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Fragipan horizons in soils on moraines near Garpenberg, Sweden

"Fragipan"-horisonter i moränen i Garpenberg

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Abstract

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Fragipan horizons in soils on moraines near Garpenberg, Sweden exhibit platy structure, brittleness, numerous 0.1 mm diameter discontinuous pores and segregation of sand, silt and clay in former root channels. The underlying parent material lacks these characteristics. Infilling of root channels by segregation products shows that pedogenic processes are active at the present time within the fragipan horizons.

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Content

Introduction

Soils with fragipan horizons have been described in Canada, Belgium, Scotland, and the United States, among other places. In Sweden fragipan horizons have been recognized in soils on moraines for many years by geologists and soil scientists and named "pressed moraine" because they were thought to result almost entirely from weight of glacial ice. This same concept existed in the United States for many years and the term "hardpan" was used as a name for the hard, dense, brittle material found in many soils on glacial till. In 1948 Nikiforoff, Humbert and Cady made a thorough study of the hardpan in a well known and extensive soil on the Coastal Plain of the eastern United States and described many features that were undeniably of pedogenic origin. Soon after many of these same features were recognized in the hardpan of soils on glacial till as well as in soils on loess, colluvium, residuum and other kinds of deposits. The term fragipan was introduced in 1951 (Soil Survey Staff) as a means of calling attention to the brittleness and as an aid in distinguishing several kinds of hardpans. The genesis and properties of soils with fragipan horizons in the eastern United States are discussed in detail by Grossman and Carlisle (1969) and they also review previous work.

It is the purpose of this report to describe characteristics of fragipan horizons in soils near Garpenberg, Sweden and to call particular attention to pedogenic features of these horizons. Fragipan horizons identical in many respects to the ones at Garpenberg were observed in the Paxton soils at the Harvard Forest (Lyford, Goodlett and Coates, 1963) by the junior author in 1965 and this led to the joint study reported in this paper.

1 Description of study area

The study area at Garpenberg, Dalarna, Sweden is an area where several soil investigations have been made previously (Troedsson, 1953, 1965, Nõmmik, 1967, Troedsson and Tamm, 1969). The well drained soils are Podzols (Spodosols), have well expressed fragipan horizons and are representative of rather extensive areas of similar soils in Sweden. The soils are immediately above the postglacial shore line and so have not been influenced by wave washing, ice rafting or solifluction. They are developed on gently rolling, stony, sandy glacial moraine (till) derived principally from slightly reddish leptite rock and as a result the parent material has a slight brownish hue. Convex areas on the gently rolling landform are 100—200 meters across and have 2—10 percent slope gradients. Concave areas are 50—100 meters wide and tend to be permanently wet and filled with peat.

The plot area where the detailed study of the fragipan was made has a well managed, closed-canopy stand of Norway spruce (*Picea abies*) and Scotch pine (*Pinus sylvestris*) about 40 cm in diameter and 20 meters high. Moss-covered stumps of former trees are uniformly spaced on the plot. The surface of the soil is almost completely covered by mosses; principally *Hylocomium splendens, Pleurozium Schreberi,* and *Ptilium crista-castrensis,* whith clumps of Dicranum spp. and Sphagnum spp. 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 and also have about this same spacing within the solum.

Pits and mounds of former tree throws are almost as prominent as stumps and stones and exhibit a microrelief of 2—30 cm in height. Where there has been a recent tree throw and the upturned root system still persists the microrelief may be as much as 1—2 meters.

2 Procedure

Two areas, each 10×30 meters in size and about 500 meters apart, were used for the fragipan study. Each area was gridded into two-meter squares and vegetation, micro-relief, stones and soil boundaries mapped in detail. Ants and earthworms were identified and their action in moving soil was studied. Trenches were dug in each area and the soil profiles mapped to scale. Soil samples were collected for each horizon in the usual manner, one above the other. Replicate small samples of certain horizons were collected from several places. Chemical and physical analyses were made at the Royal College of Forestry and the methods used were those used by the Soil Survey Laboratories, Soil Conservation Service, U.S. Dept. of Agriculture. Analyses of the soil at this site have been published by previous investigators and Troedsson and Lyford (1973) described the horizons above the fragipan in a paper dealing with biological disturbances.

3 Characteristics of soil horizons

All soils at Garpenberg have numerous stones and boulders on the surface and throughout the solum. In the mineral soil horizons coarse fragments 2—10 mm in diameter range from 10—20 percent by weight, sand from 35—45 percent by weight and silt and clay 35—45 and 15—25 percent respectively.

For convenience in 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 with intermingled recently fallen needles, twigs and bark is called the S layer after Forsslund (1944). 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, and 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 and twigs in various stages of disintegration occur throughout the forest floor horizons and in places woody material is prevalent enough to be included in many samples collected at random.

Sod horizons are the uppermost mineral horizons, so interpenetrated by live grass roots (largely *Deschampsia flexuosa*), that the soil material when removed, holds together as a unit much like the sod from field or lawn. The sod-like appearance of these upper mineral horizons has never been noted in forest soils of northeastern United States, presumably because grass in forested areas is not anywhere near 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 as tongues or pockets. The A1 is massive and held together by roots and mycelium and has enough organic matter content to give it the dark color. In places ant mounds of small size and aggregations of earthworm casts are conspicuous on the surface of the A1 when the forest floor carpet is removed. Ants and earthworms—and probably other fauna—are active enough to keep the A1 well mixed and this to a great extent prevents formation of the thick gray leached A2 horizon so 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 and brownish substances characteristic of the B horizons 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 in undisturbed soils. The subdivisions are made primarily 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).

4 Characteristics of the fragipan-parent material sequence

This sequence consists of the B(x), Bx and C horizons. The brittle, platy, hard fragipan horizon itself is the Bx and it lies about 50 cm below the soil surface. Overlying it is the B(x) horizon which exhibits both weak fragipan and weak sesquioxide-humus properties. For this reason it is often designated as one of the lowermost B2 horizons or even the C horizon. The hard, dense, massive parent material or C horizon lies directly under the Bx horizon at a depth of about one meter.

In the United States some soils with fragipans have a fragipan-parent material sequence consisting of four rather than three horizons. Overlying the B(x) is a grayish, weak platy horizon, the A′2, that in places is nearly continuous and in other places exists as anastomosing sandy vein-like bodies. In a vertical section of the soil these vein-like bodies appear to be discontinuous sandy lenses but when the soil is examined in three dimensions the sandy bodies are shown to be interconnected like the veins and arteries of the human body. Although most of the A′2 material tends to lie horizontally above the Bx horizon it also interpenetrates the fragipan horizon as tongues and is particularly evident where the fragipan has a coarse prismatic structure for then it occurs as conspicuous gray sandy or silty linings between the polygon faces. Particular attention is called to this A′2 horizon because, even though it is not as conspicuous in the fragipan of the soil at Garpenberg as in the Paxton soil of the Harvard Forest where the fragipan is characterized by coarse prisms, yet it does occur on a much smaller scale as infillings along former root channels.

The following detailed description of the fragipan horizon at Garpenberg is mostly from observations made in an excavation four meters wide and 10 meters long. The fragipan was exposed over the whole area. It was examined and sampled by gradually removing the soil material cm by cm.

4.1 B(x) horizon

The upper part of this horizon lies about 40 cm below the surface of the mineral soil and the horizon averages about 10 cm in thickness. It rests in most places directly on the Bx horizon but in places is supplanted by the B23 horizon (Fig. 1). The material in the B(x) horizon is friable to firm in place and can be removed fairly well with a shovel in contrast to the much harder material in the Bx horizon just below which requires a pick to loosen. It is noticeably firmer in consistence than the friable material in the B23 or B24 horizons and it has a well developed, though weakly expressed, thick platy structure in contrast to the massive material in the B2 horizons. Individual platy peds separate from each other readily and are brittle and rigid. The overall impression is of an olive color about like that in the B23 and B24 horizons. Each ped face has a brown color when moist (10 YR 5/6, Munsell Notation) and clay cutans are small but numerous. Interior color is 10 YR 5/3 towards 2.5 Y 5/3. When studied in connection with the horizon below the material in the B(x) horizon seems to be pedogenically related because they both have platy structure, brittleness and clay cutans. Whether the B(x) horizon represents a stage of disintegration of a former Bx or some aspect of fragipan development, or neither, is impossible to say without further study.

4.2 Bx horizon

This is the true fragipan horizon and it is used for diagnostic purposes at a high level

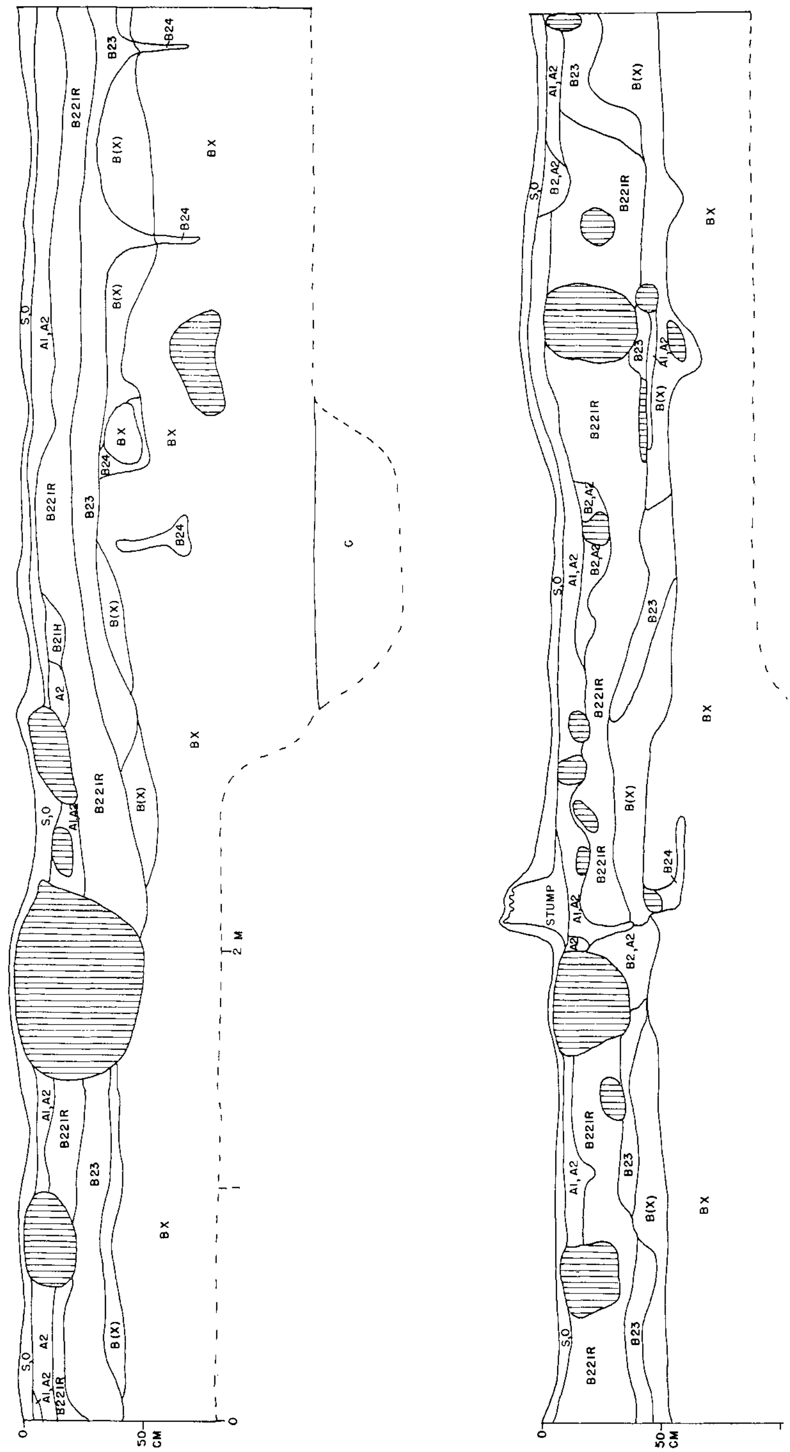

Fig. 1. Scale diagram of soil horizons exposed in both sides of the trench where fragipan horizons were examined in detail. Fragipan horizons are designated by B(x) and Bx. The upper boundary of the Bx horizon is smooth and continuous except in the few places where it is penetrated by tongues of the B24 horizon. Vertically lined areas are stones and boulders.

in the 1965 USDA Classification. In the soil at Garpenberg its main features are the marked contrast in hardness, rigidity, brittleness and structure as compared with the horizons above and below.

The material in this horizon, in gross appearance, is brown when moist (10 YR 5/3), toward light yellowish brown (2.5 Y 5/4). Close inspection shows local color differences that are described later in connection with clay cutans and root channels. The upper boundary of the fragipan lies at a depth of about 50 cm and is abrupt, smooth and parallels the surface as a continuous plane. A few irregularities in the surface smoothness occur in those places where the upper few cm of the fragipan were displaced by tree throw, or where the fragipan is partially penetrated by B24 tongues. The lower boundary is gradual over a thickness of 20—30 cm and is usually at a depth of 1—1 1/2 meters from the surface of the mineral soil. The lower limit can be identified by absence of pores, cutans, platy structure, and by diminution of hardness and brittleness. The lower limit of this horizon is much more gradual than the upper boundary.

Hardness and brittleness are the morphological features first noted for the Bx horizon but platy structure with its associated pores and cutans are also distinct features. Platy peds are 1/2—1 cm thick in the upper part of the horizon and 2—5 cm thick in the lower part. The thinner peds in the upper part are angular and generally somewhat longer (2—5 cm) than wide (1—3 cm). Many of the peds are more or less equidimensional. The platy peds separate readily in planes parallel to the surface of the soil and upper surfaces have denser, siltier appearances than lower surfaces. Peds tend to overlap one another somewhat like shingles on a roof and when separated the edges often have freshly broken fracture faces because the vertical partings are much less distinct than the horizontal partings. Thicker peds in the lower part of the horizon do not separate from each other as readily as those in the upper part, either in the plane horizontal with the surface, or at the edges.

Although nearly as dense as the horizon below the fragipan has numerous discontinuous 0.1 mm diameter pores. There are no vertically oriented gray-surfaced fracture planes or polygon faces such as occur in some fragipans in the United States and, aside from former root channels, there are no places for water to penetrate rapidly. For example, in a trench excavated to the top of the fragipan, water stood for several days following a rain. Individual drops of water placed on the surface of a platy ped were absorbed only after 10 seconds.

Some properties of the fragipan such as pore distribution, clay cutans, silt caps and root channel fillings vary markedly over distances as short as 5 cm whereas the underlying parent material is uniform over long distances. These local variations provide some measure of the amount of pedogenic change now going on—or that has gone on in the very recent past—and show why the fragipan is thought to result mostly from pedogenic rather than geogenic processes.

4.2.1 *Pores*

Both large and small pores occur throughout the fragipan horizon at Garpenberg. Small pores are generally 0.1 mm in diameter and are just visible to the naked eye. Circular entrances to the small pores are common on the upper face of the platy peds and the pores extend into the peds. Most pores, however, are closed on the lower face so the pores do not extend completely through. Pores branch a good deal within the peds and lie in horizontal as well as vertical positions. Mycelial strands often occur within these fine pores and grass roots occur in a few. Although the pores are about the same diameter as the grass roots there is no actual evidence that grass roots cause the pores. As a matter of fact it is difficult to envisage penetration of the dense rigid peds by any kind of roots. Yet grasses, especially *Deschampsia flexuosa,* become the dominant vegetative cover and grow vigorously when the forest is cut or burned. Possibly during these times grass roots are implicated in the formation of pores.

Large pores ranging up to 1 mm in diameter occur between the platy peds and are especially obvious when the platy structure is well developed. These large pores are visible as open channels along the surface when the peds are separated. Rootlets of trees and their decayed remains were seen in these open channels often enough to suggest that these larger pores result from tree root penetration along the zone of weakness between peds.

Most pores in the fragipan are nearly cylindrical and lined with silt or clay. A few are lined with clean fine sand and the inside of these pores resembles sandpaper.

4.2.2 *Clay cutans*

The thin, well developed, platy peds in the upper part of the Bx horizon, when moist, have a faint reddish color on the upper horizontal surfaces. At first glance this reddish material seems to be the sesquioxide-humus substance characteristic of the coats and bridges of the B2 horizons. Close examination under 10—30 power magnification shows that the reddish areas on moist peds are shiny, glazed, gelatinous, discontinuous patches of reddish clay. When dry the reddish colors fade and the surface becomes light gray. If the reddish clay cutans are 1/2—1 mm thick cracks form when the gelatinous material dries. If the material is thin it shrinks and ends up as scattered bits of silt-sized gray clay aggregates. The dry surface of the ped then appears to be covered with numerous "silt" particles. This is the silt-like material often seen around pore openings and in "silt-lined" pores.

4.2.3 *Silt caps—sand beds*

Pebbles, stones and other coarse fragments in the Bx horizon and in C horizon are capped with silt and rest in beds of sand (Fig. 2). The silt cap is 0.5—2 mm thick and covers the top of each coarse fragment and is even on individual sand grains. The silty capping is distinctly finer textured than the adjacent soil material and it adhers strongly to the coarse fragment. It tends to feather out in thickness at the edges of the coarse fragment on which it rests but in places can be traced horizontally into the surrounding finer soil material. In many instances the color of the silty capping is yellower than that of the surrounding material.

The sand bed on which the coarse fragment rests is about 1 mm thick and the loose sand grains appear to be clean and uncoated. When the stone or pebble is removed the loose sandy material that was underneath can be sampled easily with spatula or spoon.

Silt cap and sand bed materials were sampled on and under two stones about 15 cm in diameter. Percent sand and silt for one stone were 25 and 48 respectively for the silt cap and 43 and 26 for sand bed. For the other stone percent sand and silt were 35 and 47 for the silt cap and 62 and 20 for the sand bed.

Silt caps on coarse fragments have been recognized in the northeastern United States by soil scientists for a number of years (they were first pointed out to the senior author by F. J. Carlisle about 1950) and Grossman and Carlisle (1969) call attention to them. They occur in the lower solum of many sandy soils, whether or not the soils have fragipans, and they are also conspicuous deep in the parent material. Apparently the sand bed feature has not been described previously.

The silt cap-sand bed characteristic is a result of segregation of particles and because the platy peds as well as the coarse fragments exhibit this same feature it seems likely that local segregation of sand, silt and clay is an integral part of the process of fragipan formation. Indeed, movement of silt, so well shown by silt caps, may be an important general process that has implications both for geology and pedology. Soil scientists have paid much attention to clay movement and its accumulation within the soil and have devoted very little attention to silt movement.

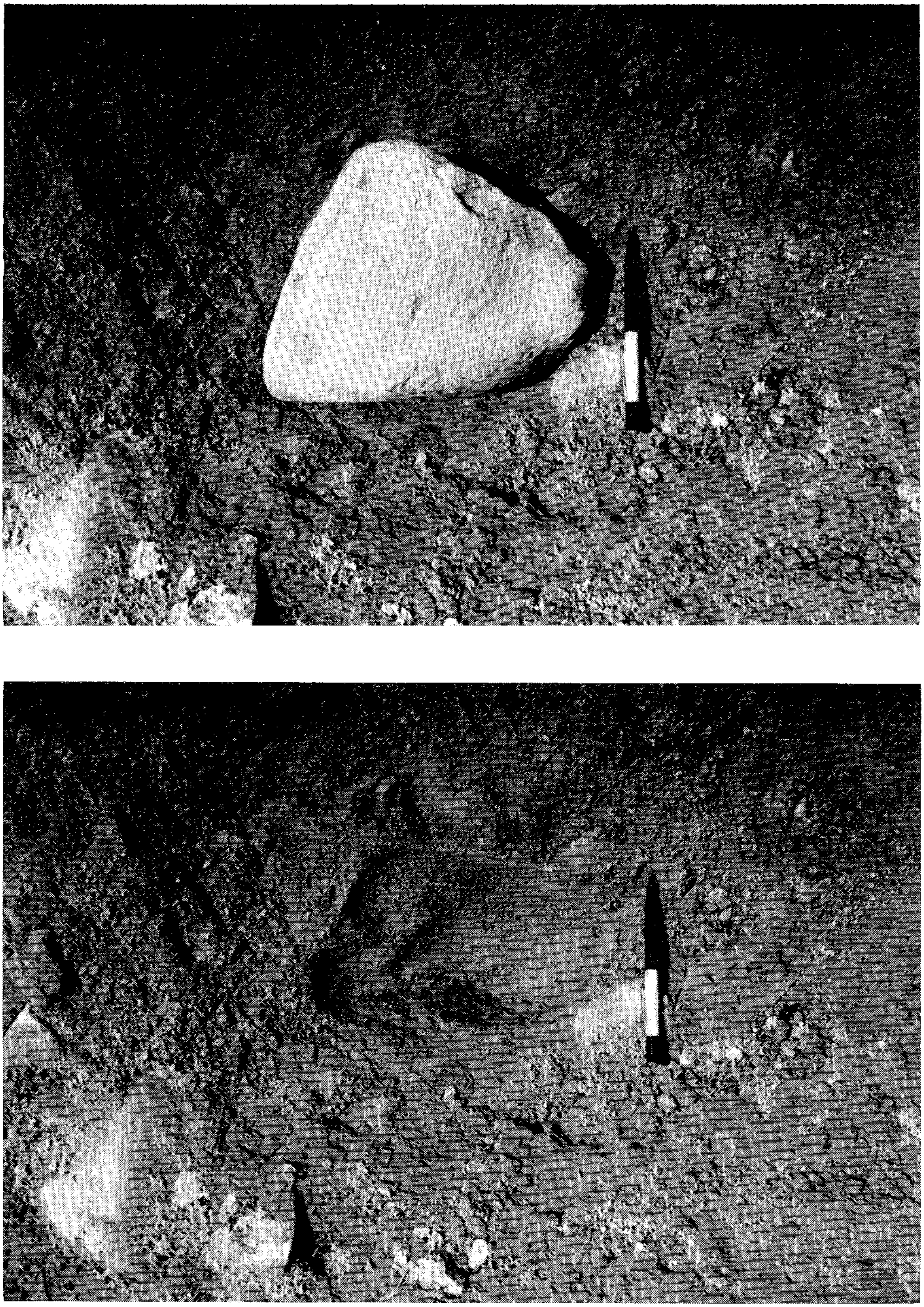

Fig. 2. Silt caps occur on top of stones; sand beds are underneath. The silt cap on top of the exposed stone in the photo shows as a gray surface. Loose sandy material in the cavity that remained when the stone was removed does not show distinctly but the absence of silty material is evident. Silt caps are visible on the nearby partially buried coarse fragments.

Table 1. Particle size distribution of soil materials in root channels within the fragipan.

	Percent		
	Sand 2—.05 mm	Silt .05—.0002	Clay Less than .0002
Open root channel			
Gray sandy A′2-like filling	45.5	37.0	17.5
Gray silty A′2-like filling	35.7	43.3	21.0
Reddish clay-cutan border	35.4	36.2	28.4
Brown fragipan matrix	39.0	37.1	23.9
Filled root channel			
Gray sandy A′2-like filling	46.2	36.2	17.6
Gray silty A′2-like filling	36.6	44.6	18.8
Reddish clay-cutan border	44.4	34.9	20.7
Gray sandy A′2-like filling	49.0	34.0	17.0
Gray silty A′2-like filling	43.9	38.4	17.7
Reddish clay-cutan border	37.5	34.3	28.2
Parent material	41.8	35.8	22.4

4.2.4 *Root channels*

Three features of the fragipan horizon result from the penetration of the fragipan by tree roots. These three are designated as B2 horizon tongues, open root channels and filled root channels.

B2 horizon tongues are funnel shaped and protrude downward at intervals of a meter or so into the hard fragipan layer for 20—30 cm. These tongues of friable B2 horizon material are thought to fill channels formerly occupied by large woody roots that grew at the immediate base of the tree. Taproots or other obliquely descending large woody roots often penetrate the soil deeper at the base of the tree than at other places. Cavities were formed when these large woody roots disintegrated and these cavities were filled with friable B23 or B24 materials as the root decayed. Slumping or collapse of soil material into the root cavities occurs readily when the friable B2 horizon materials are saturated with water. This process certainly takes place continually because persistent open root channels seldom are observed in forested soils and are especially rare in sandy soils.

Open root channels, 2—5 cm in diameter, occur occasionally in the fragipan at Garpenberg. They descend obliquely into the fragipan at an angle of about 45 degrees and extend nearly to the base of the horizon. The channels are filled in the upper part of the fragipan and remain open in the lower half. These open channels appear to be cavities that persist for a considerable time after the woody roots decay although no wood or bark actually was observed in the cavities themselves. Perhaps the lower portions of these root channels were not filled with friable B2 soil material because the woody root material persisted longer here than in the upper part. If not filled the rigid character of the fragipan would prevent subsequent collapse into the open cavity. These open root channels are conspicuous when a trench or pit is dug because they have a light gray lining of silty or sandy materials and contrasting thin red borders. These colors stand out in contrast to the brown color of the surrounding fragipan matrix. The gray material is friable and consists of distinctly sandy soil fairly well distributed around the sides of the channel and siltier material in the bottom of the channel. The adjacent 2—5 mm thick reddish border is very firm and appears to be weakly cemented. The two kinds of gray materials, the reddish bordering material, and the adjacent fragipan ma-

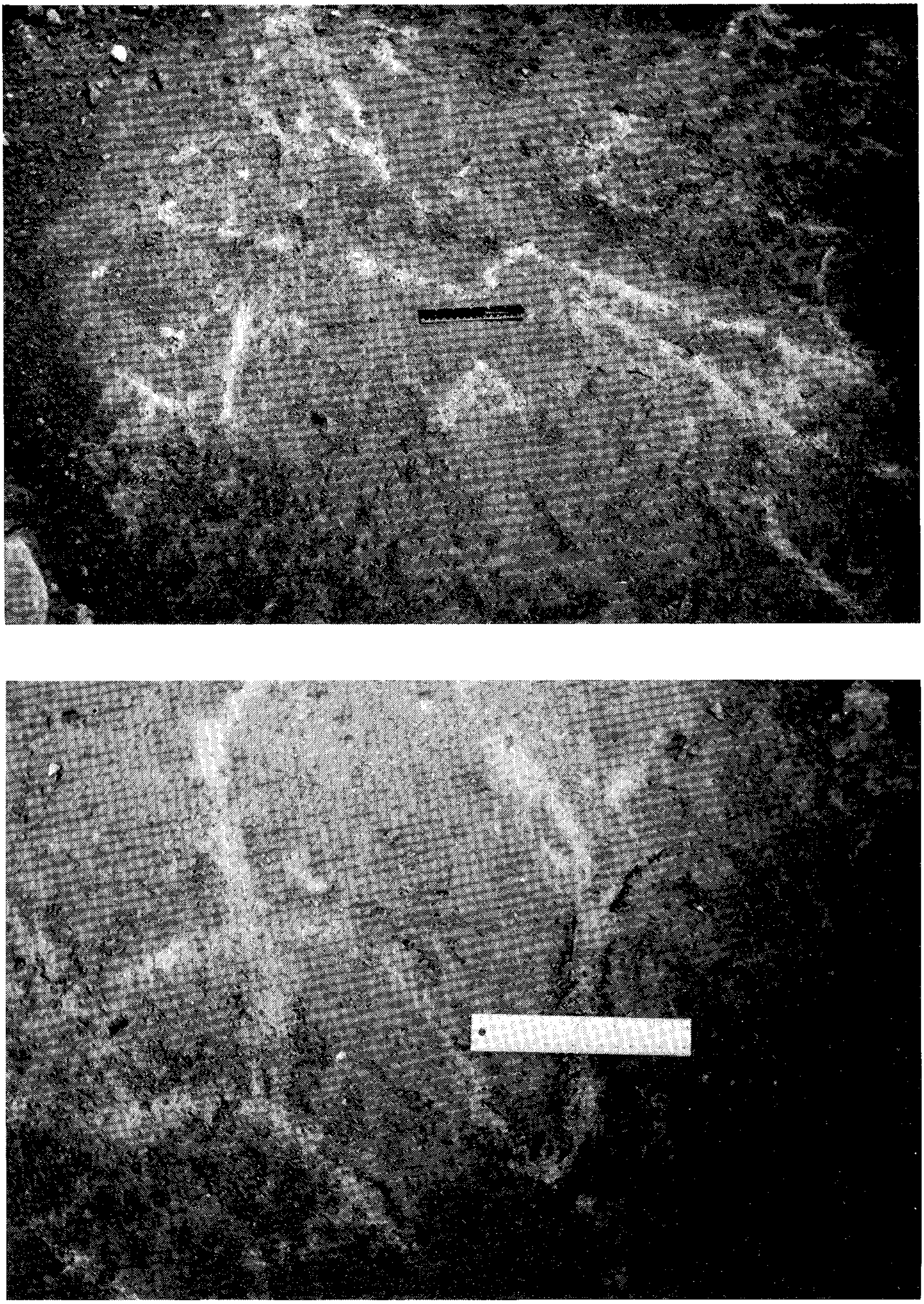

Fig. 3. Horizontal sections through the fragipan horizon. The gray streaks are the gray sandy and silty A′2-like materials in the filled root channels. Strongly expressed reddish clay cutan borders are visible as dark narrow bands just above the 15 cm white scale.

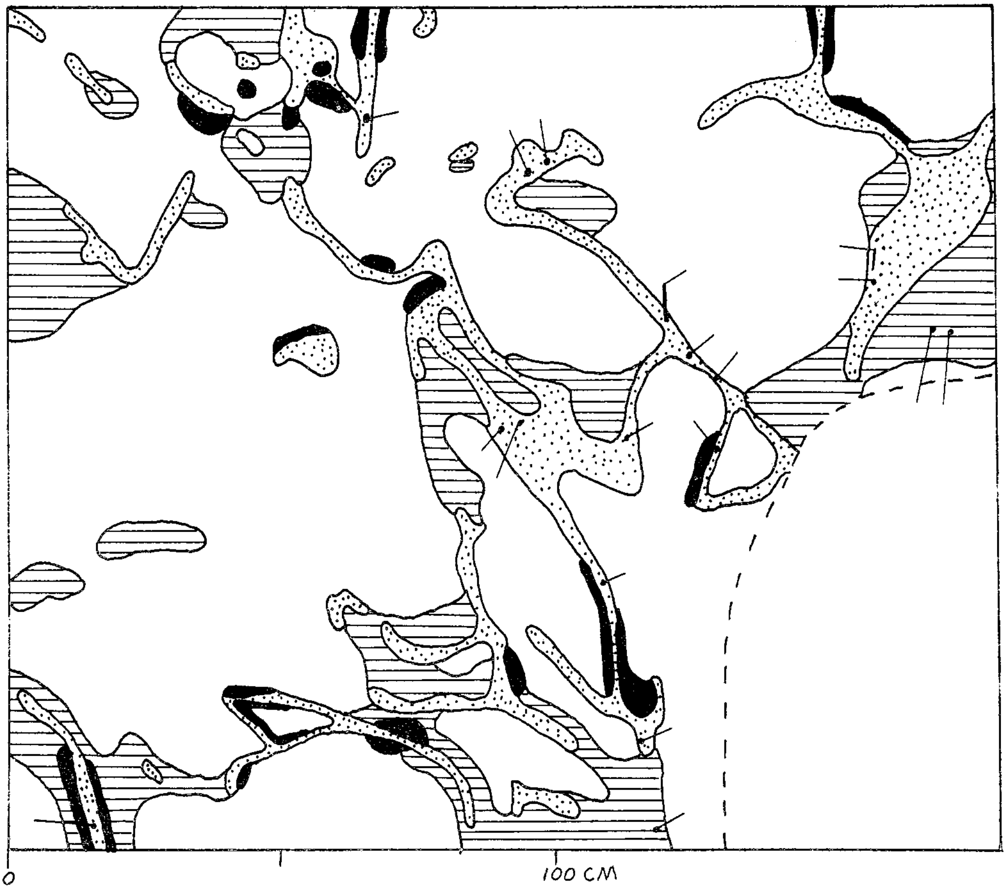

Fig. 4. Scale diagram of a horizontal surface within the fragipan horizon showing the soil pattern around and in filled root channels. Dotted areas—Gray, sandy or silty, friable A'2-like material. Black areas—Reddish, hard, brittle clay cutan material. Lined areas—Gray and reddish materials mingled in about 50—50 proportion. Plain areas—Brown, hard, brittle fragipan matrix. Single bars point to the location of small live roots, most of which are growing vertically downward in friable materials.

trix were sampled carefully in one of the open channels and the particle size analysis is shown in *Table 1.* Although differences exist they are not as pronounced as was anticipated from the contrasting appearance and feel.

Filled root channels occur throughout the fragipan horizon. At first glance these look like gray and red mottled areas such as those in gleyed soils. Close examination shows that the grayish and reddish areas are in filled horizontal channels of former roots. These channels are now filled with gray (10 YR 7/2) friable sandy, or firm silty, materials and are bordered by brown (7.5 YR—10 YR 5/4) materials that have a reddish cast when in place. These reddish areas in some places are mingled with gray and in other places diffuse into the adjacent brown (10 YR 5/3) matrix of the fragipan. Clay cutans are readily visible in these reddish bordering areas. In places both live and dead 1—2 mm diameter tree roots were observed in the friable, gray sandy material but these roots are thought to be secondary and the channels were originally made by larger roots.

Patterns of the materials in the filled root channels are shown in Figs. 3 and 4. Filled root channels have a thickness of 2—3 cm, a width of 10—15 cm, and are oriented horizontally. The horizontal arrangement of the root channels is probably related to the fact that tree roots mostly grow horizontally because of the weakness between the platy peds and they extend to the next level through the zones of weakness at the edges of the peds. This means that the pattern changes markedly over depths of as little as 3—4 cm. Prevalence of the filled root channels is less with depth and at depths greater than one meter below the surface these features are infrequent.

Particle size distribution of component materials in two of the filled root channels is shown in Table 1. The sandy gray fillings have a much higher percentage of sand than the silty fillings but the silt and clay content of these sandy fillings is not as low as expected on the basis of feel between the fingers. The reddish border material has more clay than the adjacent silty gray material and considerably more than the gray sandy material. Considering all samples there is support for the conclusion that the reddish material has at least 2—5 percent more clay than the immediately adjacent materials.

Fragipan horizons in wet soils at Garpenberg are much like those in the well drained soils except there is more cementation, more gray and brown mottling and more reddish clay coatings on the surface of the platy brittle peds.

4.3 C horizon

The parent material (C horizon) is dense, massive and hard. It is uniformly brown (10 YR 5/3) or yellowish brown (10 YR 5/4) in color and there are very few variations of pattern or texture like those of the Bx horizon just above. Although hard in place it is distinctly less firm and brittle than the material in the Bx and the change in brittleness is evident while the pit is being dug. Two other features distinguish it from the fragipan. First, a lack of pedogenic platy structure and second, a lack of fine pores. The C horizon has about the same particle size distribution as the fragipan.

Discussion and summary

The two sites selected for study of fragipan horizons at Garpenberg were both above the upper coastal limit so the parent materials have not been modified since deposition. Fragipan features, therefore, are inherited from the parent material directly or have additional characteristics developed since deposition by pedogenic processes. Obvious changes continually result from the action of ants, earthworms, uprooting of trees and other processes and are easily observed in the upper part of the soil. Results of pedogenic processes in the fragipan horizon are somewhat less obvious. They are evident as platy structure, tongues, pores, clay cutans and open and filled root channels.

Soil scientists regarded the fragipan horizon for many years solely as the upper part of the parent material and called it the C horizon. They seldom had occasion to dig deeply into the underlying material. Following the thorough description of a fragipan by Nikiforoff, Humbert and Cady in 1948 hardpans of all kinds were reexamined closely and it was discovered that hardpans in many soils on glacial till had many of the same features as pans in soils on sedimentary deposits. Gradually soil scientists came to the conclusion that fragipans in glacial till were not necessarily formed by the weight of glacial ice. To be sure Fitzpatrick (1956) made a study of fragipans in Spitzbergen and related the nature of these horizons there primarily to ice action and he pointed out that ice lenses may have been the primary cause of platy structure. And certainly ice once covered the study areas at Garpenberg so it is likely that at least some of the fragipan and parent material characteristics are due to weight of ice or to frost action. However, the fact that fragipan horizons similar in most respects to those at Garpenberg are also found far south of the glacial drift border and are strongly developed in loess deposits argues against the hypothesis that all fragipan characteristics are geogenic. In view of the segregation of sand, silt and clay in fairly recently formed root cavities it is difficult to conceive of this horizon as completely relict. In fact there is much to suggest that pedogenic processes are continually taking place in this horizon.

Sammanfattning

”Fragipan”-horisonter i moränen i Garpenberg

I den geologiska litteraturen har man ofta påvisat s.k. presstruktur i den övre delen av moränerna (G. Lundqvist 1940, Möller och Stålhös 1965 m.fl.). Den skivformigt utbildade presstrukturen anses ha uppkommit genom inlandsisens tryck. På grund av moränernas höga vattenhalt i förening med isens elasticitet är uppkomsten av en sådan struktur tänkbar i samband med moränens bildning.

Ingående markmorfologiska studier (av bl.a. Nikiforoff, Humbert och Cady 1948) har emellertid visat att samma markstrukturfenomen finns i vattensedimentära bildningar, lössbildningar etc., där pressfenomen ej förelegat inom t.ex. icke nedisade områden. I USA har man definierat denna struktur redan 1951 och kallat den för ”fragipan” som i fri översättning skulle bli ”bräcklig skenhälla”, därmed i viss mån angivande att uppkomsten var av pedogenetisk art. I föreliggande arbete beskrivs fragipan-förekomster från Garpenberg. Vid detaljstudier av den inom området förekommande moränen är fragipan eller ”presstruktur” mycket vanlig. Morfologiskt kan man urskilja en tydlig uppdelning av mineralpartiklarna. Sålunda finns rotkanaler, som klätts eller helt utfyllts med lerpartiklar. Porsystem och andra kaviteter kännetecknas också av strukturfenomen, som närmast må hänföras till frostens inverkan.

Fragipan förekommer huvudsakligen i den övre delen av markprofilen (B(x)-, Bx- och C-horisonterna) där de pedogena processerna är mindre intensiva, men dock ständigt pågående. Man kan därför förmoda att fragipan är i högre grad resultat av pedogena processer än att den utgör en reliktstruktur från de geologiska bildningsprocesserna av moränerna.

Acknowledgements

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