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Soil Conservation Service

Northeast NTC
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Subject: SOI - Bedrock Study; Hancock County, Maine; April 14-17, 1986

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To: Ronald E. Hendricks
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PURPOSE

To use GPR techniques to evaluate the depth to bedrock in a select map unit and to compare these results with those obtained with conventional sampling methods.

PARTICIPANTS

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EQUIPMENT

The equipment used during this field study was the SIR System-8 with the ADTEK SR-8004H graphic recorder. The 120 MH_z antenna with the Model 705DA transceiver was used. The scanning time on the control unit was 72 nanoseconds, which, assuming a dielectric constant of 13 for the investigated soils, provided an approximated scanning depth of 3.0 meters.

Field Methods

Two study sites were selected within Hancock County, Maine. Each site is in hayland and is representative of areas which are being surveyed as map unit 62B, Tunbridge-Lyman complex, 3 to 8 percent slopes.

A 370-by-100-foot rectangular grid was established at Site 1 and a 200 by 150 foot rectangular grid was established at Site 2. An engineering transit was used to establish grid corners and surface elevations at each observation point. A nylon line, with markers affixed at 10-foot intervals, was stretched between opposite grid corners and flags were placed at each 10-foot marker to establish transect end points. In this manner, all end points were located and flagged. As the radar survey progressed across each study site, the nylon line was relocated and stretched between opposite transect end-points. This technique economized field time and provided 418 and 336 equally spaced (10-foot apart) observation points at Sites 1 and 2, respectively.

Four additional transects were completed within each study site using conventional methods. These transects produce 48 and 41 observation points within study Sites 1 and 2 respectively.

DISCUSSION

In many upland areas, it is exceedingly difficult to examine soil profiles and to determine the depth to bedrock with conventional soil surveying tools. Rock fragments and dense layers of basal till limit the effectiveness of spades, augers, picks, and mechanical probes. Soil scientists are fatigued and frustrated, and work is slowed as tools are repeatedly stopped by rock fragments. The probability of encountering a rock fragment increases with soil depth and, therefore, limits the potential of observing deep or very deep soils. At most sites, it is uncertain whether penetration is halted by a rock fragment or bedrock. Decisions are often made in the field based on the anticipated rather than the confirmed depths to bedrock.

Inferences and broad assumptions must be made concerning the depth to bedrock, and the composition and interpretations of soil map units. Limited by the tools he uses, soils scientists infer the anticipated depth to bedrock from landscape position. In areas having uniform or less variable depths to bedrock, these inferences are undoubtedly, fairly accurate. In areas of highly variable or irregular depths to bedrock, these inferences are more inaccurate. Unfortunately, even in areas of bedrock controlled landforms, the nature of the underlying bedrock cannot be determined from the landscape.

In areas of highly variable and irregular depths to bedrock, soil depths are more likely to be underestimated as a result of the limitations of conventional surveying tools and the inhibiting nature of the medium. The composition and interpretation of soil map units are often based on insufficient, incomplete, and often bias data collected from a limited number of observation points or inferred from the landscape.

The ground-penetrating radar (GPR) can chart the depth to bedrock and can be effectively used in most areas of New England to improve the descriptions and interpretations of soil map units. However, few documented, bedrock studies have been conducted with the GPR. Extensive research has not been carried out on the variability of the depth to bedrock within map units. For these reasons, this study was proposed with the following objectives: (1) to compare depth to bedrock data collected by GPR methods with data gathered by conventional sampling methods; (2) to determine the variability of the depth to bedrock within similar areas of the Tunbridge-Lyman complex, 3 to 8 percent slopes; and (3) to produce computer generated three-dimensional surface net diagrams and two-dimensional contour maps of the depth to bedrock relative to surface elevations for inclusion in soil survey reports.

Graphic Imagery - The GPR performed well and provided clear and interpretable imagery at each site.

Figure 1 is a representative profile from Site 2. The horizontal scale represents units of distance traveled. As the horizontal scale is dependent upon the speed of antenna advance along the transect line, it varies slightly across Figure 1. The vertical scale is a time or depth scale which is based upon the velocity of signal propagation. On most graphic profiles, the vertical scale is exaggerated. As a consequence of the vertical exaggeration (about 6:1), the apparent topography of the underlying bedrock has been slightly distorted. The dashed vertical lines are event markers inserted on the graphic profile by the field operator to indicate known antenna positions or reference points along the transect. A marker was depressed each time the antenna passed an observation point. The evenly spaced horizontal lines are scale lines. Scale lines provide reference planes for relative depth assessments.

In Figure 1, the surface of the bedrock has been highlighted with a dark line. This surface is irregular and varies in depth from 11 to 68 inches. Areas of coherent bedrock can be distinguished from areas of fractured or more intensely weathered bedrock. Areas of fractured or intensely weathered bedrock produce segmented and complex imagery which contrasts with the smooth and more linear imagery from area of coherent bedrock. Areas having broad transitions from bouldery or stony deposits to bedrock produce weak or complicated radar reflections.

Features within the bedrock can also be discerned in Figure 1. In the lower right-hand portion of this profile, a pattern can be seen within the bedrock. This feature is related to a vein of dissimilar material(s), exfoliation, or a fracture plane. While less pronounced in this figure, the image of the contact of ablation till with basal till is apparent between depths of 27 and 33 inches. Rock fragments, identified by their hyperbolic patterns, are evident in the upper part of this profile. Segmented portions of a major subsurface horizon, the spodic horizon, appear in the upper part of this profile. Segmentation is a result of tree-throw, cultivation, or other forms of pedoturbation.

Correlation Analysis of GPR and Auger Data - Presently, ground-truth soil boring data provides the basis upon which the radar imagery is scaled and compared. Regardless of the operator's confidence in the radar, most users consider ground-truth auger measurements to be true, while radar imagery novel, untried, and at best inexact.

Figure 2 is a scatter diagram plotting the covariation between ground-truth auger measurements and scaled radar imagery. Data for this portion of the study was collected from 14 observation points within study Site 1. The area from which the data was collect is characterized by uniform and relatively shallow (10 to 49 inches) depths to bedrock.

In Figure 2, all data are expressed in inches. The correlation coefficient is 0.84. The positive correlation implies that as the scaled radar depths increase, measured auger depths will also increase. This correlation is significant at the 0.01 level and a linear correlation is said to exist between the two data sets.

As evident in Figure 2, for any particular scaled radar value, a range in the augered depth to bedrock can be expected. This inexactness is due, in part, to (1) normal observation errors, and (2) the highly irregular bedrock surface.

Auger measurements can and often do contain an inherent degree of error. Observation errors can be attributed to the habit of rounding-off measurements or guesstimating depths, non-vertical probing, and failing to detect and augering past the upper boundary of an interface. In addition, in many upland areas of New England, observation errors can be attributed to the uncertainty as to whether augering was halted by a rock fragment or bedrock. Furthermore, slight spatial discrepancies often exist between the site of auger measurements and the radar track. As a result of these and other sources of observation errors, variations exist between auger measurements and the depth scaled on graphic profiles.

The surface of the bedrock is, on a micro-scale, highly variable. The underlying bedrock is phyllite. As in other areas of New England, the phyllite is imbricated and steeply inclined, producing a highly irregular micro-topography. The irregular micro-topography of the bedrock surface produces small but significant variations in the depth to bedrock over short distance. This variation is responsible, in part, for the lack of agreement between radar and ground-truth measurements collected at many observation sites.

In a study conducted in Vermont, the variation in the depth to phyllite bedrock within a 24-inch radius of several observation sites was as great as 20 inches. In the present study, a 6-inch variation in the depth to bedrock was observed when augering was repeated at a distance of less than 12 inches at one observation site. With such variations in the depth to bedrock over small distances, it is unlikely that any method of measurements could produce identical results.

The GPR profiles are based on a composite of scans which have been averaged for each interface across the arc of radiation beneath the antenna. Therefore, the GPR profile more closely reflects the "average" depth to bedrock and is less influenced by extremes.

Table I compares the data on the depth to bedrock as derived by the two methods over the fourteen observation sites. The variation in the averaged depth to bedrock is slightly greater than 2 inches. This difference is considered insignificant. The match between auger boring and radar imagery is considered remarkable and attests to the reliability and accuracy of the GPR.

Table I

Comparison of Conventional and GPR Methods

Parameter	Auger	GPR
Number of observations	14.0	14.0
Average depth to bedrock	26.8	29.2
Standard deviation	5.8	6.4

Comparison of Data on the Depth to Bedrock - Figures 3 and 4, and Table II compare the distributions of depths to bedrock at each site and for each method of observation. In general, there is a close agreement in the data collected by the two techniques at Site 1 and by the auger between the two sites. However, there is significant difference between the techniques at Site 2.

Bartlett's test for homogeneity of variance was completed on the data sets. Variance is significantly different among the radar data at Site 2 and the auger data at both sites and the radar data at Site 1. Variance is not significantly different and is assumed to be similar among the auger data at both sites and the radar data at Site 1.

It is believed that the similarity between the auger data at the two sites is artificial. The similarity in the data obtained with the auger reflects the limitation of conventional surveying tools to effectively and consistently probe beyond depths of 30 to 40 inches. The probability of an auger encountering a coarse fragment increases with depth. Small rock fragments lodged in the dense basal till can halt the penetration of augers as effectively as larger stones or boulders.

All tools have limitations. In many upland areas of New England, the GPR is the most effective tool for determining the depth to bedrock. In this study, the two sites were defined by the auger as being nearly identical in terms of depth to bedrock. However, the sites are dissimilar according to the GPR survey. Site 1 has an average depth of 22.7 inches and a standard deviation of 4.8; Site 2 has an average depth of 43.4 inches and a standard deviation of 23.2. Both sites occupy similar landscape position. However, the underlying bedrock topography is deeper and more variable at Site 2 than at Site 1.

Site 1 is characterized by relatively uniform depths to bedrock and shallow and moderately deep soils. As expressed in Table II, the data obtained by the two methods at Site 1 are similar. This similarity of results is expected in areas having bedrock predominantly within depths of 40 inches.

At Site 1, the average depth to bedrock varies from 22.7 inches with the radar to 27.8 inches with the auger. The difference between these data sets is attributed to normal observation errors and unequal sampling sizes. A t-Test for unequal samples was used to determine whether the difference in the means was significant. The difference was not significant. Accordingly, it must be assumed that the observed difference (5.1 inches) in the average depth to bedrock as compiled by the two techniques is within the normal errors of observation.

The median depth to bedrock at Site 1 is 22.9 inches (radar), and is nearly identical with the mean. The lower quartile is 19.0 inches, and the upper quartile is 26.2 inches. One-half of the observations occur between the interquartile range of 19.0 to 26.2 inches. This data attest to the low variability and relative uniformity in the depth to bedrock at Site 1.

Results obtained by the two methods at Site 2 were significantly different. The GPR characterized this site as having more variable depths to bedrock with predominantly deep and very deep soils intermingled with areas of moderately deep and shallow soils.

The mean depth to bedrock at Site 2 is 43.4 inches which closely approximates the median and the mode (both 42.6 inches). The lower quartile is 34.3 inches, the upper quartile is 51.1 inches, and the interquartile interval is 16.8 inches. One-half of the observations have depths to bedrock occurring between 34.3 and 51.1 inches.

Table II

Comparison of Data on the Depth to Bedrock
as Collected with GPR and Auger Techniques

SITE	METHOD	NO. OBS	MEAN	STD DEV	MIN	MAX	MEDIAN
1	auger	48	27.8	5.7	13.0	42.0	27.0
1	radar	418	22.7	4.8	11.0	35.5	22.9
2	auger	41	25.2	6.9	14.0	48.0	23.0
2	radar	336	43.4	23.2	11.1	81.9	42.6

(all depths in inches)

Map Unit Composition - Both study sites were within delineated areas of map unit 62B, Tunbridge-Lyman complex, 3 to 8 percent slopes. Tunbridge is a coarse-loamy, mixed, frigid Typic Haplorthods and Lyman is a loamy, mixed, frigid Lithic Haplorthods. In the Hancock County, Maine, soil survey manuscript the map unit is described as consisting of:

> "nearly level to gently sloping areas of somewhat excessively drained, shallow to bedrock Lyman soils, and well drained, moderately deep Tunbridge soils. It is on bedrock controlled landforms in the coastal areas and on upland hills and ridges. The areas are irregular in shape and range from 4 to over 100 acres in size.
>
> Tunbridge soils make up about 50 percent of this complex....
>
> Lyman soils make up about 30 percent of this complex....
>
> Included in mapping are areas of well drained Marlowe soils; moderately deep, moderately well drained soils; moderately well drained Dixfield soils; somewhat poorly drained Colonel soils, small areas of poorly drained Brayton soils; and a few rock outcrops...."

This is a rather comprehensive description of the composition of this map unit. Table III lists the composition of this map unit as defined with the GPR at the two selected sites.

The proportion of soils within each site is different. Site one typifies the concept of map unit 62B, with an average composition of 72 percent Tunbridge and 28 percent Lyman. Site 2, while occupying a similar position in the landscape, is deeper and more variable to bedrock. The average composition of Site 2 is 50 percent Soil A, 31 percent Tunbridge soil, 10 percent Marlowe soil, and 9 percent Lyman soil. Soil A is a deep, well drained soil. Marlowe soil has been treated in Table III as a similar soil to Soil A.

It is presently neither desirable nor feasible to subdivide map unit 62B into two separate units based on transect data. However, the following description can be made based upon the composite of 59 GPR transects completed within the two study areas:

> In 95 percent of the areas mapped as Tunbridge-Lyman complex, 3 to 8 percent slopes, Tunbridge, Lyman, and their similar soils make up 91 to 99 percent of the map unit. Generally, the mapped areas are about 74 percent Tunbridge and similar soils, and about 21 percent Lyman soils. The components of this map unit are so intricately intermingled that it is not practical to map them separately at the scale used.

In this description, the deep, well drained Soil A has been treated as a similar soil to Tunbridge soil. It is noteworthy that the composition expressed in the map unit description closely approximates the average composition of the two study sites (Tunbridge, 50 versus 58%; Lyman, 30 versus 21%).

Table III

Average Composition of
Tunbridge-Lyman Complex, 3 to 8 Percent Slopes
(as determined by GPR Techniques)

				Confidence		Inclusions	
Area	Transects	Soils	Percent	Interval	Level	Soils	%
Site 1	21	Tunbridge	72	67-78	95%		
		Lyman	28	21-34	95%		
Site 2	38	Soil A	50	40-59	95%	Lyman	9
		Similar	10				
		Tunbridge	31	22-40	95%		
Composite	59	Tunbridge	58	51-65	95%	Marlowe	3
		Soil A	18	11-25	95%		
		Lyman	21	16-26	95%		

Computer Generated Three-Dimensional Block Diagrams - Though a three-dimensional entity, soils are most often observed, conceptualized, and classified on the basis of a limited number of widely spaced, one- or two-dimensional exposures. Generally, observations of soils and soil properties have been restricted to auger and excavation holes. Computer processing of GPR data can provide economical three-dimensional plots of subsurface conditions. These plots are useful for gaining a rapid, visual picture of subsurface conditions, summarizing variations in the depth and lateral extent of soil horizons, and aiding interpretations.

The enclosed three-dimensional computer generated plots of the study site are from various plane and viewing angles. All were prepared using a PC and the SCSTAT (tm) software package. These crude plots represent the first and unfinished attempt to provide three-dimensional block diagrams of subsurface feature from the Maine study sites based on GPR data. Efforts are being continued in an attempt to provide a ready for publication print of the subsurface bedrock topography.

RESULTS

This study represents the first major bedrock study conducted by SCS with ground-penetrating radar. Based on the established objectives, this study has been a success. It is concluded from this study that:

1. GPR can be used as an effective tool for determining the depth to bedrock and the composition of soil map units based on soil depth criteria.

2. A high, positive correlation exists between scaled radar data and actual ground-truth measurements. The GPR is a highly accurate tool for determining the depth to bedrock beneath the loamy tills of New England.

3. The effectiveness and reliability of hand and mechanical augers for determining the depth to bedrock appears to be limited and is questioned. It appears that the utility of conventional tools in some areas of New England is restricted to areas of shallow and moderately deep soils. These tools can produce erroneous results when used in areas of highly irregular or variable depths to bedrock and in areas of deep or very deep soils.

4. Techniques of GPR and computer graphics or processing are compatible and can be used to enhance our understanding of soils and soil conditions.

I strongly recommend the continuation of this study in other areas and/or other soil conditions. The adaptability and utility of the GPR has been successfully demonstrated in three diverse areas of Maine during the past year. Work from two studies (plow pan study, Aroostook County; bedrock study, Hancock County) is incomplete and is being continued at the NENTC and the SNTC.

My praise is extended to Don Clark, Glen Jordan, and Bob Joslin for the extra effort which they expended on this project.

With kind regards.

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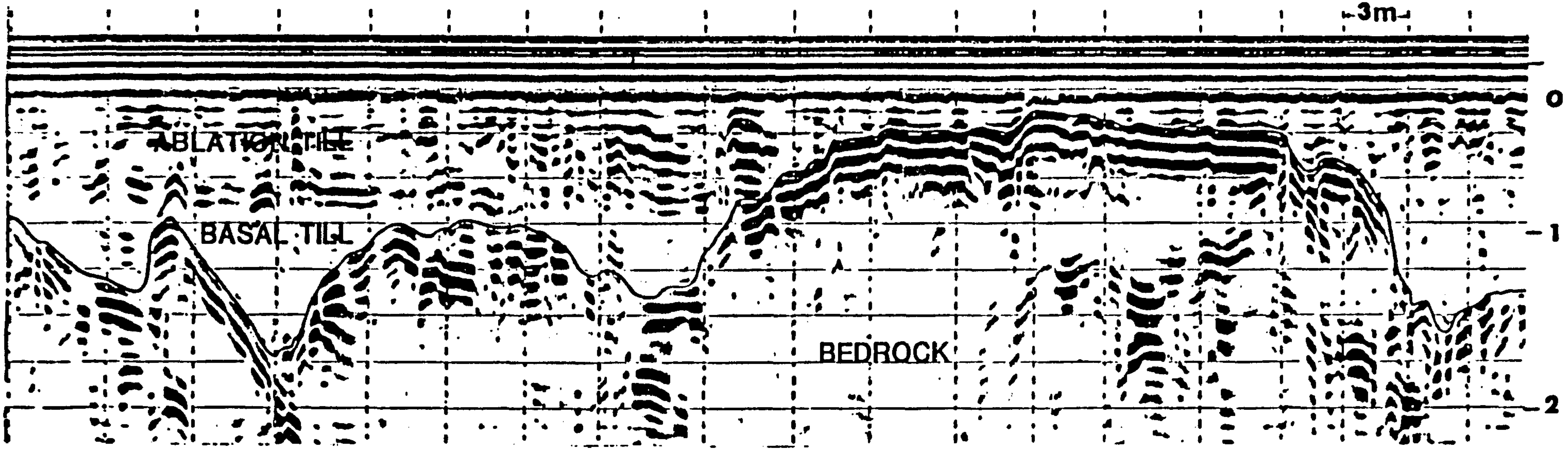
FIGURE 1



DEPTH TO BEDROCK

TUNBRIDGE – LYMAN COMPLEX, 3 TO 8 PERCENT SLOPES

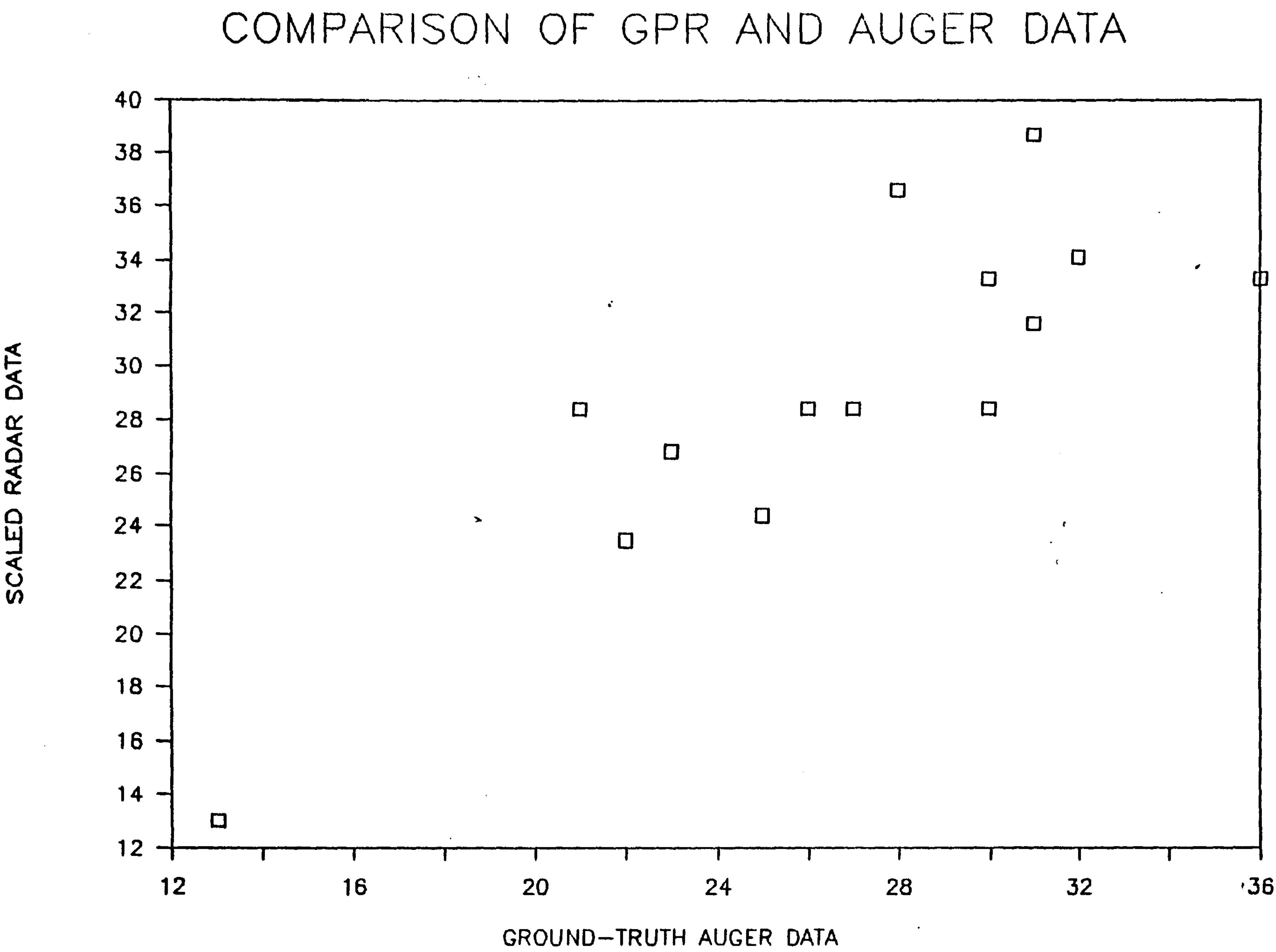

COMPARISON OF GPR AND AUGER DATA
SCALED RADAR DATA
GROUND-TRUTH AUGER DATA
40
38
36
34
32
30
28
26
24
22
20
18
16
14
12
12
16
20
24
28
32
36

FIGURE 2

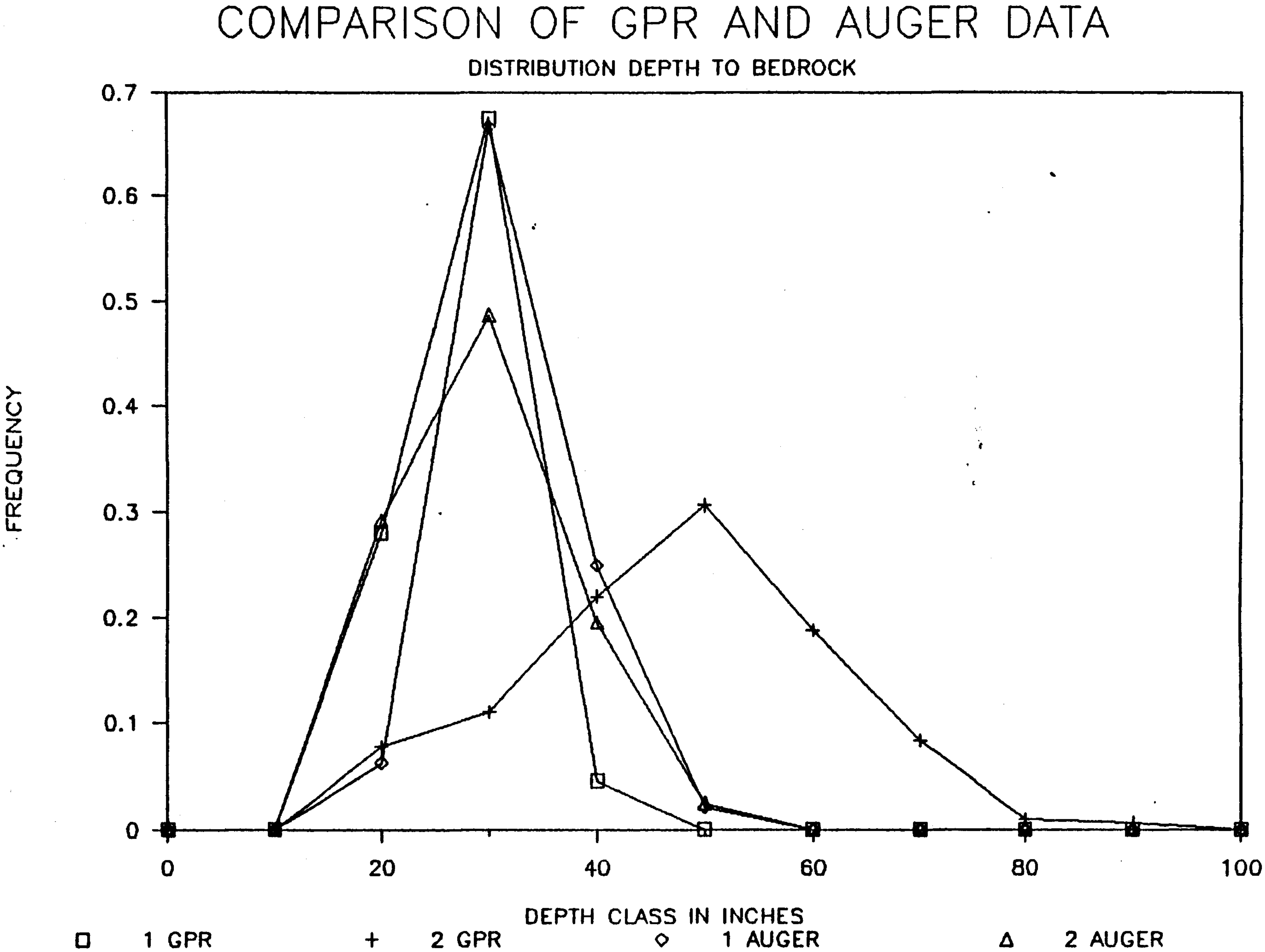
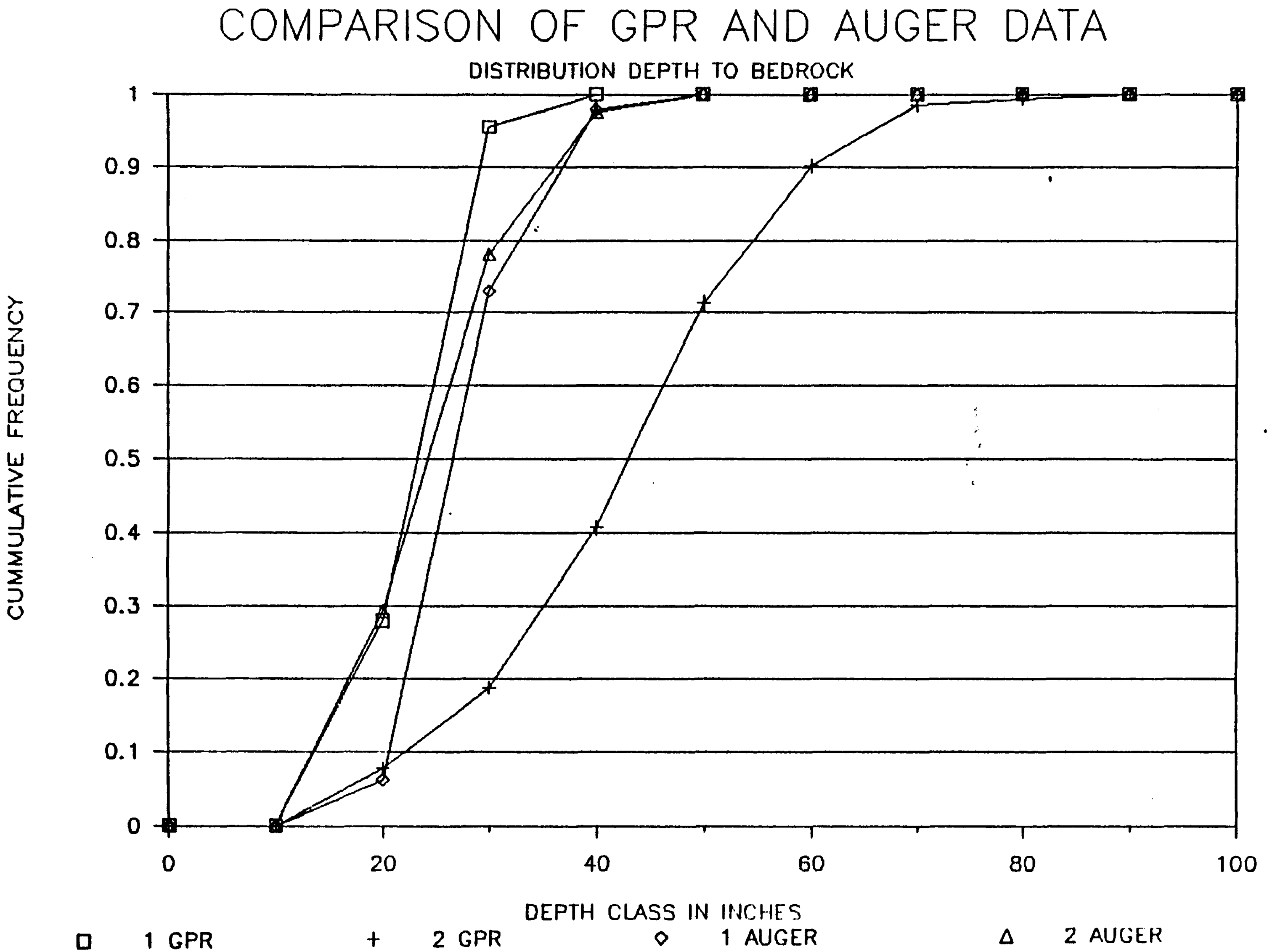
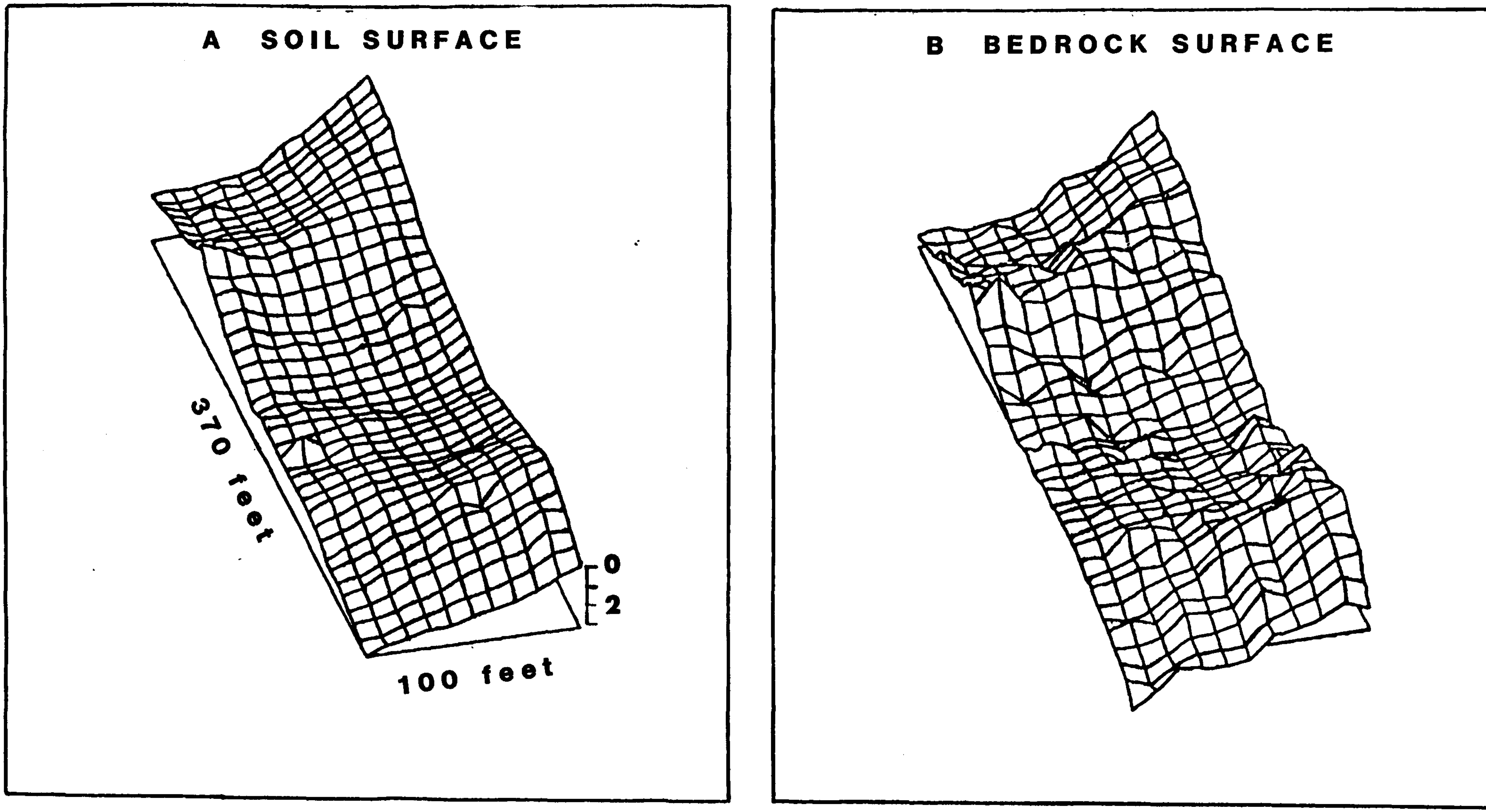

COMPARISON OF GPR AND AUGER DATA
DISTRIBUTION DEPTH TO BEDROCK
FREQUENCY
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
20
40
60
80
100
DEPTH CLASS IN INCHES
1 GPR
2 GPR
1 AUGER
2 AUGER

FIGURE 3

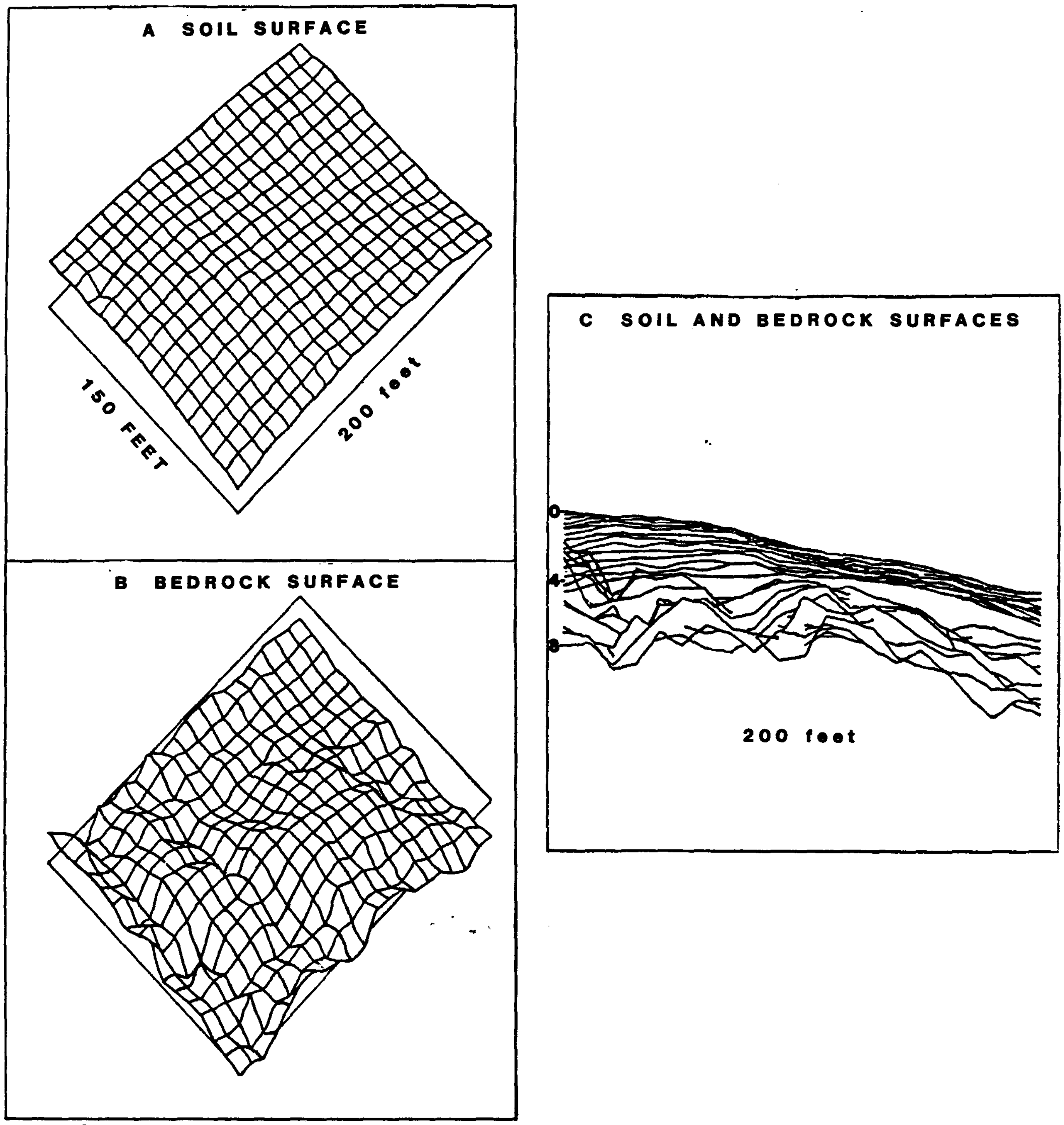


COMPARISON OF GPR AND AUGER DATA
DISTRIBUTION DEPTH TO BEDROCK
CUMMULATIVE FREQUENCY
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
20
40
60
80
100
DEPTH CLASS IN INCHES
1 GPR
2 GPR
1 AUGER
2 AUGER

FIGURE 4



BLOCK DIAGRAMS OF (A) SOIL SURFACE, AND (B) BEDROCK SURFACE IN AN AREA OF TUNBRIDGE-LYMAN COMPLEX, 3 TO 8 PERCENT SLOPES



BLOCK DIAGRAMS OF (A) SOIL SURFACE, (B) BEDROCK SURFACE, AND (C) BOTH SURFACES IN AN AREA OF TUNBRIDGE-LYMAN COMPLEX, 3 TO 8 PERCENT SLOPES