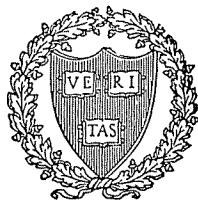


COARSE FRAGMENTS IN THE  
GLOUCESTER SOILS OF THE  
HARVARD FOREST

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## ABSTRACT

Boulders, stones, cobbles and pebbles occupy more than half the volume of many Gloucester soils and take up space that otherwise might be occupied by fine earth, air and moisture. In this sense the coarse skeleton "dilutes" the soil.

Small volumes of soil do not provide adequate samples for determining the amount of coarse skeleton in bouldery stony soils. This is shown by comparison with large samples 30 to 60 cubic feet in volume. Total amount of coarse skeleton in bouldery stony soils generally will need to be estimated because it is not often feasible to sample large volumes of soil.

## INTRODUCTION

Half the volume of some Gloucester soils in New England consists of rock fragments ranging from pebbles up to boulders<sup>2</sup> in size. This coarse skeleton (rock fragments larger than 2 mm in diameter) needs to be taken into account in any plant-soil study requiring evaluation of moisture or nutrient relationships of the soil. Boulders, stones, cobbles and pebbles, occupy space that otherwise might be filled with fine earth (portion of the soil with particles less than 2 mm in diameter) in which is stored most of the moisture, nutrients and air used for growth of plants.

Because of the difficulty of sampling stony soils there has been a tendency to concentrate field studies on non-stony soils. When stony soils are used the samples generally include only coarse fragments smaller than one and one-half inches (4 cm) in diameter and there is a tendency to disregard completely the content of fragments larger than this. In some very stony soils this introduces considerable error in calculations designed to find the amount of moisture or nutrients in given volumes, such as those occupied by the root systems of single trees.

This report calls attention to the amount of coarse skeleton in the bouldery stony Gloucester soils of the Harvard Forest and to the possibility of errors if only small samples are collected or if only the fine earth portion of the soil is used in evaluation. The study is based on results obtained by weighing and sieving relatively large volumes of soil.

Grateful acknowledgement is made to J.G. Cady, K.W. Flach, R.B. Grossman, H.M. Raup, and E.L. Stone for helpful discussion at various times during the course of the study. Funds for this publication have been supplied from generous gifts by the Friends of the Harvard Forest.

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<sup>2</sup> Terminology in this paper follows that of the Soil Survey Manual, U.S. Dept. Agri. Handbook 18, 1951.



Figure 1. Stony Gloucester sandy loam in a pasture near the Harvard Forest. Rock fragments on the surface range in size from cobbles to boulders and are as numerous throughout the soil as on the surface.

#### LITERATURE REVIEW

Finnish scientists were among the first to assess the amount of boulders and stones in soils. Viro (1947) developed a method for estimating the amount of stones in the upper 12 inches (30 cm) of the soil by driving a steel rod one centimeter in diameter repeatedly into the soil and measuring the depth of penetration. This same method was used by Valanko (1951) and Viro (1952) as a means of determining the feasibility of clearing stony land for agricultural crop production. Some of the soils Viro worked with had more than 60 percent by volume of coarse fragments.

In the United States, Reinhart (1961) has reviewed the various methods used for evaluating coarse skeleton and has emphasized the need for considering more than the fine earth portion or even the portion collected in cores of known volume. Crocker and Major (1955) dealt with the problem of sampling stony soil materials on freshly deposited

moraines in Alaska. Donahue (1940) was one of the first in the United States to deal adequately with large rock fragments in forested soils. He weighed all the stones and boulders that occurred in fairly large pits in the Adirondacks and determined their volume. Volumes of coarse fragments in his pits ranged from about 10 to 30 percent of the whole soil based only on the coarse fragments heavier than about one-half pound in weight. Bethlahmy (1952) used pits with three-foot-square cross sections and determined rock fragment content. The volume of coarse fragments in some of his soil horizons ranged up to 57 percent.

## PROCEDURE

Samples were collected from pits in forested areas of Gloucester sandy loam in Compartments I and VIII, Prospect Hill Tract, Harvard Forest, Petersham, Mass.

The Gloucester soils of the Harvard Forest are typical of the Gloucester soils elsewhere in New England and New York. They are well or somewhat excessively drained Brown Podzolic soils developed from bouldery, stony, sandy glacial till of Wisconsin Age derived from granite, gneiss, or mica schist. The coarse fragments are relatively unweathered, essentially non-porous and typically occur in large numbers both on the surface and throughout the soil (Fig. 1). Geology, vegetation and other features of the Harvard Forest have been described previously (Stout, 1952). Details of the genesis and morphology of the Gloucester soils can be obtained from recent publications (Northeast Soil Research Comm., 1954; Prince and Raney, 1961).

Sample sites were selected on nearly level areas near the tops of knolls to minimize erosion and slope effects. Access pits (Fig. 2) 2 by 6 feet (60 by 180 cm) in cross section and about 5 feet (150 cm) deep were dug at a distance of at least 4 to 5 feet from trees to avoid large roots. Samples were collected by horizons from sections of soil 1 to 2 feet wide, 6 feet long and about 5 feet deep bordering the access pit. Straight-edge boards were used as level reference base lines (Fig. 3) and all measurements were made from these rather than the surface of the soil.

In three pits, adjoining sections, 6 or 12 inches (15 or 30 cm) wide, were sampled as duplicates to gain information about the variation to be expected by sampling sections of varying widths.

Sides of the pits were kept vertical by use of a plumb bob. In stony soils this seems to be the most practical method, but it is also the largest source of error. Corrections for the volume of protruding stones or for cavities left when stones are removed were made by estimate. For small stones a satisfactory means of doing this was to weigh a fragment that appeared to be of the same size as that of the protruding portion. For large stones and boulders, particularly those of irregular shape, scale diagrams of the cross section at about 4 inch intervals were used as a basis for weight and volume estimates.

Sampling was by horizons. Average thickness of material removed from each horizon was obtained by taking about 30 depth measurements on a 6 inch grid pattern from the level base line to the surface of the newly exposed next lower horizon.

Rock fragments larger than 3 inches in diameter were hand-sorted into size classes. All soil material less than 3 inches (8 cm) in diameter was sieved in the field, using



Figure 2. Boulders in the Gloucester soils of the Harvard Forest.

- A. Prospect Hill I 10-60 access pit in a formerly cultivated area from which most of the surface stones and boulders have been removed and placed in stone fences. The boulders in the pit were not visible before the pit was dug.
- B. Prospect Hill VIII pit. The boulders in this pit were not visible before the pit was dug, in fact, the location was chosen to avoid boulders as much as possible.

either 1/2 or 1 inch (12 or 25 mm) square-holed screens. The 1/2 inch screen proved to be too fine for soils at field capacity or wetter. The 1 inch screen was satisfactory both for wet and dry soils and the rock fragments screened out had very little adhering fine material even when the soil was wet.

Weight of each size class was obtained to the nearest pound by use of a 100 pound (45.4 kg) capacity spring scale. A 4 or 5 pound subsample of the material that passed through the screen was used for moisture determination and for sieving into smaller size classes.

Bulk density was determined by use of the saran-clod and irregular-hole methods. Use of cylindrical cores is not feasible in soils like the Gloucester that have a large content of closely spaced rock fragments. The saran-clod method (Brasher et. al., 1962), a modification of the older well-known paraffin method, consists of dipping a soil fragment in a solution of acetone and Dow saran resin F-220 (a polyacrylic product of



Figure 3 Prospect Hill I 10-60 pit showing the level straight-edge board from which all measurements were made and also the simple sieving and weighing equipment.

Dow Chemical Company, Midland, Michigan). After drying, a tough thin surface film remains and this enables subsequent rather rough handling of the clod for weight and volume determinations. The irregular-hole method is the one commonly used for gravelly or stony soils. It consists of digging a hole 4-6 inches in diameter and about 4 inches deep, weighing the soil removed, and determining the volume of the hole by filling with sand, water, or other substance. In these studies a gallon-sized thin polyethylene bag was used to line the hole and the volume determined by filling with water.

Table 1

PERCENT COARSE SKELETON IN FOUR LARGE PITS IN GLOUCESTER SOIL.

Location and designation of pits	Approx. volume of sample in cu ft	PERCENT COARSE SKELETON ON WHOLE-SOIL OVEN DRY BASIS	
		By weight	By volume
Prospect Hill I			
10-60 pit	30	47	30
12-61 pit	45	56	41
Slab City II			
8-60 pit	30	70	53
Prospect Hill VIII			
7-62 pit	60	78	61
Average		63	46

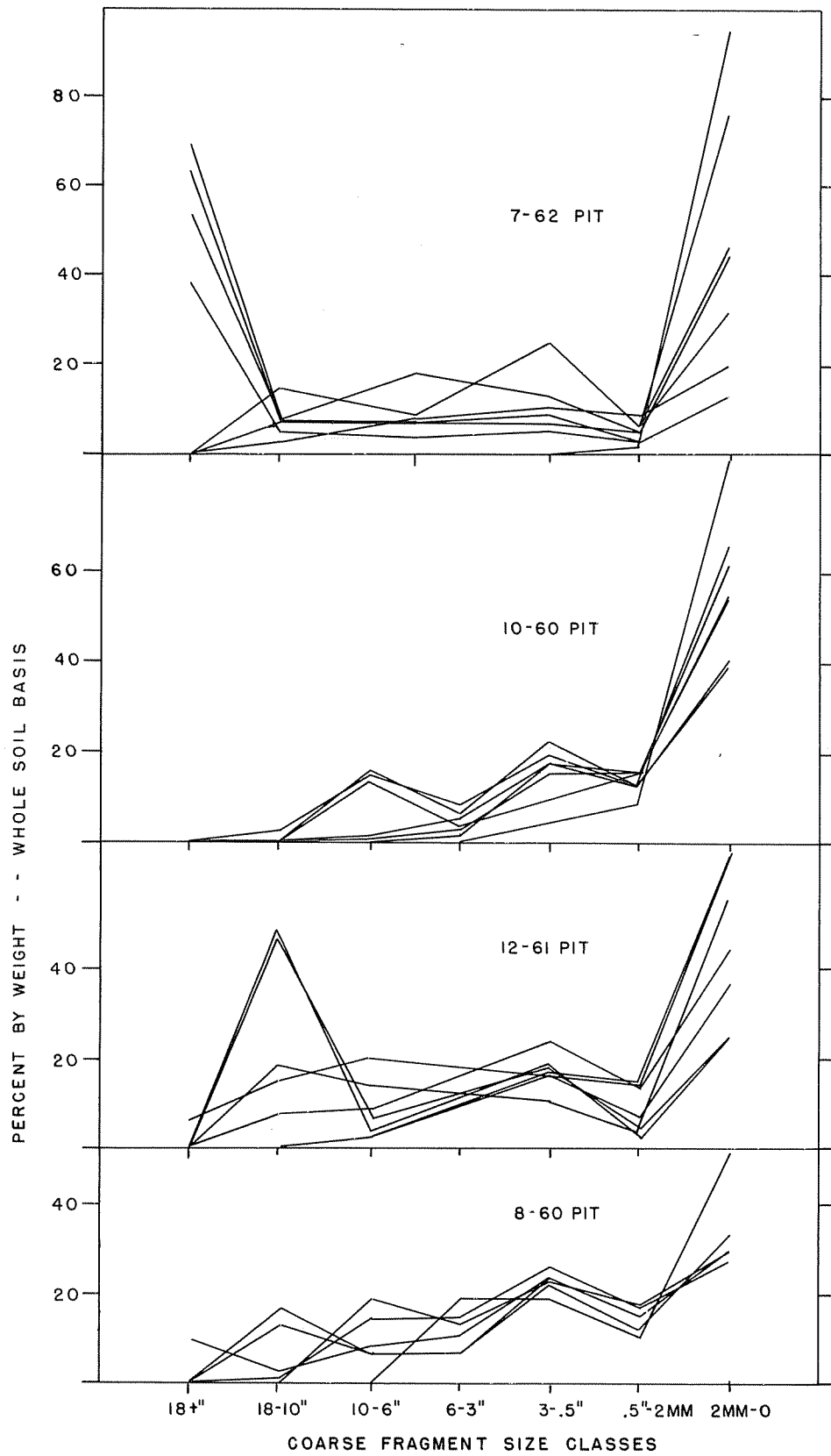


Figure 4 Families of curves showing distribution of coarse fragments by horizons in each of the four large sample pits.



## RESULTS

### VARIABILITY IN AMOUNT OF COARSE SKELETON.

Coarse skeleton in the Gloucester soils of the Harvard Forest averages about 60 percent by weight and 50 percent by volume if calculated on the basis of the whole soil section, including all stones and boulders (Table 1). The range is from 47 to 78 on a weight basis and 30 to 61 by volume. The soils at the four sites are representative of the Gloucester soils of New England in that they cover the range commonly encountered in sampling these soils. The two samples in the Prospect Hill I compartment are thought to be about in the central part of the range so far as coarse skeleton is concerned.

Size distribution of coarse fragments by individual horizons in the four pits is shown by families of curves in Figure 4. These curves are based on the oven dry weight of soil including all boulders and stones. If the thin A horizons are excepted, all sizes of rock fragments up to 10 inches in diameter occur in each horizon, in each of the four pits. Three of the pits have rock fragments larger than 18 inches in at least one horizon. Figure 2 shows boulders in the 10-60 and 7-62 pits.

No one size class of coarse skeleton clearly predominates in all four pits. In fact, the size classes in the 10 inch to 2 mm range are of about the same magnitude when compared with each other in any one pit or among the four pits. Each of these size classes ranges around the 10-20 percent mark.

To test variability between adjacent sections in the same pit, duplicate 6 inch wide and 6 foot long sections were sampled in two pits and duplicate 12 inch wide sections in another. These data, shown in Table 2, suggest that a range of about 10 percent in total coarse skeleton can be expected in duplicate samples of 6 inch wide sections and about 5 percent in 12 inch wide sections.

Table 2

VARIATION IN PERCENT COARSE SKELETON BETWEEN ADJOINING SECTIONS.

Horizon	8-60 PIT		10-60 PIT		7-62 PIT	
	(6" wide sections)		(6" wide sections)		(12" wide sections)	
	a	b	a	b	a	b
	Percent by weight - whole soil, oven dry basis.					
A11	43	50	4	20	5	6
A12	-	-	-	-	29	16
Ap	-	-	33	34	-	-
B21	63	75	-	-	53	58
B22	63	74	64	63	53	56
B23	-	-	64	52	69	68
B3	66	77	59	42	-	-
C1	69	76	-	-	76	84
C2	75	70	-	-	86	88
C3	-	-	-	-	85	90

Percents coarse skeleton by weight for three 12-inch-diameter cylindrical hole samples from Prospect Hill VIII were 39, 45 and 45. These differences are not nearly so great as among the four 6-foot-long large pit samples (Table 1), principally because no large stones or boulders were encountered in the smaller pits. Two of these 12-inch cylindrical sample pits are about 3 feet apart and therefore serve as duplicates. Values for these two, 39 and 45, are about what would be expected on the basis of the results shown for duplicates from the larger pits shown in Table 2.

But these two small pits are only about 30 feet from the large 7-62 pit and 70 feet from the 12-61 pit. The values for all four sample sites (all within a distance of 70 feet of each other) show a great variation in coarse skeleton content, namely, 78, 56, 45, and 39 percent by weight, but this is no more than would be expected if large stones and boulders are encountered in some pits and not in others.

#### PATTERN OF COARSE SKELETON.

Rock fragments in the Gloucester soils, irrespective of size, tend to occur in some kind of pattern rather than being uniformly distributed. Patterns are repetitious over a distance of several inches in the case of the smaller sizes (pebbles and cobbles) and over several or many feet for larger stones and boulders.

Patterns for pebbles and cobbles are shown in Figures 5 and 6. Fragments of these sizes generally are within 2 or 3 inches of each other, and there are few spaces larger than 6 inches. Consequently in samples collected from pits about 12 inches in diameter there is relatively small chance of avoiding coarse fragments in the 3-8 inch class.



Figure 5 Pattern of coarse fragments in a 12 inch wide, 2-3 inch thick portion of the B2 horizon in the 7-62 pit.

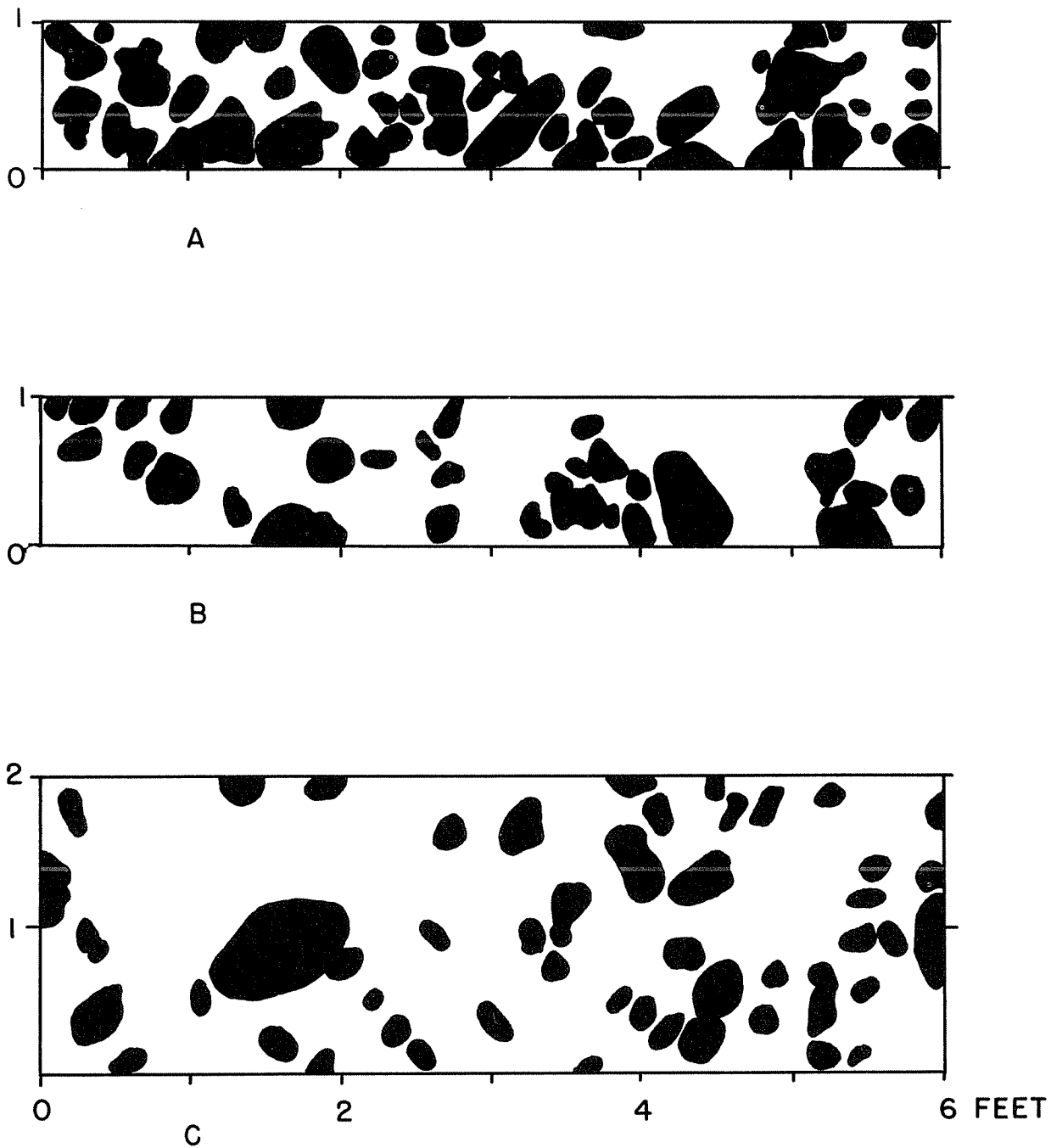


Figure 6 Horizontal plane pattern of rock fragments larger than two inches in diameter in 2 inch thick portions of the B horizon of two different pits.

- A. 10-60 pit at 8-10 inch depth.
- B. 7-62 pit at 3-5 inch depth.
- C. 7-62 pit at 8-10 inch depth.

Some idea of the spacing of the larger stones and boulders in Gloucester or Gloucester-related soils can be obtained from Figure 1 and from published scale diagrams (Lutz et. al., 1937; Donahue, 1940; Husch, 1959; Lyford, 1938). In general,

boulders within the body of the Gloucester soils are isolated and spaced about 5 to 10 feet apart. For this reason there is only a small chance of encountering boulders (rock fragments larger than 24 inches in diameter) when sampling, especially if the pits are only a foot or two in diameter. In the present study boulders occurred in the sampled sections in only one of the four large pits. In one other pit boulders occurred in the access pit but just missed being in the sampled section at the side.

Patterns of pebbles and cobbles probably result from soil disturbance by tree-throw or root-growth. Patterns for large stones and boulders on the other hand probably are related more closely to solifluction processes that were active shortly after deposition of the soil material from the melting glacier, 12,000 years or so ago, before the material was stabilized by vegetation.

### BULK DENSITY.

Bulk densities determined by the saran-clod and irregular-hole methods compare well with one another but, in general, are smaller than those obtained when the whole horizon is sampled (Table 1).

To adjust for differences in bulk densities caused by presence of unusually large pebbles or stones in the samples, hypothetical bulk densities can be calculated for the hypothetical-fine earth-void-soil that presumably would exist if all coarse fragments somehow were removed without disturbing in any way the arrangement of the fine earth portion of the soil with its intermingled voids. The hypothetical volume occupied by this coarse skeleton-free-soil can be calculated by subtracting the volume of coarse skeleton (weight divided by 2.65) from the volume of the sample as collected. The values for the hypothetical bulk densities, (Table 3), based on the fine earth-void portion of the soil are appreciably smaller than those based on the undisturbed whole soil, reflecting the effect caused by the heavy rock fragments.

Table 3

TRUE AND HYPOTHETICAL BULK DENSITIES FOR SEVERAL HORIZONS OF THE PROSPECT HILL VIII 7-62 PIT DETERMINED BY THREE METHODS.

Horizon	Section	IRREGULAR-HOLE		SARAN-CLOD		WHOLE HORIZON	
		Whole soil basis	Hypoth. fine earth-void basis	Whole soil basis	Hypoth. fine earth-void basis	Whole soil basis	Hypoth. fine earth-void basis
A11	b	-	-	.59	.59	.58	.55
A12	a	-	-	.78	.76	.80	.64
	b	-	-	.90	.88	.82	.73
B21	a	-	-	.93	.90	1.31	.84
	b	-	-	.92	.91	1.33	.77
B22	a	-	-	1.14	1.04	1.24	.78
	b	-	-	.98	.90	1.42	.89
B23	b	1.38	1.14	1.30	1.15	1.40	.89
C1	a	-	-	1.51	1.35	2.18	1.38
	b	1.84	1.61	1.78	1.57	2.32	1.39
C2	b	1.95	1.76	1.90	1.67	2.54	1.93

## DISCUSSION

### COMPARISON OF SAMPLING METHODS.

Because of the difficulty of sampling bouldery stony soils, the problem often is avoided, either by placing experimental plots on soils that have a small amount of coarse skeleton, or by disregarding stones and boulders entirely and expanding to an acre basis from data obtained on the fine earth portion of the soil. For soils having 50 percent by volume of coarse skeleton the error due to extrapolation from the fine earth to the whole-soil basis is great, particularly if no allowance is made for the dilution effect of the coarse skeleton.

Studies of soils in the past were conducted for the most part on loose bulk samples of from quart to gallon (1 to 4 liters) size. These samples were carried to the laboratory, dried, and sieved through a 2 mm screen. In many instances coarse skeleton was completely disregarded in presentation of the data. If expressed at all, it was of necessity given on the basis of the sample originally collected. There was no method of converting back to "true-field-soil" basis except by use of estimates.

In recent years there has been an increasing tendency to sample known volumes of soil so that the results can be expressed on a volume as well as weight basis. This sampling of known volumes has been stimulated both by soil genesis studies and by work on available moisture. But in general, the volumes sampled are no larger than the bulk samples formerly collected, and are even smaller if sampling is done by 3 inch cylindrical cores. Thus even by present methods a large part of the coarse skeleton of the Gloucester soils, of necessity, remains unsampled.

The largest rock fragments saved in the ordinary collection of loose bulk samples are about one and one-half inches in diameter. All other fragments are thrown out. Only recently have estimates routinely been made of the amount of larger fragments. For this reason most of the published data on percent rock fragments larger than 2 mm can be interpreted to mean that this figure is the value for coarse fragments in the one and one-half inch to 2 mm size class. In other words, the data given takes no account of the pebbles, cobbles, stones and boulders larger than one and one-half inches in diameter.

Figure 7 shows the size distribution of all coarse fragments from three horizons in the 7-62 pit and focuses attention on the problems of sampling soils with large amounts of coarse fragments in the pebble to boulder size range. Each size class is represented, but there is an unusually large proportion in the boulder size class.

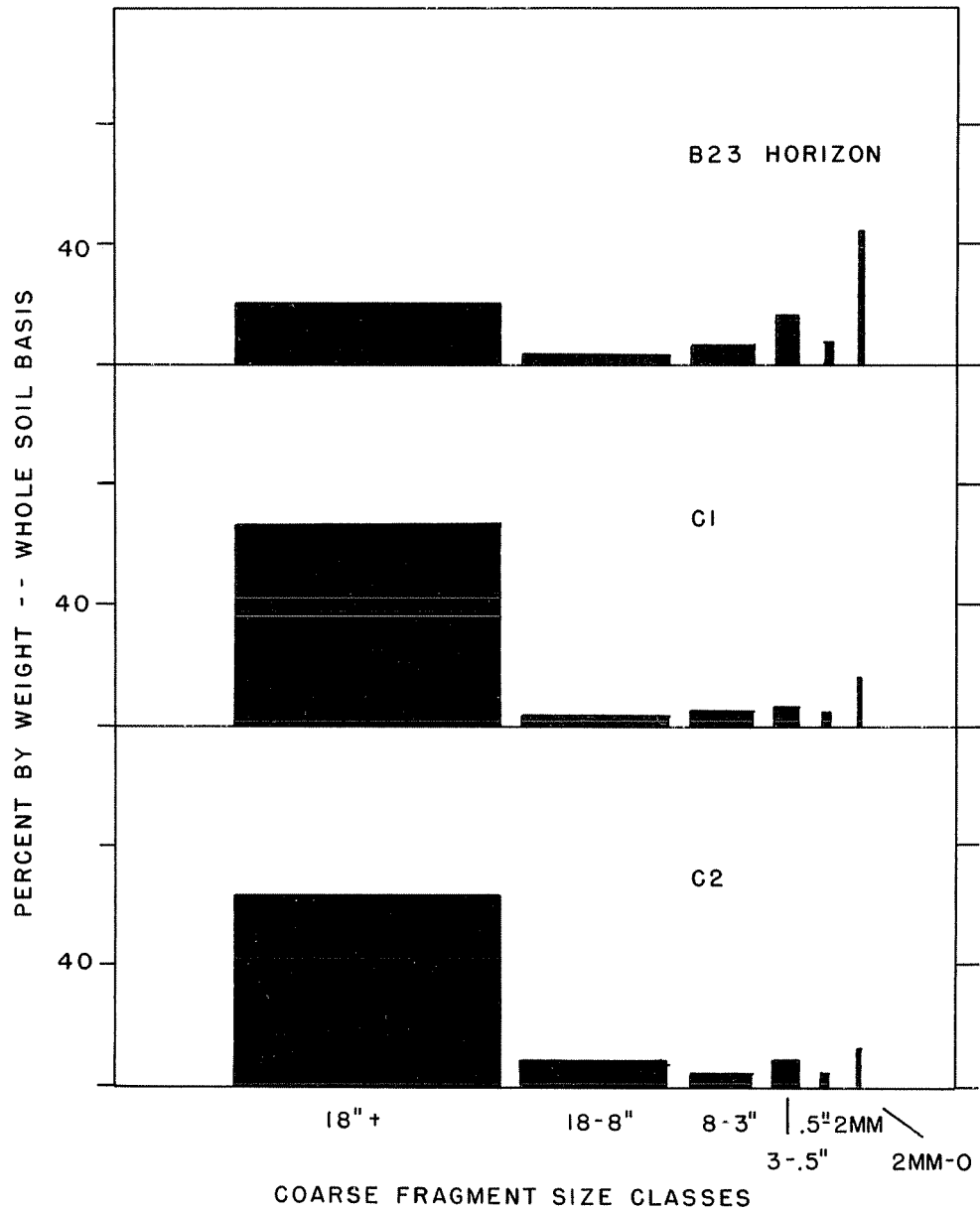


Figure 7 Distribution of coarse fragments by size classes, (percent by weight), in three horizons of the 7-62 pit. Size class width on the graph is proportional to the actual size class diameter range so the chart gives a rough idea of the volume occupied by the coarse fragments as well as the percent by weight.

These same three horizons were also sampled by the saran-clod and irregular-hole methods (Table 4). Values for coarse skeleton as determined by these two methods are of about the same magnitude, but they are only about half as great as those determined by sampling the whole horizon. This, of course, is because all stones and boulders are weighed when the whole section is sampled whereas very few fragments larger than one and one-half inches in diameter are sampled by the saran-clod and irregular-hole methods.

Table 4  
PERCENT COARSE SKELETON IN THREE HORIZONS OF THE 7-62 PIT

Horizon	SAMPLED VALUES			CALCULATED VALUES	
	Saran-clod method	Irregular-hole method	Whole horizon method	Less than 1 inch dia.	Less than 3 inch dia.
Percent by weight - whole soil, oven dry basis.					
B23	22	30	55	23	35
C1	28	33	84	29	38
C2	32	39	88	33	49

As a means of judging what portion of the whole section is sampled by the saran-clod and irregular-hole methods, calculations of the actual percent coarse skeleton in the less than 1 inch and less than 3 inch portions of the soil were made. These calculations are possible because all the soil in these size classes in the whole section was sieved and weighed. These calculated values, in effect, simulate an accurate sampling of the soil by containers 1 and 3 inches in diameter. Comparison of these simulated values with the actual values obtained by the saran-clod and irregular-hole methods (Table 4) show that the saran-clod method, based on seven to nine samples per horizon, sampled the less than 1 inch size portion of the soil remarkably well. The irregular-hole method, based on either two or three samples per horizon, did fairly well for the less than 3 inch size portion but was consistently low. Had data been available to calculate the less than one and one-half inch size probably it could be shown that the irregular-hole method sampled this portion a little better than it did the less than 3 inch size class. For example, only two out of nine irregular-hole samples from the B and C horizons of the 7-62 pit had rock fragments larger than 2 inches in diameter whereas all but one had rock fragments in the 1-2 inch size class.

This case study points up the fact that even if all rock fragments up to 3 inches in size are collected, there is still a rather large portion of the soil unaccounted for because such a large portion of the Gloucester soil is made up of cobbles, stones, and boulders.

The 1-3 inch size class is probably sampled fairly well by the 3 inch cylindrical cores now commonly used to collect soil samples, but it is not likely that rock fragments larger than about one half the diameter of the core, or one and one-half inches, are sampled adequately. Certainly there will be very few instances when rock fragments exactly 3 inches in diameter will be sampled, and generally a good deal of trial will be necessary to find places where the core sampler fits into the spaces between the

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