

CHARACTERIZATION OF SOILS AND PARENT  
MATERIAL OF THE ARNOTT MORAINÉ IN  
PORTAGE COUNTY, WISCONSIN

by

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## ABSTRACT

The Arnott moraine is a landscape unit located four miles east of Stevens Point in Portage County, Wisconsin. It is a low ridge with 50 to 80 feet relief, is 1/2 mile wide, and extends 18 miles in a north-south direction. The purpose of this investigation is to study the soils and geology of this landscape feature in order to evaluate two theories regarding its origin. The two possible origins are as follows; (1) it is an end moraine of early- or pre-Wisconsinan glacial advance and is composed of glacial drift (hence its name), or (2) it has weathered from granite bedrock, is underlain by weathered residuum and has a granite core.

Significant differences are apparent when topography, drainage pattern, land use, and soil drainage characteristics of the Arnott moraine are compared to those characteristics of the Outer moraine, a Woodfordian end moraine located 2 miles east of the Arnott moraine. The Outer moraine has steep, irregular slopes, many undrained depressions, and the deranged or internal drainage pattern of a youthful glacial landform. Many of the depressions are well drained indicating the moraine is composed of permeable sandy glacial drift.

The Arnott moraine has gentle, smooth slopes with a well integrated drainage pattern characteristic of an older landscape feature. The underlying materials are dense and slowly permeable as indicated by the presence of standing water in road ditches, a few shallow undrained

depressions, and a significant area of somewhat poorly drained soils on the features gently sloping uplands.

Field investigations of soils and observations in 2 soil pits on the Arnott moraine revealed the presence of 2 or 3 different layers of materials in each soil profile. The C horizon or parent material at each site was sandy loam to loamy sand in texture and contained numerous rounded erratics of gabbro and basalt which often had pronounced weathering rinds.

Well drillers provided samples and logs for wells drilled in the Arnott moraine. Materials penetrated by these wells consisted of 50 to 80 feet of dense loam underlain by coarse sand and gravel considered to be glacial outwash. Ice-wedge casts have been observed on the Arnott moraine and are not found on the Outer or other Woodfordian moraines to the east. This suggests the Arnott moraine was ice-free and subjected to permafrost conditions before or during the time when the Outer moraine was being deposited.

Based on the field observations and data from laboratory analyses, the Arnott moraine is considered to be a remnant of a moraine formed during an early-Wisconsinan (Altonian) or pre-Wisconsinan (Illinoian) ice advance. This landform was largely buried by the more recent advance of the Woodfordian age Green Bay lobe of the Wisconsinan ice sheet. The small portion of this older moraine not covered by deposits of the Green Bay lobe is the landscape unit currently designated as the Arnott moraine.

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## INTRODUCTION

The Arnott moraine studied in this thesis is a landscape unit located four miles east of Stevens Point in the township of Stockton in Portage County, Wisconsin (Fig. 1 and 2). This ridge of glacial drift extends approximately 18 miles in a north-south direction. The soils of this region have developed in sandy materials over glacial till under mixed deciduous and conifer vegetation.

As a landscape unit, the Arnott moraine is unique in this part of Portage County because of its composition, stratigraphy, and surface topography. The smooth, gently sloping topography and the lack of undrained depressions or kettles strongly indicate this feature is older than moraines a few miles to the east. The Outer, Second, and Eldron moraines in eastern Portage County exhibit youthful topography with steep slopes and numerous undrained depressions.

Questions have been raised about the origin of the Arnott moraine. Two possibilities have been suggested; (1) the feature is a remnant of an older glacial end moraine that has been partially buried by the westward advance of the Woodfordian ice sheet out of Green Bay, or (2) it is a bedrock controlled landform with a solid granite core. Its origin as a glacial end moraine is generally accepted, but the recent soil survey of Portage County (SCS Interim Soil Survey Report) shows soils underlain by granitic bedrock on the portion of the moraine studied in this thesis.

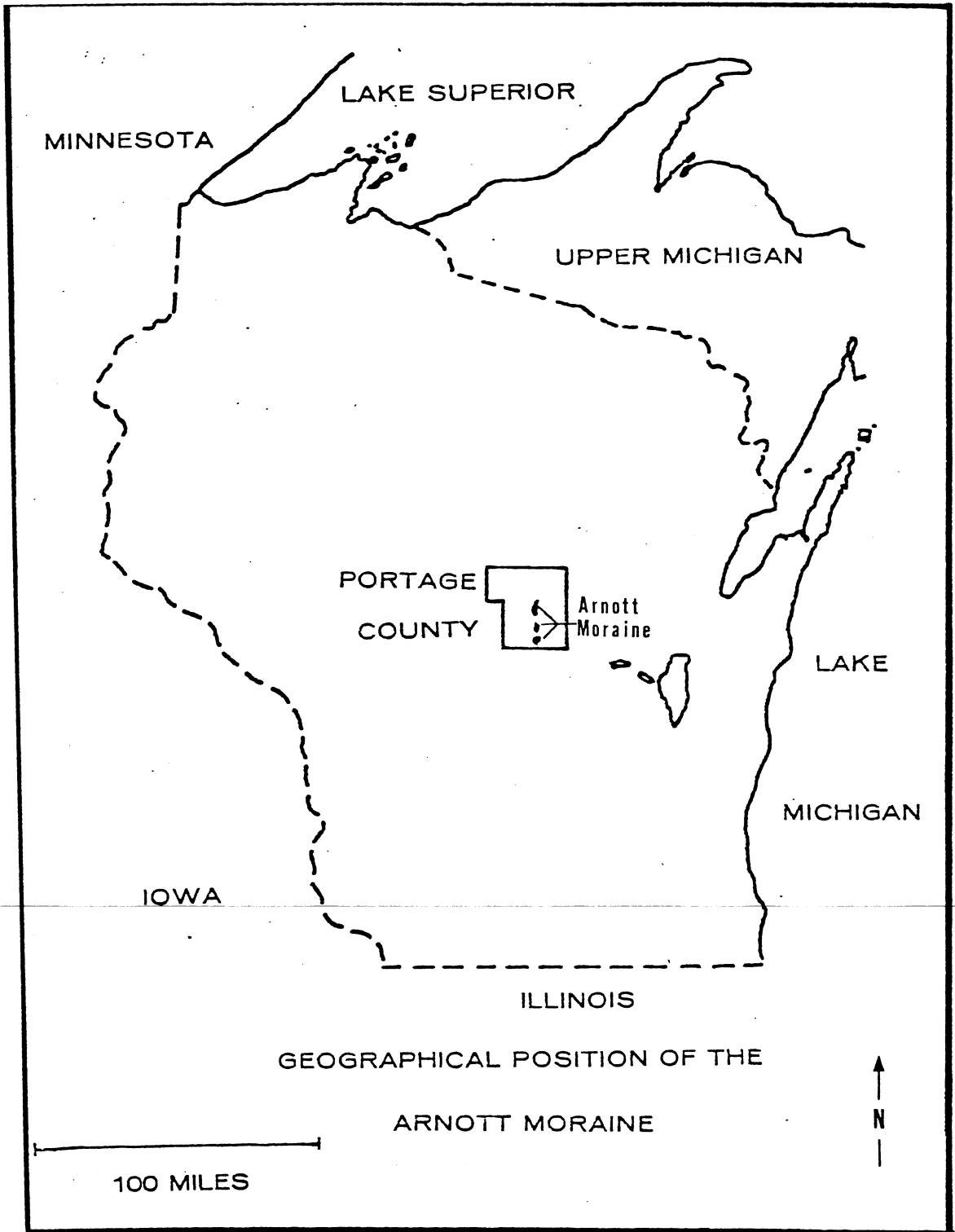


Figure 1. Location of the Arnott moraine in Central Wisconsin.

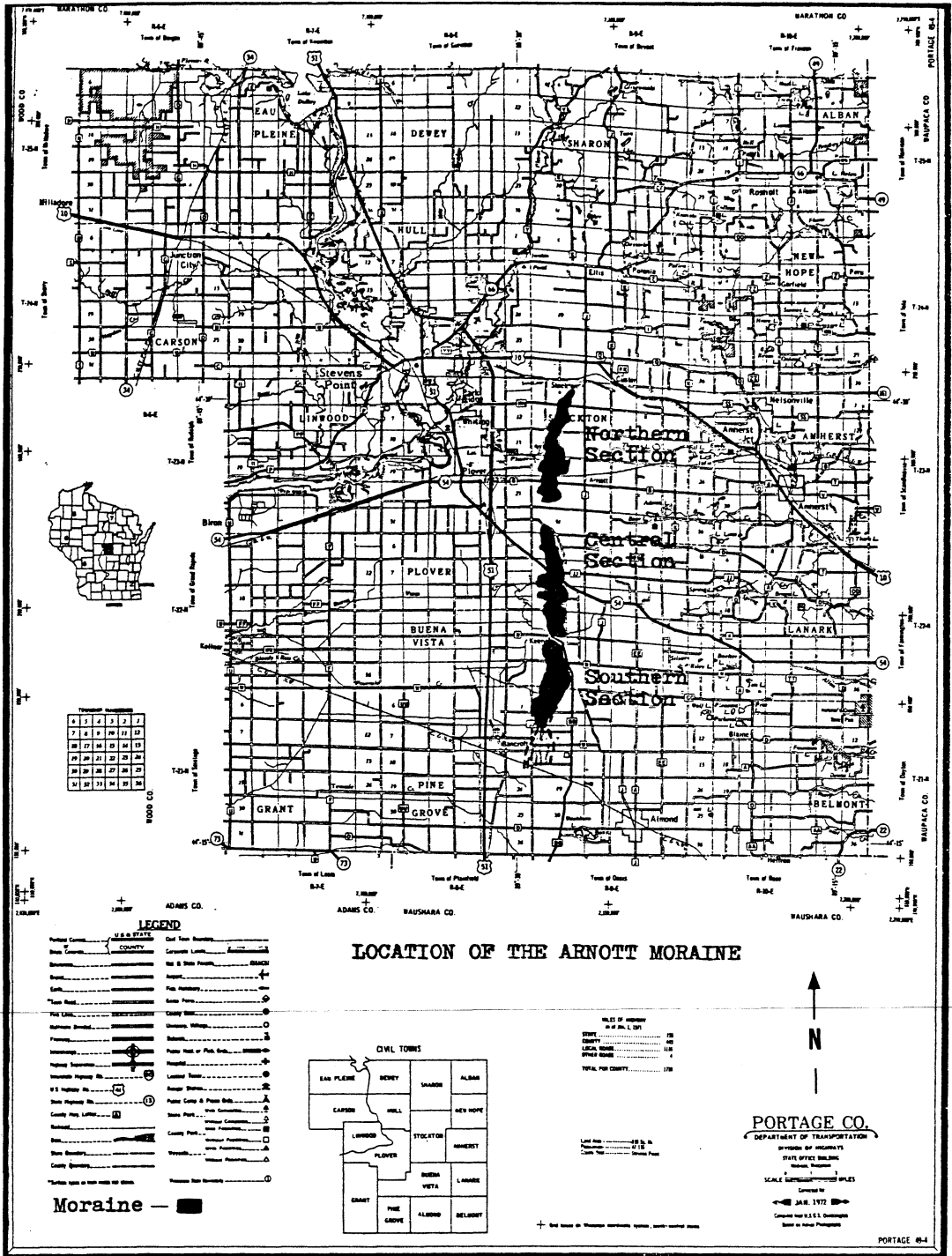


Figure 2. Location of the Arnott moraine in Portage County.

The purpose of this paper is a geologic and pedologic study of the Arnott moraine and includes three primary objectives. These objectives are; (1) acquisition of data to determine the origin of this landscape feature, (2) complete a chemical and physical analysis of the dominant soil series found on the feature's northern section, and (3) compare present and past land uses to determine changes in land use since 1938.

The data presented in this thesis includes physical and chemical characterization of soil profiles from two locations on the Arnott moraine. Soil properties described at both sites included color, texture, structure, consistence, and horizon designations and boundaries. Laboratory analyses of samples included bulk density, particle size distribution, pH, organic matter content, exchangeable cations, exchange acidity, and cation exchange capacity.

Additional field investigations were conducted to answer questions regarding the origin of this landscape feature. These included discussions with land owners and the acquisition of subsurface samples from well drillers.

## LITERATURE REVIEW

## Glacial History

The Wisconsinan Stage of glaciation began approximately 75,000 years ago and is divided into five major substages, three glacial and two interglacial. These substages and their durations are shown in table 1.

Table 1. Substages of the Wisconsinan Stage of Glaciation. Time is in radiocarbon years before present. After Frye et al. (1968).

Name of Substage	Time in Years Before Present	Length of Duration	Type of Substage
Valderan	5,000 to 11,000	6,000	Glacial
Twocreekan	11,000 to 12,500	1,500	Interglacial
Woodfordian	12,500 to 22,000	9,5000	Glacial
Farmdalian	22,000 to 28,000	6,000	Interglacial
Altonian	28,000 to 75,000	47,000	Glacial

The exact time for deposition of the Arnott moraine is uncertain. This feature is generally considered to be older than the Woodfordian moraines to the east. In the past, several Authors (Leverett 1932, Thwaites 1946, and Weidman 1907) have suggested this feature to be Illinoian in age. However, Hole (1942) is uncertain whether the time of deposition was Illinoian or early Wisconsinan.

The Illinoian and Wisconsinan Stages of glaciation are separated by the Sangamonian Interglacial period which lasted approximately 100,000 years. The Sangamonian period was characterized by a warm, moist climate with temperatures averaging 2 to 3 degrees warmer than today (Flint 1971). This would be very conducive to chemical weathering of parent materials in the drift and clay formation in soils.

The majority of the glacial drift in the moraine contains enough clay to be classified as a loam. Much of this clay may have formed to the north and east of what is now Portage County during the Sangamonian Interglacial period. Advancing glaciers of the Altonian Substage may have picked up these weathered materials and deposited some of them in a terminal moraine. This terminal moraine probably existed as a more extensive landscape feature until the advance of the Green Bay lobe of the Woodfordian Substage. As the Green Bay lobe advanced it buried or covered nearly all of the moraine, except for a short section in Portage County. The section or remnant of the Altonian moraine not buried is the Arnott moraine of today (Figure 3). According to this hypothesis, the Arnott moraine would be Altonian or early Wisconsin in age, but it may be older. The main factors used to age the moraine are the surface topography and the clay in the glacial drift, assuming these clays could only have formed during the Sangamon Interglacial period or possibly before.

An interesting feature of some stones and cobbles found in the glacial drift of a soil profile near highway HH was the presence of weathering rinds (Figures 4 and 5). These weathering rinds were observed on all gabbro and diorite samples found in the II B horizons. Granitic stones were lacking in these horizons while chert and quartz pebbles did not show any signs of weathering.

The rinds on all samples are relatively soft and can be removed by rubbing or scratching with a fingernail.

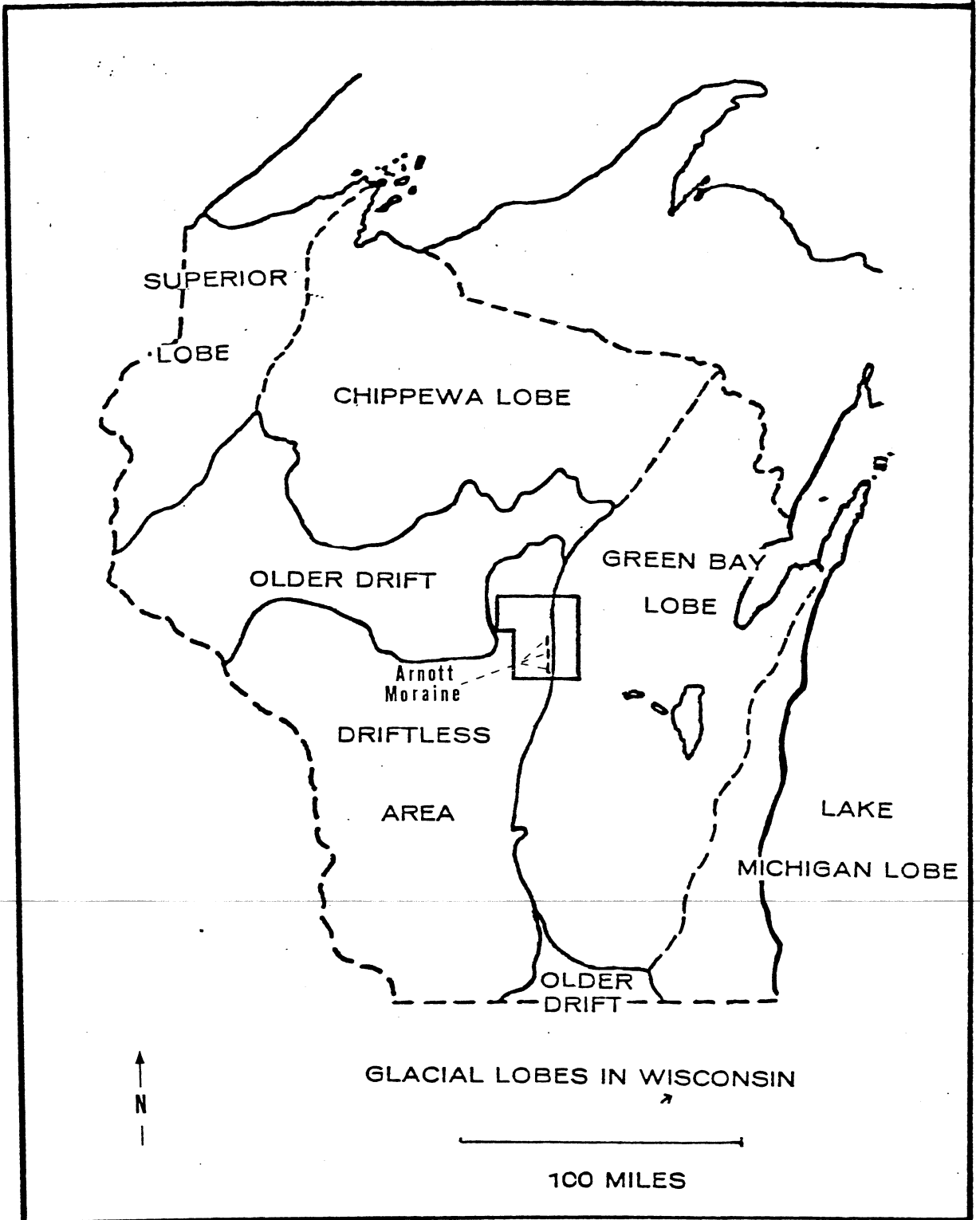


Figure 3. Location of the Woodfordian glacial lobes in relation to the Arnott moraine. After Martin (1932).



Figure 4. Weathering rind on a sample of gabbro. Surface cut and polished.



Figure 5. Weathering rind on a sample of gabbro. Surface freshly broken.

For this reason, it is assumed any glacial transport and abrasion would have easily removed the weathered material. Therefore, the present weathering rinds are assumed to have formed after deposition of the moraine.

Weathering rinds are a product of chemical weathering with their rates of formation depending on time, climate, parent material, vegetation, and position in the weathering profile (Colman 1977). The most important lithologic factors affecting the rate of weathering are grain size, degree of fracturing, and compositional zonation of the constituent minerals. According to Colman (1977), the formation of weathering rinds on basic stones is due to degradation of the primary minerals rather than to formative processes. These studies also indicated that the primary minerals in basic stones weather to an amorphous mixture of allophane and iron oxide-hydroxide. For this reason, weathering rinds do not contain significant amounts of crystalline clay minerals.

~~Based on models studied for dated deposits, weathering~~  
rind thickness appears to be a logarithmic function of time, and both Birkeland (1974) and Colman (1977) believe they can be used as relative age indicators. However, since the factors affecting weathering can vary considerably, the logarithmic time function must be calibrated for the local area under investigation. A search of road cuts and borrow pits in the Outer moraine did not reveal the presence of weathering rinds. However, detailed field investigations were not conducted and the presence or absence of weathering

rinds in the younger moraines was not established.

Another question concerning the Arnott is one of mode of formation or origin. Nearly all past literature has considered the Arnott ridge as a glacial feature. However, a recent study of soils in this region (SCS Interim Soil Survey Report) has indicated granite bedrock may lie within a few feet of the surface. The slow permeability and fine textured materials observed by the Soil Conservation Service personnel has been interpreted as indicating the presence of granitic residual material, suggesting this feature is a bedrock controlled landform. This information was also reported in the Portage County Areawide Planning Committee, Report No. I (1973).

#### Previous Investigations Of Glacial Materials And Soils

The Arnott moraine has not been intensively studied to date. It has been discussed by several authors, but usually in relation to research being conducted in the surrounding area. The comments by these authors usually referred to possible ages and correlation with other glacial deposits. Weidman (1907) thought the moraine was Illinoian in age. Leverett (1929) and Thwaites (1946) briefly discuss the moraine and indicate its formation may have occurred during Illinoian time. Hole (1942) mentions the moraine, but is uncertain whether it is Illinoian or early Wisconsin in age.

Other work on the Arnott moraine includes a study of the ground water hydrology and water table measurements in the Little Plover River drainage basin by Weeks et al (1965).

This study indicates the ground water flows unrestricted beneath the moraine. Holt (1965) describes the Arnott moraine but only gives a short description of work already done by Ieverett, Thwaites, and Hole.

Black (1971) reported on a study of ice-wedge casts at several sites in Wisconsin, including a site on the Arnott moraine 9 miles southeast of Stevens Point, Wisconsin. This study was aimed at locating and describing ice-wedge casts and little information was presented on the moraine itself. Black did describe two generation casts at the site and indicated these were not found at other sites in Wisconsin, indicating again the greater age of this feature when compared with surrounding glacial features.

The two generations of ice-wedge casts described by Black seem to indicate two periods of permafrost conditions following the formation of the moraine. According to Black's observations, the two generations of ice-wedge casts are separated by a "slight discontinuity". He further states that the tops of both upper and lower casts have been truncated and "the upper casts do not penetrate the discontinuity nor do they join or cut the lower casts". This information seems to indicate that a second glacier or the readvance of the original glacier may have covered this portion of the moraine. The site described by Black was not located during the field work for this paper. This exposure may have been covered by vegetation or possibly destroyed by removal of gravel and road fill.

An interim report on the soil survey of the Arnott

moraine and its surrounding area by the SCS is available. This report contains soil interpretation sheets and soil maps which show the northern section of the moraine to be dominated by two soil series, the Mosinee and the Point. The Mosinee series is characterized as a well drained loamy soil underlain by weathered residuum from granitic bedrock. This soil is moderately permeable and has a medium available water capacity. The Point series is classified as a somewhat poorly drained sandy soil over acid loam residuum from weathered igneous bedrock. This soil is moderately permeable with a medium available water capacity. These soils were mapped only on the northern section of the moraine and this study is confined to that portion of the moraine.

## PROCEDURES

### Field Procedures

#### General Description of the Arnott Moraine

The Arnott moraine extends in a north-south direction and is approximately 18 miles long (Figure 2). The Average width is approximately 1/2 mile with elevations ranging between 50 and 80 feet above the surrounding outwash plain. The northern end of the moraine appears to be buried by the Outer Woodfordian moraine in an area one mile west of Custer, Wisconsin. The southern end of the moraine appears to be eroded and gradually fades out in the area between Bancroft and Almond, Wisconsin.

The moraine is divided into three segments by two erosion cuts; the northern cut being 1/2 mile south of highway 54 and the southern cut located 2 1/2 miles south of the junction of highways 54 and BB. These erosion cuts were probably formed by melt water from the Green Bay lobe of the Woodfordian ice sheet.

Erosion has been an important factor in shaping this feature. The surface topography consists of smooth, uniform slopes averaging four per cent with a well integrated drainage pattern which contrasts with the poorly integrated drainage pattern and variable slopes on the Woodfordian moraine. The moraine is surrounded by a plain of sandy outwash. The portion of the plain lying to the east of the moraine is 15 to 50 feet higher in elevation than the plain to the west. The increased elevation to the east is due to a "damming" effect of the Arnott moraine. When the

Woodfordian (Cary) ice sheet began to retreat, the Arnott moraine held back or dammed up large amounts of glacial outwash. This glacial outwash partially filled in the narrow valley between the Arnott moraine and the retreating ice sheet, resulting in elevations 15 to 50 feet higher for the eastern plain.

Soils were examined on the moraine using a spade and auger, and by observation in soil pits and building excavations. These observations provided general information on the types and variations of soils and parent materials in the moraine.

#### Sampling Site

Soil profile samples from a soil pit near highway HH and a building excavation along highway B (Figure 6) were studied in the laboratory. Location of the soil pit was decided on after examining several potential sites with a spade and soil auger. The final site was located approximately 300 feet south of highway HH in the NE 1/4, NW 1/4, NW 1/4, of Sec. 7, T23N, R9E in Portage County, Wisconsin. (Figure 6). This site is located in the northern section of the moraine which is the main area of study and where the Point and Mosinee soils were mapped by the SCS.

A soil pit was dug by hand to a depth of 86 inches. Deeper excavation was stopped by a layer of closely packed stones and boulders that could not be penetrated with a barrel auger. Each horizon was sampled for laboratory analysis starting with the lowest horizons and working up to avoid contamination of the lower horizons. Samples

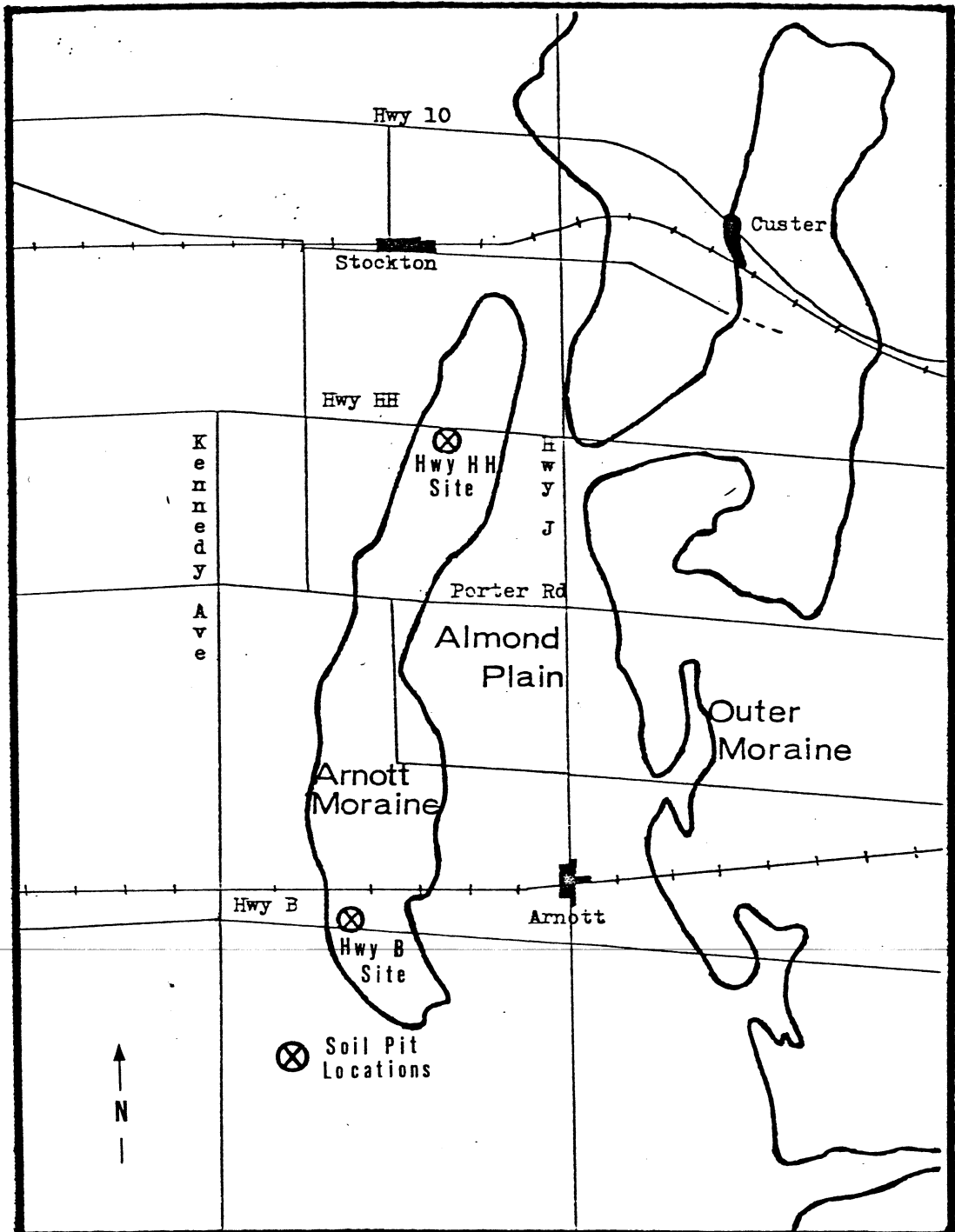


Figure 6. Location of the highway HH and highway B soil sites.

from a second profile for laboratory analysis were obtained from a basement excavation along highway B.

Additional subsurface samples and information about depths to various materials were obtained from local well drillers working on the moraine. These samples provided information about the interior stratigraphy of the moraine, general composition and types of materials both in and beneath the moraine.

All of these samples were obtained by the "cable drilling method" which operates on the same basic principle as a pile driver. A 12 foot long, 400 pound steel shaft attached to a steel cable and drilling tower is repeatedly raised and dropped inside a 4 inch steel casing. While the shaft is operating, water is poured down the casing and the "pounding action" of the shaft produces a

slurry which is removed by a cylindrical bucket with a one-way door. Figure 7 shows the cable drilling rig used



Figure 7. Cable drilling rig used at the Porter road site.

at the Porter road site. This method is ideal for use in areas with glacial or alluvial deposits where bedrock is not encountered and wells need not be larger than 4 inches in diameter. Particle size analysis of these samples is not possible because the size distribution is altered by the drilling process.

Additional subsurface data was also obtained using the Soiltest 120 seismometer. Information on the subsurface stratigraphy was obtained at the Porter road site in September, 1977 with the assistance of Gene Tubbs. Use of the seismometer requires a starting point at which subsurface data is already available. Since a well had recently been drilled at the Porter road site and subsurface data was available, this area was selected for seismic study. Due to interference from vehicular traffic, aircraft and wind, the gain on the seismometer had to be reduced, resulting in less than optimum data. However, conformation of some subsurface data was obtained.

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#### Laboratory Procedures

##### Particle Size Distribution Analysis

Particle size distribution analysis was accomplished by mechanical sieving and the Hydrometer method of Bouyoucos (1962). Soil samples were air dried for six days in air drying ovens at 80° C. U.S. Standard 8 inch diameter sieves were used to separate the fine earth fraction from the gravel fraction and to separate the gravel fraction into six size classes.

The hydrometer method is based on Stokes' law which

states the diameter of a spherical particle of known density can be determined from the rate at which it falls in a liquid of known viscosity. Stokes' law is expressed by the equation;

$$v = \frac{2r^2 (d_p - d_f) g}{9m}$$

Where  $V$  = velocity in centimeters per second  
 $r$  = radius of particle in centimeters  
 $d_p$  = density of particle in grams per cubic centimeter  
 $d_f$  = absolute density of fluid in grams per cubic centimeter  
 $g$  = force of gravity in centimeters per second squared  
 $m$  = viscosity of fluid in centipoises

Stokes' law can be applied to determine the percentages by weight of the different particle size classes present in a given soil sample. The rate at which a particle falls through a liquid medium is dependent on the difference between the upward and downward forces.

In order to achieve accurate measurements the particles must be completely separated or dispersed without any aggregates remaining. This can best be accomplished by using a dispersant such as sodium hexametaphosphate -  $\text{Na}(\text{PO}_3)_6$ . If the particles are cemented by organic matter, iron, or other cementing agents, these cements must be broken down to free the individual soil particles. Soils undergoing organic matter removal with hydrogen peroxide ( $\text{H}_2\text{O}_2$ ) must also be treated by dialysis to remove soluble salts.

The A1 horizon samples were treated with hydrogen peroxide (30%) for removal of organic matter. Soluble

salts formed during the organic matter treatment were removed by placing the soil samples in dialysis membranes. Soil samples were placed in membranes and allowed to stand in a flowing water bath for 48 hours. All soil samples were then oven dried for 24 hours at 105° C.

Hydration of soil particles and slaking of soil aggregates was accomplished by placing 50 gram soil samples in a dispersing solution of sodium hexametaphosphate -  $\text{Na}_6(\text{PO}_3)_6$ . The  $\text{PO}_3^-$  anion in the dispersing solution precipitates the exchangeable and soluble cations which are replaced by the  $\text{Na}^+$  cation. Since the sodium cation has a large hydrated radius and an electrical charge of only plus one, dispersion is readily accomplished. To aid in further particle separation, all samples were placed in electric mixers for 10 minutes following the 24 hour hydration period.

When particle dispersion was completed the samples were placed in graduated cylinders and brought to a volume of 1000 milliliters with distilled water. Using the modified equation derived from Stokes' law, the time required for particle size classes of .05, .05 to .02, .02 to .005, .005 to .004, .004 to .002, and .002 millimeters was calculated. Each suspension was agitated by hand and timing was started immediately after agitation. The following formulas were used to determine the percentages of clay, silt, and sand.

$$\% \text{ Clay} = \frac{\text{Corrected 6 hr. 52 min. hydrometer reading}}{\text{Weight of sample}} \times 100$$

$$\% \text{ Silt} = \frac{\text{Corrected 40 sec. hydrometer reading}}{\text{Weight of sample}} \times 100 - \% \text{ Clay}$$

$$\% \text{ Sand} = 100 - (\% \text{ Clay} + \% \text{ Silt})$$

### Bulk Density

Measurements of bulk density were made by two different methods. The bulk density of the loose, sandy upper horizons was determined with the core sampler using the method described in Black (1971). Measurements of the lower clayey horizons were accomplished by the Saran coated clod method described in the Soil Survey Investigation Report No. 1 (1972). This method uses the resin Dow Saran F310 and methyl ethyl ketone as a solvent.

Natural soil clods approximately 50 cubic centimeters in size were immersed in a 1:8 ratio solution of Saran to solvent. After the Saran solution had dried, the clod was weighed in air and water to determine its volume. The clod was then oven dried at 110° C. for 24 hours and weighed again. Clods were broken apart to check for rock fragments larger than 2 millimeters in diameter. Bulk densities were then determined as oven dry weight divided by the volume of the clod.

### Organic Matter Content

The organic matter content of the A1 horizons was determined by the Walkley-Black method (Black, 1973). Soil samples were ground to pass a 0.5 millimeter sieve and then oven dried at 105° C. for 24 hours. Samples weighing 0.5 grams were thoroughly mixed with 10 milliliters of potassium dichromate ( $K_2Cr_2O_7$ ) and then added to 20 milliliters of concentrated  $H_2SO_4$ . This solution was allowed

to stand for 30 minutes and then diluted with 200 milliliters of distilled water to which four drops of mixed indicator had been added. The solution was titrated with 0.5 N ferrous sulfate ( $\text{FeSO}_4$ ) to a red endpoint.

The per cent of organic carbon present in the soil was calculated by using the equation;

$$\% \text{ Organic Carbon} = \frac{\text{Meg K}_2\text{Cr}_2\text{O}_7 - \text{Meg FeSO}_4 \times 0.003}{\text{Grams Soil}} \times 1.33$$

The result of this equation was multiplied by 2.6 to obtain the per cent of organic matter present in the soil.

### Soil pH

Soil reaction was measured using the method described in Black (1973). Soil samples of 20 grams were added to 20 milliliters of distilled water and stirred several times during a 30 minute period. The soil suspension was then allowed to stand for one hour so most of the suspended clays would settle from the solution.

The Corning Model 12 Research pH Meter was used to make all measurements. The electrodes were positioned so that the glass electrode was immersed in the settled suspension with the calomel electrode immersed only in the clear supernatant solution. Reading were taken to the nearest 1/10 pH unit.

### Exchangeable Bases

Exchangeable calcium, magnesium, potassium, and sodium were determined using Chapman's methods of ammonium saturation (Black, 1973). Soil samples of 10 grams were added to 250 milliliters of neutral 1N  $\text{NH}_4\text{OAc}$  and allowed to stand for 24 hours. The suspension was then filtered and

the sample was leached with additional 1N  $\text{NH}_4\text{OAc}$ .

The amount of calcium and magnesium present in the solution was determined in parts per million using the Perkin-Elmer 139 Spectrophotometer. These results were compared to a standard curve to obtain the amounts in milliequivalents per 100 grams of soil.

The amount of potassium and sodium in solution was determined with the assistance of Dick Stephens using the Perkin-Elmer Model 360 Atomic Absorption Spectrophotometer. The results were compared to a standardized curve to obtain parts per million in the soil and milliequivalents per 100 grams of soil.

#### Exchange Acidity

Exchange acidity was determined by the Barium Chloride-Triethanolamine method (Black, 1973). Soil samples of 10 grams were added to 100 milliliters of 0.5N  $\text{BaCl}_2$ -0.055N triethanolamine extracting solution and allowed to stand over night. The soil suspension was then filtered and leached with additional extracting solution to a volume of 255 milliliters. After leaching, the extracting solution was used to bring the suspension to a final volume of 250 milliliters.

The leachate was placed in a 500 milliliter Erlenmeyer flask to which 5 drops of mixed indicator solution had been added. The solution was then titrated with 0.2N hydrochloric acid to a pink end point. This same procedure was done on 250 milliliters of blank extracting solution without a soil sample.

The exchange acidity was calculated in milliequivalents per 100 grams of soil using the equation;  $EA = (B-S)10N$ .

Where EA = exchange acidity  
 B = milliliters of acid required to titrate  
 250 milliliters of extracting solution  
 S = milliliters of acid required to titrate  
 the soil extract  
 N = normality of the acid

### Cation Exchange Capacity

The total cation exchange capacity was determined by summation of the exchangeable cations as described in Black (1973). The amounts of  $Ca^{++}$ ,  $Mg^{++}$ ,  $K^+$ ,  $Na^+$ , and  $H^+$  and  $Al^{+++}$  were added together to give the total cation exchange in milliequivalents per 100 grams of soil.

### Land Use

A study was made of the land use on the Arnott moraine in 1938 and 1977 and a comparison drawn between these two studies to show the changes in land use over the 40 year period. Land use in 1938 was determined from 1:15,840 scale black and white air photos. After land use categories had been determined, areas of specific land use were traced on transparent overlays. The land use in 1977 was determined from a study of 1:48,000 scale black and white 1975 air photos and up dated with field observations.

The information on the plastic overlays was transferred to a base map using the Alan Gordon Model 260 Vertical Sketchmaster. The base map had been prepared from 7.5 minute quadrangles with a scale of 1:24,000. The area of each land use category was determined with a dot grid using the overlays as the source for this information.

The land use categories used in this survey are shown in Appendix 1.

## RESULTS AND DISCUSSION

The soil profile described and sampled at the highway HH site was located in the NE 1/4, NW 1/4, NW 1/4, of Sec. 7, T23N, R9E in Portage County, Wisconsin and was identified as a representative of the Fallcreek Soil Series. Soil features of this profile are shown in Figures 8 through 13. The detailed description follows:

- O 2 to 0 inches (5 to 0 cm) a layer of leaves and needles underlain by a thin, dark brown layer of partly decomposed leaves, twigs, and needles.
- A1 0 to 3 inches (0 to 8 cm) very dark brown (10YR 4/3) sandy loam; weak medium granular structure; very friable; many roots; extremely acid (pH 4.1); abrupt wavy boundary.
- A21 3 to 13 inches (8 to 33 cm) brown to dark brown (10YR 4/3) sandy loam; weak medium subangular blocky structure; friable; many roots; very strongly acid (pH 4.7); gradual wavy boundary.
- A22 13 to 18 inches (33 to 46 cm) strong brown (7.5YR 5/6) and reddish yellow (7.5YR 6/6) sandy loam; weak fine subangular blocky structure; friable; very strongly acid (pH 4.8); clear smooth boundary.
- A&B 18 to 26 inches (46 to 66 cm) brown (7.5YR 5/2) and yellowish red (5YR 5/6 and 5YR 4/6) sandy loam; with a few coarse distinct mottles of pinkish gray (7.5YR 6/2); weak to moderate medium subangular blocky structure; friable; very strongly acid (pH 4.8); vertical seams of light gray fine sand tongue down into the underlying horizon; abrupt smooth to irregular boundary.
- II B&A 26 to 32 inches (66 to 81 cm) reddish gray (5YR 5/2) and reddish brown (5YR 4/4) heavy loam; many medium distinct mottles of gray to light gray (5YR 6/1);

tongues of fine sand extend down along cleavages into the B2t; moderate to strong medium subangular blocky structure; firm; strongly acid (pH 5.1); abrupt irregular boundary.

II B2t 32 to 67 inches (81 to 170 cm) strong brown (7.5YR 5/6) clay loam; ped interiors with common medium distinct gray (7.5YR 5/0) mottles; gray colors extend down along cleavage surfaces; strong coarse angular blocky structure; very firm; strongly acid (pH 5.1); abrupt wavy boundary.

III C 67+ inches (170+ cm) strong brown (7.5YR 4/6) sandy loam; massive to weak coarse subangular blocky structure; many cobbles, stones, and boulders; firm; medium acid (pH 5.8).

This site was sampled in July 1977 by John Nelson and C. J. Milfred. A soil pit to 86 inches revealed the three different parent materials and horizons described. The topography is gently sloping with uniform slopes of 4 per cent to the west-northwest. The vegetation consists of mixed hardwood and conifer trees; dominant species are red maple, sugar maple, red oak, white oak, and white pine.

The understory consists of hazel, cherry, bush honeysuckle, and maple seedlings; with an herbaceous layer of sedge, violet, sessile bellwort, large leafed aster, lady fern, interrupted fern, false solomon's seal, partridgeberry, and canada mayflower.

The soil described and sampled at the highway B site was located in the SW 1/4, SW 1/4, SE 1/4, W 1/2, Sec. 19, T23N, R5W, in Portage County, Wisconsin and was identified as a representative of the Amery Soil



Figure 8. Plan view of the A&B horizon showing top of sand tongues. Tape in centimeters.



Figure 9. Glossic condition of the A&B and II B&A horizons (18 to 32 inches).



Figure 10. Highway HH profile,  
0 to 10 inches.



Figure 11. Highway profile,  
10 to 28 inches.



Figure 12. Highway HH profile,  
25 to 47 inches.



Figure 13. Highway HH profile,  
38 inches to base of soil pit.

Series. The detailed description of this profile follows:

- A1 0 to 4 inches (0 to 10 cm) very dark gray (10YR 3/1) loamy sand; moderate medium granular structure; very strongly acid (pH 4.8) abrupt irregular boundary.
- A2 4 to 18 inches (10 to 45 cm) reddish yellow (7.5YR 7/6) loamy sand; weak medium subangular blocky structure; very friable; strongly acid (pH 5.0); clear smooth boundary.
- B21 18 to 35 inches (45 to 90 cm) yellowish red (5YR 5/8) loamy sand; moderate medium subangular blocky structure; friable; very strongly acid (pH 5.0); clear smooth boundary.
- I&II B22t 35 to 51 inches (90 to 130 cm) red (2.5YR 4/6) sandy loam; moderate medium to coarse subangular blocky structure; friable to firm; very strongly acid (pH 5.0); abrupt wavy boundary.
- II B23t 51 to 69 inches (130 to 175 cm) red (2.5YR 4/6) sandy loam; moderate medium to coarse subangular blocky structure; firm; strongly acid (pH 5.1); clear smooth boundary.
- II B3 69 to 81+ inches (175 to 205+ cm) red (2.5YR 4/6) loamy sand; moderate coarse angular blocky structure; firm; strongly acid (pH 5.1).

This site was sampled in June 1973 by Dr. C. J. Milfred.

### Physical Characteristics

#### Particle Size Distribution

The gravel and fine earth fractions were separated by weighing and sieving each sample to extract fractions greater than two millimeters. The gravel size classes for both samples are shown in tables 2 and 3. The gravel content is fairly constant throughout the highway B profile

but shows three distinct breaks in the highway HH profile. The A horizons, the II B horizons, and the III C horizon are the three regions with uniform gravel percentages which correspond to the three lithologic units identified as three parent materials in the profile description.

The fine earth fraction was separated into the clay fraction, four silt fractions, and the sand fraction by the hydrometer method. After taking the hydrometer readings, the sand fraction was separated into five classes by mechanical sieving. Results from the particle size distribution analysis of both samples are shown in tables 4 and 5 and figures 14 and 15. The particle size classes in the highway HH sample reflect the three parent materials of the soil profile. These three parent materials include; (1) an eolian sand cap in which the A horizons have formed, (2) a loamy glacial drift in which the II B horizons formed, and (3) a sandy, bouldery drift which includes the III C horizon. The textural classifications of the horizons are as follows; all A horizons are sandy loams, the B&A horizon is a heavy loam, the II B<sub>2t</sub> horizon is a clay loam, and the III C horizon is a sandy loam. There is a noticeable difference between the sandy loam of the A horizons and the sandy loam found in the III C horizon. Although the silt and sand fraction in the A horizons is dominated by medium and fine sand, the sand in the III C horizon is made up mainly of very coarse and coarse sands.

The highway B profile has developed in sandy parent materials. These sands are largely unsorted but the medium

Table 2. Particle size distribution of the gravel fraction in per cent. Highway "HH" sample - includes per cent of fine earth fraction less the 2 mm.

Horizon	Particle size classes of gravel fraction - inches							Total Fine Gravel	Earth
	2.5	2.5- 1.25	1.25- 5/8	5/8- 5/16	5/16- 4mm	4mm- 2mm	2mm		
A1	0	0	0	0	0.3	1.5	1.8	98.2	
A21	0	0	0	0.7	3.9	3.7	8.3	91.7	
A22	0	0	0	0.6	1.4	2.6	4.6	95.4	
A&B	0	0	1.9	0.5	1.9	3.3	7.6	92.4	
II B&A	0	0	0.5	0.1	0.1	0.2	0.9	99.1	
II B2t-34"	0	0	0	0	0.1	1.3	1.4	98.6	
II B2t-44"	0	0	0	0.1	0.1	0.2	0.4	99.6	
II B2t-54"	0	0	0.7	0.2	0.2	2.6	3.7	96.3	
III C	0	0	2.3	4.9	7.3	8.9	23.4	76.6	
III C	0	0	0	0.8	4.1	20.5	25.4	74.6	

Table 3. Particle size distribution of the gravel fraction in per cent. Highway "B" sample - includes per cent of fine earth fraction less than 2 mm.

Horizon	Particle size classes of gravel fraction - inches							Total Fine Gravel	Earth
	2.5	2.5- 1.25	1.25- 5/8	5/8- 5/16	5/16- 4mm	4mm- 2mm	2mm		
A1	0	0	0	0.2	0	0.5	0.7	99.3	
A2	0	0	3.5	4.0	6.4	4.7	18.6	81.4	
B21	0	0	0	0.7	2.4	3.1	6.2	93.8	
I&II B22t	0	0	0	3.7	5.7	6.1	15.5	84.5	
II B23t	0	0	2.3	3.5	4.3	7.3	17.4	82.6	
II B3	0	0	0.6	4.4	3.5	5.3	13.8	86.2	

Table 4. Particle size distribution in per cent. Highway HH sample.

Depth in inches	Horizon	% VCS	% CS	% MS	% FS	% VFS	% Co. Silt	% Med. Silt	% Fine Silt	% V. Fine Silt	% Clay
0-3	A1	1.9	15.0	32.6	19.4	4.1	5.0	10.0	1.0	3.0	8.0
3-13	A21	2.7	17.1	27.0	23.0	5.2	8.0	8.0	1.0	1.0	7.0
13-18	A22	1.8	12.8	38.5	22.2	4.7	4.0	3.0	1.0	1.0	11.0
18-28	A&B	1.8	14.5	27.9	25.1	6.7	6.0	1.0	1.0	1.0	15.0
26-32	II B&A	1.6	10.2	17.9	11.6	2.7	8.0	16.0	3.0	4.0	25.0
32-42	II B2t	1.6	9.1	13.5	9.4	2.4	7.0	16.0	2.0	6.0	33.0
42-52	II B2t	0.8	6.1	14.2	11.1	3.8	12.0	17.0	2.0	5.0	28.0
52-67	II B2t	1.7	9.2	14.3	12.1	2.7	7.0	17.0	4.0	5.0	27.0
67-80	III C	18.6	23.0	4.1	14.0	7.3	5.0	7.0	3.0	3.0	15.0
80-86	III C	11.3	25.8	12.3	16.7	8.9	4.0	6.0	2.0	2.0	11.0

Table 5. Particle size distribution in per cent. Highway B sample.

Depth in inches	Horizon	% VCS	% CS	% MS	% FS	% VFS	% Co. Silt	% Med. Silt	% Fine Silt	% V. Fine Silt	% Clay
0-4	A1	1.8	19.8	24.4	25.7	6.3	3.0	8.0	2.0	2.0	7.0
4-18	A2	3.5	20.0	24.6	30.3	4.1	4.1	6.2	1.0	2.1	4.1
18-35	B21	3.8	32.2	21.3	23.8	2.7	3.0	1.0	1.0	2.0	9.1
35-51	I&II B22t	4.7	30.7	21.8	19.2	2.3	3.0	3.0	1.0	3.0	11.1
51-69	II B23t	8.6	43.7	10.4	11.3	1.8	3.0	3.9	2.1	2.1	13.1
69-81+	II B3	7.4	40.5	20.4	13.1	1.5	2.0	2.0	1.0	3.1	9.0

# PARTICLE SIZE DISTRIBUTION ANALYSIS

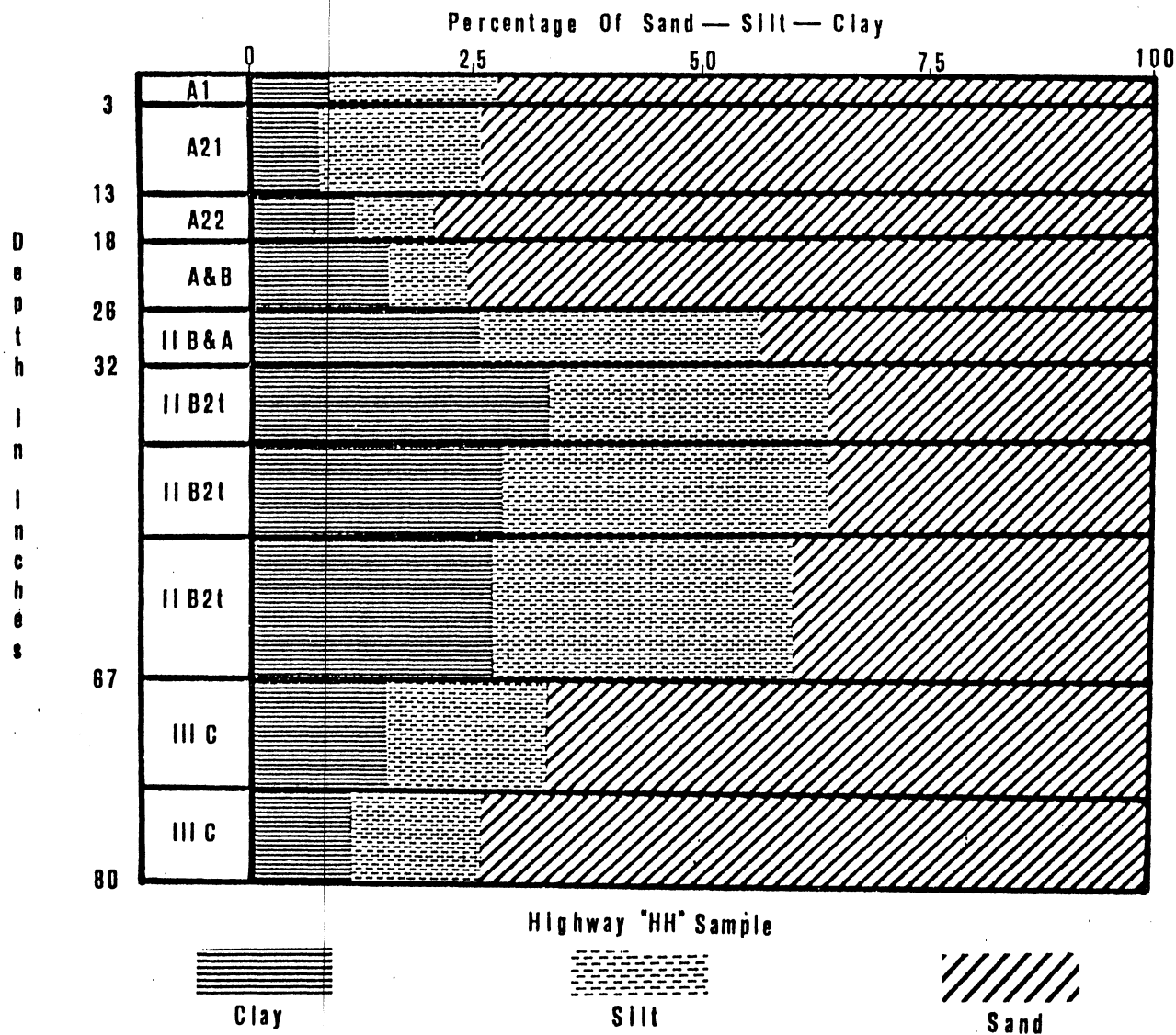


Figure 14. Percentage of sand, silt, and clay in the highway HH sample.

# PARTICLE SIZE DISTRIBUTION ANALYSIS

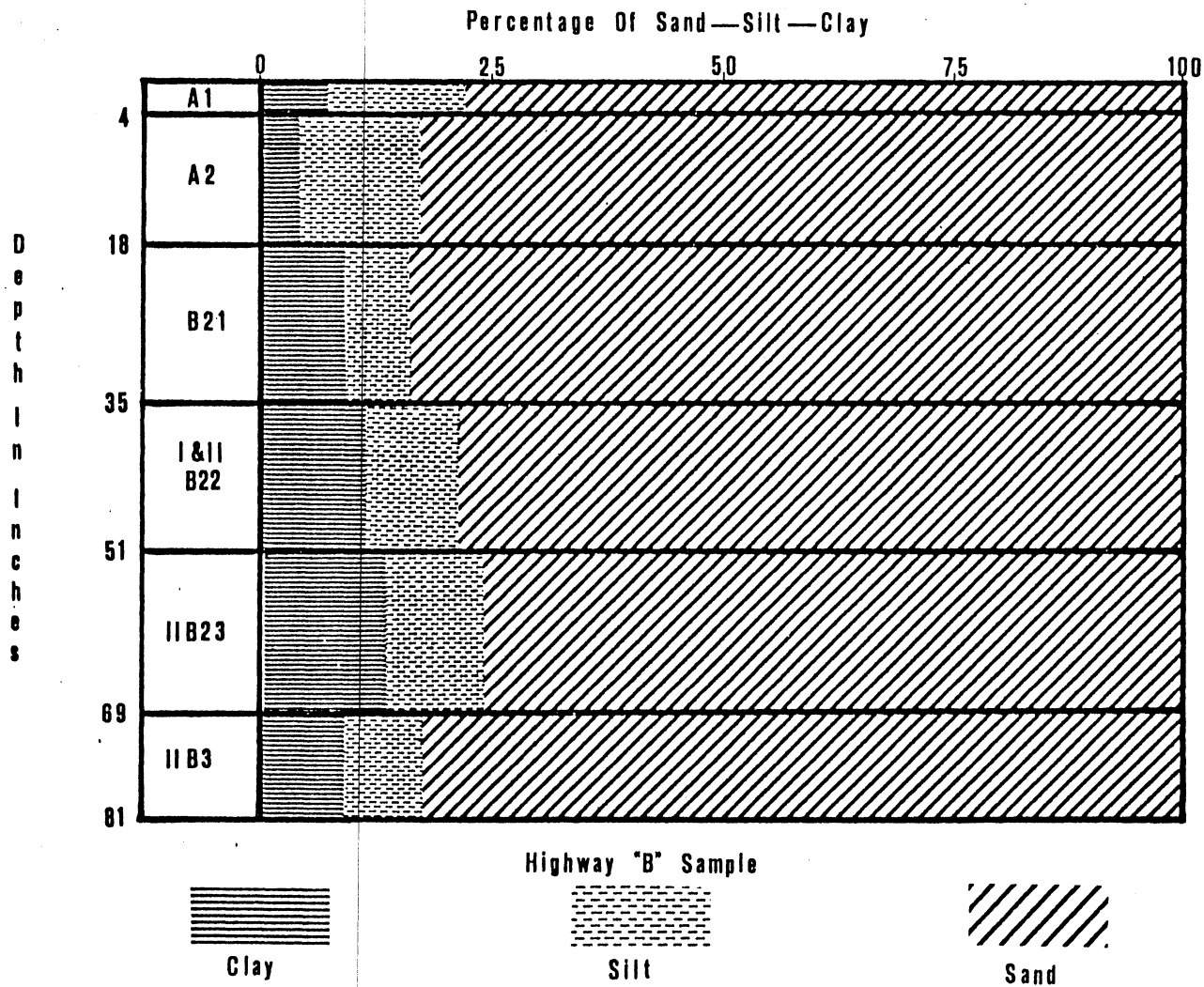


Figure 15. Percentage of sand, silt, and clay in the highway B sample.

size classes are dominant. All horizons of this profile are loamy sands except the II B22t and the II B23t which are sandy loams due to the illuviation of some clays from the overlying horizons.

#### Bulk Density

The bulk densities of three horizons in the highway HH sample are as follows; A2 = 1.42, A&B = 1.53, and II B2t = 1.69. Although bulk density is usually greater in coarse material and less in finer material, the affects of two factors have made the reverse true for this profile. First, the pore spaces between the larger soil particles have been filled by the illuviation of clay from overlying horizons. This has resulted in decreased porosity and a greater mass per unit of volume. Secondly, the weight of the overlying horizons tends to increase the compaction of the lower horizons, again resulting in decreased porosity and increased mass per unit of volume.

#### Chemical Characteristics

##### Organic Matter Content

The organic matter content in the A1 horizons of both samples was determined by the Walkley-Black method. The results, 8.1% in the highway HH sample and 4.8% in the highway B sample, reveal the organic matter content of the highway HH site to be nearly double the amount found in the highway B site.

##### Soil Reaction - pH

The pH values were determined using a 1:1 ratio of soil and distilled water. The pH values for each horizon

are shown in tables 6 and 7.

The measurements of the highway HH sample show a general decrease in acidity with depth. These measurements can be grouped into three categories which reflect the three parent materials of the profile. The three groups include; values less than 5.0 for the A horizons, values of 5.0 to 5.2 for the II B horizons, and values of 5.8 or greater for the III C horizon.

Table 6. Highway "HH" sample - Soil reaction.

Horizon	pH	Horizon	pH
A1	4.1	II B2t 34"	5.0
A21	4.7	II B2t 44"	5.2
A22	4.8	II B2t 54"	5.1
A&B	4.8	III C 72"	5.8
II B&A	5.1	III C 84"	5.9

Table 7. Highway "B" sample - Soil reaction.

Horizon	pH	Horizon	pH
A1	4.8	I&II B22t	5.0
A2	5.5	II B23t	5.1
B21	5.0	II B3	5.1

The highway B profile again shows a general decrease in acidity with depth, but the range in pH values is much less than with the HH sample.

#### Exchangeable Cations and CEC

The exchangeable cations measured included calcium, magnesium, potassium, sodium, hydrogen, and aluminum. Since hydrogen and aluminum are difficult to separate they were measured together as exchange acidity. Calcium,

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magnesium, potassium, and sodium together make up the basic cations and are referred to as the exchangeable bases. The amount of each cation in milliequivalents per 100 grams of soil is shown in tables 8 and 9.

The total cation exchange capacity for each horizon was determined by summation of the individual exchangeable cations. The results of cation summation along with total exchangeable bases, exchange acidity, and base saturation are shown in tables 10 and 11.

In the highway HH sample the A horizons have low amounts of both basic cations and acidic cations, resulting in a low cation exchange capacity. The relatively high exchange acidity of the A1 horizon is due to the high content of organic matter and humus. The humus fraction in this horizon has the ability to retain large quantities of exchangeable cations, mainly hydrogen and aluminum. The remaining A horizons are composed mainly of sands which lack the capacity to retain exchangeable cations.

The II B horizons have nearly the same exchange acidity as the A horizons but the exchangeable bases have increased by a factor of six to ten. The increase in the II B horizons is due to the greater amounts of clay which will retain more cations.

Although the III C horizon is composed mainly of sand and coarser materials, the exchangeable bases and exchange acidity decrease only slightly. Since the clay fraction is responsible for retaining cations, this may indicate the clays in the III C horizon are different than those

in the A and II B horizons.

Table 8. Highway "HH" sample - Exchangeable cations in meq per 100 grams of soil.

Horizon	Ca <sup>++</sup>	Mg <sup>++</sup>	K <sup>+</sup>	Na <sup>+</sup>	H <sup>+</sup> & Al <sup>+++</sup>
A1	0.6	0.5	0.7	0.05	17.0
A21	0.2	0.3	0.9	0.04	4.8
A22	0.8	0.6	0.8	0.03	4.8
A&B	0.8	1.1	0.3	0.05	7.2
II B&A	3.5	4.6	0.3	0.10	7.6
II B2t 34"	5.4	7.5	0.6	0.24	8.0
II B2t 44"	5.7	7.1	1.2	0.22	6.4
II B2t 54"	5.8	7.6	1.6	0.16	6.0
III C 72"	5.7	6.6	0.6	0.13	4.8
III C 84"	5.7	4.6	0.4	0.13	4.2

Table 9. Highway "B" sample - Exchangeable cations in meq per 100 grams of soil.

Horizon	Ca <sup>++</sup>	Mg <sup>++</sup>	K <sup>+</sup>	Na <sup>+</sup>	H <sup>+</sup> & Al <sup>+++</sup>
A1	4.3	1.5	0.7	0.03	9.2
A2	1.4	0.7	0.5	0.03	2.8
B21	1.4	1.6	0.8	0.03	5.0
I&II B22t	2.2	3.1	0.9	0.05	6.2
II B23t	2.4	5.4	0.6	0.08	4.6
II B3	3.3	4.1	0.4	0.05	3.8

The total cation exchange capacities of the highway HH samples are related to the texture of each horizon. In general, as the percentage of clay increases the cation exchange capacity also increases. The A1 horizon has a high cation exchange capacity due to the presence of organic matter. The A21, A22, and A&B horizons have relatively low cation exchange capacities due to their coarse textures and leaching which has probably removed

Table 10. Exchangeable bases, exchange acidity, and total cation exchange capacity in meq per 100 grams of soil - highway "HH" sample.

Horizon	Exchangeable Bases	Exchange Acidity	Total CEC	Per Cent Base Saturation
A1	1.88	17.0	18.88	9.96%
A21	1.39	4.8	6.19	22.46%
A22	2.24	4.8	7.04	31.82%
A&B	2.24	7.2	9.44	27.73%
II B&A	8.49	7.6	16.09	52.77%
II B2t 34"	13.72	8.0	21.72	63.17%
II B2t 44"	14.17	6.4	20.57	68.89%
II B2t 54"	15.14	6.0	21.14	71.62%
III C 72"	13.05	4.8	17.85	73.11%
III C 84"	10.85	4.2	15.05	72.10%

Table 11. Exchangeable bases, exchange acidity, and total cation exchange capacity in meq per 100 grams of soil for the highway "B" sample.

Horizon	Exchangeable Bases	Exchange Acidity	Total CEC	Per Cent Base Saturation
A1	6.54	9.2	15.74	41.55%
A2	2.59	2.8	5.39	48.05%
B21	3.80	5.0	8.80	43.18%
I&II B22t	6.22	6.2	12.42	50.08%
II B23t	8.44	4.6	13.04	64.72%
II B3	7.82	3.8	11.62	67.30%

some of the clay sized particles. The II B horizons have higher cation exchange capacities due to larger amounts of clay. The III C horizon also has a relatively high cation exchange capacity which does not fit the relationship of texture to exchange capacity established by the overlying horizons.

Since the III C horizon represents a change in parent

materials, the cause of the high cation exchange capacity may be due to a different clay mineral. Differences in the cation exchange capacities for various clay minerals is due to the strength of the negative charge on the surface of the clay particle. This negative charge is due to the degree and type of isomorphic substitution within the crystal lattice and to the dissociation of hydroxols along the crystal edge (Baver, 1972).

The cation exchange capacity of the clays in the A and II B horizons averages 70 milliequivalents per 100 grams of clay while the clay in the III C horizon has an average cation exchange capacity of 170 milliequivalents per 100 grams of clay. With these exchange capacities, the clays in the A and II B horizons could be mixtures of kaolinite, halloysite, illite, or montmorillonite. The clay types of the III C horizon would contain larger amounts of clays with higher cation exchange capacities. This horizon was found to contain relatively large quantities of the mineral muscovite. Birkeland (1974) indicates that muscovite can weather to vermiculite and montmorillonite, both of which have cation exchange capacities high enough to account for the increase in the III C horizon. Therefore, it is possible that the high cation exchange capacity of the clay in this horizon may be due to increased amounts of vermiculite.

The highway B sample has nearly a 1:1 ratio of basic to acidic cations throughout its profile. The exchange acidity is slightly higher in the A horizons and the

exchangeable bases are slightly higher in the II B horizons. The high cation exchange capacity of the A1 horizon is again due to the presence of humus.

As expected, the cation exchange capacity drops off sharply in the A2 horizon due to leaching and lower clay content. The cation exchange capacity then begins to increase with depth to a maximum in the B2<sub>3t</sub> horizon due to increasing clay content.

The exchange capacity of the clay fraction averages 65 milliequivalents per 100 grams of clay which is similar to the exchange capacities of the clays in the A and II B horizons of the highway HH sample.

#### Origin And Textural Composition Of Materials

##### Composition and Stratigraphy

Composition and stratigraphy of the Arnott moraine is interpreted based on field observations and study of analytical data. This information was obtained from soil pits, auger samples, and cable well drilling. Additional information was provided by shallow seismic investigations and discussions with well drillers and land owners.

Based on interpretations from these sources of information, the majority of the moraine is considered to be composed of unstratified, unsorted glacial till. All subsurface samples revealed the presence of some clay throughout the interior of the moraine. Since subsurface samples were obtained by the "cable drilling method", these materials were not subjected to particle size analysis. However, the percentage of sand, silt, and clay was estimated by

hand texturing. This method was used to texture subsurface samples from three locations with the results showing the fine earth fraction of all samples to be dense loams. Pebbles and rock fragments identified from the subsurface consisted mostly of gabbro with fragments of brown chert, granite, diorite, schist, and some sedimentary rocks also present.

Based on interpretation of samples from well drillers, the sequence of materials in the moraine can be divided into three stratigraphic units. The first or upper unit consists of a thin layer of unstratified sand and silt probably eolian in origin which is also a part of the soil profile. The second unit comprises the bulk of the moraine and consists of a loamy, unsorted glacial till including numerous large boulders. This division begins immediately beneath the sand and silt cap and continues to the base of the moraine. The third unit is not a part of the moraine proper but rather the material underlying the moraine. This underlying material is composed of clean, well sorted, coarse sand and gravel (Figure 16). This material is most likely glacial outwash that was laid down prior to the deposition of the Arnott moraine.

The gravel fraction from this unit includes well rounded pebbles representing many different rock types. Figure 17 shows some of the various rock fragments present in a sample from beneath the moraine. These include basalt, gabbro, granite, schist, sandstone, limestone, and dolomite. The dolomite fragment was identified by



Figure 16. Coarse sand and gravel found beneath the Arnott moraine.



Figure 17. Various rock fragments and pebbles found in a sample from beneath the Arnott moraine.

using the cold hydrochloric acid test (Dana 1962). The mineral was not readily soluble in cold hydrochloric acid. However, it did effervesce when powdered and also when hot hydrochloric acid was applied to the mineral surface. This fragment appears to be identical to the dolomite found near Valders, Wisconsin in the Niagara formation. It is interesting to note that the Niagara formation at its closest point is well over 90 miles from the Arnott moraine. The well sorted sand and gravel in this division which includes a variety of rock types certainly suggest this material was deposited by glacial melt water.

Samples from wells drilled at the Porter road site and the highway B site (Figure 18) indicate the till portion of the moraine can be divided into three separate areas or zones as illustrated by Figure 19. These zones are defined mainly on changes in the distribution of coarse fragments and compactness of materials as described by well drillers.

The upper zone (CD in Figure 19) consists of loamy glacial till with some large stones and boulders. Drillers described this material as having little resistance to drilling except for an occasional boulder. The depth of this zone was 24 feet at the Porter road site and 16 feet at the highway B site (Figure 19).

In the second zone (CDB) the drift is more compact or dense and the number of large stones and boulders also increases. The materials in this zone were described by drillers as "tight" and having considerable resistance to penetration.

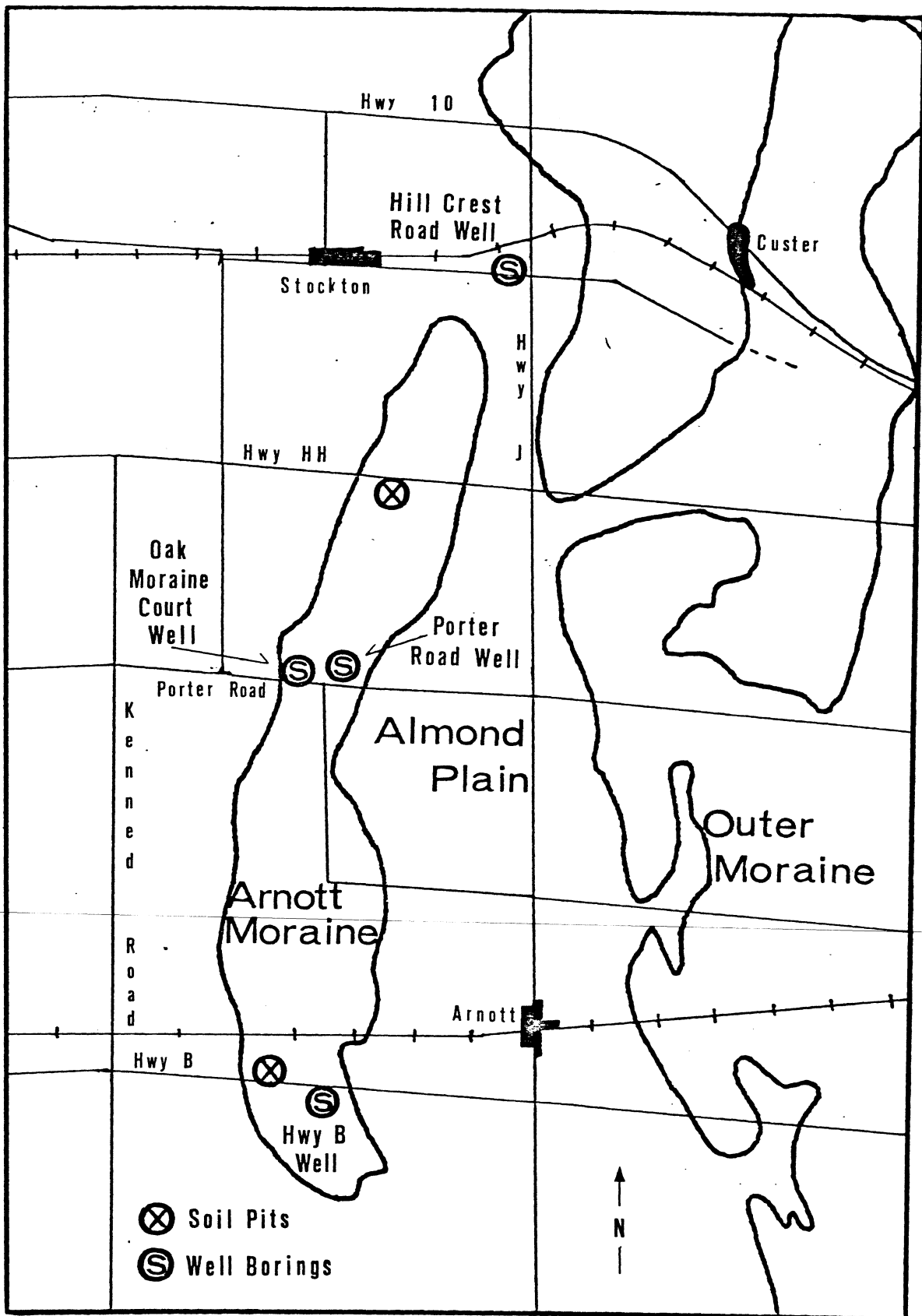


Figure 18. Location of wells and soil pits studied in this thesis.

# WELL LOGS

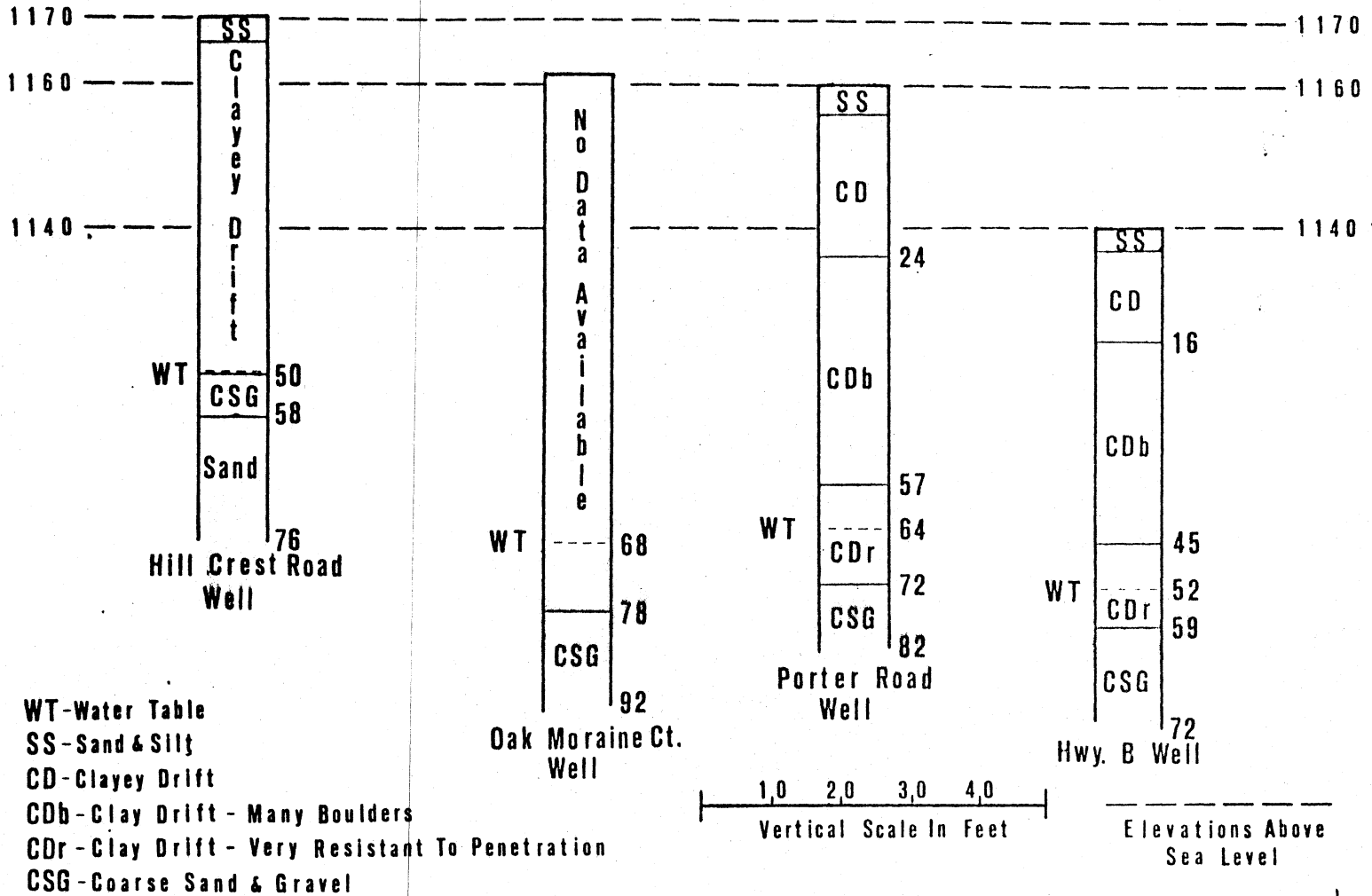


Figure 19. Data from four wells on the northern section of the Arnott moraine.

At the Porter road site this zone extended from 24 to 57 feet and 16 to 45 feet at the highway B site. The boundary between the first and second zones at the Porter road site was confirmed at 24 feet by shallow seismic investigation.

The third zone (CDr in Figure 19) was found to contain a higher percentage of gravel sized particles along with an increase in the density or compaction of the material. The driller at the Porter road site described this material as "concrete like" and having great resistance to penetration. The driller at the highway B site was unable to penetrate this zone. Three separate holes were attempted using a cable drilling rig but each time progress was stopped at the 45 foot level. The well at this site was finally completed in the first hole with a rotary drilling rig. This zone extended from 57 to 72 feet at the Porter road site and from 45 to approximately 59 feet at the highway B site.

The base of this third zone coincides with the base of the Arnett moraine. At this point a lithologic discontinuity occurs, separating the loamy glacial drift of the moraine from the underlying glacial outwash described earlier.

Additional samples from two other well borings were studied, one at the junction of Oak Moraine court and Porter road and the second near the junction of Hill Crest road and old highway 18 (Figure 19). Data for the Oak Moraine well is incomplete. A sample from 86 feet was obtained from the land owner and appeared to be identical

to the samples from beneath the moraine at the Porter road and highway B sites. The Hill Crest road site lies on a small knoll or hill just beyond the northern tip of the Arnott moraine and just west of the Outer moraine (Figure 18).

The following description of the materials encountered in the Hill Crest boring strongly suggests this well is located in material that was once part of the Arnott moraine. A sand and silt cap similar to that on the moraine to the south was found to a depth of three feet and loamy drift containing numerous gabbro stones and boulders extended from 3 to 50 feet. This material also contained some brown chert and granite and appeared to be identical to the loamy drift of the Arnott moraine. From 50 to 58 feet coarse sands and gravels were found, again very similar to the material underlying the moraine to the south. Beneath the coarse sand and gravel a layer of clean sand extended from 58 feet to the base of the well at 76 feet. This small hill or knoll is probably part of the Arnott moraine and is not related to the sandy Outer moraine.

Although the Arnott moraine is predominantly composed of loamy glacial drift, studies of auger samples, basement excavations, and local wells reveal the presence of a band of sandy outwash or wind drifted sand covering the western side of the moraine. This sandy material is very uniform and continuous along the western side of the moraine from highway B to north of Porter road. In the area around highway HH this sandy deposit appears to thin and becomes much less extensive.

Another area of sand was found 1/2 miles north of Porter road near the crest of the moraine. A soil pit revealed a sandy loam soil with some gravel and numerous stones extending to three feet and stratified sands extending from 3 to 5 feet. Continued investigation with a soil auger found a clean sand and silt material to a depth of 12 feet. The extent of this sand deposit was not determined but such deposits may be common throughout the moraine. Information was also gathered on the depths at which local wells penetrated the base of the moraine. In all cases, the lithologic discontinuity separating the loamy drift from the underlying sand and gravel was below the level of the surrounding sand plain. This indicates the floor or base of the moraine is convex or lens shaped with the center of the moraine extending to a greater depth than the edges. Figure 20 shows the possible shapes of the moraine floor along Porter road and highway B. These cross sections are based on the depths at which well borings penetrated the floor of the moraine. The dashed lines are approximations of the base of the moraine determined by interpolating from known depths of the moraine floor.

#### Consideration of Two Alternatives

As already stated, there are two theories concerning the formation and structure of the landscape feature known as the "Arnott moraine". The two theories or hypotheses are; (1) the feature is the remnant of a former glacial end moraine, and (2) it is a bedrock controlled landform with a solid granite core.

### Glacial moraine

Formation by glacial deposition is the most widely accepted hypothesis concerning the origin of this feature. The research and observations presented in this paper are considered proof that the Arnott moraine is in fact a moraine and the result of glacial deposition. This evidence comes from a study of the many wells drilled into and through this landscape feature. These wells revealed the moraine to be composed of a loamy glacial drift containing numerous cobbles, stones, and boulders. The stones and cobbles within the moraine represent several different rock types, indicating they originated from several bedrock formations and were transported to their present location. All of the wells studied revealed the interior of the moraine to be composed of loamy glacial drift. The lithologic discontinuity separating the loamy drift from the coarse outwash was penetrated by all wells, indicating the entire northern section of the moraine is underlain by glacial outwash materials. Since the materials beneath the moraine are glacial, the materials in the moraine itself must also be of glacial origin.

### Bedrock controlled

The most important point rejecting the hypothesis of a granite core is the fact that none of the wells drilled on this landform encountered bedrock. There appear to be two lines of evidence used to suggest the presence of a granite core. The first of these is that clayey material found near the surface on some portions of the moraine was



considered to be weathered granite residuum. Weathered granite residuum underlain by granite is found in the northwestern part of Portage County and a correlation between this area and the Arnott moraine is easily made. If material in the moraine was residuum from weathered granite, it would be logical to assume that granite bedrock would lie within a few feet. However, the study of well logs revealed the moraine lacks a granite core, indicating the overlying material cannot be weathered granite residuum.

The fine textured material near the surface is not residual from granite, but rather represents weathered material that was transported by glacial ice to its present location. Some of the clays found on parts of the moraine may represent a remnant of a soil profile that formed during the Farmdalian, Sangamonan, or earlier Interglacial stage. These interglacial periods were characterized by ample moisture and temperatures averaging 2 to 3 degrees warmer than those of today (Flint 1971) which would be very conducive of chemical weathering, causing the break down of glacial materials to clays as well as secondary mineralization in soils. Flint (1971) suggests the Sangamonian period lasted approximately 100,000 years which was probably a sufficient length of time for weathering to produce some of the clays found in the Arnott moraine.

A second line of evidence suggesting a bedrock core is the presence of angular stones found in the Arnott moraine

(Figure 24). These angular stones are not found on other moraines in the vicinity, leading to the speculation that they represent relatively freshly broken pieces of bedrock. However, the presence of ice-wedge casts on the moraine (Black 1971) suggests this region experienced several thousand years of cold temperatures during this period, the only weathering process available would have been physical or mechanical weathering. Finch (1957) describes physical weathering as resulting in broken, angular rock fragments and cites examples of this in higher mountain elevations where temperatures are similar to those of glacial time.

The presence of angular rock fragments should be expected when one considers the cold climate of this region during Altonian and Woodfordian time. The younger moraines in this vicinity did not exist during the time of glacial climate and therefore do not contain angular stones.

Weeks (1965) determined that water table levels on both sides of the Arnott moraine fit regional water table levels and this report indicates that ground water moves unrestricted beneath the moraine. If a granite core did exist under this landform, it would interfere with ground water movement and produce a "damming" effect. Since ground water movement is in a southwesterly direction (Weeks 1965), this damming effect would tend to increase water tables levels on the eastern side of the moraine. The measurements by Weeks do not indicate an increase in water levels on the eastern side of the moraine, therefore it can be assumed there is no restriction to water

movement and no bedrock core.

### Land Use

Land use surveys were conducted on the northern section of the Arnott moraine and its surrounding area for the years of 1938 and 1977. The area surveyed covered 15 sections or approximately 13,034 acres in the townships of Stockton and Plover. The land use of 1938 and 1977 are shown on maps (Figures 21 and 22) with the descriptions of the land use categories shown in Appendix 1. Tables 12 through 15 show land use by section in both acres and per cent. Tables 16 and 17 are a comparison of the land use on the moraine and the entire area surveyed for 1938 and 1977.

The overall pattern of land use has changed only slightly between 1938 and 1977. However, there was and still is a sharp contrast in the land uses between the moraine and the surrounding sand plain. In 1938 agriculture was already well developed on the sand plain and covered more than 75 per cent of the total area. In contrast, the moraine had little land under cultivation and over 75 per cent of the area was in forest. The 1977 survey shows this situation has remained relatively unchanged, with nearly the same percentages of land in agriculture and forest as is 1938.

The sharp contrast in land use is a direct result of the contrast between the two soil types found on the moraine and on the sandy outwash plain. The soils of the sand plain are level, have few stones and boulders, have

# LAND USE SURVEY OF THE ARNOTT MORAINE NORTHERN SECTION 1938



Figure 21. Land use on the Arnett moraine in 1938.

# LAND USE SURVEY OF THE ARNOTT MORAINE NORTHERN SECTION 1977

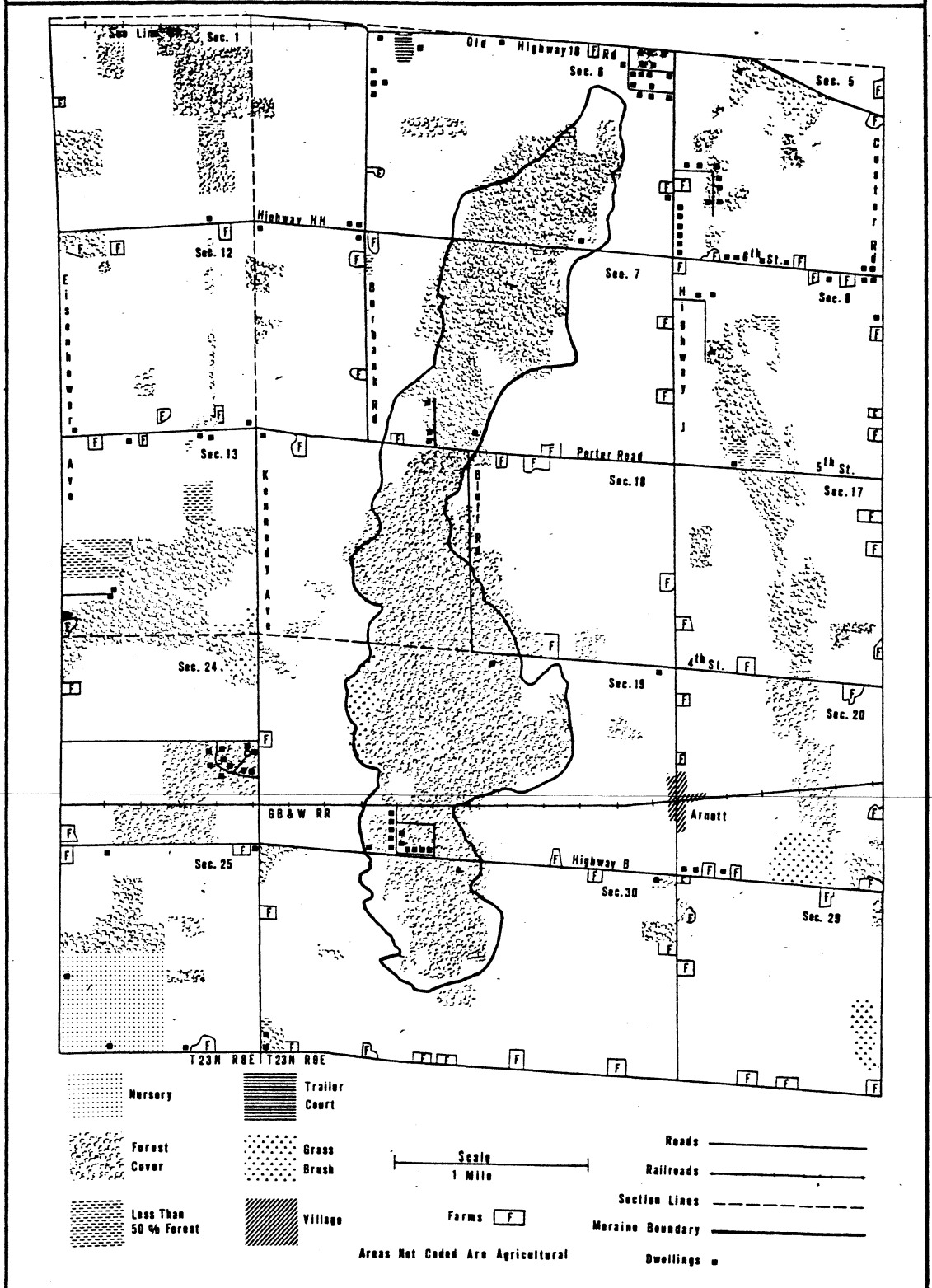


Figure 22. Land use on the Arnett moraine in 1977.

Table 12. Land use of the Arnott moraine and surrounding area for 1938. Area in acres by township and section. + add 7.8 acres for the village of Arnott. ++ add 9.3 acres for the village of Arnott.

Sec-	Total	Ag	Farms	Forest	50%	Grass	Rail-	Roads
tion	Area	Land			Forest	Brush	roads	
T23N R8E								
1	668.3	407.3	2.2	229.9	2.5	6.0	12.1	8.3
12	644.6	545.5	8.7	72.2	6.2	0	0	12.0
13	627.6	462.7	7.8	134.0	11.2	0	0	11.9
24	639.8	357.5	11.1	162.2	68.9	0	12.1	28.0
25	640.1	503.7	8.8	96.3	15.3	0	0	16.0
T23N R9E								
5	640.1	513.9	19.2	82.1	0	6.4	0	19.2
6	1322.6	1017.1	23.9	217.2	11.8	13.9	9.1	29.6
7	1319.8	873.9	24.8	371.5	13.0	8.6	0	28.0
8	642.2	514.0	19.1	82.5	10.6	0	0	16.0
17	641.7	501.4	16.6	107.1	0	0	0	16.5
18	1319.2	880.7	21.1	396.4	0	0	0	21.1
19	1318.8	792.0	14.8	419.2	0	40.2	24.7	20.1 +
20	642.5	493.3	19.7	91.3	0	0	12.6	16.3 ++
29	643.5	602.6	13.0	11.9	0	0	0	16.0
30	1322.9	997.7	25.6	270.6	4.3	0	0	24.7

good internal drainage, and excellent tilth, which made them very attractive for agricultural development when the area was first settled. These factors are the main reasons for the high degree of agricultural development on the sand plain. The soils of the moraine are generally unsuited for agricultural development and are characterized by severe limitations for most land uses. These soils exhibit problems due to slope, perched water tables, numerous glacial erratics, and poor subsurface drainage

Table 13. Land use of the Arnott moraine and surrounding area in per cent by township and section for 1938. + add 0.6% for the village of Arnott. ++ add 1.5% for the village of Arnott.

Sec- tion	Ag Land	Farms	Forest	50% Forest	Grass Brush	Rail- roads	Roads
T23N R8E							
1	60.9	0.3	34.5	0.4	0.9	1.9	1.2
12	84.6	1.3	11.2	1.0	0	0	1.9
13	73.7	1.2	21.4	1.8	0	0	1.9
24	55.9	1.7	25.4	10.8	0	1.9	4.3
25	78.7	1.4	15.0	2.4	0	0	2.5
T23N R9E							
5	80.2	3.0	12.8	0	1.0	0	3.0
6	76.9	1.8	16.4	0.9	1.1	0.7	2.2
7	66.2	1.9	28.1	1.0	0.7	0	2.1
8	80.0	3.0	12.9	0	0	0	2.6
17	78.1	2.6	16.7	0	0	0	2.6
18	66.8	1.6	30.0	0	0	0	1.6
19	60.1	1.0	31.8	0	3.1	1.9	1.5 +
20	76.8	3.0	14.2	0	0	2.0	2.5 ++
29	93.7	2.0	11.9	0	0	0	2.5
30	75.4	1.9	20.4	0.4	0	0	1.9

(Figures 23 and 24). These factors caused problems for agricultural use and made the soils unattractive for agricultural development. Because of these soil conditions, the sand plain is a well developed agricultural area and the moraine is relatively undeveloped.

Other important changes that occurred since 1938 which do not involve large areas of land are the number of farmsteads and private non-farm dwellings. In 1938 there were 86 active farmsteads in this region with an average of 100 acres per farm under cultivation. As of

Table 14. Land use of the Arnott moraine and surrounding area for 1977. Area in acres by township and section. + add 7.8 acres for village of Arnott. ++ add 9.3 acres for village of Arnott. Dwellings = number of dwellings, not per cent of area.

Sec- tion	Ag Land	Farms	Forest	50% Forest	Grass Brush	Rail- roads	Roads	Number of Dwellings
T23N R8E								
1	469.3	2.2	173.9	2.5	0	12.1	8.3	1
12	590.9	8.7	33.0	0	0	0	12.0	1
13	370.5	4.7	177.5	47.9	15.1	0	11.9	6
24	385.0	7.4	196.6	0	7.5	12.1	31.2	10
25	542.5	6.6	75.0	0	0	0	16.0	4
T23N R9E								
5	519.1	16.0	80.1	0	6.4	0	19.2	14
6	1021.1	8.6	244.9	0	0	9.1	38.9	24
7	884.4	19.3	386.1	0	0	0	30.0	4
8	510.4	19.1	82.5	10.6	0	0	19.6	4
17	489.2	13.9	122.1	0	0	0	16.5	0
18	884.2	17.6	396.3	0	0	0	21.1	1
19	806.0	4.5	408.7	0	40.2	24.7	26.9	14 +
20	458.3	19.7	78.8	0	47.5	12.6	16.3	1 ++
29	575.1	13.0	11.9	0	27.5	0	16.0	0
30	1054.8	23.0	218.5	1.9	0	0	24.7	4

1977, 75 farms remained of which at least 10 are inactive, leaving 65 active farmsteads with an average of 147 acres under cultivation. In addition to the farms increasing in size, the number of "Pivot" irrigation systems has also increased over the last several years, resulting in higher yields per acre of snapbeans and potatoes. This data clearly follows the national trend of farms decreasing in number while increasing in size.

A second significant land use change since 1938, both

Table 15. Land use of the Arnott moraine and surrounding area for 1977. Area in per cent by township and section. + add 0.6 per cent for village of Arnott. ++ add 1.4 per cent for village of Arnott.

Sec- tion	Ag Land	Farms	Forest	50% Forest	Grass Brush	Rail- roads	Roads
T23N R8E							
1	70.3	0.3	26.0	0.4	0	1.8	1.2
12	91.7	1.3	5.1	0	0	0	1.9
13	59.1	0.7	28.3	7.6	2.4	0	1.9
24	60.2	1.2	30.7	0	1.2	1.8	4.9
25	84.8	1.0	11.7	0	0	0	2.5
T23N R9E							
5	81.0	2.5	12.5	0	1.0	0	3.0
6	77.2	0.7	18.5	0	0	0.7	2.9
7	67.0	1.5	29.5	0	0	0	2.3
8	79.5	3.0	12.8	1.7	0	0	3.0
17	76.2	2.2	19.0	0	0	0	2.6
18	67.1	1.3	30.0	0	0	0	1.6
19	61.2	0.3	31.0	0	3.0	1.9	2.1 +
20	71.3	3.1	12.3	0	7.4	2.0	2.5 ++
29	89.4	2.0	1.8	0	4.3	0	2.5
30	79.8	1.7	16.5	0.1	0	0	1.9

on the moraine and the sand plain, is an increase in the number of privately owned, non-farm dwellings. In 1938 non-farm dwellings did not exist in this area. As of 1977, non-farm dwellings numbered 41 on the moraine and 105 in the entire area surveyed. Although the area taken up by these dwellings is relatively minor, it does represent a significant shift in living patterns and tax values.

Further development of the moraine for either agricultural use or dwellings is not recommended as soil



Figure 23. Small pool near highway B on the Arnott moraine due to perched water table. Club mosses growing near edge of water indicate permanent nature of pool.



Figure 24. Numerous glacial erratics in a field north of Porter road. This field has already had stones removed at two different times with a mechanical rock picker.

Table 16. Land use on the northern section of the Arnott moraine in 1938 and 1977. Upper number in acres, lower number in per cent.

Total Area	Ag Land	Farms	Forest	50% Forest	Grass Brush	Rail-roads	Roads	No. of Dwellings
1938								
1785.3	307.7	2.6	1402.2	5.1	43.4	5.7	18.6	0
	17.2	0.1	78.6	0.3	2.4	0.3	1.0	
1977								
1785.3	309.4	2.6	1396.4	0	43.8	5.7	27.4	19
	17.3	0.1	78.2	0	2.5	0.3	1.5	

Table 17. Land use of entire area surveyed in 1938 and 1977. Upper number in acres, lower number in per cent. Does not include 17.1 acres (0.1%) for the village of Arnott.

Total Area	Ag Land	Farms	Forest	50% Forest	Grass Brush	Rail-roads	Roads	No. of Dwellings
1938								
13034.4	9463.3	236.4	2744.4	143.8	75.1	70.6	283.7	0
	72.7	1.8	21.1	1.1	0.6	0.5	2.2	
1977								
13034.4	9560.8	184.3	2685.9	62.9	144.2	70.6	308.6	105
	73.5	1.4	20.6	0.5	1.1	0.5	2.4	

Limitations for both uses are severe. The building of any additional dwellings should be restricted to those areas with soil conditions suitable for septic systems. Sandy areas located primarily on the western side of the moraine are examples. The central and eastern sections of the moraine contain clayey, bouldery drift and are generally unsuited to either dwelling or agricultural development. If future development does take place on the moraine, housing and dwelling densities should be kept to a minimum.

Since a normal septic system may be inadequate on these soils, other systems would be required if develop-

ment occurs. The use of holding tanks or the experimental "mound septic systems" are possibilities which may permit future development. The potential shrink-swell of these soils is low and would probably not inhibit construction of dwellings. However, the perched water tables on the moraine may necessitate the use of foundation drains and sump pumps to keep basements from filling with water. The initial cost, subsequent maintenance and up-keep of holding tanks, mound septic systems, and equipment to deal with perched water tables would have to be borne by the home owner. However, these measures are necessary to insure that the absorption capacity of the soils would not be over taxed.

As far as further use of the moraine is concerned, several land uses are possible which would not cause significant environmental damage. The first of these is to leave the moraine undeveloped and allow it to progress under natural conditions. A second possible land use could be the establishment of hardwood forests and pine plantations. These soils are relatively fertile and profitable stands of sugar maple, red pine, and white pine can be produced. Since the majority of land is already under forest cover, thinning and proper forest management could produce satisfactory timber yields. Other land uses could include various park and recreational uses.

## CONCLUSIONS

### Origin of the Arnott Moraine

One of the main objectives of this paper was to determine the origin of the Arnott moraine. The data obtained from field investigations and well borings clearly shows the composition of this feature to be a heterogeneous glacial drift with particles ranging in size from clay to boulders. This evidence shows the feature to be a glacial moraine and not a bedrock controlled landform. Data from well borings revealed the moraine is underlain by a coarse sand and gravel outwash deposit. However, the age and origin of this coarse sand and gravel deposit has not been determined.

The location and orientation of the Arnott moraine relative to younger Woodfordian moraines indicates it was once part of a much larger end moraine from an earlier glacial period, probably Altonian. When the Green Bay lobe advanced to its maximum stage it buried most of the Altonian moraine, leaving only a small remnant, the Arnott moraine exposed.

The subdued topography and well developed drainage system of the Arnott moraine contrasts sharply with the youthful, kettled topography of the Woodfordian moraines a short distance to the east. Since the Arnott moraine is at least 35,000 years older than the Woodfordian moraines, the forces of erosion have had a greater time to erode and shape this landform. In addition to the age differential, solifluction may have played an important part in

shaping the moraine while the Woodfordian ice was present just to the east. Although there is no direct evidence of solifluction, ice-wedge casts observed in the moraine (Black 1971) prove that permafrost once existed in this area. Since permafrost was present, it can be assumed solifluction would also occur in areas with relatively minor slopes. This process was probably a major cause of aggradation and filling of depressions and kettles in the Arnott moraine.

As far as the age of this feature is concerned, the information presented in this paper suggests formation during early Wisconsin or Altonian time. The presence of ice-wedge casts, which are rare in the Woodfordian moraines, indicate the age of the Arnott moraine to be older than the Woodfordian moraines in this area. The high percentage of clay and compact till found in the northern section of the Arnott moraine suggest the weathering and soil formation occurred after the Sangamon Interglacial period. This leaves only the early Wisconsin or Altonian Substage as the time of formation.

The Arnott moraine was located a short distance in front of the Green Bay lobe and acted as a dam to melt water from the Woodfordian ice sheet. These melt waters cut two outlet channels through the moraine dividing it into three sections of nearly equal length. The damming of melt waters also caused outwash sediments to fill the area between the moraine and the ice sheet. The differences in elevation caused by filling behind the Arnott

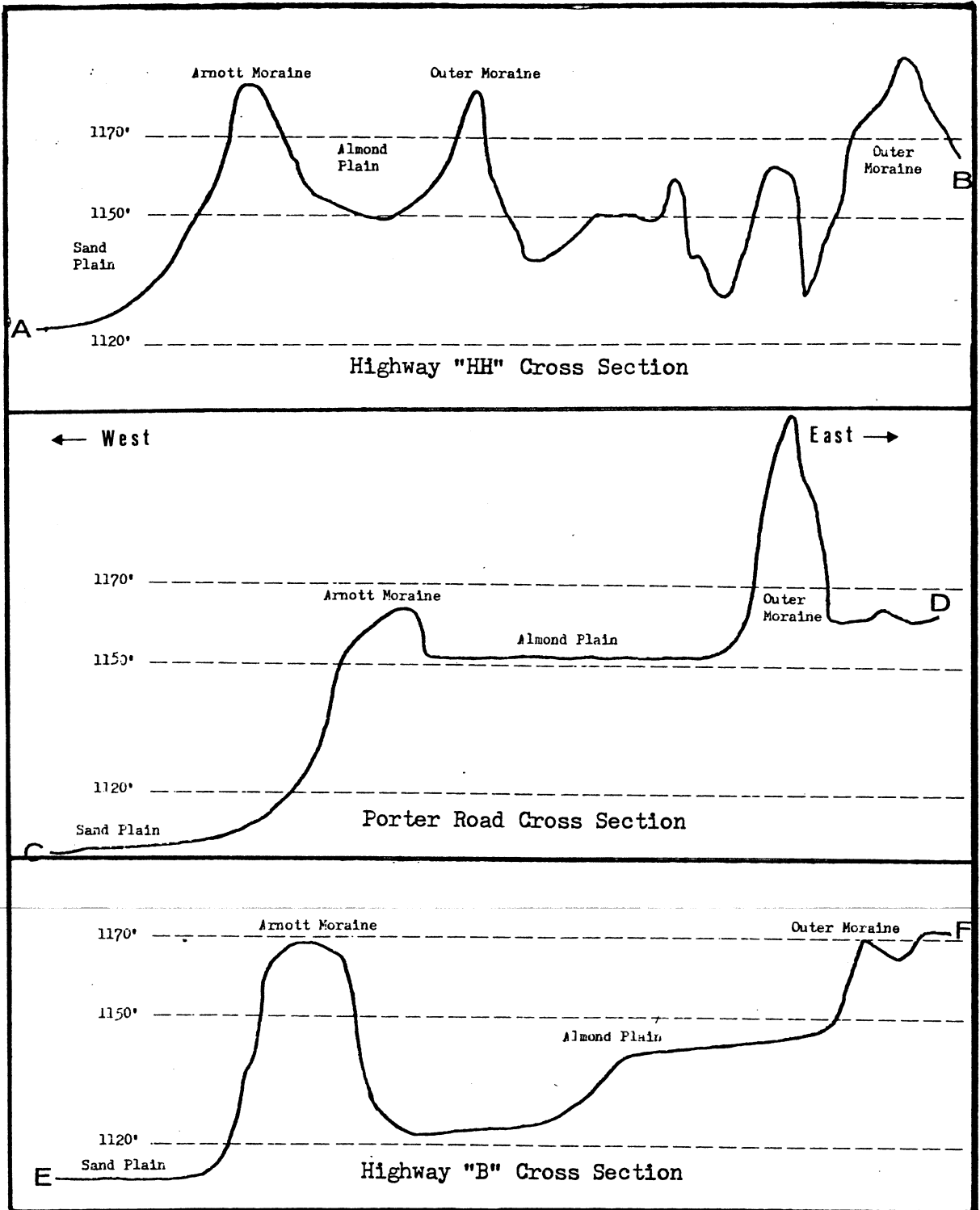


Fig. 25. Three east-west cross sections of the Arnott moraine showing the difference in elevation between the western sand plain and the eastern sand "Almond" plain. The map in figure 26 shows the location of each cross section. The vertical exaggeration equals 63.

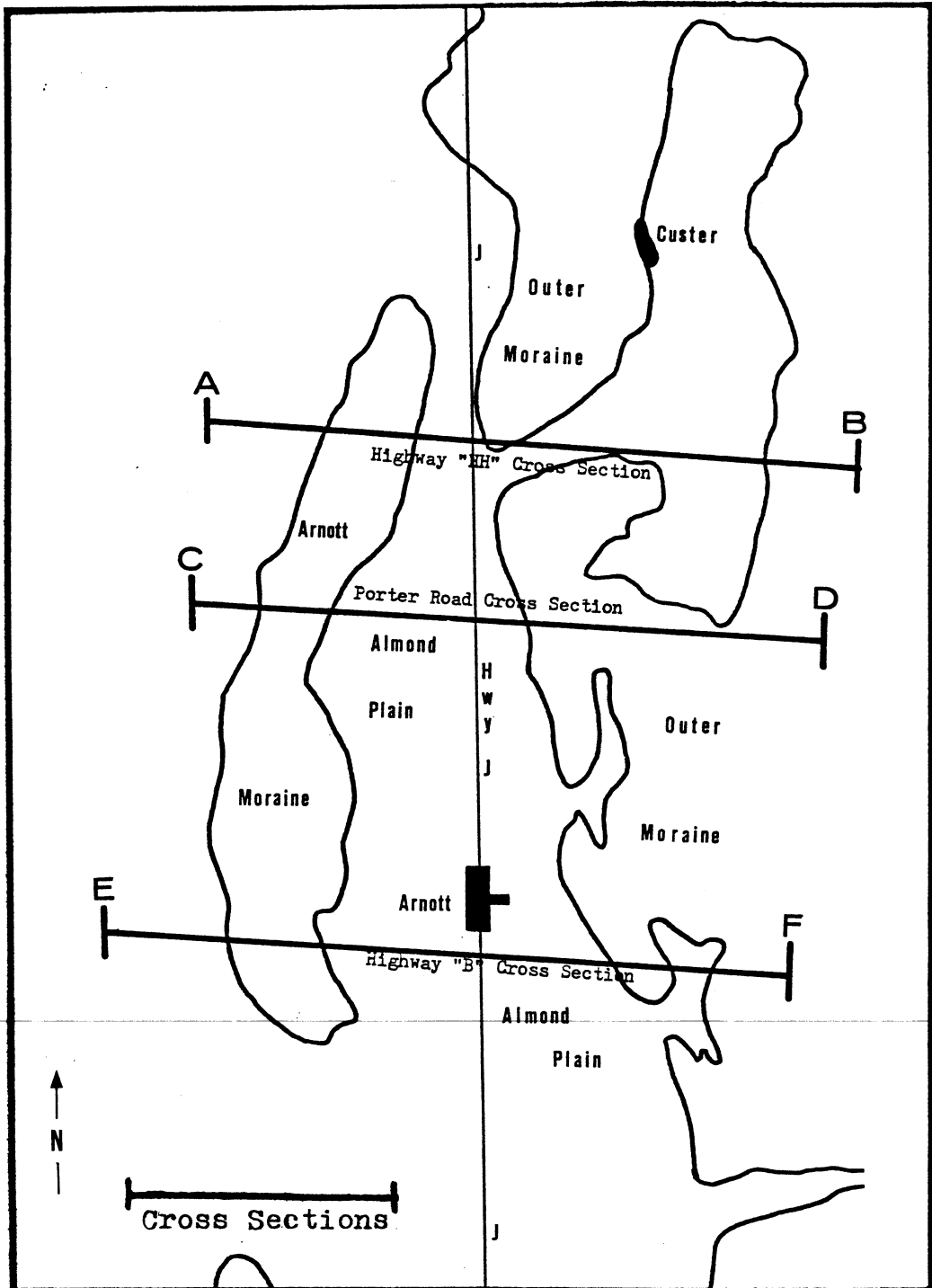


Figure 26. Location of cross sections shown in Figure 25.

moraine is clearly shown in the cross sections of Figure 25. The increased elevation of the eastern or Almond plain over the western sand plain varies from 15 feet near highway B to nearly 50 feet at the Porter road cross section.

The results described above are considered proof that this feature is in fact a glacial moraine. The strongest evidence for this being the loamy drift found within the feature and the fact that well borings never encountered bedrock.

#### Soils Of The Moraine

The soils on the moraine were mapped as Point and Mosinee series by the Soil Conservation Service (SCS Interior Soil Survey Report). It is suggested the Amery and Fallcreek soil series be substituted for Point and Mosinee on the northern section of the moraine. Both Amery and Fallcreek soils have formed in glacial parent materials. The parent material of the Amery series is a loamy sand glacial till and the Fallcreek parent material is a loamy acid glacial till. The profile of the Amery is basically sandy loams over loamy sands. The soil profile at the highway B site is also sandy loams over loamy sands which is identical to the Amery profile description. The Fallcreek profile is basically sandy loam over clay loam over sandy loam. This profile is also characterized by vertical sand tongues or a glossic condition and mottles in the clay loam horizon. The profile at the highway HH site is nearly identical with the profile description of the Fallcreek series.

Since the parent material of the Mosinee and Point series is igneous and granitic bedrock, and the moraine is composed of glacial drift, these series cannot adequately describe the soils on the northern section of the Arnott moraine. Guide lines for County soil surveys established by the Soil Conservation Service do not permit mapping separate series for acreages as small as the area studied in this thesis. However, because the profile characteristics are similar and the parent material is a compact, sandy loam glacial drift, it is suggested the soils on the moraine be called the Amery and Fallcreek series.

The profile description of the Fallcreek series at the highway HH site indicates the presence of three distinct parent materials. The upper material is an eolian or water deposited sandy loam cap containing a few stones and cobbles. The second material is a clay loam which is mottled and has glossic characteristics in the form of numerous vertical sand tongues. The third material is a compact sandy loam with closely packed stones and boulders which occupy approximately 50 per cent of the volume. The stones and boulders may be a lag deposit marking an old erosion surface which was later covered by finer materials.

This soil profile is extremely acid in the upper horizons with both pH and cation exchange capacity increasing with depth. Textures reflect the parent materials and vary from sandy loams in the A and III C horizons to clay loams in the II B horizons. Distinguishing char-

acteristics of this profile are classic characteristics in the form of sand tonguing (Figures 8 and 9) and mottling in the II B horizons. Low permeability, perched water tables, and numerous glacial erratics (Figures 21 and 22) also characterize the Fallcreek series, creating severe limitations for both housing and agricultural development.

The profile studied at the highway B site is not as complex as the HH profile and differs in many respects. The texture of this soil is loamy sand in the upper horizons and sandy loam in the II B horizons. The tonguing is not as evident as it is in the Fallcreek profile at the highway HH site. The profile is well drained and not mottled. This soil profile fits the range of characteristics given for the Amery series and the profile at the highway B site should be correlated in the Amery series.

#### Land Use - Past And Present

Land use on the northern section of the moraine between 1938 and 1977 has remained relatively unchanged. This is also true of the surrounding sand plain on which the land use has changed little since 1938. However, the land uses on the moraine and the sand plain are notably different.

By 1938 the sand plain had already been developed for agriculture and has since remained in this land use. During the same time period forest cover was the dominant land use on the moraine. Several factors are responsible for agricultural development on the sand plain and not the moraine. The ease of clearing and cultivating the sand

plain soils have made this area very attractive for farming. At the other extreme; topography, slowly permeable till and abundant glacial erratics, and general problems in clearing and cultivation have made the moraine unattractive for agricultural development. Since the sand plain soils were easier and less expensive to cultivate, this area was rapidly developed for agricultural uses.

### Practical Applications

Although major land use changes have not occurred since 1938, several significant changes which utilize only minimal acreage have taken place. The first of these is the development of non-farm dwellings or private housing units. In 1938 this type of land use was nonexistent and all dwellings were associated with farmsteads. By 1977 there were 105 non-farm dwellings with the greatest concentration in sections 5 and 6 near the northern tip of the moraine. The remaining dwellings are relatively evenly distributed across the entire area with a small concentration on the Arnott moraine along highway B. The soils of the sand plain have slight limitations for dwellings and septic systems and are generally well suited for this type of development. The one exception to the use of the sand plain for development is the potential pollution of ground water from septic systems due to the high permeability of the sandy soils. The slope factors, slow permeabilities, and perched water tables on the moraine result in severe limitations for these land uses. For these reasons, development of the moraine for dwellings and agriculture is not

recommended. Many of the soils are unable to adequately absorb effluent from septic systems and perched water tables can create problems of wet basements. If development on the moraine does proceed, dwelling density must be kept to a minimum to avoid over taxing the carrying capacity of the soils and deterioration of the environment. The main limitation to agriculture is the presence of glacial erratics which must be removed by mechanical means and at considerable expense (Figure 24). Besides the initial cost of removal, frost action would bring additional stones to the surface on a yearly basis resulting in the need for continued removal.

Considering the diverse land ownership on the moraine it probably is not feasible to develop a long term land use plan, but from an environmental standpoint the best land use that could be practiced on the moraine would be one of the following; (1) the moraine could be left alone and allowed to progress in a natural state, or (2) leave it in its natural state of forest vegetation and harvest the trees for either timber, pulp, or firewood. The latter land use would result in economic productivity of the moraine and could also include the establishment of pine plantations. More importantly, using the moraine for forest production would be a land use for which the soils are best suited.

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APPENDICES

## APPENDIX I

## Land Use Categories

Agricultural - Includes all land under any type of crop or agricultural use excluding forests.

Farms - Includes all buildings and land on farmsteads not used directly for agricultural or crop production.

Forest - Includes all plantations and natural forests both coniferous and deciduous with at least 50% crown cover.

Forest with less than 50% crown cover - Includes all forested areas both coniferous and deciduous with less than 50% crown cover. Understory may be either grass, brush, or small trees.

Grass and Brush - Includes all grasslands, marsh, and brush areas not under agricultural use. These areas may also include minor surface water areas such as small ponds and small creeks.

Railroads - Includes the roadbed and right-of-way of all rail lines. An average right-of-way of 100 feet was used to determine area measurements.

Roads - Includes all, state, county, and town roads. An average right-of-way of 4 rods or 66 feet was used to determine the area of all roads. Roads dividing sections were considered as belonging to both sections and the area was divided evenly between these sections. This category does not include driveways or field access roads.

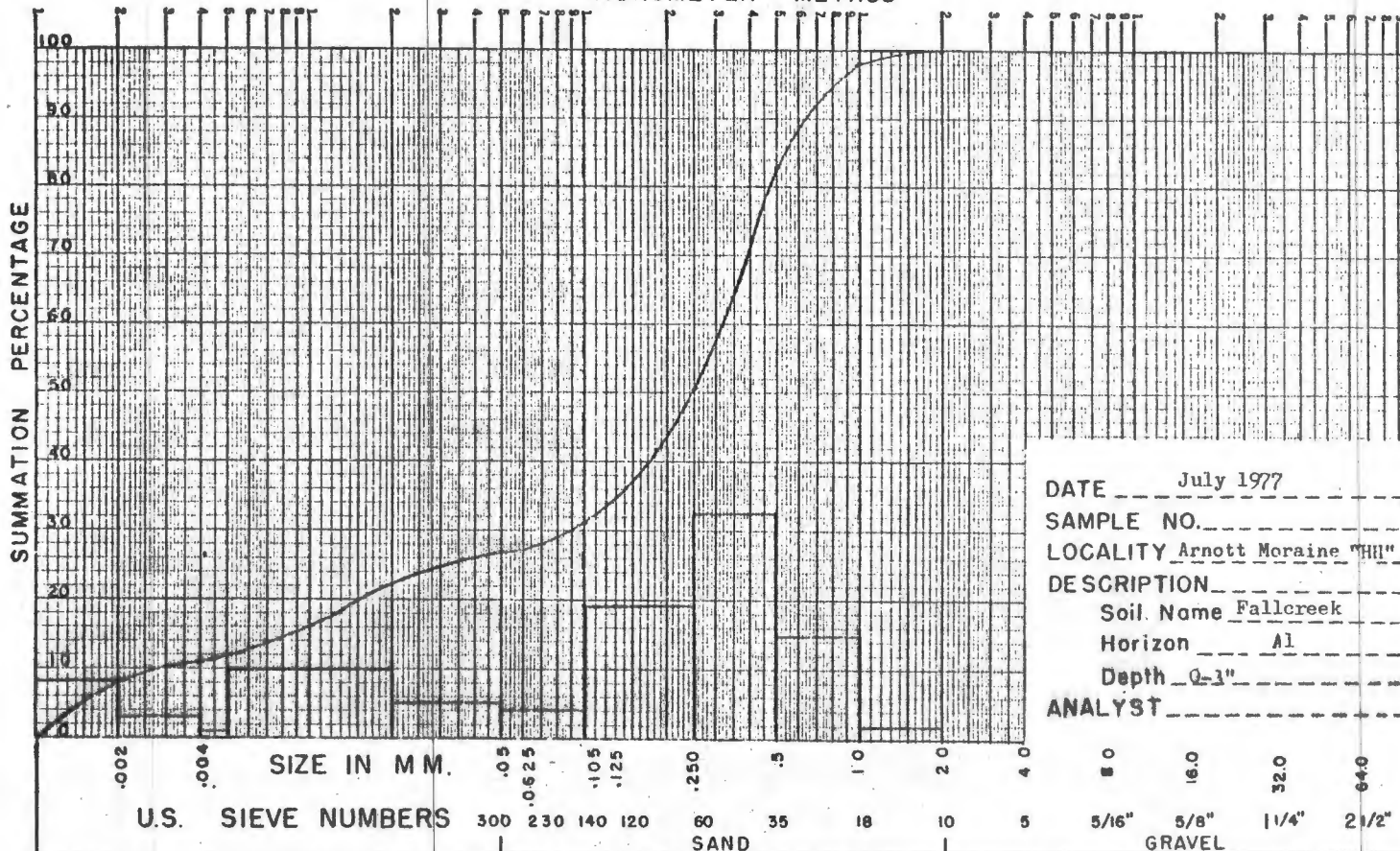
Village - Includes only the village of Arnott, Wisconsin.

## APPENDIX II

Particle Size Summation Curves and Distribution  
Histograms for the Horizons of the  
Fallcreek Series

# PARTICLE SIZE DISTRIBUTION ANALYSIS

HYDROMETER METHOD

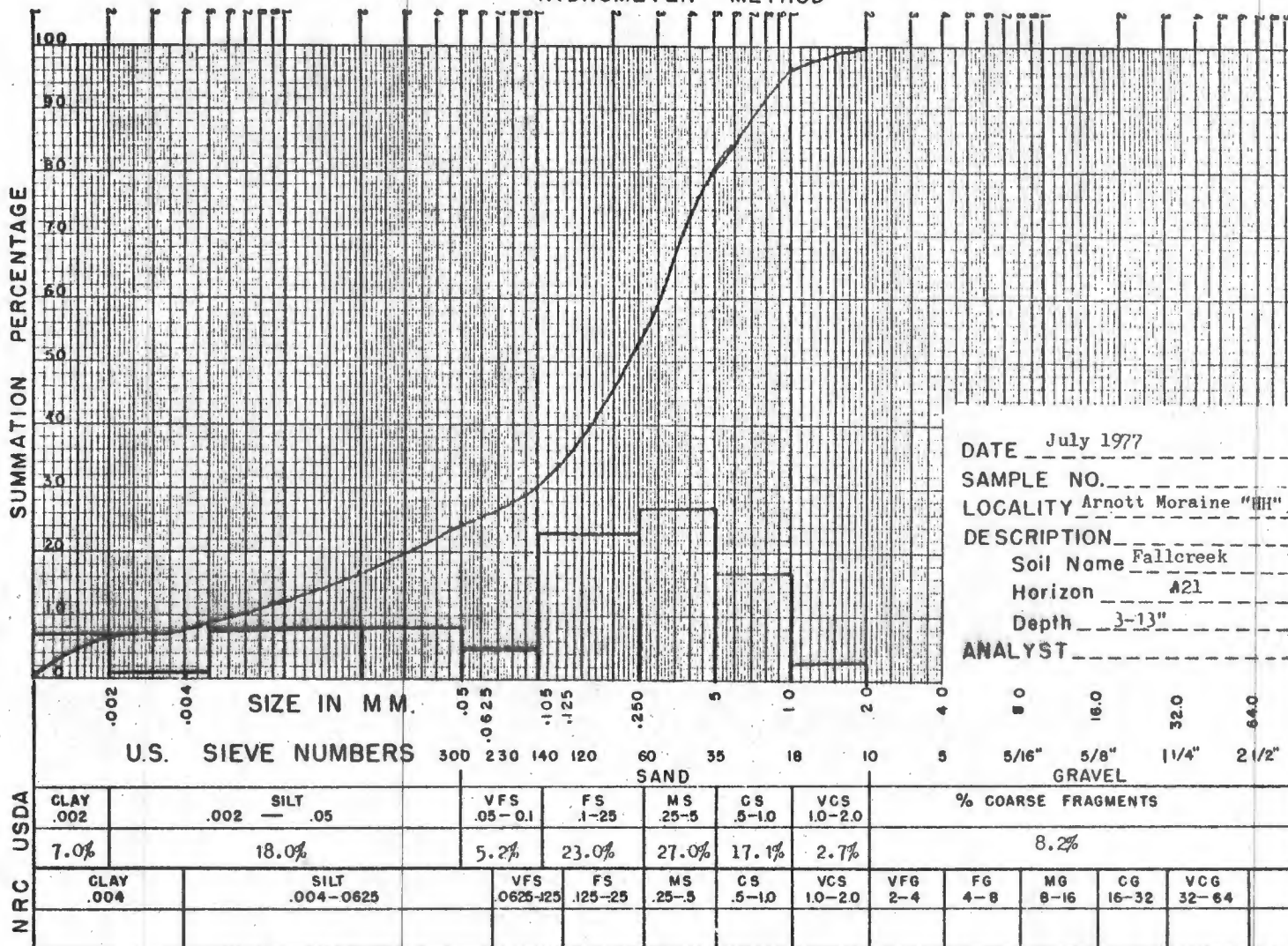


DATE July 1977  
 SAMPLE NO. \_\_\_\_\_  
 LOCALITY Arnett Moraine "HH"  
 DESCRIPTION \_\_\_\_\_  
     Soil Name Fallcreek  
     Horizon A1  
     Depth 0-1"  
 ANALYST \_\_\_\_\_

NRC	USDA													
	CLAY .002	SILT .002 — .05		VFS .05 — .01	FS .1 — .25	MS .25 — .5	CS .5 — 1.0	VCS 1.0 — 2.0	% COARSE FRAGMENTS					
	8.0%	19%		4.1%	19.4%	32.6%	15.0%	1.9%	1.8%					
NRC	CLAY .004	SILT .004 — .0625			VFS 0.0625 — .125	FS .125 — .25	MS .25 — .5	CS .5 — 1.0	VCS 1.0 — 2.0	VFG 2 — 4	FG 4 — 8	MG 8 — 16	CG 16 — 32	VCG 32 — 64

# PARTICLE SIZE DISTRIBUTION ANALYSIS

HYDROMETER METHOD



DATE July 1977  
 SAMPLE NO. \_\_\_\_\_  
 LOCALITY Arnett Moraine "III"  
 DESCRIPTION \_\_\_\_\_  
 Soil Name Fallcreek  
 Horizon A21  
 Depth 3-13"  
 ANALYST \_\_\_\_\_

NRC USDA

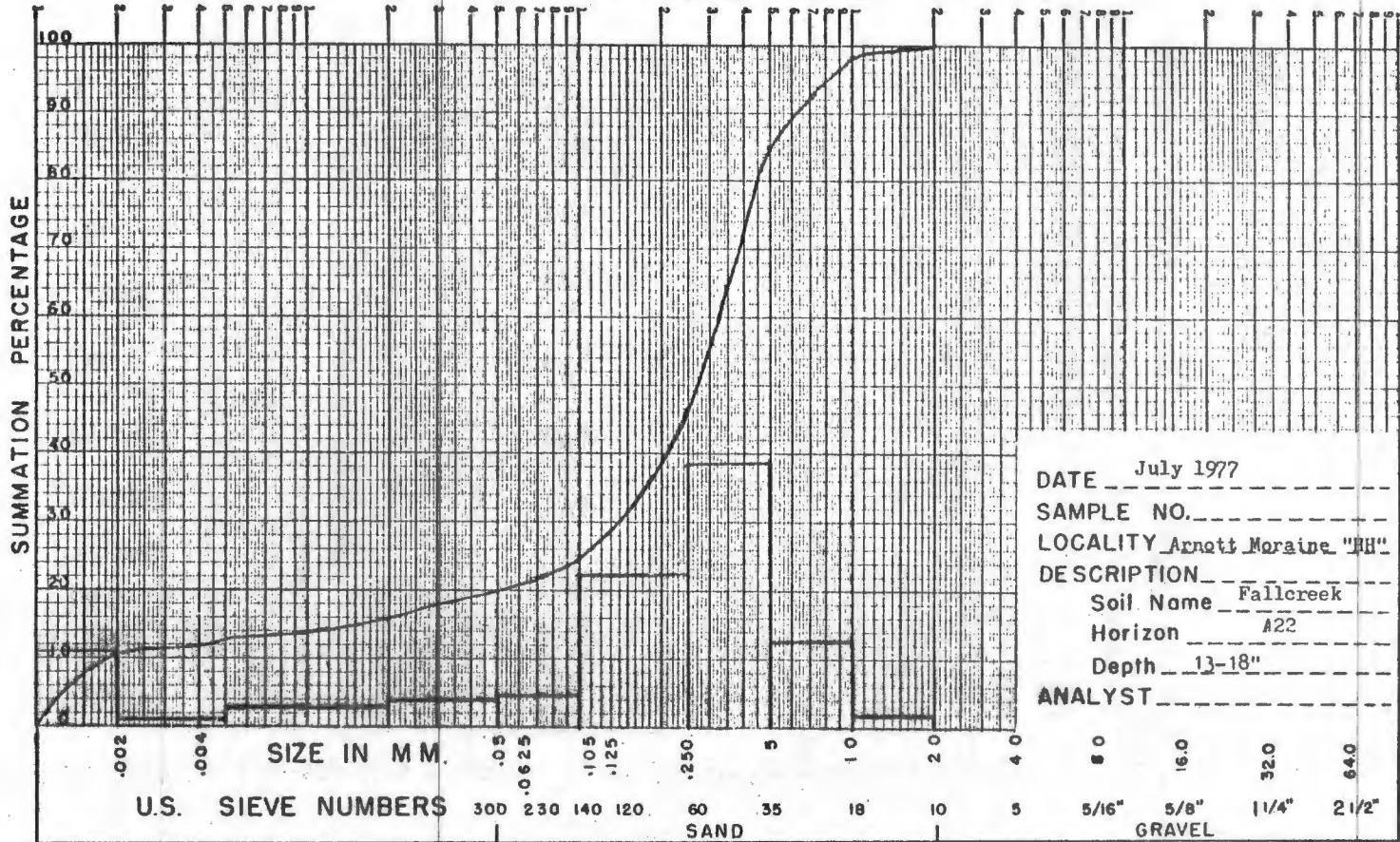
CLAY .002	SILT .002 - .05	SAND					% COARSE FRAGMENTS
		VFS .05 - 0.1	FS .1 - 25	MS 25 - 5	CS .5 - 1.0	VCS 1.0 - 2.0	
7.0%	18.0%	5.2%	23.0%	27.0%	17.1%	2.7%	8.2%

CLAY .004	SILT .004 - 0.625	SAND					GRAVEL				
		VFS .0625 - .125	FS .125 - .25	MS .25 - .5	CS .5 - 1.0	VCS 1.0 - 2.0	VFG 2 - 4	FG 4 - 8	MG 8 - 16	CG 16 - 32	VCG 32 - 64

# PARTICLE SIZE DISTRIBUTION ANALYSIS

HYDROMETER METHOD

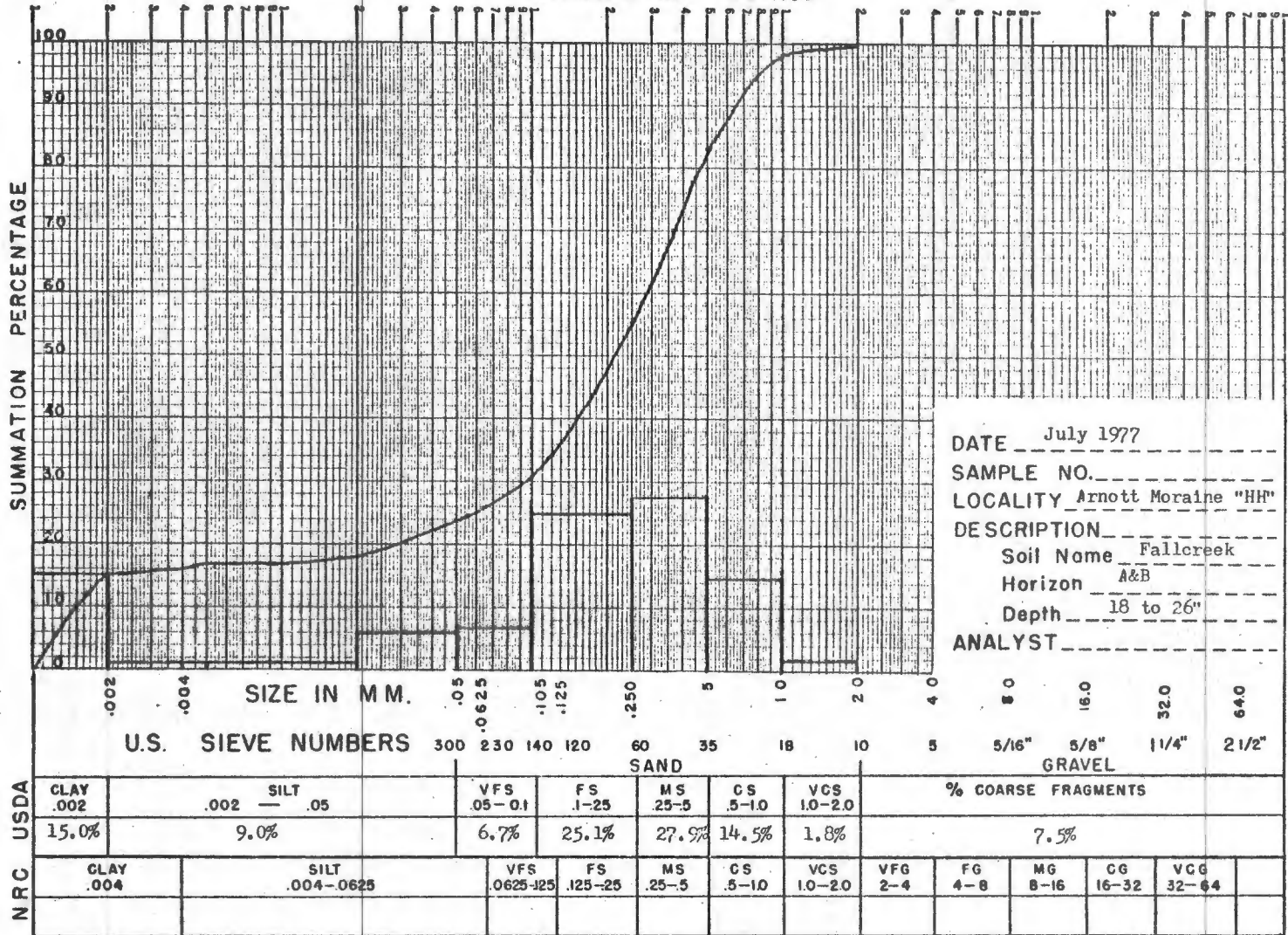


DATE July 1977  
 SAMPLE NO. \_\_\_\_\_  
 LOCALITY Arnett Moraine "PH"  
 DESCRIPTION \_\_\_\_\_  
     Soil Name Fallcreek  
     Horizon A22  
     Depth 13-18"  
 ANALYST \_\_\_\_\_

NRC USDA	SAND							% COARSE FRAGMENTS					
	CLAY .002	SILT .002 - .05		VFS .05 - 0.1	FS .1 - 25	MS .25 - 5	CS .5 - 1.0	VCS 1.0 - 2.0					
	11.0%	9.0%		6.7%	25.1%	27.9%	14.5%	1.8%	4.5%				
	CLAY .004	SILT .004 - 0.625		VFS 0.625 - 125	FS .125 - 25	MS .25 - 5	CS .5 - 1.0	VCS 1.0 - 2.0	VFG 2 - 4	FG 4 - 8	MG 8 - 16	CG 16 - 32	VCG 32 - 64

# PARTICLE SIZE DISTRIBUTION ANALYSIS

HYDROMETER METHOD



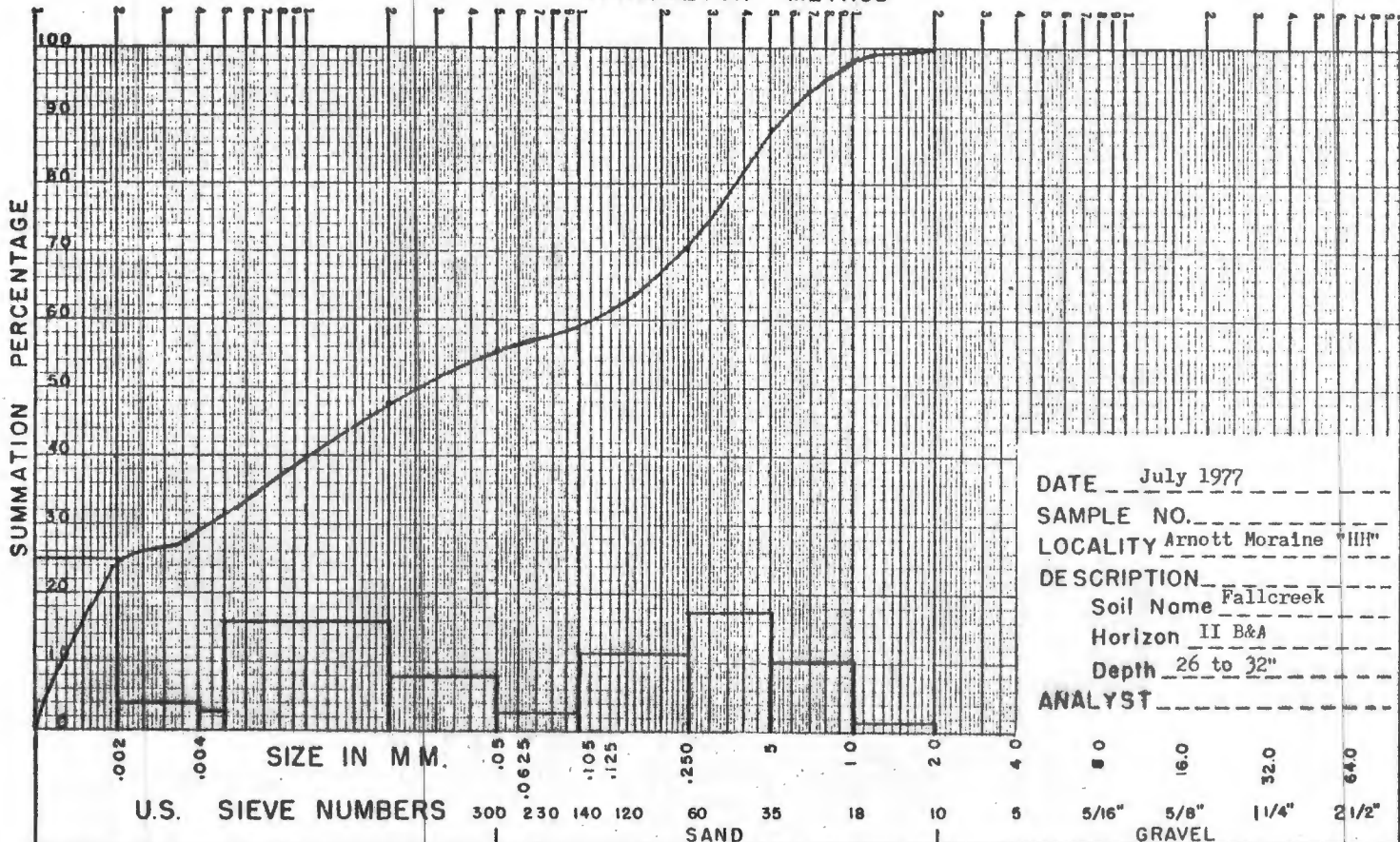
DATE July 1977  
 SAMPLE NO. \_\_\_\_\_  
 LOCALITY Arnott Moraine "HH"  
 DESCRIPTION \_\_\_\_\_  
 Soil Name Fallcreek  
 Horizon A&B  
 Depth 18 to 26"  
 ANALYST \_\_\_\_\_

NRC USDA

CLAY		SILT		SAND					% COARSE FRAGMENTS				
.002		.002 - .05		VFS	FS	MS	CS	VCS					
				.05 - 0.1	.1 - 25	25 - 5	.5 - 1.0	1.0 - 2.0					
15.0%		9.0%		6.7%	25.1%	27.9%	14.5%	1.8%	7.5%				
CLAY	SILT	VFS	FS	MS	CS	VCS	VFG	FG	MG	CG	VCG		
.004	.004 - 0.625	.0625 - .125	.125 - 25	.25 - 5	.5 - 1.0	1.0 - 2.0	2 - 4	4 - 8	8 - 16	16 - 32	32 - 64		

# PARTICLE SIZE DISTRIBUTION ANALYSIS

HYDROMETER METHOD

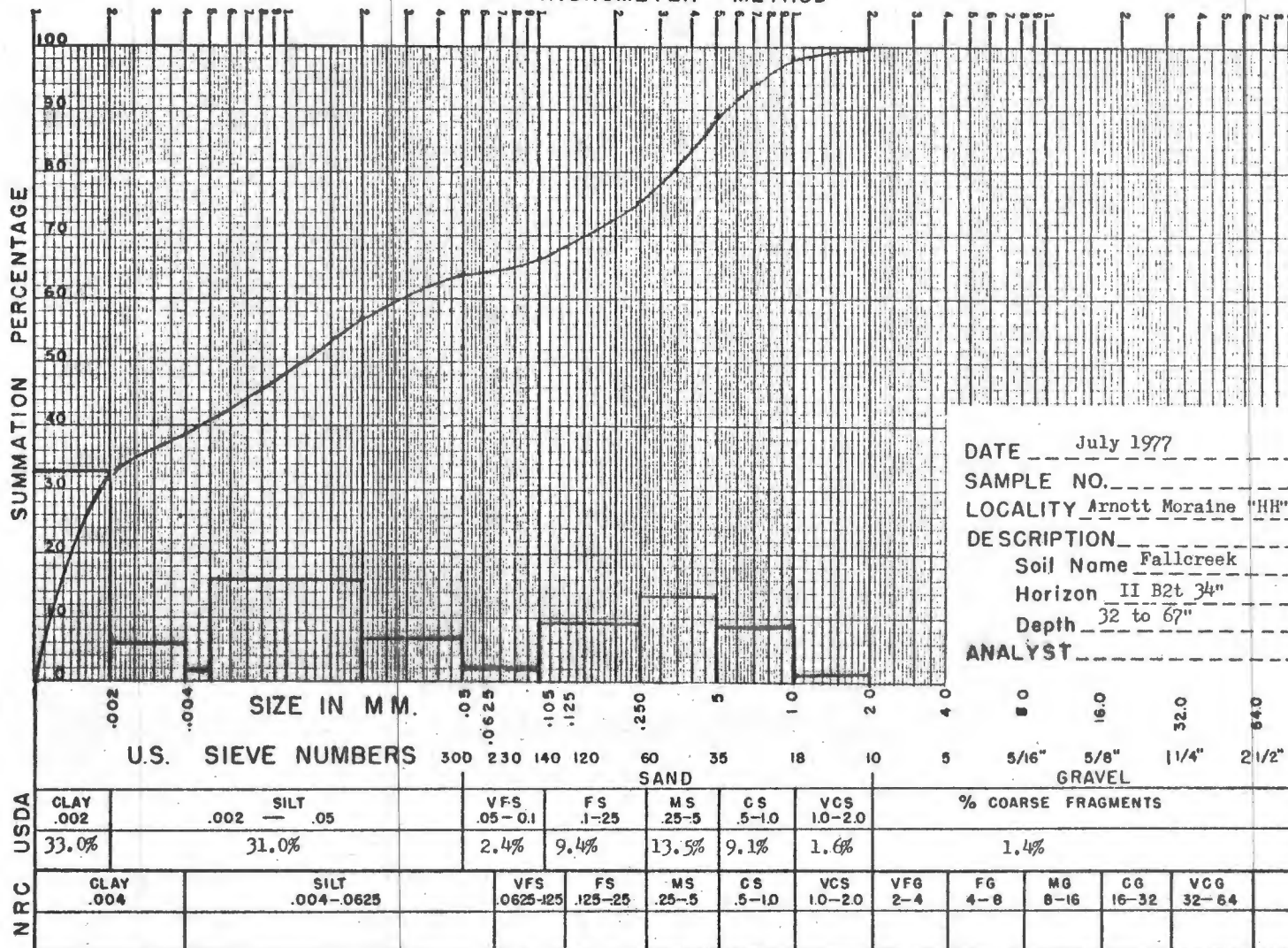


DATE July 1977  
 SAMPLE NO. \_\_\_\_\_  
 LOCALITY Arnott Moraine "III"  
 DESCRIPTION \_\_\_\_\_  
 Soil Name Fallcreek  
 Horizon II B&A  
 Depth 26 to 32"  
 ANALYST \_\_\_\_\_

NRC	U.S. SIEVE NUMBERS												
	300	230	140	120	60	35	18	10	5	2 1/2"			
CLAY .002	SILT .002 — .05			VFS .05 — 0.1	FS .1 — 25	MS 25 — 5	CS .5 — 1.0	VCS 1.0 — 2.0	% COARSE FRAGMENTS				
25.0%	31.0%			2.7%	11.6%	17.9%	10.2%	1.6%	0.9%				
CLAY .004	SILT .004 — 0.625			VFS .0625 — 125	FS .125 — 25	MS .25 — 5	CS .5 — 1.0	VCS 1.0 — 2.0	VFG 2 — 4	FG 4 — 8	MG 8 — 16	CG 16 — 32	VCG 32 — 64

# PARTICLE SIZE DISTRIBUTION ANALYSIS

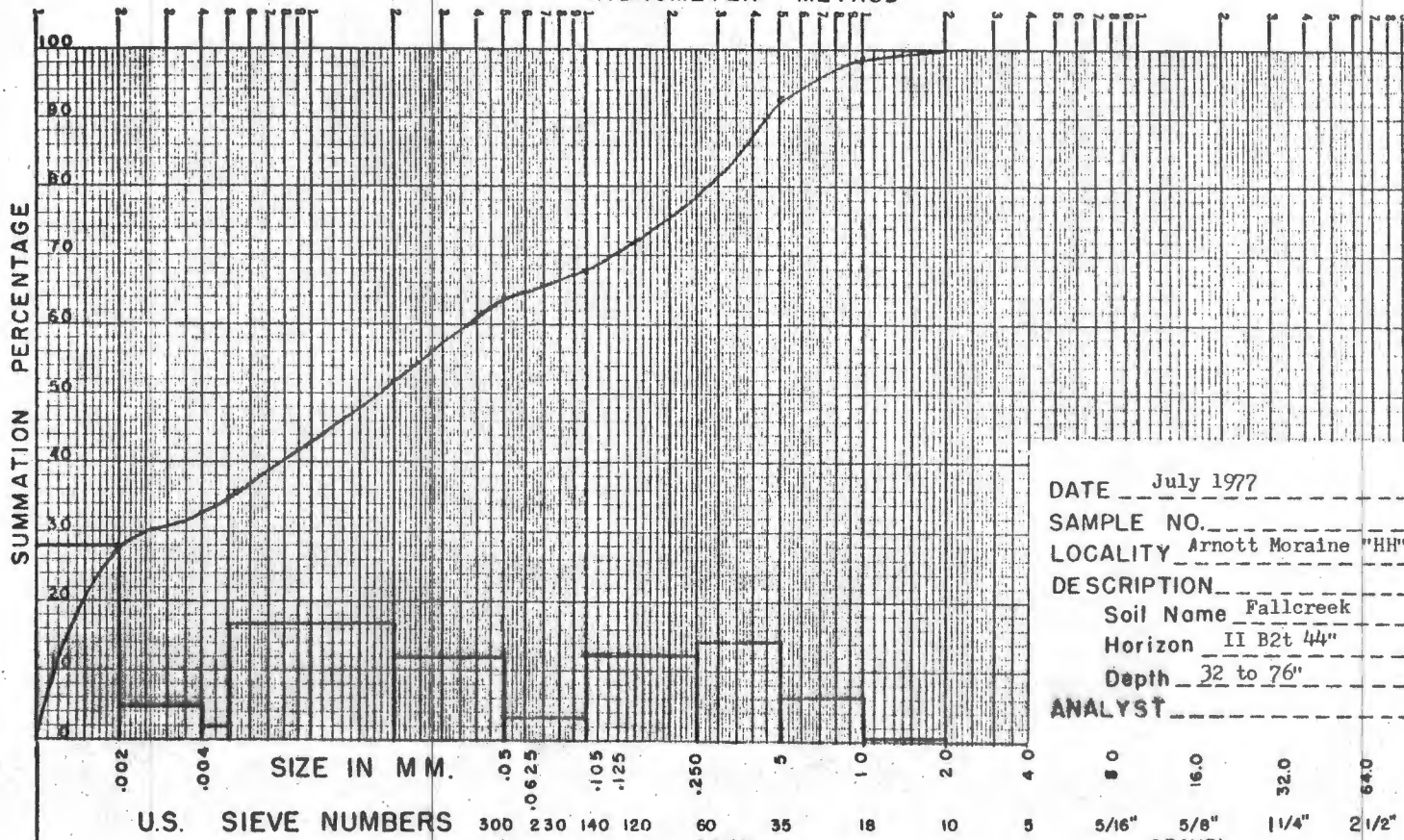
HYDROMETER METHOD



DATE July 1977  
 SAMPLE NO. \_\_\_\_\_  
 LOCALITY Arnett Moraine "HH"  
 DESCRIPTION \_\_\_\_\_  
 Soil Name Fallcreek  
 Horizon II B2t 34"  
 Depth 32 to 67"  
 ANALYST \_\_\_\_\_

# PARTICLE SIZE DISTRIBUTION ANALYSIS

HYDROMETER METHOD

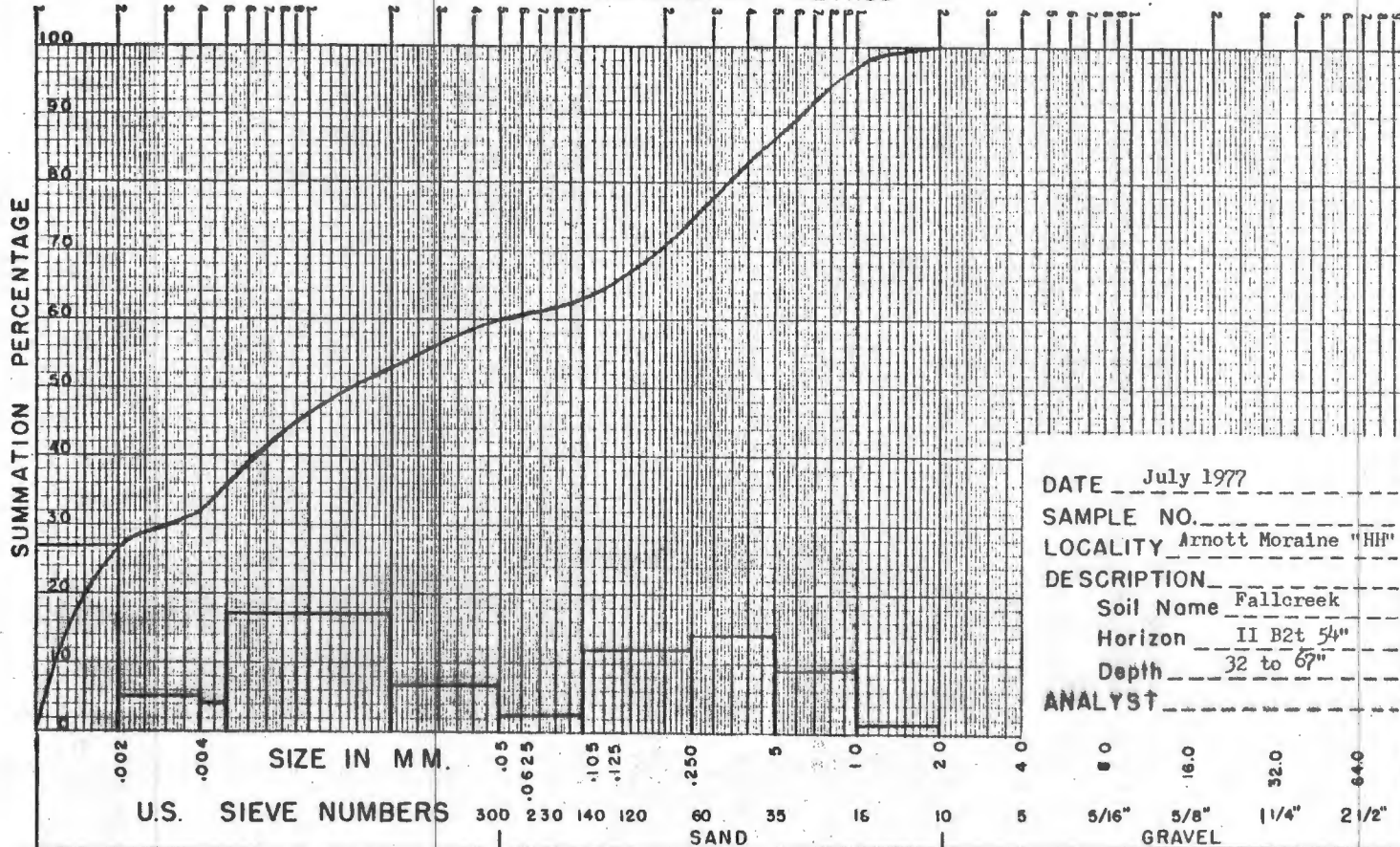


DATE July 1977  
 SAMPLE NO. \_\_\_\_\_  
 LOCALITY Arnott Moraine "HH"  
 DESCRIPTION \_\_\_\_\_  
     Soil Name Fallcreek  
     Horizon II B2t 44"  
     Depth 32 to 76"  
 ANALYST \_\_\_\_\_

NRC	CLAY		SILT		SAND					GRAVEL				
	.002	.004	.002	.05	VFS	FS	MS	GS	VCS	VFG	FG	MG	CG	VCG
					.05-0.1	.1-25	.25-5	.5-1.0	1.0-2.0	2-4	4-8	8-16	16-32	32-64
USDA	28.0%		36.0%		3.8%	11.1%	14.2%	6.1%	0.8%	0.4%				
					0.625-125	.125-25	.25-5	.5-1.0	1.0-2.0					

# PARTICLE SIZE DISTRIBUTION ANALYSIS

HYDROMETER METHOD

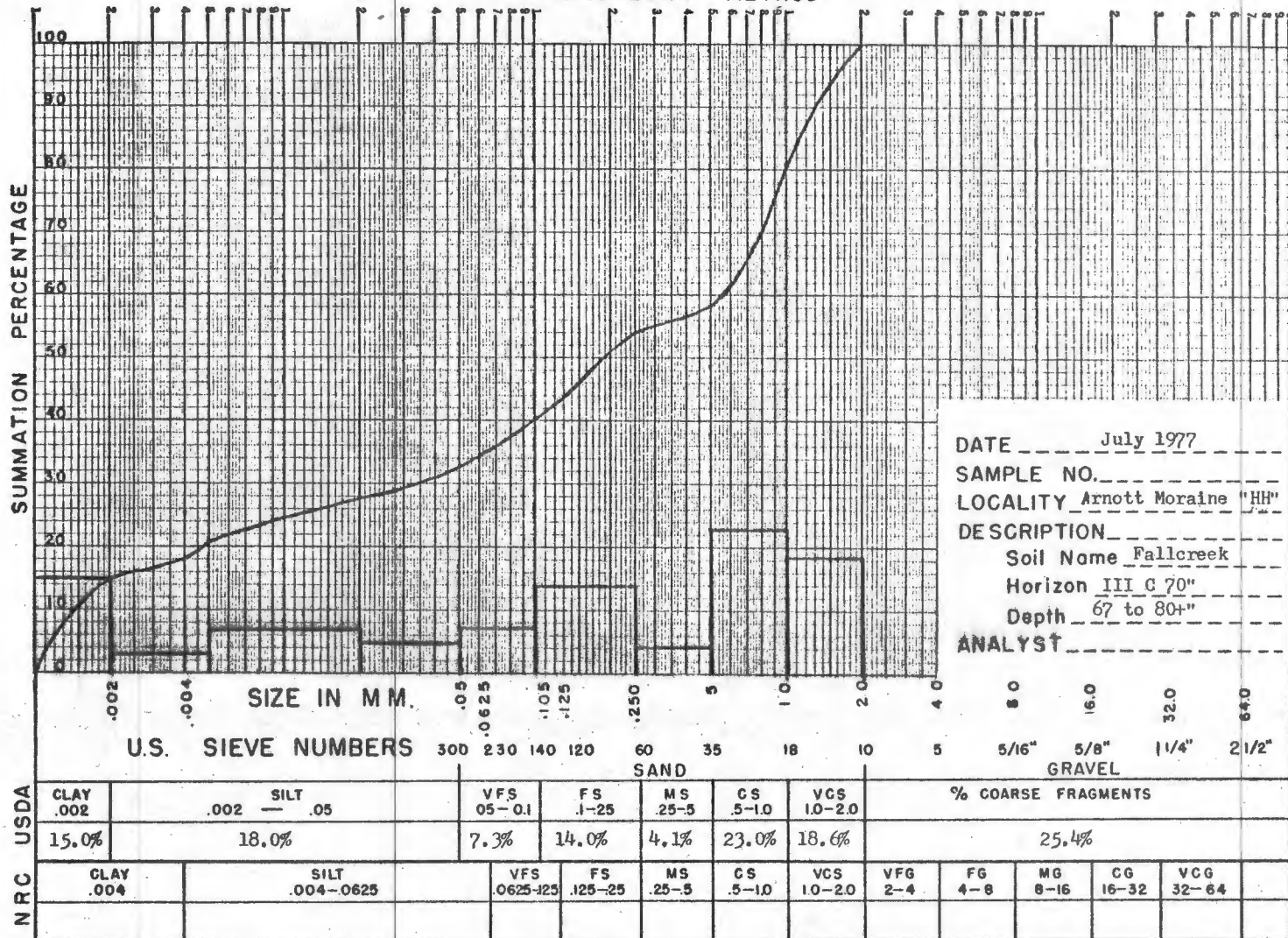


DATE July 1977  
 SAMPLE NO. \_\_\_\_\_  
 LOCALITY Arnott Moraine "HH"  
 DESCRIPTION \_\_\_\_\_  
     Soil Name Fallcreek  
     Horizon II B2t 54"  
     Depth 32 to 67"  
 ANALYST \_\_\_\_\_

USDA	CLAY		SILT		SAND					GRAVEL					% COARSE FRAGMENTS
	.002	.004	.002	.05	VFS .05-.1	FS .1-25	MS .25-5	CS .5-1.0	VCS 1.0-2.0	VFG 2-4	FG 4-8	MG 8-16	CG 16-32	VCG 32-64	
	27.0%		33.0%		2.7%	12.1%	14.3%	9.2%	1.7%						3.7%
NRC	CLAY .004		SILT .004-.0625		VFS .0625-.125	FS .125-.25	MS .25-.5	CS .5-1.0	VCS 1.0-2.0	VFG 2-4	FG 4-8	MG 8-16	CG 16-32	VCG 32-64	

# PARTICLE SIZE DISTRIBUTION ANALYSIS

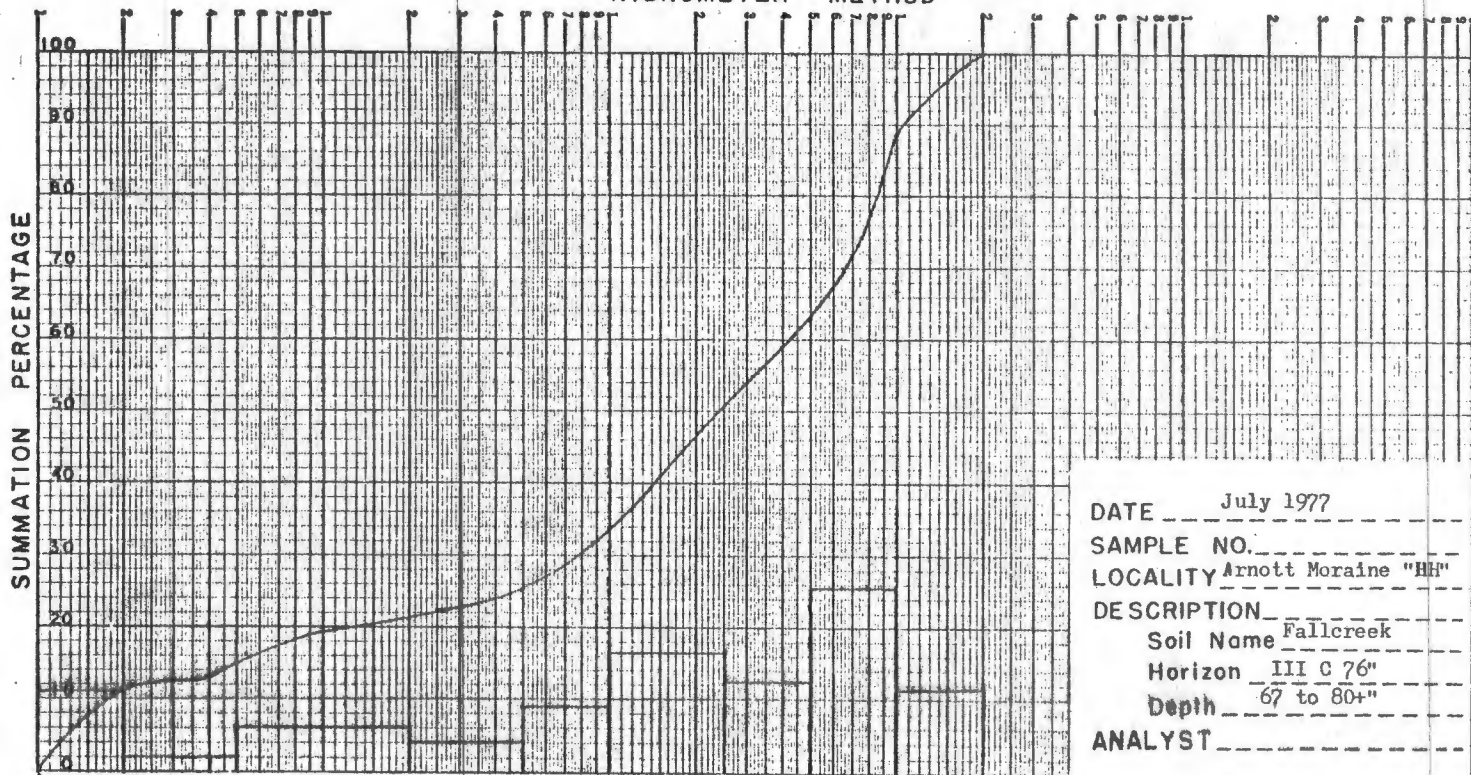
HYDROMETER METHOD



DATE July 1977  
 SAMPLE NO. \_\_\_\_\_  
 LOCALITY Arnott Moraine "HH"  
 DESCRIPTION \_\_\_\_\_  
     Soil Name Fallcreek  
     Horizon III G 70"  
     Depth 67 to 80+"  
 ANALYST \_\_\_\_\_

# PARTICLE SIZE DISTRIBUTION ANALYSIS

HYDROMETER METHOD



DATE July 1977  
 SAMPLE NO. \_\_\_\_\_  
 LOCALITY Arnett Moraine "HH"  
 DESCRIPTION \_\_\_\_\_  
 Soil Name Fallcreek  
 Horizon III C 76"  
 Depth 67 to 80+"  
 ANALYST \_\_\_\_\_

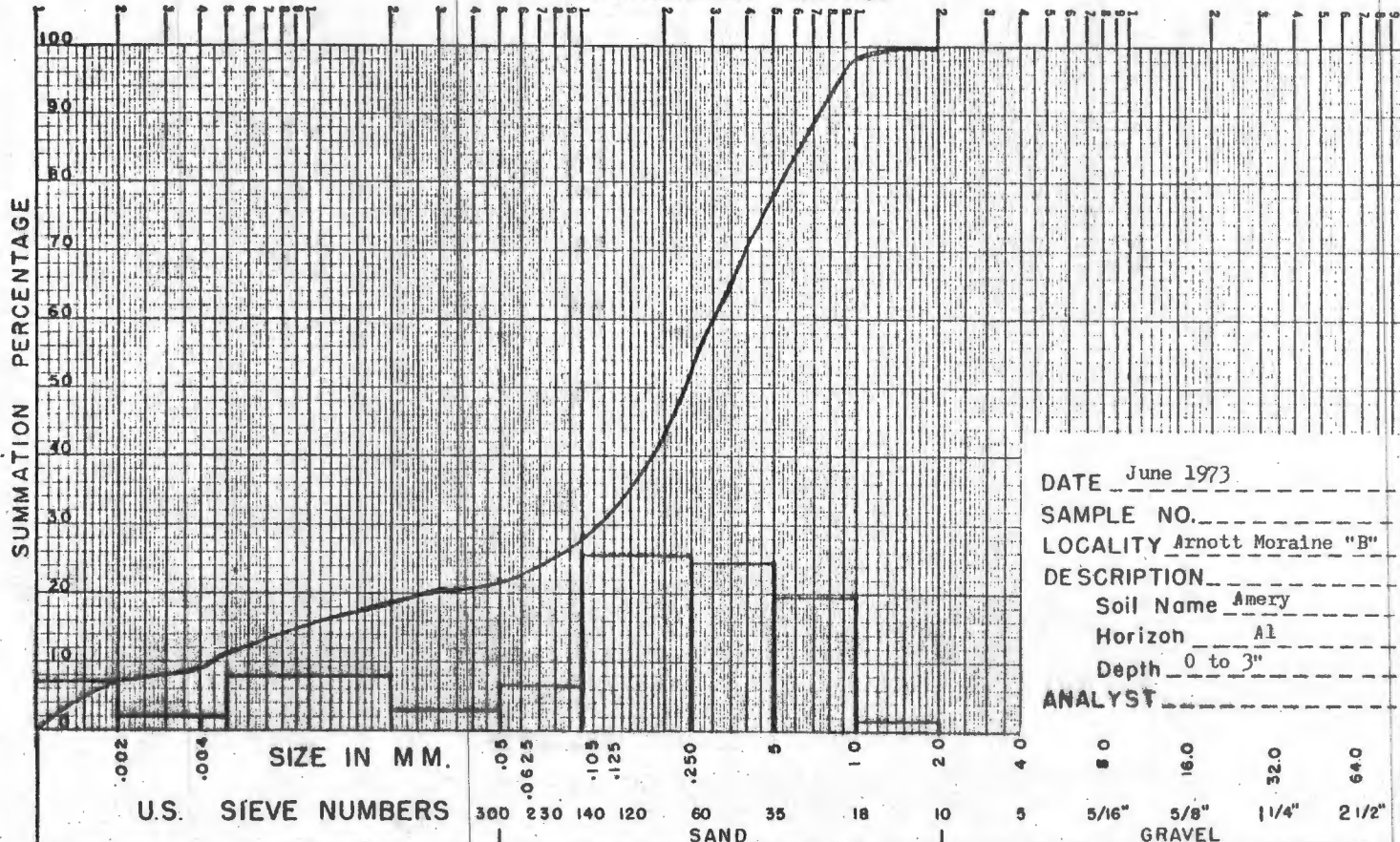
NRC USDA	CLAY		SILT		SAND		% COARSE FRAGMENTS							
	.002	.002	.002	.05	VFS	FS	MS	CS	VCS					
	.004	.004-0625	.0625-125	.125-25	.25-5	.5-1.0	1.0-2.0	VFG	FG	MG	CG	VC6		
	11.0%	14.0%	8.9%	16.7%	12.3%	25.8%	11.3%	23.4%						
								2-4	4-8	8-16	16-32	32-64		

## APPENDIX III

Particle Size Summation Curves and Distribution  
Histograms for the Horizons of the  
Amery Series

# PARTICLE SIZE DISTRIBUTION ANALYSIS

## HYDROMETER METHOD

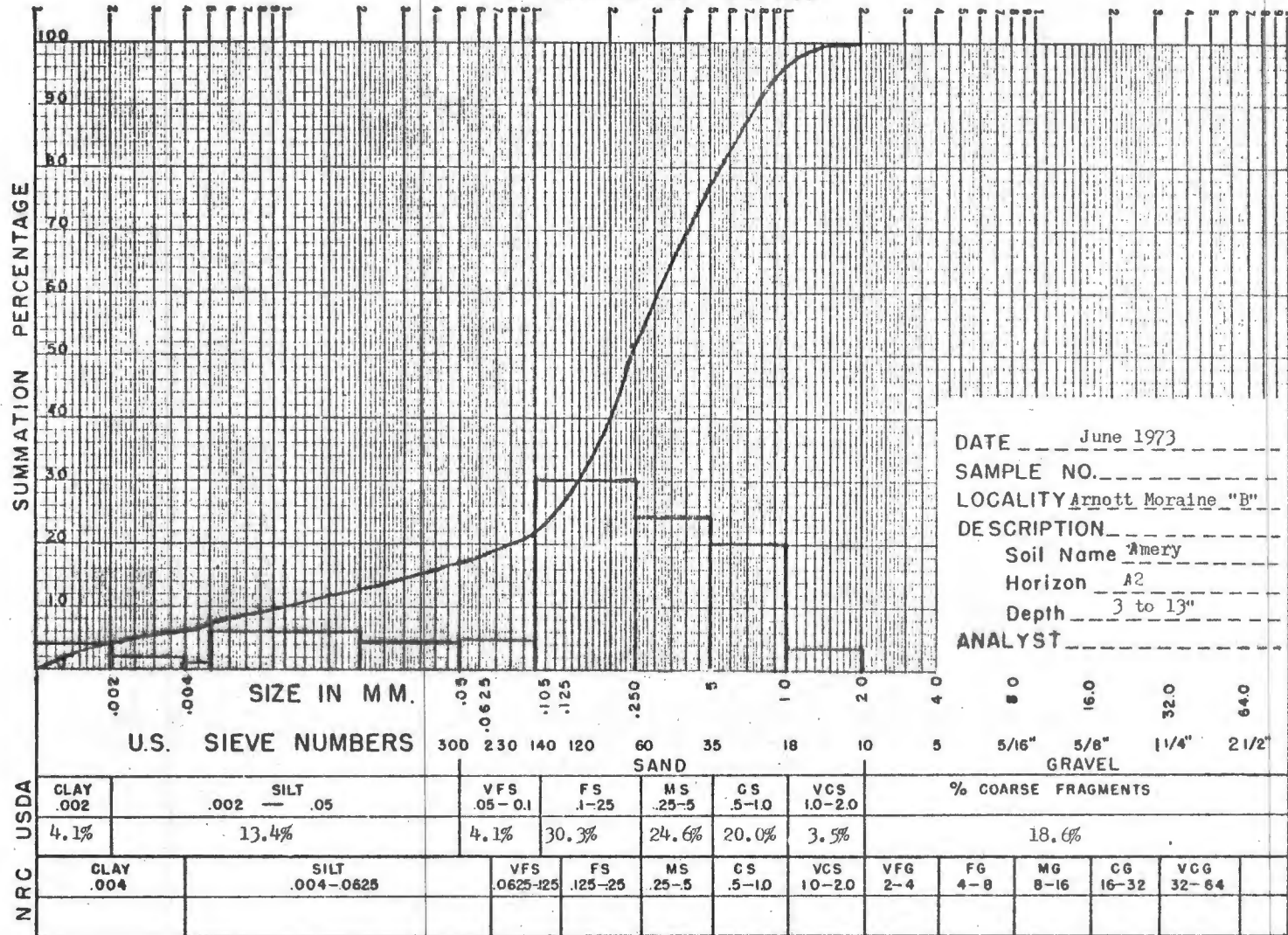


DATE June 1973  
 SAMPLE NO. \_\_\_\_\_  
 LOCALITY Arnott Moraine "B"  
 DESCRIPTION \_\_\_\_\_  
     Soil Name Amery  
     Horizon A1  
     Depth 0 to 3"  
 ANALYST \_\_\_\_\_

NRC USDA	CLAY		SILT		SAND					GRAVEL					% COARSE FRAGMENTS	
	.002	.004	.002	.05	VFS .05-.1	FS .1-25	MS 25-5	CS .5-1.0	VCS 1.0-2.0	VFG 2-4	FG 4-8	MG 8-16	CG 16-32	VCG 32-64		
	7.0%		15.0%		6.3%	25.7%	24.4%	19.8%	1.8%						0.7%	
	.004		.004-0625		.0625-125	.125-25	25-5	.5-1.0	1.0-2.0	2-4	4-8	8-16	16-32	32-64		

# PARTICLE SIZE DISTRIBUTION ANALYSIS

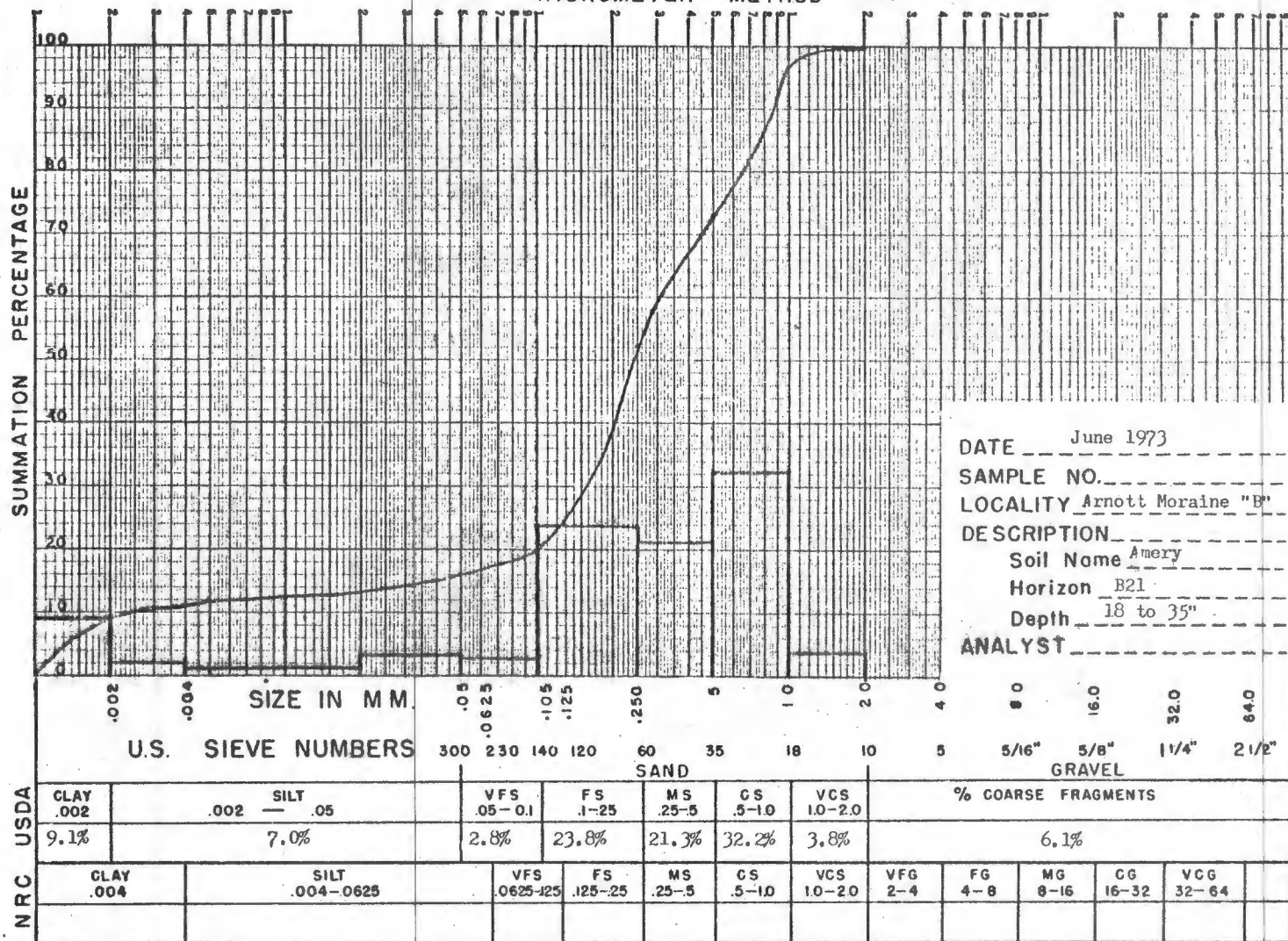
HYDROMETER METHOD



DATE June 1973  
 SAMPLE NO. \_\_\_\_\_  
 LOCALITY Arnett Moraine "B"  
 DESCRIPTION \_\_\_\_\_  
 Soil Name Amery  
 Horizon A2  
 Depth 3 to 13"  
 ANALYST \_\_\_\_\_

# PARTICLE SIZE DISTRIBUTION ANALYSIS

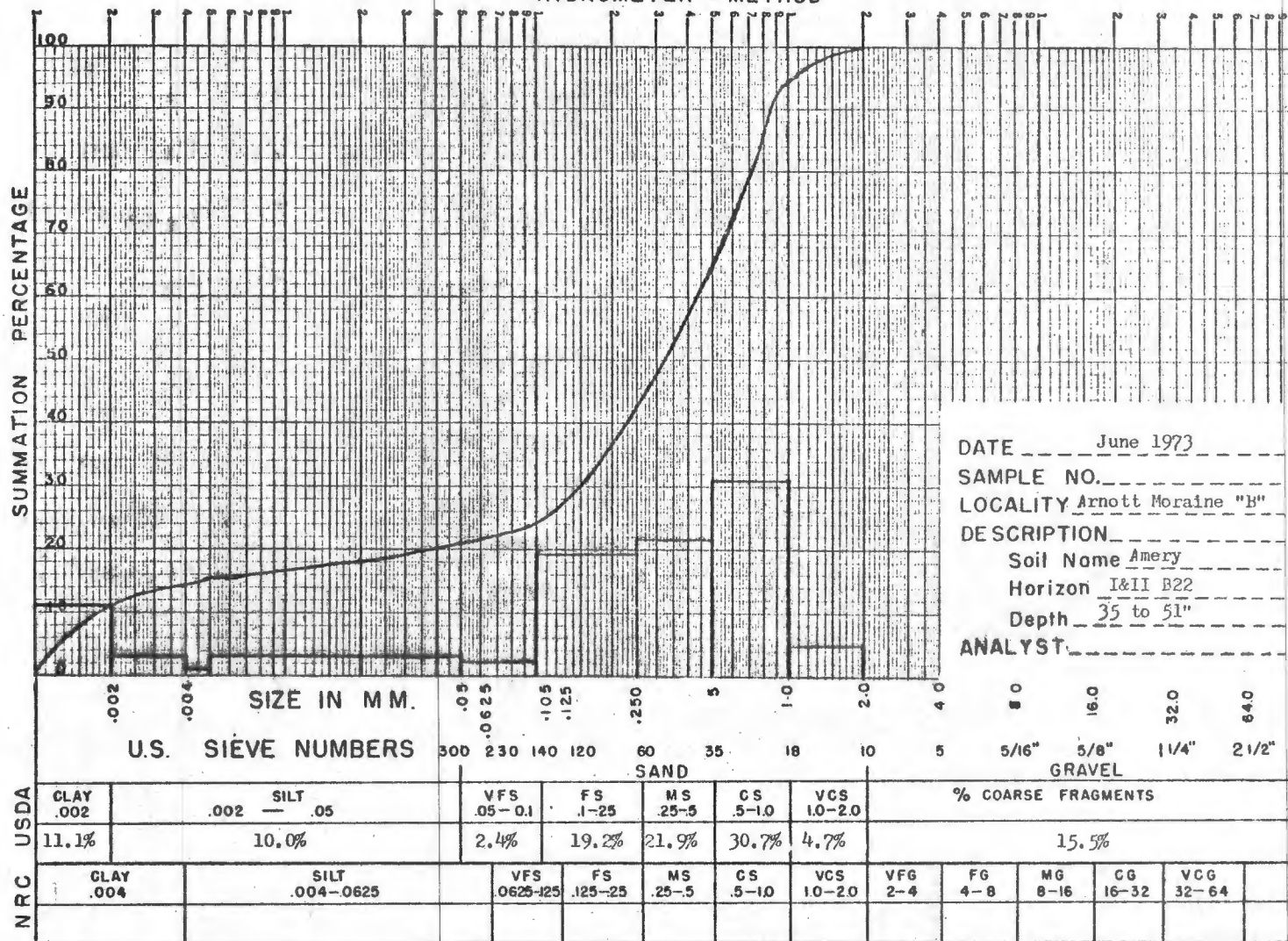
HYDROMETER METHOD



DATE June 1973  
 SAMPLE NO. \_\_\_\_\_  
 LOCALITY Arnett Moraine "B"  
 DESCRIPTION \_\_\_\_\_  
 Soil Name Amery  
 Horizon B21  
 Depth 18 to 35"  
 ANALYST \_\_\_\_\_

# PARTICLE SIZE DISTRIBUTION ANALYSIS

## HYDROMETER METHOD



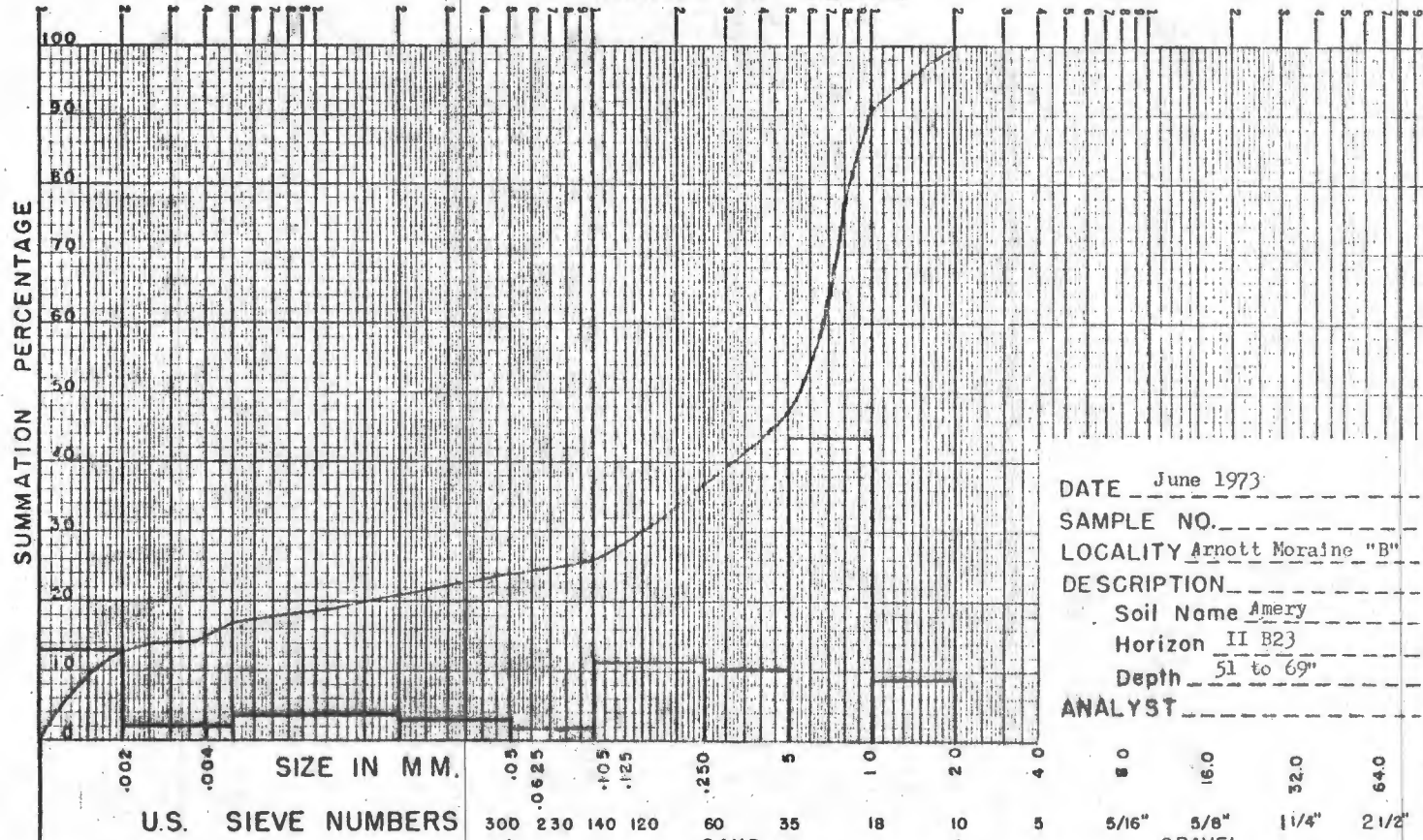
DATE June 1973  
 SAMPLE NO. \_\_\_\_\_  
 LOCALITY Arnott Moraine "B"  
 DESCRIPTION \_\_\_\_\_  
 Soil Name Amery  
 Horizon I&II B22  
 Depth 35 to 51"  
 ANALYST \_\_\_\_\_

NRC USDA

CLAY	SILT	SAND					% COARSE FRAGMENTS				
.002	.002 - .05	VFS	FS	MS	CS	VCS	VFG	FG	MG	CG	VCG
		.05-0.1	.1-25	.25-5	.5-1.0	1.0-2.0	2-4	4-8	8-16	16-32	32-64
11.1%	10.0%	2.4%	19.2%	21.9%	30.7%	4.7%					

# PARTICLE SIZE DISTRIBUTION ANALYSIS

HYDROMETER METHOD

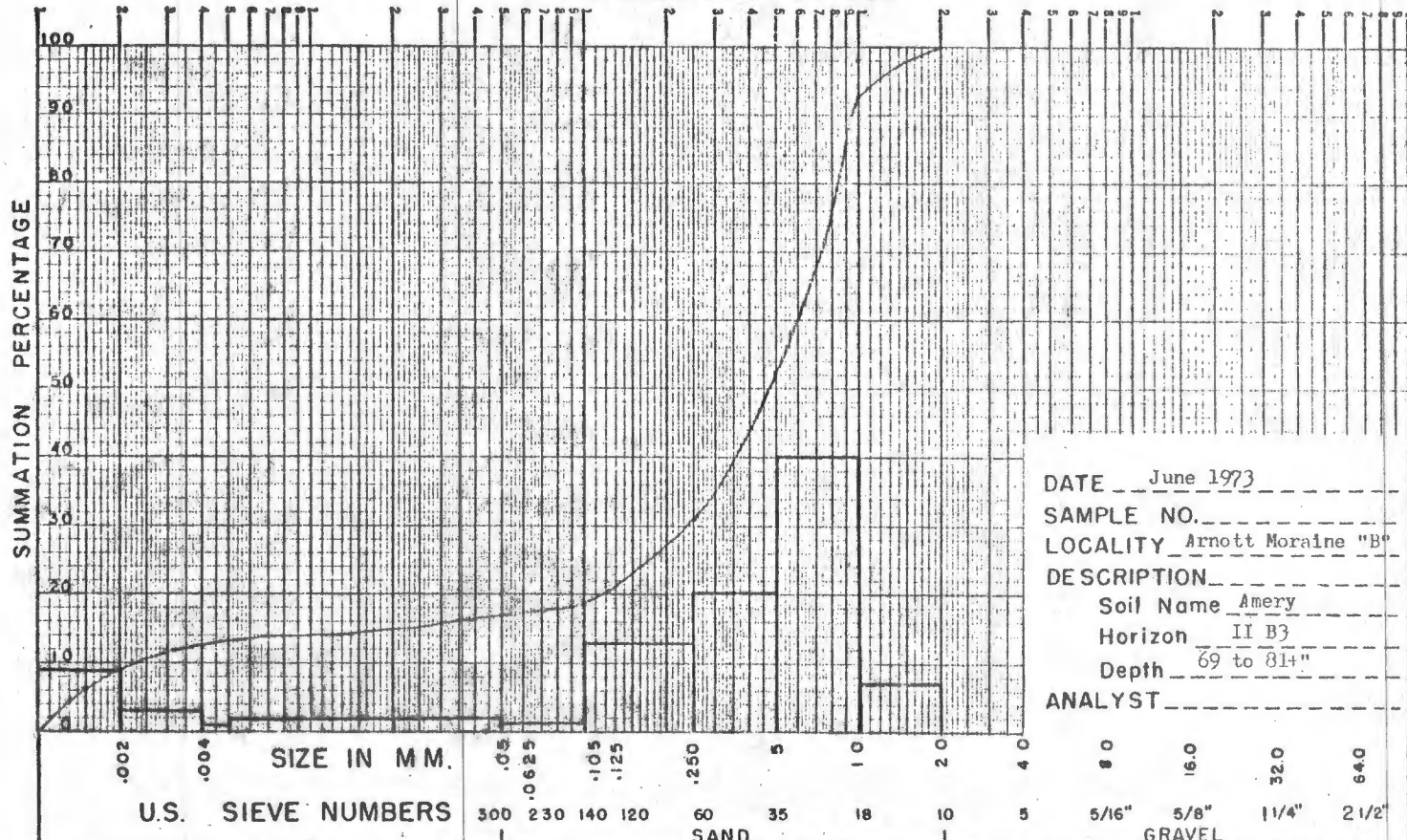


DATE June 1973  
 SAMPLE NO. \_\_\_\_\_  
 LOCALITY Arnott Moraine "B"  
 DESCRIPTION \_\_\_\_\_  
 Soil Name Amery  
 Horizon II B23  
 Depth 51 to 69"  
 ANALYST \_\_\_\_\_

NRC	CLAY		SILT		SAND					GRAVEL				
	CLAY .002	.002	SILT — .05	.05	VFS .05-0.1	FS .1-25	MS .25-5	CS .5-1.0	VCS 1.0-2.0	% COARSE FRAGMENTS				
	13.1%		11.1%		1.8%	11.3%	10.4%	43.7%	8.6%	17.5%				
	CLAY .004	SILT .004-.0625		VFS .0625-.125	FS .125-.25	MS .25-5	CS .5-1.0	VCS 1.0-2.0	VFG 2-4	FG 4-8	MG 8-16	CG 16-32	VCG 32-64	

# PARTICLE SIZE DISTRIBUTION ANALYSIS

HYDROMETER METHOD



DATE June 1973  
 SAMPLE NO. \_\_\_\_\_  
 LOCALITY Arnott Moraine "B"  
 DESCRIPTION \_\_\_\_\_  
     Soil Name Amery  
     Horizon II B3  
     Depth 69 to 81"  
 ANALYST \_\_\_\_\_

NRC USDA	CLAY		SILT		SAND			GRAVEL					% COARSE FRAGMENTS			
	CLAY .002	.002	SILT .05		VFS .05-0.1	FS .1-25	MS .25-5	CS .5-1.0	VCS 1.0-2.0	VFG 2-4	FG 4-8	MG 8-16	CG 16-32	VCG 32-64		
	9.0%		8.1%		1.5%	13.1%	20.4%	40.5%	7.4%							13.9%
	CLAY .004		SILT .004-0625		VFS 0625-125	FS .125-25	MS .25-5	CS 5-1.0	VCS 10-2.0	VFG 2-4	FG 4-8	MG 8-16	CG 16-32	VCG 32-64		