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# Biological disturbance and small-scale spatial variations in a forested soil near Garpenberg, Sweden

*Biologiska oregelbundenheter inom små ytor som orsak till variabiliteten i några av skogsmarkens egenskaper i Garpenberg*

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# Abstract

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*Uprooting of trees, collapse and infilling of former root channels, movement of soil by earthworms, ants and other fauna cause local variations in forest soils and help explain the necessity for collecting a large number of samples for some kinds of analyses.*

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# Introduction

Troedsson and Tamm (1969) made a study of the small-scale variations in a forest soil near Garpenberg, Dalarna, Sweden in connection with the determination of the number of samples required for satisfactory analytical results for pH, loss on ignition, nitrogen, phosphorus and potassium. Later Lyford and Troedsson (1973) made a study of the fragipan horizon in an area immediately adjacent and incidentally described and sampled the horizons overlying the fragipan horizon. It is the purpose of this paper to call attention to some horizon variations caused by biological disturbance and to point out some reasons for the small-scale variations noted by Troedsson and Tamm. It may be worth noting that at the time the morphological study was made it was not our intention to relate the morphological and small-scale variation investigations.

# 1 Description of study areas

Detailed morphological studies were made on two very gently sloping areas near Garpenberg. Area 1 is within 10 meters of the sample plot described by Troedsson and Tamm (1969) and is on the same soil. It is also very close to areas formerly studied by Troedsson (1953, 1965) and Nõmmik (1967). Area 1 is 30×50 meters in size and encompasses both dry and wet mineral soils and peat. Most of the detailed morphological studies were made on a nearly level 10×30 meter portion of the larger area. Area 2, 10×30 meters in size, is about 500 meters from Area 1 and is on the same kinds of soils. Both areas have Podzol (Spodosol) mineral soils with well expressed fragipans and the soils are developed on stony sandy glacial moraine (till) derived principally from slightly reddish leptite rock and containing small amounts of diabase, hyperite and other coarse fragments. The two study areas occur just above the post glacial shore line on a gently sloping moraine with a rather intricate pattern of concave and complex areas. The convex areas are about 100—200 meters across and have a 2—10 percent slope gradient. The concave areas are 50—100 meters wide and tend to be permanently wet and filled with sphagnum peat. Wet mineral soils occur in the narrow smooth areas between the convex and concave areas.

The study areas have well managed closed-canopy stands of Norway spruce (*Picea abies*) and Scotch pine (*Pinus sylvestris*) about 40 cm in diameter and 20 meters in height. Moss-covered stumps of former trees are uniformly spaced on the plots. The surface of the soil is completely carpeted by mosses, principally *Hylocomium splendens, Pleurozium Schreberi* and *Ptilium crista-castrensis* with small clumps of *Dicranum* spp. and *Sphagnum* spp. *Vaccinium myrtillus* and *V. vitis idaea* are common in portions of the study area. Moss-covered stones and boulders up to one half meter in diameter are spaced about 1—5 meters apart on the surface of the soil. Those larger than 20 cm in diameter are readily visible although it is sometimes necessary to pull the moss away to be sure whether the observed objects are stumps or stones.

# 2 Procedure

External features of the two sample areas were examined in detail. The two $10 \times 30$ meter plots were gridded with string into two-meter squares. Vegetation was mapped in detail including location, size and kinds of trees and stumps, distribution of shrubs, herbs, grasses and mosses. Microrelief, stones and boulders were mapped, several trenches were dug and soil horizons delineated. Ants and earthworms were collected for identification and their mounds and casts sampled.

Sampling for analyses was carried out with a view of obtaining some idea of the variation to be expected within as well as between horizons. A typical profile sample consisted of about one liter of soil collected in the usual manner one horizon below another. Additional smaller replicate samples of certain horizons were collected from several places in the sides of the trenches.

Particle size and chemical analyses were run at the Royal College of Forestry, following methods used by the Soil Survey Laboratories, Soil Conservation Service, United States Department of Agriculture. Particle size distribution was by the pipette method of Alexander and Kilmer; exchangeable base cations extracted and determined by procedures described by Jackson, sodium and potassium by flame photometry and calcium and magnesium by atomic absorbtion spectrometry; free iron oxide by Kilmer's method; total nitrogen by the macro-Kjeldahl process using copper and mercury as catalysts; total organic carbon by dry combustion with final furnace temperature at 740 degrees C. and carbon dioxide absorbed by ascarite; pH by glass electrode both in water and 1N potassium chloride.

# 3 Characteristics of soil horizons

The soils at Garpenberg have numerous stones and boulders on the surface and throughout the solum. Coarse fragments 2—10 mm in diameter range from 10—20 percent by weight. In the fine earth portion sand (2—.05 mm) ranges from 35—45 percent by weight, silt (.05—.0002 mm) from 35—45, and clay (less than .0002 mm) from 15—25 percent.

For convenient discussion the various horizons are grouped into forest floor, sod, sesquioxide-humus, and fragipan-parent material horizon sequences.

Forest floor horizons consist of the S, 01 and 02 horizons. The living moss carpet and the intermingled recently fallen needles, twigs and bark is called the S layer after Forsslund (1943). The underlying 01 (or F) consists mostly of partially disintegrated moss and tree needles well tied together by living mycelium and small-diameter living tree and grass roots. It is inhabited by a myriad of meso and microfauna. The nearly black 02 (or H) horizon consists of well disintegrated organic matter well interwoven with mycelium and small roots. Woody branches, twigs and roots in various stages of disintegration occur throughout the forest floor horizon sequence and in places this woody material is prevalent enough to be included in many samples that are collected at random.

Sod horizons refer to the uppermost mineral horizons that are so interpenetrated by live grass roots (largely *Deschampsia flexuosa*) that when removed they hold together as a unit much like the sod from field or lawn. The sod-like appearance of these upper mineral soils has not been noted in forest soils of northeastern United States, presumably because grass in forested areas is not nearly as common as in Sweden. The sod horizon sequence consists of the A1, A2 and B21h horizons. The dark brown, nearly black A1 horizon and the underlying grayish discontinuous A2 horizon are both thin and the A1 horizon, though continuous is only 1—2 cm thick except where it occurs in tongues or pockets. The A1 is massive and held together by roots and mycelium and has enough organic matter content to give it a dark color. In places small ant mounds and aggregations of earthworm casts are conspicuous on the surface of the A1 when the forest floor carpet is removed. Ants and earthworms are active enough to keep the A1 well mixed and this to a great extent prevents formation of the thick gray leached A2 horizon characteristic of many Podzols. The underlying 1/2—1 cm thick reddish brown B21h horizon is discontinuous and generally occurs only under the thickest portions of the A2 horizon.

The sesquioxide-humus horizon sequence encompasses horizons in which the mineral particles are coated with the reddish or brownish substances characteristic of the B horizon of Podzols. In the upper part of an undisrupted sequence there may be enough coating and bridging for the horizon to qualify as a spodic horizon by the USDA Classification (Soil Survey Staff, 1960, 1967). Coating and bridging is less with depth and the horizons lose the reddish color and become more and more like the color of the parent material. All horizons of this sequence are designated by the master symbol B2 and are subdivided into B21, B22, B23 and B24 horizons to provide an indication of sequence. The subdivisions are made principally on the basis of color. Supplementary symbols are used to show unusual accumulations of humus (h), iron oxide (ir) or the grayish mottling caused by gleying (g).

The fragipan-parent material sequence consists of the B(x), Bx and C horizons. The brittle, platy hard fragipan horizon is the Bx and is about 50 cm below the surface. Overlying it is the B(x) horizon which exhibits both weak fragipan and sesquioxide-humus properties (often designated as one of the lowermost B2 horizons or even the C horizon). The hard dense parent material, the C horizon, lies directly under the Bx at a depth of about a meter. It is hard like the fragipan horizon but lacks brittleness, platy structure and pores.

Details of the fragipan and parent material are given in a separate paper by Lyford and Troedsson (1973).

# 4 Biological disturbance

## 4.1 Uprooting of trees

An external feature about equally as prominent in some places as stumps and stones is the microrelief of the surface of the soil. In large part the microrelief pattern is due to former disturbance of the soil by the uprooting of trees. This process is well known in Sweden and has been described many times, for example, by Hesselman (1925) and Malmström (1949). It is also a current process. Two recently uprooted trees near the study areas are shown in Fig. 1. This process has been studied a good deal in the United States and a fairly recent study was made in Canada (Lyford and MacLean, 1966). Where there is a recent tree fall the surface relief may be as much as 1—2 meters. In general the microrelief varies in height from about 20—30 cm.

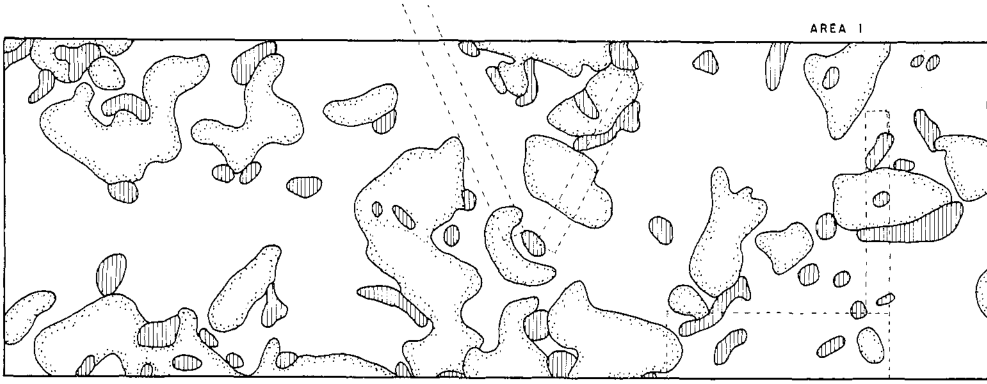
When disrupted by the uprooting of a tree the soil at first adhers to the root system as a rather large mass. As the root system decays the soil gradually subsides and for many years—possibly several hundred years —there remains a rather characteristic microrelief consisting at first of a rather distinct mound-pit pair, and later, by faintly expressed mounds and pits. The distinct mounds and pits on the two study areas at Garpenberg are delineated in Fig. 2. They cover about a third of the area.

Mounds and pits appear to be characteristic of most forested areas. Their absence suggests that cultivation or heavy pasturing has taken place at some former time. Distinctness of the mounds and pits provides some indication of the length of time since the trees were uprooted. Shape of the mounds and pits provides some indication of the kind and size of the trees that overturned but shape is complicated by whether the tree fell up or down slope and whether a single tree or several trees fell.

Soil horizons are disrupted when trees fall. These effects persist as internal features of the soil for a long time and even where the mound-pit pairs are faintly expressed on the surface the disruption can be detected within the soil. In fact the effects can be seen in almost any trench dug in formerly forested areas and even if the soil has been plowed the irregularity of the B horizons below the plow layer usually provides some evidence of former disturbance. Disruption of horizons is shown in the scale diagram of three trenches made through portions of the soil where there is distinct microrelief (Fig. 3). In two of the trenches the A horizons are continuous over the surface but are noticeably thicker in former pits. In these trenches the upper B horizons are discontinuous and in many places the B23 or B24 horizons lie directly under the A horizons. In one of the trenches the A horizons are completely absent in one place and the B23 horizon then lies directly under the forest floor and is the topmost mineral horizon. With the passage of time microrelief becomes more and more subdued and the uppermost mineral horizons tend to become continuous.

Disruption and overturn of the soil by tree-throw is a major reason for variations within and between B horizons. Some idea of the variation in physical and chemical characteristics of A2 and B horizons from place to place is shown by the analyses of replicate samples in *Tables 1* and *2*. Particle size distribution does not vary greatly either within or among B horizons. Chemical properties are somewhat more variable as reflected by cation exchange capacity, base saturation and free iron oxide values. In general values for one horizon overlap those of another and the soil is so variable within a single horizon that even though this hori-

*Figure 1.* Recently fallen trees near Area 1. Note that a large mass of soil adhers to the upturned root system. When the root system decays this soil material falls to the surface of the soil and persists for several hundred years as a distinct mound. The pit from which the soil was torn when the tree uprooted also persists for a long time.



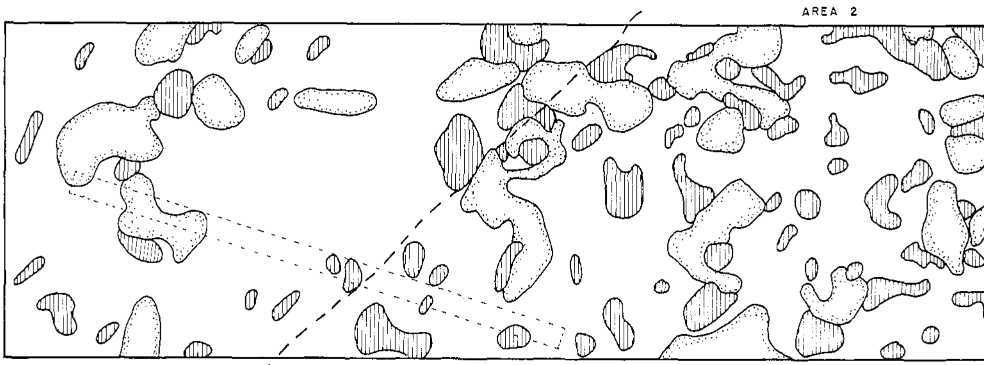




*Figure 2.* Distinct mound and pit microrelief on Areas 1 and 2. Stippled areas are distinct mounds. Vertically lined areas are distinct pits. (Faintly expressed mounds and pits are not delineated.) The dashed heavy line in Area 2 is the location of the soil boundary between wet soils (right of diagram) and dry soils. The dashed light lines outline the location of trenches where soils were studied. Plots are 10×30 meters in size.

zon may appear to be uniform in color, consistence, structure of other visible properties, the chemical properties are enough different to make it unlikely that a single sample, or even two or three samples, can characterize any one horizon adequately. This, of course, was the conclusion of Troedsson and Tamm.

In addition to the marked disturbance of soil horizons caused by overthrown trees there is a pattern of coarse fragments that can be related to tree throw. Coarse fragments in the uprooted mass of soil tend to fall into the concave pit area before much fine material is dislodged. As a result there are often concentrations of coarse fragments in pits and these resemble eggs in a nest. Conceivably one could locate many former pits if a map of the "nests" were made.

## 4.2 **Infilling after root disintegration**

Volume of the root system of forest trees amounts to a quarter or a third the volume of the portions above ground. As roots grow soil is gradually pushed out of its normal position and conversely when roots disintegrate soil collapses or slumps into the areas once occupied by the living woody roots. This process is so well known that its magnitude easily can be overlooked. The fact that few open root channels occur in the soil of continuously forested areas in spite of at least 4—5 generations of trees each thousand years suggests repeated and substantial local soil movement. In general the soil that fills the root cavity is exactly like that originally pushed away and so the

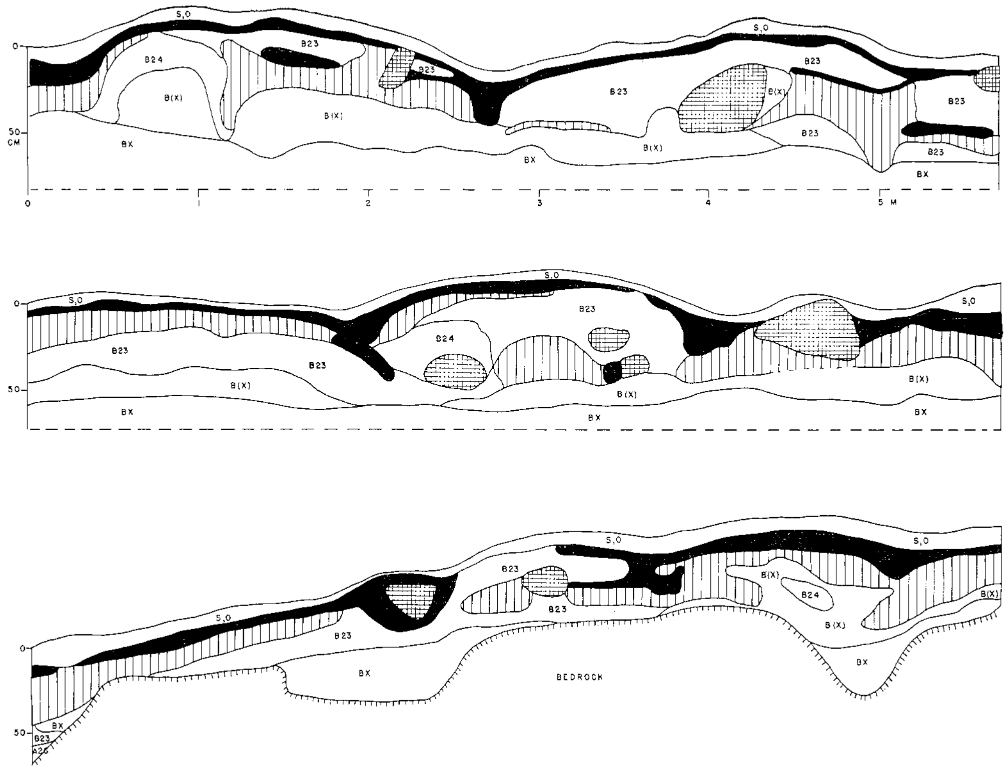



*Figure 3.* Horizons exposed in trenches dug through distinct mound-pit microrelief. A horizons are solid black. B22ir horizons have vertical lines. Large stones and boulders are cross hatched.

old root cavities can not be identified. There are instances, however, where vertical root channels are filled with soil from contrasting horizons above. An example of this in the soil at Garpenberg are the tongues of friable B24 horizon material that extend downward into the hard fragipan horizon. Another example are the former root channels within the fragipan that are now filled with gray sandy or silty materials that contrast in structure, color and consistence with the surrounding fragipan matrix. These two features are described in detail in the paper by Lyford and Troedsson (1973) that deals principally with the fragipan horizon.

## 4.3 **Charcoal**

Present day disturbance of forest soil by man and his machines is so much a part of our everyday experience that it needs no description. Technology changes rapidly, however, and for this reason attention is called to a disturbance that dates from an earlier period.

Black charcoal bits are very numerous in the soil of Areas 1 and 2 but are confined to A1 and A2 horizons or to places where by reason of disturbance from tree-throw these two horizons are below B horizons. In only one or two instances was it observed intermingled with B horizons. Former charcoal pits in the vicinity of the study area are very numerous and in these there is considerable charcoal just below the carpet of moss and grass. These pits are spaced roughly 1—200 meters apart and are about 10—20 meters in diameter. They result from the production of charcoal for smelting iron and copper ores that have been mined in the vicinity of Garpenberg since about 700 AD. Maximum use of the forests for charcoal

Table 1. Particle size distribution of replicate samples from several horizons

| Horizon and sample | Particle size classes in mm | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | More than 2 mm | 2—1 | 1—.5 | .5—.25 | .25—.10 | .10—.05 | Total sand | .05—.002 | Less than .002 |
| | Percent by weight Whole sample basis | | | Percent by weight Less than 2 mm basis | | | | | |
| *Earthworm casts area 1* | | | | | | | | | |
| | 0.6 | 0.7 | 6.1 | 8.3 | 11.8 | 12.0 | 38.9 | 33.7 | 27.4 |
| | 0.0 | 1.3 | 5.9 | 7.3 | 0.6 | 13.1 | 28.2 | 31.5 | 40.3 |
| *Ant mounds replicates* | | | | | | | | | |
| | 14.4 | 3.9 | 7.4 | 7.8 | 1.5 | 11.5 | 32.1 | 37.1 | 30.8 |
| | 9.1 | 6.2 | 9.8 | 8.7 | 5.3 | 8.5 | 38.5 | 34.3 | 27.2 |
| | 6.5 | 3.5 | 8.0 | 8.7 | 9.3 | 9.3 | 38.8 | 36.2 | 25.0 |
| | 12.8 | 4.0 | 8.8 | 7.8 | 5.0 | 8.3 | 33.9 | 34.3 | 31.8 |
| | 2.9 | 3.3 | 8.0 | 9.5 | 1.5 | 8.2 | 30.5 | 35.2 | 34.3 |
| | 6.9 | 4.4 | 7.4 | 8.1 | 7.8 | 12.0 | 39.7 | 40.7 | 19.6 |
| *A2 pocket replicates* | | | | | | | | | |
| | 17.3 | 4.5 | 10.1 | 9.8 | 4.6 | 14.0 | 43.0 | 40.0 | 17.0 |
| | 28.6 | 4.4 | 10.2 | 10.3 | 9.4 | 6.3 | 40.6 | 38.7 | 20.7 |
| | 12.7 | 4.3 | 12.1 | 13.2 | 13.0 | 9.1 | 51.7 | 31.6 | 16.7 |
| | 11.9 | 2.5 | 6.5 | 7.9 | 8.2 | 13.5 | 38.6 | 42.6 | 18.8 |
| *B22ir replicates* | | | | | | | | | |
| | 48.3 | 3.8 | 9.4 | 9.4 | 13.6 | 6.3 | 42.5 | 36.5 | 21.0 |
| | 8.1 | 4.6 | 7.2 | 8.2 | 6.9 | 14.2 | 40.5 | 39.3 | 20.2 |
| | 7.5 | 3.7 | 7.9 | 9.1 | 6.1 | 12.5 | 39.3 | 38.6 | 22.1 |
| | 19.9 | 4.7 | 8.9 | 9.6 | 3.3 | 11.9 | 38.4 | 36.0 | 25.6 |
| | 14.2 | 4.6 | 7.7 | 7.7 | 5.6 | 9.7 | 35.3 | 37.0 | 27.7 |
| | 16.9 | 5.0 | 7.8 | 7.9 | 1.9 | 14.9 | 37.5 | 37.8 | 24.7 |
| | 20.3 | 8.0 | 10.5 | 9.2 | 2.8 | 10.9 | 41.4 | 36.7 | 21.9 |
| | 18.9 | 5.2 | 7.4 | 7.3 | 8.8 | 11.2 | 39.9 | 36.7 | 23.4 |
| | 27.5 | 3.7 | 7.1 | 8.6 | 7.7 | 9.1 | 36.2 | 37.9 | 25.9 |
| *B23 replicates* | | | | | | | | | |
| | 27.4 | 6.5 | 9.3 | 8.7 | 2.7 | 11.5 | 38.7 | 37.9 | 23.4 |
| | 13.9 | 4.1 | 7.5 | 8.5 | 6.4 | 15.0 | 41.5 | 39.8 | 18.7 |
| | 14.9 | 4.1 | 7.7 | 8.6 | 4.8 | 13.3 | 38.5 | 39.4 | 22.1 |
| | 28.3 | 6.4 | 9.9 | 10.1 | 7.1 | 12.2 | 45.7 | 33.9 | 20.4 |
| | 16.9 | 4.4 | 7.6 | 8.2 | 9.7 | 6.9 | 36.8 | 38.6 | 24.6 |
| | 16.9 | 4.0 | 6.9 | 7.6 | 10.1 | 11.7 | 40.3 | 39.0 | 20.7 |
| | 12.0 | 3.9 | 7.2 | 7.3 | 6.4 | 13.1 | 37.9 | 44.9 | 17.2 |
| *B24 tongue replicates* | | | | | | | | | |
| | 13.5 | 3.8 | 7.6 | 7.7 | 11.1 | 8.7 | 39.0 | 41.5 | 19.5 |
| | 7.3 | 4.0 | 7.9 | 8.5 | 10.9 | 14.1 | 45.4 | 36.2 | 18.4 |
| | 20.4 | 4.0 | 7.8 | 8.6 | 4.7 | 16.2 | 41.3 | 39.5 | 19.2 |
| | 13.4 | 4.0 | 8.0 | 8.2 | 10.9 | 13.5 | 34.6 | 37.8 | 17.6 |

probably was in the 1700 and 1800's and at that time most of the land may have been cleared of large trees. The amount of soil disturbance during the period can only be guessed at; probably most of the disturbance was in the surface horizons.

### 4.4 **Earthworm activity**

Earthworm activity is common in the A horizon of well drained soils in Areas 1 and 2 and was also noted in a few places in wet soils. This activity, as judged by presence of

Table 2. Chemical properties of replicate samples from several horizons

| Horizon and sample | Exchangeable cations | | | | | | Base sat. | Free iron oxide | $H_2O$ | pH KCl | Org. mat. $H_2O_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | H | Ca | Mg | K | Na | CEC | | | | | |
| | Milliequivalents per 100 grams | | | | | | % | % | | | % |
| *Earthworm cast replicates* | | | | | | | | | | | |
| Area 1 | 15.4 | 1.6 | 0.3 | 0.5 | Tr. | 17.8 | 13.9 | 0.8 | — | — | 12.4 |
| Area 1 | 29.2 | 10.0 | 1.3 | 1.7 | 0.1 | 42.3 | 31.1 | 0.5 | — | — | 30.5 |
| Limestone fragments | 3.5 | 0.1 | Tr. | Tr. | Tr. | 3.7 | 6.3 | 1.3 | 4.8 | 4.6 | 1.2 |
| Limestone fragments | 3.0 | 17.3 | 0.4 | 0.2 | 0.1 | 21.1 | 85.8 | 0.8 | 6.4 | 6.2 | 8.3 |
| *Ant mound composite* | | | | | | | | | | | |
| | 13.3 | 0.3 | 0.1 | 0.3 | Tr. | 14.0 | 5.5 | 1.1 | — | — | 7.3 |
| *A2 pocket replicates* | | | | | | | | | | | |
| | 4.9 | 0.2 | 0.1 | 0.1 | Tr. | 5.3 | 8.3 | 0.3 | — | — | 2.1 |
| | 6.9 | 0.1 | Tr. | 0.1 | Tr. | 7.2 | 4.8 | 0.3 | — | — | 3.2 |
| | 5.0 | Tr. | Tr. | Tr. | Tr. | 5.2 | 2.8 | 0.2 | — | — | 2.0 |
| | 7.5 | 1.1 | 0.2 | 0.2 | Tr. | 9.0 | 16.7 | 0.5 | 4.3 | 3.6 | 3.6 |
| *B22ir replicates* | | | | | | | | | | | |
| | 10.0 | 0.5 | 0.1 | 0.1 | Tr. | 10.7 | 6.6 | 0.8 | 4.0 | 3.7 | 5.1 |
| | 9.1 | 0.3 | Tr. | Tr. | Tr. | 9.5 | 4.4 | 0.7 | — | — | 5.0 |
| | 5.8 | 0.2 | Tr. | Tr. | Tr. | 6.1 | 5.7 | 1.4 | — | — | 3.0 |
| | 5.0 | 0.1 | Tr. | Tr. | Tr. | 5.2 | 3.0 | 1.1 | — | — | 2.5 |
| | 9.8 | Tr. | Tr. | 0.1 | Tr. | 10.1 | 2.7 | 1.5 | — | — | 5.6 |
| | 5.4 | 0.2 | Tr. | 0.1 | Tr. | 5.8 | 5.9 | 1.2 | — | — | 2.8 |
| | 2.2 | Tr. | Tr. | 0.1 | Tr. | 2.4 | 6.9 | 1.0 | — | — | 1.2 |
| | 6.8 | 0.4 | 0.1 | 0.1 | Tr. | 7.4 | 8.1 | 1.3 | 4.7 | 4.5 | 3.8 |
| | 6.9 | 0.5 | 0.1 | Tr. | Tr. | 7.5 | 8.5 | 0.8 | 4.8 | 4.6 | — |
| | 5.8 | 0.3 | Tr. | 0.1 | Tr. | 6.3 | 6.9 | 1.0 | 4.9 | 4.6 | 2.8 |
| *B23 replicates* | | | | | | | | | | | |
| | 8.4 | 0.3 | Tr. | 0.1 | Tr. | 8.8 | 4.6 | 1.4 | 4.4 | 4.3 | 4.5 |
| | 4.4 | 0.1 | Tr. | Tr. | Tr. | 4.6 | 4.0 | 0.4 | — | — | 3.1 |
| | 3.9 | 0.2 | Tr. | Tr. | Tr. | 4.2 | 7.2 | 0.6 | — | — | 2.7 |
| | 3.1 | Tr. | Tr. | Tr. | Tr. | 3.2 | 3.9 | 0.6 | — | — | 2.0 |
| | 5.4 | 0.1 | Tr. | Tr. | Tr. | 5.5 | 2.9 | 0.5 | — | — | 3.0 |
| | 4.5 | 0.2 | Tr. | Tr. | Tr. | 4.9 | 5.6 | 0.4 | — | — | 2.6 |
| | 2.1 | 1.3 | 0.1 | 0.1 | Tr. | 3.6 | 41.7 | 0.4 | 5.5 | 5.2 | 1.4 |
| *B24 tongue replicates* | | | | | | | | | | | |
| | 4.0 | 0.1 | Tr. | Tr. | Tr. | 4.2 | 5.3 | 0.5 | 4.7 | 4.7 | 2.7 |
| | 2.9 | Tr. | Tr. | 0.1 | Tr. | 3.1 | 5.2 | 0.3 | — | — | 1.5 |
| | 2.5 | 0.2 | Tr. | Tr. | Tr. | 2.8 | 10.8 | 0.3 | — | — | 0.9 |
| | 2.6 | 0.1 | Tr. | Tr. | Tr. | 2.8 | 8.8 | 0.3 | — | — | 1.0 |

casts on the surface of the A1 horizon, just under the forest floor carpet, is local in the forest and confined mostly to isolated areas 20—30 cm in diameter. Evidence of the presence of earthworms is given by aggregations of casts lying directly on the surface of the A horizon. When the living carpet of moss, grass and other plants is removed recent earthworm casts are readily visible because the carpet pulls away cleanly from the local areas of recent casts.

On the forested Areas 1 and 2 earthworms are particularly common in two different habitats; near limestone fragments and near *Anemone nemorosa* plants. Earthworm distribution in cultivated areas was not studied but they were found to be very numerous in old field (Hässlen) about 1/2 kilometer away. Details of the occurrence in these three habitats are given in order to call attention to the manner in which these fauna influence soil development and morphology.

Two angular limestone fragments were encountered while digging the trench in Area 2. They were conspicuous because of their angularity and because they were partially weathered to a brown porous material in some portions of the fragment. The presence of carbonate was shown by effervescense in hydrochloric acid. Source of the limestone is probably distant (Sjörs, 1965). There were an unusual number of earthworms around the two limestone fragments in Area 2 and their casts also were very numerous. A collection of earthworms was made from around the two limestone fragments and all were *Allolobophora caliginosa* (Sav.). Earthworms also occur in several other places in Area 2 and were not associated with limestone fragments. Here, however, they are not so numerous. Two samples of the earthworm casts were obtained from around one of the limestone fragments and the analyses are shown in Tables 1 and 2.

Earthworms also occur in Area 1 but here no carbonate stones were noted. On this area however, there is a possible relationship between the presence of earthworms and *Anemone nemorosa*. This plant is fairly common on both Area 1 and 2 and is in scattered and isolated clumps consisting of several stems growing from fleshy rhizomes. When the forest floor is removed from around these plants a cluster of earthworm casts is often noted; in fact they were noted in 18 out of 24 examinations or about 75 percent of the time. Earthworms themselves seems to be more numerous under *A. nemorosa* and were identified as *Allolobophora caliginosa* (Sav.), *Dendrobaena octaedra* (Sav.) and *Lumbricus rubellus* Hoffm. Analyses of casts from these sites are shown in Tables 1 and 2.

In a formely cultivated field on a nearby abandoned farm (Hässlen) earthworms are also active. They are numerous in the 20—25 cm thick former plow layer and their vertical tunnels filled with dark brown Ap soil material are conspicuous in the underlying reddish B2 horizon. Tunnel volume in the B2 horizon is probably only 1—2 percent and so the character of this horizon as a whole has not been modified appreciably by the earthworm action; aside from the presence of the Ap filled tunnels it remains much like that of the B2 horizons at corresponding depths on nearby forested soils.

Earthworms occur elsewhere in the vicinity of Areas 1 and 2 but always in small local areas. *Allolobophora caliginosa* and *Lumbricus rubellus* were collected from a forested area about one kilometer away. In other places in Sweden, especially where soils have a high content of carbonate coarse fragments, earthworms are common in forested areas. Earthworms are endemic and have found suitable ecological nitches where they persist. From these nitches it is probable they can expand rapidly if conditions change for the better.

Particles larger than 2 mm are not often ingested by earthworms and most particles are smaller than 1 mm. Thus the earthworms have the ability to segregate the soil into finer particle sizes and this becomes noticeable where they are very active in coarse textured soils. It is not noticeable if the soils are silty or clayey to start with. In Areas 1 and 2 the earthworm casts by feel seemed to have a high proportion of silt but this was not substantiated by the analyses (Table 1).

Chemical analyses shows that the four samples of earthworm casts (that were studied) are extremely variable even though the duplicate samples were collected close together. For example, the two samples of earthworm casts from Area 1 have exchangeable calcium of 10.0 and 1.6 mill-equivalents/ 100 gm and those near the limestone fragments have 17.3 and 0.1. Similarly the organic matter as determined by hydrogen peroxide varies in the four samples from 1 to 30 percent.

### 4.5 Ant activity

Small ants, one to two mm in length, build concealed small mounds within the forest

*Figure 4.* Ant mound exposed when the forest floor is removed. The ant mound, composed of B horizon material, originally was placed within the 02 horizon. If the mound is carefully overturned a thin layer of 02 material can be seen under it.

floor in many places (Lyford, 1964) and are common in the study areas at Garpenberg. Neither the mounds nor the ants are ever seen on the surface of the soil. Size of the roughly circular or elliptical mounds varies from 5—7 cm in diameter and 1—2 cm in height (Fig. 4). At certain times of the day ants are busy in the mounds moving soil particles or carrying their eggs or pupa. At other times of the day they are in their chambers and tunnels within the B horizons.

Collections were made from eight of the litter-concealed mounds. *Myrmica ruginodis* Nyl. was the species in five of the mounds. In the other three mounds the species were *Myrmica sulcinodis* Nyl., *M. lopicornis* Nyl. and *Formica fusca* L.

Locations of the concealed ant mounds are shown in Fig. 5. There are about 2—5 mounds per square meter and more are on tree-throw mounds than elsewhere. Most of the ant mounds are recent and are in the process of formation as attested by the activity of the ants around them on a warm day and by the freshly placed material on and in the litter. The newly made ant mounds are composed mostly of brown or reddish brown B horizon material brought from the soil below and originally deposited, for the most part, between the 01 and 02 horizons. This B horizon material is moved upward into the forest floor more or less constantly during the season as the ants build and repair tunnels and chambers in their underground nests. About half the mounds are gray in color and firm in consistence. These seem to be older because there is less evidence of loose, recently moved brown soil particles on their surface. Where the gray A2 soil horizon is thick some of the recent ant mounds are composed entirely of this gray material, but in general the most recent ant mounds are made of reddish or brownish B2 horizon material. Some of the mounds are gray on the outside and reddish within and this suggests that the gray color results from leaching in place and these gray mounds are in fact old enough for notice-

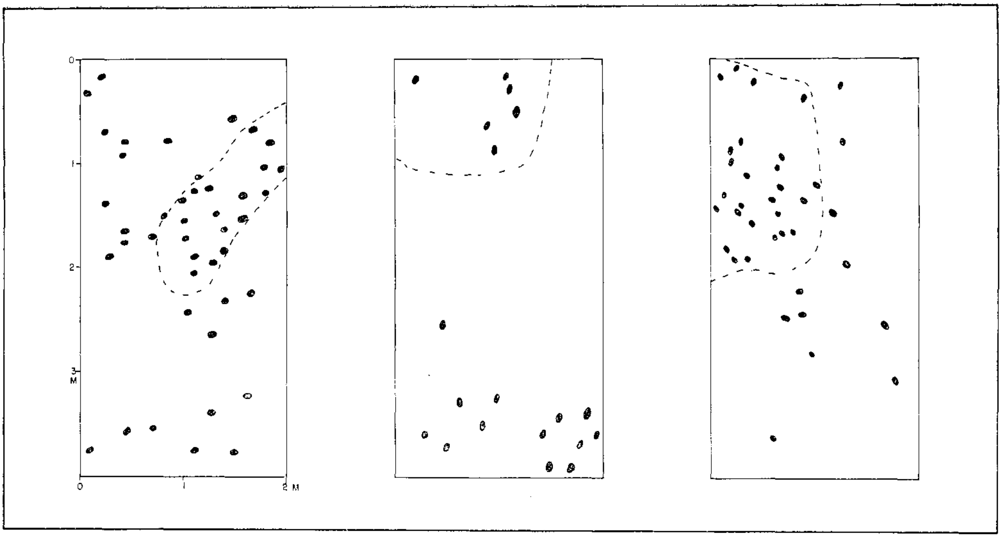



*Figure 5.* Location of small, concealed ant mounds in three 2×4 meter plots on Area 1. Solid black areas show the location of the ant mounds. Dashed lines outline distinct tree-throw mounds.

able leaching to have occurred. This suggests that a study of the ant mounds might provide one means for determining the rate of soil development.

The size range of particles determined for six individually sampled ant mounds is essentially the same as for the soil as a whole. Ants carry particles much larger than their own size but there is of course an upper limit. For this reason there is a tendency for particle size segregation near the surface of the soil in stony and gravelly soils. This effect becomes appreciable over hundreds of years. If for example each of the small ant mounds contains a volume of 30 cc and there are two new mounds per year on each square meter there would be build-up of about 6 cm of soil material on the surface in a period of 1000 years. Ants then may play an appreciable role in the burial of archaeological materials and stones and pebbles.

Large conspicuous ant mounds up to a meter in height and two meters in diameter, composed mostly of needles, occur throughout the forest at intervals of 50—100 meters. These are made by larger ants than the ones that make the litter-concealed small mounds and these larger ants are often seen on the surface of the soil and particularly on their well-marked 1—2 cm wide trails that lead for many meters from mound to mound. Ants collected at two of the large mounds were identified as *Formica lugribris* Zett. and *Formica rufa* L. These large ants carry materials along their pathways but most of the accumulation in the mounds seems to be organic rather than mineral and their influence on the soil is perhaps less than that of the ants that make the much smaller mineral mounds.

# Discussion and summary

The soil in our study area is the result of processes now going on as well as those that have gone on in the past. The present soil represents an integration of many processes working over a long time. In spite of many different processes the soil seems to have a general uniformity from top to bottom and horizons readily can be delineated. For the most part horizons are more or less continuous over long distances and their very presence suggests that the processes now going on are not greatly disrupting the whole body of the soil at once. The day to day disturbance by ants, earthworms, larvae of various kinds, to say nothing of burrowing animals, is easily demonstrated but these disturbances take place within a limited area and except in unusual circumstances the upper horizons preserve their identity for long periods of time.

The trench diagrams used in this study illustrate why one can never be very certain of the overall characteristics of the soil just by looking at the conformation of the surface or relying solely on samples from one or two places. The diagrams show further why Troedsson and Tamm (1969) found that a rather large number of samples must be collected to obtain satisfactory results. Certainly in forested areas the implication of microrelief should be well known to the one who collects samples and eventually the soil scientist learns that each and every bump has a reason for being where it is. In the case of moundpit pairs caused by the overturning of trees the soil scientist may tend to avoid sampling the soil in pits which have a small total area and large amounts of organic matter. On the other hand he will not avoid mound-pit pairs completely because in the aggregate they cover from a quarter or one third of the landscape.

The study we made at Garpenberg is of course exceptionally detailed and this type of study cannot be made everywhere samples are collected. It does provide some idea about the number of different agencies that can act on the soil in any one place and cause it to vary rather markedly from cm to cm.

Considerable emphasis has been made in our study on the importance of living organisms. Ants and earthworms, for example, carry portions of soil from one place to another and may serve a rather important role in some areas in keeping the upper 2—5 cm of the mineral soil constantly mixed so that the soil does not stay in one place long enough for any appreciable thickness of a bleached A2 horizon to develop. Fossorial small mammals (moles, shrews, voles, lemmings, mice) are far more effective than ants and earthworms in moving and stirring the soil but we did not observe their runways at our study area. In the forest floor horizons a myriad of micro and mesofauna also play a large role in decomposition and disintegration of organic matter and they also move it from place to place.

Perhaps the most important function ants perform pedologically (and perhaps ecologically), is to return B horizon material to the surface. This serves the dual function of placing illuval material on top of eluvial material and promoting on the surface of the soil a gradual build-up of mineral material that once was in the horizons below. This return of material to the surface has some importance archaeologically because over a period of a thousand years the effect of burial can be substantial.

The return of mineral material to the surface also means that some of the organic matter within the forest floor is covered by B horizon material and locally at least this makes for an enormous difference in properties. Furthermore, one can make a good case that all the present A1 horizon at Garpenberg at one time was B horizon material returned to the surface by ants. This in turn suggests that there must have been considerable leaching of the sesquioxide-humus substances that once coated the B horizon particles and if so there may be a cyclic process for sesquioxide-humus substances. Still further it is conceivable that the presence of fresh mineral soil in the forest floor may be important for seed germination, root growth or other biological processes.

# Sammanfattning


**Biologiska oregelbundenheter inom små ytor som orsak till variabiliteten i några av skogsmarkens egenskaper i Garpenberg**

Såväl Troedsson och Tamm (1969) som helt nyligen Falck (1973) har för svenska skogsjordar påvisat de kemiska markanalysernas variation inom helt små, likformigt utvalda provytor. De har påvisat nödvändigheten av en statistisk provinsamling för att erhålla representativa analysresultat.

För den pedologiska grundforskningen är det emellertid nödvändigt att detaljstudera orsakerna till variationerna. I föreliggande arbete har endast några få markmorfologiska förhållanden studerats vilka dock i hög grad får anses påverka markens biologiska egenskaper.

Sålunda har bl.a. betydelsen av de levande organismerna studerats. Såväl myror som maskar har stor förmåga att bearbeta och förflytta material i de översta 2—5 cm av mineraljorden, vilket måste påverka A2-horisontens utseende och egenskaper. Intensiteten av myrornas inverkan på markprofilen var mycket tydligt iakttagbar inom provytorna. Även den vindfällda skogens betydelse för markprofilens egenskaper har studerats. Med kemiska och mekaniska analyser påvisas de markmorfologiska oregelbundenheterna.

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