm; Undecomposed sugar maple leaves; many very fine and fine roots; clear smooth boundary.
Oa	2-0 cm; Black (N 2/0) decomposed hardwood leaves; many very fine and fine, common medium roots; clear wavy boundary.
E	0-16 cm; Pinkish gray (5 YR 6/2) sand; weak fine granular structure; friable moist; common fine, medium, and coarse roots; clear wavy boundary.
Bhs	16-21 cm; Dark reddish brown (5 YR 2.5/2) fine sand; weak fine subangular blocky structure; friable moist; many fine and medium roots; clear irregular boundary.
Bs1	21-37 cm; Dark red (2.5 YR 3/6) fine sand; single-grained, friable moist; common fine and medium roots; clear irregular boundary.
Bsm	37-51 cm; Dark reddish brown (5 YR 3/4) and very dark gray (5 YR 3/1) fine sand; single-grained; very firm moist; strongly cemented; gradual irregular boundary.
Bs2	51-64 cm; Strong brown (7.5 YR 4/6) fine sand; weak medium subangular blocky structure; firm moist; slight cementation; gradual smooth boundary.
C	64-133+ cm; Brown (7.5 YR 5/4) sand; single-grained; loose moist.

METHODS

Eight pit/mound pairs were excavated by digging a trench from the mound crest, through the center of the treethrow pit, onto a relatively undisturbed adjacent pedon. Large mounds were sought, as it was believed they would reveal the most intricate internal horizonation. The trench floor typically extended well into the C horizon. Horizonation was sketched for one or more faces of the trench. Upon completion of several trenches and coring through many more, it became apparent that the mound/pit pairs could be separated into two sets: (1) those on gentle to moderate slopes which exhibited mixed and contorted horizonation within mounds, and (2) those on steep slopes where horizons within mounds were inverted with little or no mixing. The latter mound type often contained abundant charcoal in and between the buried A horizons, with lesser amounts in E horizons which lie both above and below the A. Hypotheses concerning the formation of the two types of mound soil patterns were formulated and tested by further coring and excavation.

RESULTS AND DISCUSSION

Figure 2 exemplifies a mound where profile inversion has occurred. This site (BUR 1) was located on a 19° slope of NNE aspect within a hemlock forest. The slope is on the side of a sandy, kame-like deposit draping a recessional moraine. The lower portion of the treethrow mound contains a buried, intact soil profile with a common Spodosol horizon sequence (A-E-Bs1-Bs2-BC-C). Above the buried A horizon is found an inverted profile with the A-E-Bs1-Bs2 sequence extremely well preserved, but it is in reverse order from the underlying one. Very little inter-horizon mixing is observed within the inverted profile. Recent pedogenesis (i.e., subsquent to the treethrow event) has created a thin solum in the topmost part of the mound.

The A, and to a lesser extent, E horizons contain abundant charcoal fragments. This charcoal, which provides a maximum age for the uprooting event, has been dated at 2010 ± 70 RCYBP (Illinois State Geological Survey #1462). Complete fold-over has been observed in other mounds, all of which occur on slopes exceeding 12°, and contain charcoal within the buried A horizon.

The horizonation within the BUR 1 pit is characteristic of many treethrow pits in the region. Preferential leaching has created a deep tongue of E horizon material below the pit center. These tongues are deepest in pits which best concentrate leachate and runoff, as for example in deep pits of small diameter. Strong leaching (both greater quantities, as well as more acidic leachate due to thick litter accumulations at the surface) is suggested as one possible cause of the tongues (Veneman et al., 1984), analogous to those reported by Lag (1951) for microtopography in Norway. The litter here is composed of hemlock needles and deciduous leaves. Hemlock is dominant and known for being very acidic and promoting Spodosol development (Messenger, Whiteside, and Wolcott, 1972; Hole, 1976).

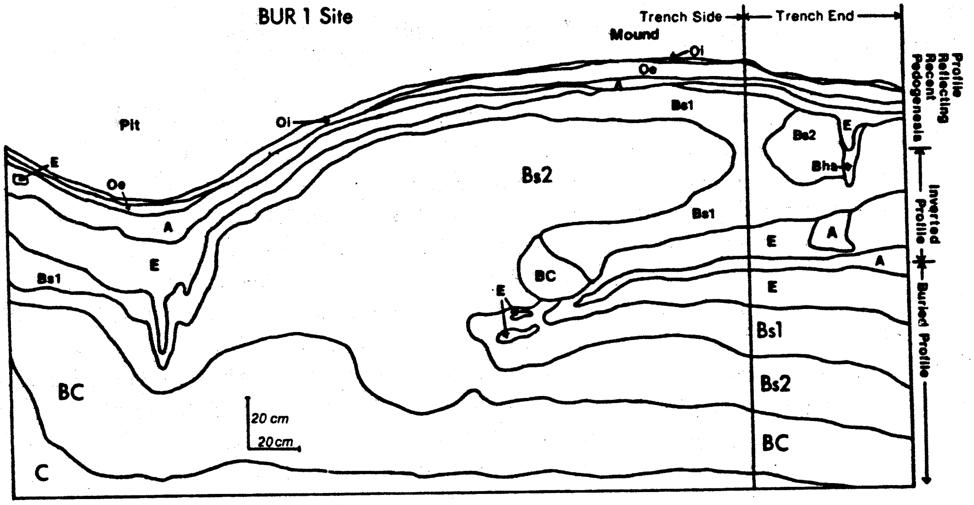

Fig. 2. Trench face horizonation for the BUR 1 site, an example of complete profile overturning. Horizon designations follow the U.S. Soil Taxonomy system.

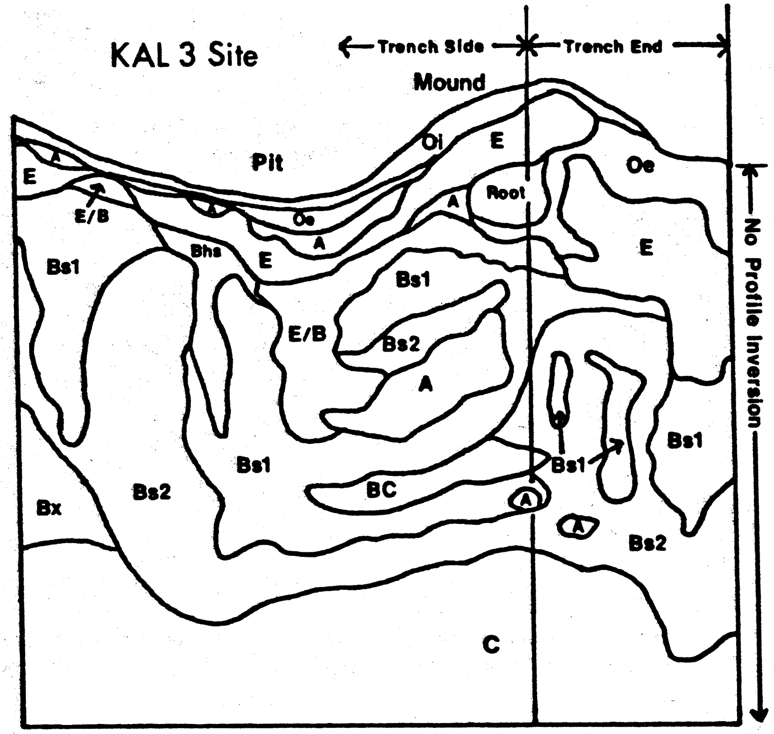

Fig. 3. Trench face horizonation for the KAL 3 site, an example of mixed mound horizonation caused by treethrow on flat or gentle slopes

The horizon pattern for a more typical mound/pit pair is shown in Figure 3. This site (KAL 3) was located on the flat crest of the kame discussed above, and lies 40 m from the previously described site (BUR 1). The decaying remains of the uprooted tree extended away from the mound/pit pair as a linear ridge. Two hemlocks growing on the decaying trunk were cored and their rings counted, yielding a minimum age for the treethrow event of 150 years. Hemlock ages provide a close approximation of treethrow dates because the species rapidly colonizes decaying trunks (Henry and Swan, 1974; Lorimer, 1980).

Site KAL 3 exhibits more horizon mixing due to treethrow than does BUR 1. Both large and small masses of E and A horizon material are apparently scattered at random within the mound (Fig. 3). Small pieces of A horizon are located deep in the mound. Decaying root channels may have provided avenues for soil material from above to move to deeper levels. Horizons in this mound also exhibit deep and pronounced tongueing presumably due to preferential movement of organic acids and other soil constituents in decaying root channels. The KAL 3 site typifies mounds reported elsewhere (e.g., Lutz, 1940; Karpachevskiy, Kiseleva, and Popova, 1968; Troedsson and Lyford, 1973). In the study area, the mixed horizon pattern is commonly found in mounds which are on slopes of less than 12°. Occasionally, horizons within these

Fig. 4. A root plate on a steep slope showing the tendency for overturning, Potter County, Pennsylvania. The plate is over 5 years old and shows considerable soil loss from the roots.

mounds will exhibit a crude vertical component within an otherwise random orientation, suggestive of slump from the vertical root plate with lesser amounts of mixing.

Hypotheses are advanced to explain the differing horizonation patterns in these two mound types. Most trees on steep slopes fall downslope upon uprooting. These trees are likely to have overhanging root plates, with the degree of overhang dependent on slope steepness (Fig. 4). Treethrow on gentle slopes will produce root plates which are nearly vertical. With rapid deterioration of the trunk, the root plate on the steep slope will fall completely over onto the undisturbed groundsurface below in a nearly intact fashion. This scenario produces intact, overturned soil profiles in treethrow mounds (Fig. 2). Rapid destruction of the trunk and/or roots in a plate which is standing vertically causes considerable mixing of the horizons during slump (Fig. 3), or a crude vertical arrangement of horizon boundaries (Lutz and Griswold, 1939). The latter pattern, although uncommon, can occur in recent mounds.

The presence of charcoal in many of the folded-over (steep slope) mounds may indicate the process whereby rapid destruction of trunk and roots is accomplished. Charcoal is the byproduct of incomplete oxidation of woody materials. The charcoal layer within the buried A horizons of fold-over mounds suggests that fire played an important role in destroying the tree trunk and the binding roots within the root plate. Veneman et al. (1984) suggested that fold-over can occur, but failed to provide a mechanism by which the trunk is eliminated. If overturning of the root plate occurs without ensuing or accompanying fire, the presence of the trunk and large protruding roots must undoubtedly cause considerable disturbance to soil horizons as this material is released from the root plate. Indeed, considerable mixing is observed in the mound described by Veneman et al. (1984). Also, if fire is not invoked, slow natural root decay would allow considerable time for mixing processes (freeze-thaw, faunalturbation and saturated soil slump) to erode, redistribute, and mix horizons. In northern Pennsylvania, 10-year-old root plates on steep slopes, which had experienced no fire, showed signs of considerable slump of soil from the plate (T. W. Small, pers. comm.). No indication of overturning of these plates was evident, nor did it seem likely to occur. Rapid destruction of both the trunk and roots following uprooting seems a necessary requirement to obtain intact overturned horizons, as depicted in Figure 2.

It is hypothesized that fire burns the tree trunk and some (possibly most) of the binding roots, which allows the plate to fall completely over onto the soil surface. The fire could be of lightning origin, accompanying a windstorm which uprooted the tree, or it could be simply a ground fire which swept along the surface shortly after treefall. Mitchell (1954) noted that early explorers' records tell of vast fires which burned for weeks in the Great Lakes region. Local residents near the study area report that Indians routinely (annually or biannually) burned the outwash plain forests to promote blueberry growth.

Fire would consume most of the trunk before collapse of the root plate onto the ground surface would cause profile inversion. After the root plate falls upon the burning trunk, the oxygen supply to the fire is greatly diminished, leading to the eventual formation of charcoal. Complete smothering of the fire is not accomplished because of the sandy, porous nature of the soil in the overlying root plate. The combustion scenario also explains the complete lack of O horizon material buried between the inverted and buried profiles.

Evidence from a third site (BUR 2) can be used to support this hypothesis. The BUR 2 site is a pit/mound pair on a 30° slope. The parent material, however, is silt loam glacial till, which is more dense ($D_b = 1.41$ g cm^{-3}) than the outwash sands (1.20 g cm^{-3}). The mound at BUR 2 exhibits an inverted profile. This site differs from others in that no clear charcoal layer is present. Rather, a thick (>20 cm) horizon of wood, which is only partly burned or charred, is found between the buried profile and the overlying, inverted root plate soil. This configuration suggests that the root plate collapsed upon the burning trunk and roots and smothered the fire, in part owing to the less porous nature of the overlying soil mass.

Appreciation of inverted soil profiles is clearly important to a variety of applications in soil science, geomorphology and Quaternary studies. Knowledge of inverted profiles has direct application to soil mapping in forested regions. Treethrow on slopes is an important form of mass wasting; recognition of the inversion process will lead to more accurate predictions of creep rates. Lastly, the effects of inversion (or mixed horizonation) have important bearing upon past and future soil genesis in mound and pit microtopographic locations.

CONCLUSIONS

Mixed and contorted soil horizons within treethrow mounds have been reported in the literature, and are often the pattern to be expected. This study has shown, however, that complete overturning of the soil profile can be accomplished, even in soils of sandy textures. Moreover, the overturning can be accomplished with minimal destruction of the previous horizon sequence. The process responsible for overturning requires (1) steep slopes where the root plate comes to rest in an overhanging position, and (2) concurrent or subsequent fire to destroy the trunk and binding roots, allowing the soil to fall onto the surface in a relatively undisturbed manner. Treethrow on gentle slopes results in mixed mound horizonation because the root plate is too steeply inclined to be folded over in an intact state, even if fire is included in the scenario.

Acknowledgements: The author acknowledges the guidance of his dissertation committee at the University of Illinois. Personnel at the Ford Forestry Center, L'Anse, Michigan aided the field study. T. W. Small assisted in the field and edited early drafts. L. R. Follmer, D. L. Johnson, S. G. Shetron, and C. J. Sorenson reviewed drafts of the paper. The research was supported by grants from the Graduate College and the Department of Geography, University of Illinois, and a Grant-in-Aid of Research by Sigma Xi, The Scientific Research Society. The Illinois State Geological Survey provided ^{14}C dating of buried charcoal.

BIBLIOGRAPHY

Brewer, R. and Merritt, P. G. (1978) Wind throw and tree replacement in a climax beech-maple forest. *Oikos*, Vol. 30, 149–152.

Bryson, R. A. and Wendland, W. M. (1967) Radiocarbon isochrones of the retreat of the Laurentide ice sheet. *Univ. of Wisc., Dept. of Metr.*, Tech. Rept. No. 35, 28 pp.

Denny, C. S. and Goodlett, J. C. (1956) Microrelief resulting from fallen trees. In Surficial Geology and Geomorphology of Potter County, Pennsylvania. *USGS Prof. Paper*, Vol. 288, 59–66.

Falinski, J. B. (1978) Uprooted trees, their distribution and influence on the primeval forest biotope. *Vegetatio*, Vol. 38, 175–183.

Henry, J. D. and Swan, J. M. A. (1974) Reconstructing forest history from live and dead plant material—An approach to the study of forest succession in southwest New Hampshire. *Ecology*, Vol. 55, 772–783.

Hole, F. D. (1976) *Soils of Wisconsin.* Madison: Univ. of Wisc. Press, 223 pp.

Karpachevskiy, L. O., Kiseleva, N. K., and Popova, S. I. (1968) Mixed character of soils under a broadleaf-spruce forest. *Soviet Soil Science*, Vol. 1, 7–22.

Lag, J. (1951) Illustration of the influence of topography on depth of A2 layer in Podzol profiles. *Soil Sci.*, Vol. 71, 125–127.

Lorimer, C. G. (1980) Age structure and disturbance history of a southern Appalachian virgin forest. *Ecology*, Vol. 61, 1169–1184.

Lutz, H. J. (1940) Disturbance of forest soil resulting from the uprooting of trees. *Yale School of For.*, Bull. 45.

________ and Griswold, F. S. (1939) The influence of tree roots on soil morphology. *Am. J. Sci.*, Vol. 237, 389–400.

Messenger, A. S., Whiteside, E. P., and Wolcott, A. R. (1972) Climate, time, and organisms in relation to podzol development in Michigan sands. I. Site descriptions and microbiological observations. *Soil Science Soc. America Proc.*, Vol. 36, 633–638.

Mitchell, J. A. (1954) Forest-fire control in the Lake States. *USDA Forest Serv.*, Misc. Rept. No. 32, 11 pp.

Rozmakhov, I. G., Serova, P. P., and Yurkina, S. I. (1963) Effect of forests on microcomplexity of soils. *Sov. Soil Sci.*, Vol. 12, 1131–1136.

Soil Survey Staff (1975) Soil Taxonomy. *USDA Agric. Handbook No. 436*. Washington, DC: U.S. Govt. Printing Office.

Thompson, J. N. (1980) Treefalls and colonization patterns of temperate forest herbs. *Am. Midl. Nat.*, Vol. 104, 176–184.

Troedsson, T. and Lyford, W. H. (1973) Biological disturbance and small-scale spatial variations in a forested soil near Garpenburg, Sweden. *Studia For. Suecica*, Vol. 109, 23 pp.

Veneman, P. L. M., Jacke, P. V., and Bodine, S. M. (1984) Soil formation as affected by pit and mound microrelief in Massachusetts, USA. *Geoderma*, Vol. 33, 89–99.