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An Investigation of Bergmounds as Analogs to Erosion Control Factors on Protective Barriers

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Executive Summary

Included in several of the final disposal strategies proposed in the Interim Hanford Waste Management Plan (DOE-RL 1986a) is design of a protective barrier to isolate the underlying waste sites from the environment. The conceptual protective barrier design requires a fine-grained sediment to retain precipitation near the top of the barrier where evapotranspiration can recycle the moisture back into the atmosphere. The design incorporates gravel into the topsoil as one way to reduce its erosion. Information is needed to determine the optimal ratio of gravel to topsoil needed to reduce erosion without significantly reducing evapotranspiration, and its effect on erosion.

Bergmounds are mounds with a gravelly surface that were formed about 13,000 years ago and represent natural analogs to the topsoil portion of the protective barrier. The primary goal of this study was to identify characteristics of bergmounds and the effects of these characteristics, especially the gravelly surface, on the amount and rate of erosion. A secondary goal was to apply a technique normally used to estimate vegetation cover to measure percent gravel cover, and to compare this technique with particle size distribution based on weight percent.

Four bergmounds were investigated for this study, two in a windy site and two in a more sheltered site. Each bergmound was sampled in eight locations. Two methods were used to estimate the amount of surface gravel: the ocular point-intercept method which estimates the percent gravel cover, and sieved samples of the surface sediments which measure the percent gravel by weight. Holes were dug at each bergmound's eight sampling sites to examine and sample the subsurface sediments.

From this study, it was determined that 90% of the gravel occurs on the north, west, and south sides of the bergmounds in both the windy and more sheltered sites. There was virtually no gravel beneath the surface. This does not fit the hypothesis that the gravelly layer had at one time been relatively uniform over the entire bergmound and that erosion and freeze-thaw processes had caused the variations in the amount of surface gravel. Based on this study, the distribution of gravel is now hypothesized to be a relict of the way in which the bergmound actually formed. The bergmound did not form directly beneath the iceberg as the debris-laden ice melted, but rather on the downstream (east) side of the iceberg where it was sheltered from erosion by the receding floodwaters. Most of the iceberg debris -- and, therefore, gravel -- was deposited on the west side of the bergmounds immediately beneath the iceberg, with less gravel on the north and south sides only partially beneath the iceberg, and the least amount on the east side where little of the mound was covered by the iceberg. Although evidence of erosion could be seen in areas between bergmounds, none was found on the bergmounds themselves, implying that they are less susceptible to long-term erosion. However, since erosion is not the cause of the observed distribution of surface gravel, no measurement of the effects of gravel on erosion can be made.

However, there are a number of features present on the bergmound which have probably played a role in erosion resistance of the bergmound. These include vegetation, cryptogams (moss and lichens

on the soil), a crust on the sandy silt, the texture and calcium carbonate content of the subsurface sediments, and the graveled surface. Wind tunnel tests have been performed to determine the importance of some of these features in protection against erosion (Ligotke 1993). One recommendation is to use bergmounds to evaluate the effectiveness of evapotranspiration in preventing moisture infiltration below a specified depth.

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1.0 Introduction

The Interim Hanford Waste Management Plan (HWMP) (DOE-RL 1986a) presents a strategy for the final disposal of defense wastes at the Hanford Site. This strategy includes isolating some waste sites from the environment by means of a protective barrier that would serve to minimize moisture movement, erosion, and intrusion by humans, animals, and plants into the waste site. These barriers will be required to perform these functions without human maintenance for up to 1000 years. Technical issues which must be resolved relative to protective barriers are presented in the Hanford Waste Management Technology Plan (HWMTP) (DOE-RL 1986b). The major technical issues concerning protective barriers are determining which materials and configuration will best impede processes that can potentially cause radionuclide transport.

The protective barrier prototype (WHC 1993) is a mounded multi-layer system that minimizes migration of precipitation down through the barrier and prevents plant, animal, or human intrusion into the underlying contaminated sediments (Figure 1.1). One primary design feature utilizes the concept of capillary barriers, by which saturation of an overlying fine-grained sediment must be attained before moisture can migrate down into coarser-grained sediments. In the prototype barrier design, this takes the form of multiple layers of crushed basalt and fill, overlain by a topsoil ranging in consistency from a silty very-fine to fine sand, to a sandy silt. This topsoil has a high moisture-retention capability so that precipitation is retained near the surface where evapotranspiration can recycle moisture back to the atmosphere rather than allowing it to accumulate and percolate down into the waste zone. The crushed basalt also serves to prevent animal intrusion into the waste zone. A geotextile placed between the sand and gravel prevents sand from filtering down into the gravel, maintaining the integrity of the layers both during construction and for the life of the barrier.

Erosion, especially wind erosion, is a concern because the topsoil is fine-grained and susceptible to wind transport. If the barrier is to perform as required over a long time period, the topsoil must maintain a minimum thickness sufficient to contain moisture from extreme precipitation events and to allow sufficient plant growth for evapotranspiration of moisture. Excessive topsoil erosion on the barrier could severely limit the effectiveness of this crucial component of the capillary barrier. The sides of the barrier are protected from erosion and animal intrusion by a thick layer of riprap and gravel; however, this is not possible on the top portion of the barrier if the desired plant population and evapotranspiration rate are to be achieved. Thus, the conceptual protective barrier design calls for gravel to be mixed into the upper 1 m (3 ft) of topsoil, which should act as a protective armor against erosion.

To develop a gravel armor for the surface of a protective barrier, more information is needed on physical factors that can reduce erosion. An example is the optimum percent gravel cover required to prevent erosion from weather conditions prevalent or expected on the Hanford Site, as well as the range of particle sizes that can be protected by such a cover. A literature search for pertinent studies of wind and water erosion and a field search for potential natural analogs to the top layer of the conceptual protective barrier were performed. Bergmounds and stony desert pavements appeared to have

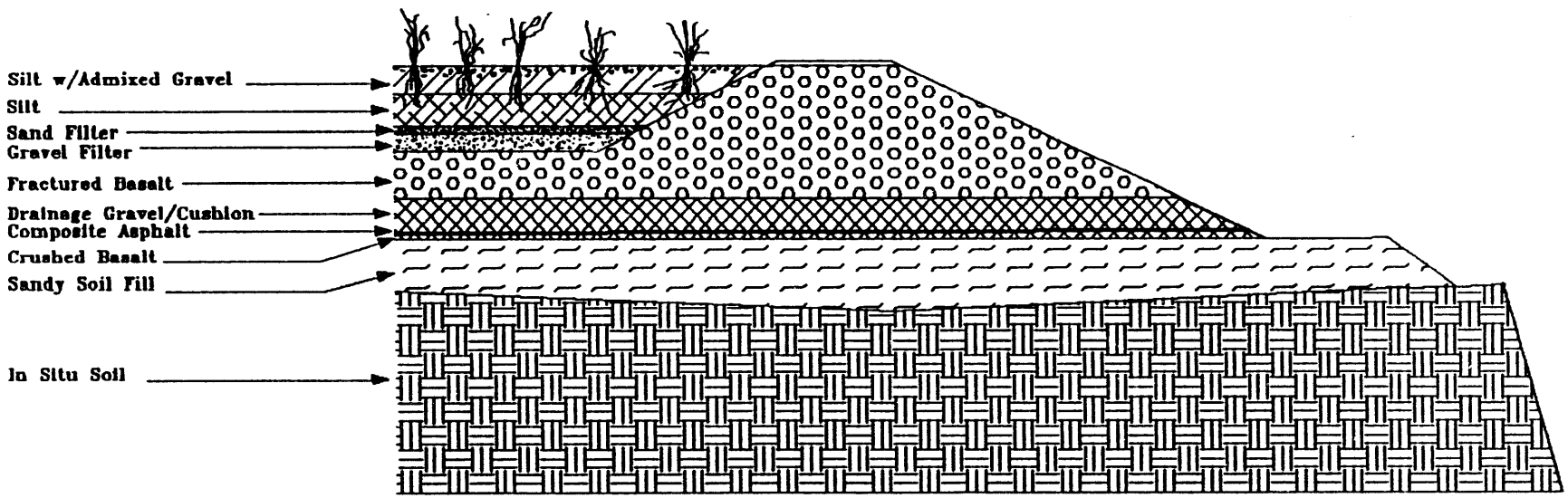

Figure 1.1. Schematic Cross Section of the Engineered Protective Barrier Prototype (after WHC 1993)

features similar to the surface of the conceptual barrier. In addition, bergmounds are found lying on the same fine-grained sediments that will be used in the protective barriers.

Bergmounds were chosen for further study because they consist of fine-grained sediments covered with a stony desert-type pavement. Although the bergmounds are mounded rather than a flat surface like the barrier design, this difference should add some conservatism to the estimate of having erosion resistance. The study was to determine the actual characteristics of bergmounds, and whether any of these characteristics, particularly graveled surfaces, have affected erosion in the past 13,000 years.

If the data collected during this study indicate that bergmounds can provide needed information on features affecting erosion, then a more detailed study of these features will be recommended. This document describes the study and results, and provides recommendations for other studies to further develop the best design for protective barriers.

2.0 Background Information

In semi-arid environments, gravel is commonly found in higher concentrations at the surface than in the underlying fine-grained sediments (Mabbutt 1977). These gravels form a stony desert pavement, an irregular surface that protects the surrounding and underlying finer-grained sediments from erosion. Stony desert pavements may form through one or more of the following processes: 1) erosion of fine-grained particles by wind, 2) erosion of fine-grained particles by water, 3) upward movement of gravel by bioturbation, and/or 4) upward movement of gravel by wetting/drying or freeze/thaw actions within the soil. Mabbutt (1977) states that wind erosion is virtually ineffective when gravel cover reaches 50 percent. In studies performed in Arizona (Simanton et al. 1984), erosion due to rainfall was found to be inversely proportional to the percentage of rock fragments in the top layer of a soil.

Bergmounds in the vicinity of the Hanford Site consist of fine-grained sediments with a partially graveled surface that has characteristics of a stony desert pavement. These bergmounds are low hills up to 5.5 m (16 ft) high and 50 m (164 ft) in diameter (Fecht and Tallman 1978).

The bergmounds in this area formed approximately 13,000 years ago toward the end of the last ice age. Ice dams located in northern Idaho occasionally failed, causing cataclysmic flooding across the Columbia Plateau (Baker 1973). As the water swept into the Pasco Basin, it deposited sand and gravel (coarse-grained facies of the Hanford formation) in areas where the current was strong, such as the 200 Area Plateau region (Figure 2.1). In areas of weaker flood currents, such as Cold Creek Valley on the west side of the Pasco Basin (Figure 2.1), silt and sand (transitional and slackwater facies of the Hanford formation) were deposited (Baker et al. 1991). Floodwater was temporarily hydraulically dammed behind water gaps, such as at Wallula Gap, forming short-lived lakes. Covering the Pasco Basin was Lake Lewis, a lake 230 m (750 ft) deep that reached an elevation of up to 380 m (1250 ft) above sea level. Icebergs loaded with rocky debris floated in this lake, and many became grounded or stranded in shallow water and back-eddies along the western margin of the Pasco Basin. One such back-eddy was in Cold Creek Valley, where the icebergs came to rest on slackwater flood sediments (Fecht and Tallman 1978). Lake Lewis only lasted a matter of days, while the icebergs probably required weeks to completely melt. It was assumed that the melting iceberg deposited a mound of diamicton, the poorly-sorted clay- to boulder-sized sediment particles carried by the iceberg, and that this mound has been accentuated by the normal wind and water erosion of surrounding sediments.

Fecht and Tallman (1978) described the locations, general physical characteristics, and lithologic types of bergmounds in south-central Washington. The physical characteristics they described, analogous to the surface of the prototype barrier, are listed below.

- Bergmounds have survived as local topographic highs for 13,000 years, significantly longer than the proposed 1000-year life of the protective barriers.

- Bergmounds have, and the engineered barrier will likely develop, a graveled, stony pavement-like surface with fine-grained sediment beneath.

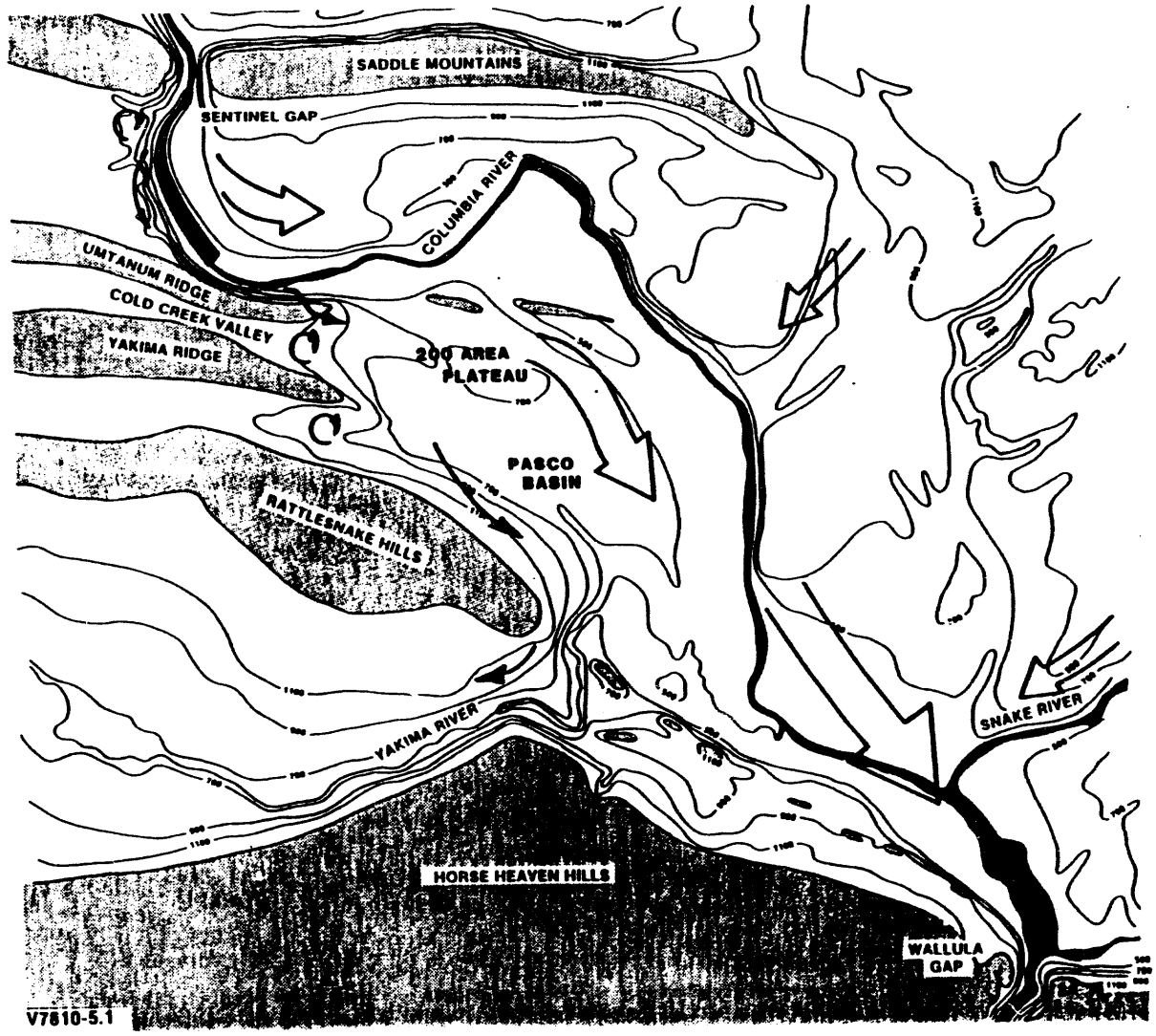

Figure 2.1. Cataclysmic Floodwater Paths in the Pasco Basin. Large arrows show main current directions; smaller arrows show areas of bergmound deposition (from Fecht and Tallman 1978).

- Both contain a fine-grained sediment/topsoil ranging from a silty, very-fine to fine sand, to a sandy silt.
- Both occur in wind-prone areas.
- Climate as well as plant and animal communities are similar.

3.0 Objectives

The objective of this study was to collect more information on the physical characteristics of bergmounds and their effect on erosion. This information will be used to determine which physical characteristics may help control erosion and, consequently, these characteristics may be tested further in other studies. These test results would eventually be used to optimize erosion-control features for a protective barrier.

This study is a preliminary investigation of the bergmounds and of methods that may be used to collect the required information. The objective is to answer the following questions:

- What are the physical characteristics of the bergmounds?
- Have bergmounds resisted erosion? If so, what characteristics have played a role in this resistance? In particular, has the gravel mixed in with the diamicton provided protection from erosion?
- Can the ocular point-intercept method be used to estimate the percent gravel cover?

This document reports the results of the investigation of bergmounds as natural analogs to the upper portion of the conceptual barrier design, and provides recommendations for future studies.

4.0 Study Design

This study was designed to 1) investigate the physical characteristics of bergmounds in greater detail than had Fecht and Tallman (1978), 2) record any evidence of erosion, and 3) determine whether these characteristics, particularly the gravelly surface, had reduced erosion. Data collected include height, diameter, areas of animal burrowing, estimate of percent gravel cover, weight percent of gravel on the surface, particle-size analysis of the surface and subsurface sediments, and areas of erosion or deposition. By using two methods to measure the amount of surface gravel present, comparisons can be made with other erosion studies using percent gravel cover (Mabbutt 1977; Simanton et al. 1984) and characterization studies using weight percent data (Last et al. 1987).

Some of the factors that may affect erosion on bergmounds are given below. Because these factors are related to specific sides of the bergmounds, any variations they produce in the amount of surface gravel will also be related to a specific side.

- Wind. The predominantly westerly winds, at least at the windy site, may selectively transport fine-grained sediments from the west side of the bergmound, leaving behind the gravel and coarser sand particles. These fines may then be deposited on the downwind, or east, side of the mound, covering the graveled surface.

- Temperature. The bergmound's south side receives more sunshine and heat, which may cause increased and/or more rapid soil moisture loss. This could affect the type and amount of vegetation and, therefore, the amount of erosion by wind or water.

- Bioturbation. Burrowing animals may prefer sunny southern exposures for warmth and the east side of the bergmounds for easier digging due to wind-blown sediments, bringing gravel to the surface and/or disturbing the gravel cover on those sides.

- Cryoturbation. During the winter the north side would tend to stay frozen all day while the south side would thaw during the day and freeze again at night. Freeze-thaw cycles help move gravels within the top 10 cm (4 in.) to the surface because water expands when freezing, pushing all sediment particles up. When the sediments thaw, the gravel delays melting of the ice directly beneath it, allowing the finer-grained sediments to fill in small cracks and holes around the gravel. This process gradually moves the gravel up to the surface.

- Vegetation. Shrubs such as sagebrush can act as sediment traps for windblown particles, causing small mounds to accumulate at their base. All vegetation also helps remove moisture from the subsurface through evapotranspiration. The more densely vegetated the surface, the less chance there is of moisture moving down to a significant depth.

- Texture. Silts become more coherent after periodic wetting and drying, forming an erosion-resistant crust (Mabbutt 1977).

4.1 Location of Study

Three criteria were used in selecting areas to study bergmounds: 1) wind condition at two sites, one windy and another less windy, to compare the effects of wind on erosion of the bergmound surface; 2) a high areal density of bergmounds; and 3) presence of diamicton overlying fine-grained sediments. These last two criteria help reduce bias in choosing specific bergmounds and assure as much similarity to the conceptual barrier design as possible.

Numerous bergmounds occur west of Washington State Highway 240 on both sides of State Road 24 along the western margin of the Pasco Basin. The high density of bergmounds with diamicton overlying slackwater deposits meet two of the three criteria. To satisfy the first criterion, two study sites were chosen within this region. Site 1, located in Cold Creek Valley between Yakima Ridge and Umtanum Ridge (Figure 4.1), was chosen as the windy site. The two ridges appear to "funnel" wind down the Cold Creek valley, causing relatively higher wind velocities and frequencies as well as a more focused wind direction, with winds primarily from the south-southwest to northwest (Stone et al. 1983). Site 2 is located on the gently-sloping, east-northeast flank of Yakima Ridge (Figure 4.1). Because of proximity to the ridge, this area is assumed to be more protected from the wind. Precipitation is assumed to be essentially equal in both areas.

4.2 Methods Used to Estimate the Percent Gravel Cover

Two methods for investigating the amount of surface gravel were used. The first method provides a direct estimate of gravel on the bergmounds by percent of surface area covered by gravel. This method, called the ocular point-intercept method, uses a frame (Figure 4) developed by Floyd and Anderson (1983a) for use in vegetation coverage estimations. This method has been shown to be more precise and less time-consuming than other methods frequently used in measurements of vegetation cover (Floyd and Anderson 1983b). Although previously used only on vegetation, this method should be applicable to gravel coverage as well.

The second method involves scraping a sample from the top 1 cm (0.2 in.) of the bergmound surface at the selected sample location. This sample is then sieved and the percent by weight of each particle size group determined and related to the original sample as a percent of the original sample weight.

It should be pointed out that these two methods measure different parameters. The first method measures the percent cover, while the second measures the weight percent, of the gravel fraction in sediments covering the bergmounds. Sieving is a standard geologic tool used to acquire what is generally qualitative or semi-quantitative data on particle size distribution, by weight, of sediments. The point-intercept method can provide quantitative data on the percent of a given surface area covered by any specific feature of interest; in this case, gravel. The purpose of using both methods was to test the

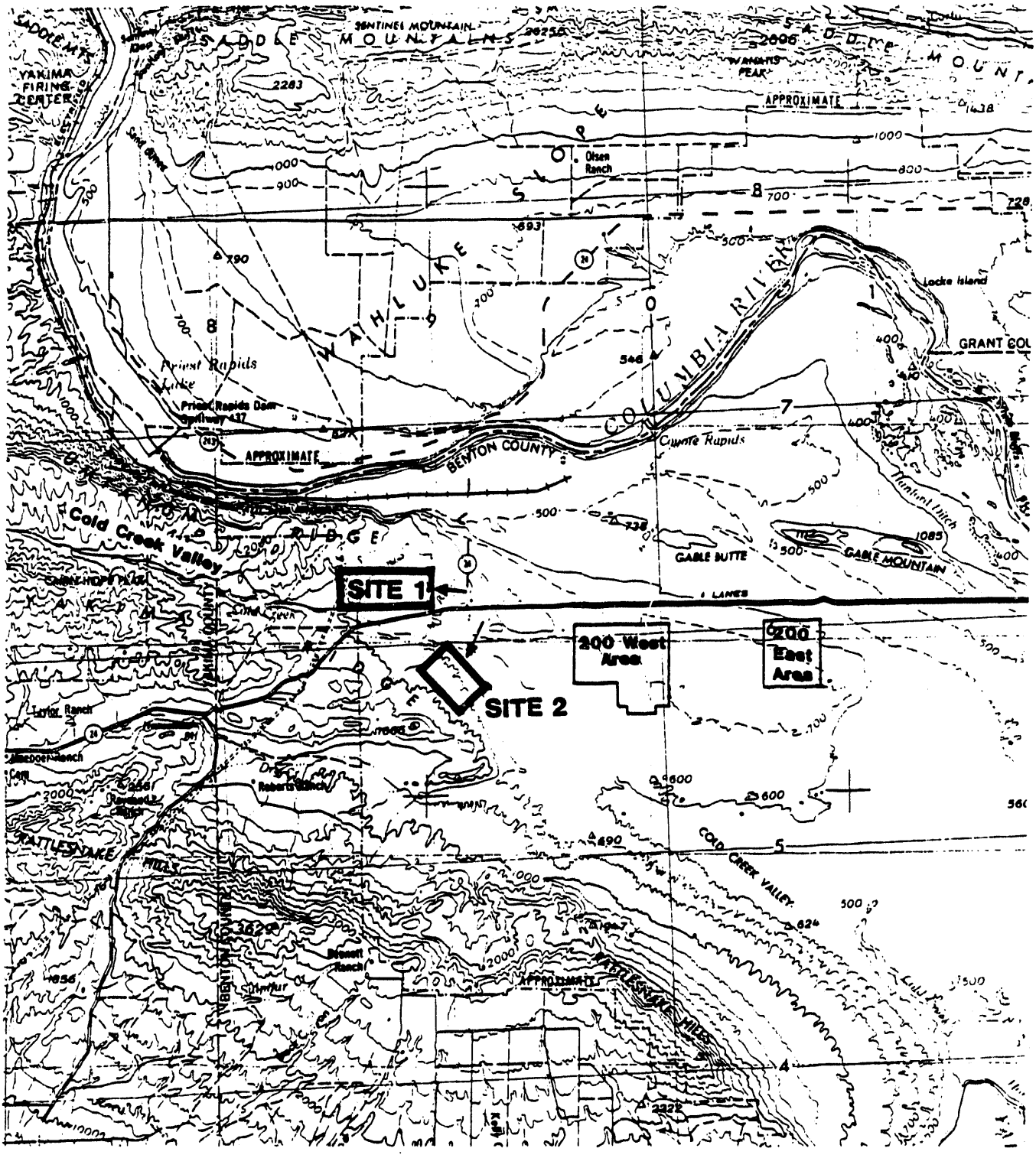

Figure 4.1. Location of Bergmound Study Areas

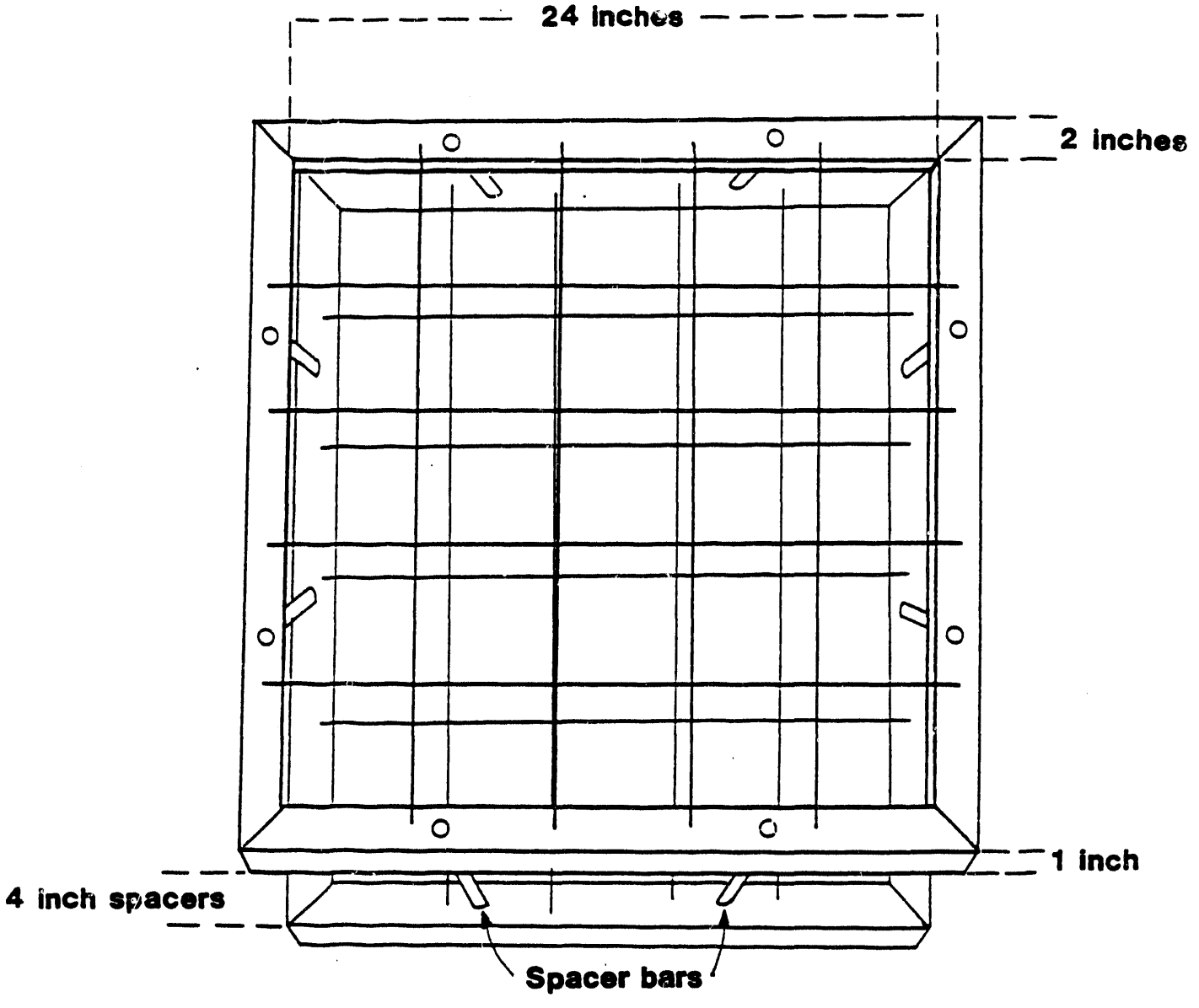

Figure 4.2. Ocular Point-Intercept Frame

point-intercept method as a means of collecting quantitative data on gravel cover of the bergmounds, while using the sieve data for a semi-quantitative comparison with similar data from previous natural analog studies, if desired.

The point-intercept frame used in this study is 60x60 cm (2x2 ft) and has two grids, one above the other, set 10.2 cm (4 in.) apart. Each grid consists of eight lines, four in either direction, with identical spacing between each line. The frame contains 16 intersections. When viewed directly from above, the alignment of intersections on both the upper and lower grid defines a unique point on the

ground surface below, which is then identified according to category of feature and recorded. For this study, five categories were defined for use with the point-intercept frame: gravel, bare ground, litter (loose, dead vegetation such as leaves or pieces of tumbleweeds), plants, and cryptogams (moss and lichens). For each gravel intercepted, its exposed long and short axes were measured and the general lithology (i.e., igneous, metamorphic, etc.) noted. Where possible, the type of plant intercepted was also noted.

4.3 Sampling Design

Two bergmounds were investigated at each site, providing a basis for estimating differences between the two sites as well as some of the variations within each site. It was determined that eight sampling locations on each bergmound, with two in each major compass direction, would provide the minimum requirements for a statistically valid test of the two methods of estimating percent gravel cover, i.e., to compare windy versus more sheltered locations, and amount of surface gravel present on one side versus another side of the bergmound. This would allow comparison between variations in the percent gravel cover and between factors that could affect the amount of surface gravel.

Specific bergmounds were selected at the two sites if they were large enough for eight sampling locations and had only a few boulders on the surface. A large number of boulders on the surface could bias the sampling and/or limit the number of sampling locations on each bergmound. Spaces between large shrubs were randomly sampled. Animal burrows were avoided. A compass was used while standing atop the bergmound to determine the four compass directions relative to the bergmound. The specific sampling locations were then chosen within a 50-degree arc centered on each major compass direction.

The point-intercept frame was used first at each of the bergmound sampling locations. Once all features intercepted with the point-intercept frame had been identified and recorded, the frame was moved aside and enough of the top 1 cm (0.2 in.) of sediment collected to fill one pint jar. By sampling the same area measured with the point-intercept frame, a consistency is established for comparing the two methods. A shovel was then used to dig a hole measuring approximately 45 cm^2 (1.5 ft^2) to a depth of 45 cm (1.5 ft) below the bottom of the diamicton. Samples were taken every 15 cm (6 in.), or where there was a change in texture. The samples were composites of all sides of the hole at each sampling depth, and assigned a unique sampling number such as 1-2-16. The left number designates the specific bergmound from which the sample was taken: bergmounds 1 and 2 are located in Cold Creek Valley at Site 1, while 3 and 4 are located at Site 2 near Yakima Ridge. The middle number refers to the specific sampling location on that bergmound: the first two were always located on the north side of the bergmound, the second two on the west side, the next two on the south, and the last two sampling locations on the east. Bergmound 1 also has one sampling site on top of the mound, designated as Site 9. The right number refers to the depth at which the sample was taken, in inches. Selected samples were then dry-sieved for particle size analysis. All samples are stored at the Hanford Geotechnical Sample Library.

Brief descriptions of the texture, color, and any other observable features were recorded, such as the 13,000-year-old Mt. St. Helens set "S" ash, root casts, and calcium carbonate deposits. Also noted were areas of erosion or deposition, and animal burrowing. The height and diameter of the bergmounds were measured using either a plane table and alidade or a Brunton compass and tape.

5.0 Results

The bergmounds in this study contained gravels of various lithologies and sizes. One bergmound contained exclusively basalt clasts, while the others had a mixture of igneous, metamorphic, and sedimentary clasts. Exact bergmound sizes were somewhat difficult to measure because they merge smoothly with the surrounding terrain. The edge of the bergmound was therefore determined to be the point at which the amount of gravel decreased to that of the areas between mounds. This is probably a slight size overestimation, since some gravels have probably moved down the slope of the bergmounds and onto the adjacent surface. Since this method was used on all of them, however, their relative sizes are consistent. Diameters range from approximately 26 m (85 ft) to 53 m (175 ft), and height ranges from 1.2 m (4 ft) to 3 m (10 ft). All of the bergmounds investigated were generally circular and symmetrical in form, with a relatively flat top. Animal burrows were found primarily on the south and east sides, and occasionally on top of the bergmounds. Areas of wind-blown sand deposition were confined to the downwind, eastern side of the mound, indicated by the loose, fine texture of sediments and by the general lack of cryptogams which require sediments undisturbed over time. Plots of the sieve data (see Appendix) indicate that almost all surface samples from the east sides of the bergmounds (holes 7 and 8 for each bergmound) contain less of the finest particle size ($\geq 4.75\phi$). This is probably due to the ability of fine silts and clays to form aggregates and crusts that are less erodible by wind; therefore, they are not found in the wind-blown deposits. Also, there are small hummocks of sand and silt beneath each sagebrush or hopsage wherever these plants occur, trapped by the dense growth of these types of plants.

There are no obvious signs of erosion on the bergmounds, such as rivulets or wind-deflated areas. A cursory examination of the areas between bergmounds showed evidence of erosion by water in the form of broad, shallow gullies and small rivulets leading to lower areas. There are far fewer gravels in these areas, and the gravels present are on average smaller than those on the bergmounds.

When the point-intercept data for percent covered by gravel were compared with the sieve data for percent gravel by weight (Table 5.1), a wide variation was found in the weight percent of gravel between different sides of any given bergmound, with a maximum difference of 65% for one bergmound.

When the 95% confidence interval for the difference between the point-intercept values and sieved values (point-intercept method minus sieving) was calculated, there was no distinguishable difference between the two methods due to the large amount of variation in the data. When a regression analysis was run on the same data, the coefficient of determination, r^2, was 0.57. In other words, only 57% of the variation in the point-intercept data correlates with variation in the sieve data; the other 43% of the variation was not common to both data sets.

To determine the number of sampling points needed to use the point-intercept frame for measuring percent gravel cover, with a confidence interval of 95% and an absolute precision of 5, the data from the west side of the bergmounds (shown in Table 5.1) were evaluated using the equation below:

Table 5.1. Summary of Point-Intercept and Sieve Data from Surface Samples of Each Bergmound

Bergmound and Location Number[a]	Side of Hill Site Located on	Point Intercept Method		Sieving Method
		Number of Gravels Hit/Site (n)	% Cover (n/16)	Weight % of Gravel from Sieving
1-1	N	6	37.5	37.6
1-2	N	4	25	38.8
1-3	W	10	62.5	60.4
1-4	W	6	37.5	44.7
1-5	S	8	50	55.3
1-6	S	9	56.3	64.7
1-7	E	5	31.3	22.6
1-8	E	1	6.3	0.6
1-9	Top	11	68.8	44.8
2-1	N	4	25	18.1
2-2	N	3	18.8	19.1
2-3	W	2	12.5	50.6
2-4	W	3	18.8	15.7
2-5	S	3	18.8	50.2
2-6	S	1	6.3	2.6
2-7	E	3	18.8	4.6
2-8	E	0	0	0.5
3-1	N	0	0	20.4
3-2	N	3	18.8	11
3-3	W	2	12.5	16.4
3-4	W	2	12.5	20.9
3-5	S	1	6.3	1.2
3-6	S	3	18.8	18.7
3-7	E	0	0	3.7
3-8	E	0	0	2
4-1	N	3	18.8	26.5
4-2	N	1	6.3	6
4-3	W	5	31.3	68.8
4-4	W	4	25	36.2
4-5	S	2	12.5	3.8
4-6	S	3	18.8	48.6
4-7	E	1	6.3	13.1
4-8	E	1	6.3	6.8

(a) Number left of hyphen indicates bergmound, while the number right of hyphen indicates which hole on that bergmound. Bergmounds 1 and 2 are in Cold Creek Valley, 3 and 4 are at Yakima Ridge.

$$N_o = \frac{Z^2 S^2}{d^2}$$

where N_o = number of sampling points
Z^2 = 1.96 for a confidence interval of 95%
S^2 = variance of the data
d^2 = absolute precision.

Generally, 10% is added to N_o when using that value to estimate the number of sampling locations to be used on other locations. Based on this analysis, approximately eight sampling locations per side of each bergmound would be required to achieve an accurate estimate of the percent gravel cover. Because only two sampling locations per side were used, there is insufficient data for an accurate estimate of the percent gravel cover. Therefore, most of the data collected using the point-intercept frame has not been included in this report. Weight percent data from the sieve analyses will be used exclusively in the remaining discussion.

As can be seen in Table 5.1, the amount of surface gravel varies depending on the aspect of the bergmound. Figure 5.1 shows the mean relative weight percent of gravel plotted against each compass direction for all bergmounds combined. On all bergmounds, the greatest amount of gravel is found on the surface of either the west or south sides, with the east side always having the least amount. Three of the bergmounds have the highest proportion of surface gravel on the west side (bergmounds 2, 3, and 4), while the fourth has the highest on the south side (bergmound 1).

Sieve data from subsurface samples indicate the sediments are sandy silts to silty very-fine sands with virtually no gravel clasts. The dry-sieving procedure used cannot distinguish between silt- and clay-sized particles, which are consequently grouped together as silt in this report. The appendix provides plots of the weight percent for each particle size for all samples sieved. This is similar to the fine-grained fraction of the surficial sediments. In all sampling locations on all four bergmounds, only three revealed gravels below approximately 5 cm (2 in.) of the surface. Those gravels found below this depth are isolated occurrences, with no evidence of other gravel or diamicton. These gravels may have been deposited as drop-stones with the slackwater deposits or rolled down animal burrows. The sampling locations containing subsurface gravel are as follows: bergmound 1, hole 1, at depths of 46 and 61 cm (18 and 24 in.); and bergmound 4, hole 7, at a depth of 25 cm (10 in.), and hole 8 at a depth of 15 cm (6 in.). The gravels found at these depths appear to be of the same lithologies as those on the surface, indicating they are associated with the flood deposits, either as dropstones or from diamicton.

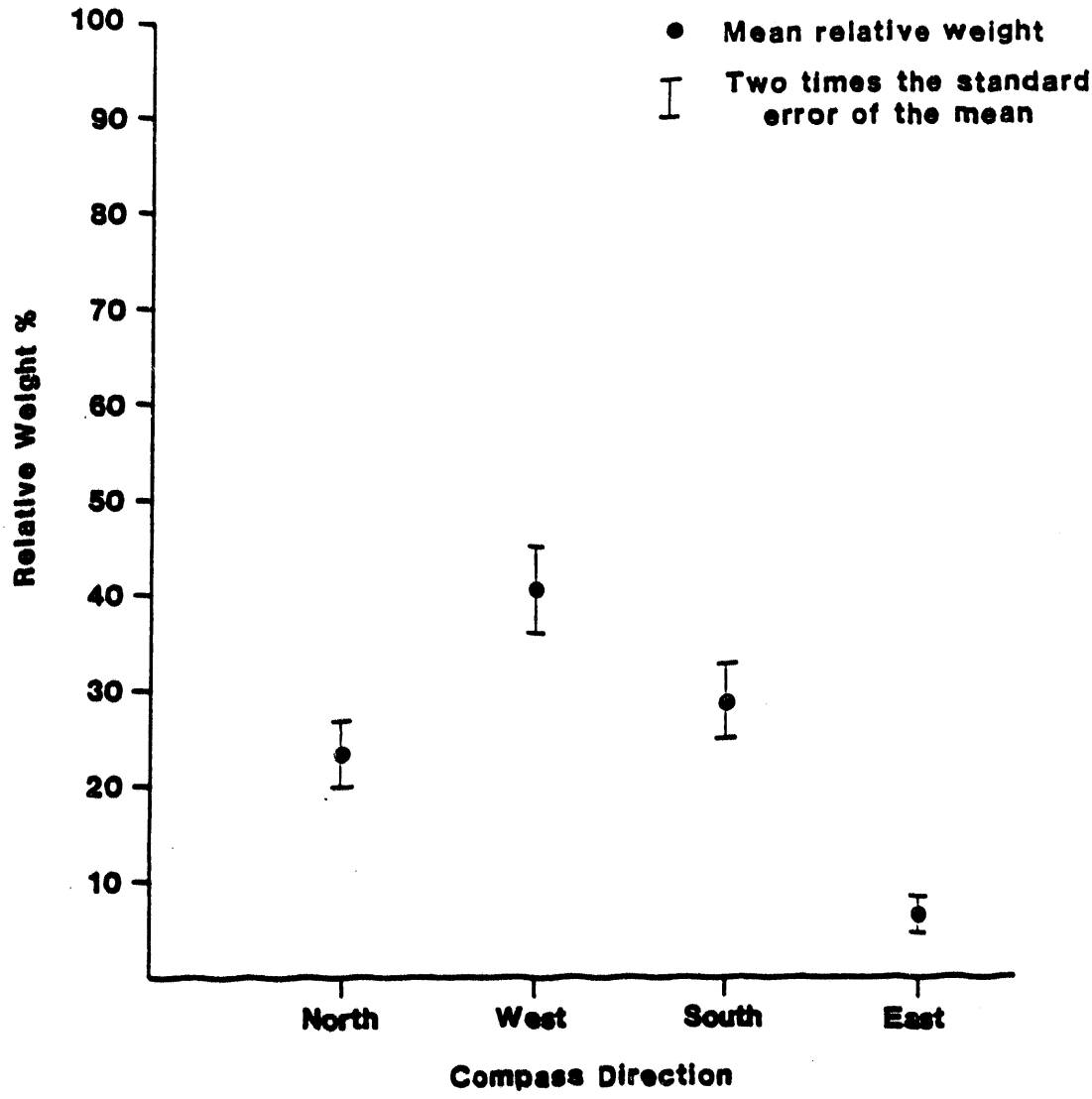

Figure 5.1. Plot of Relative Weight Percent Surface Gravel for all Bergmounds Relative to Compass Direction

The abundance of gravel at the surface and lack of it at depth fits the hypothesis that erosion, freeze-thaw and other factors could affect the amount of gravel on the surface of the bergmounds. Surface gravel on the west side would be increased by west winds blowing away fine-grained sediments and depositing them on the east side, where fewer gravels were found. More freeze-thaw cycles would also act to bring more gravel to the surface on the south side. However, there was virtually no gravel found below the surface on any side of the bergmounds. If the bergmound consists of diamicton, there should be subsurface gravels on at least the east side.

As noted earlier, stony desert pavements have a higher concentration of gravel on the surface than beneath it. Fecht and Tallman (1978) noted that the diamicton on the bergmounds was up to 45 cm

(1.5 ft) thick and apparently contained some gravel dispersed throughout it. There may be several reasons why so little subsurface gravel was found in the bergmounds studied for this investigation. The bergmounds may normally have a very thin veneer of diamicton, with only a few pockets of thicker diamicton in places. The three holes containing gravel at depth could lie within these thicker pockets, whereas the rest of the sampling locations are in areas with only a veneer of diamicton.

Although Bjornstad and Teel (in press) did not see any evidence for cryoturbation, they were looking at sites where sources of gravel are one or more meters below the surface. Freeze-thaw processes are only effective in moving gravel to the surface in the upper 10 cm (4 in.) of sediment. Since the diamicton covered the surface of the bergmounds to a depth of up to 45 cm (18 in.) (Fecht and Tallman 1978), freeze-thaw could have caused gravel to move to the surface, creating the subsurface gravel-free gap in the few sampling locations with gravel at depth. Another possibility is that erosion has removed all the fine-grained portion of the diamicton, leaving the gravel behind as a lag deposit. Or the cause may be some combination of the above. Evaluating the cause of so little subsurface gravel is complicated by the impossibility of distinguishing between the slackwater deposits and the fine-grained portion of the diamicton.

There appears to have been a fair amount of bioturbation in the study area, as indicated by Mt. St. Helens set "S" ash found in burrows and mixed with sediments in three of the bergmounds. This ash was originally deposited as one or two thin laminae of even thickness. The bioturbation and lack of distinguishing characteristics in the diamicton prevented determination both of the thickness of the diamicton and the process by which diamicton gravels reached the surface of the bergmound.

This bioturbation also prevents evaluation of the extent of erosion on the bergmounds. It was thought that erosion could be estimated by measuring the amount of gravel in relatively pristine subsurface diamicton and extrapolating the amount of diamicton that would have been eroded to arrive at the concentration of gravel found on the surface. The implications of not being able to do this are discussed further in Section 6.0.

Other features noticed in sampling the sediments include a crust on the surface and calcium carbonate and secondary vesicular horizons beneath the surface. The crustiness of the surficial sediments was exhibited by a general lack of loose sand or silt particles over much of the surface, and when excavated, the surface sediments often remained in coherent blocks several centimeters (inches) in diameter. One factor that may affect the crustiness of the surface soil is the abundance of cryptogams, small mosses and lichens which grow on soil. Cryptogams help hold sediment particles together on the surface. The crust on the surface sediments has also caused the development of a secondary vesicular zone found immediately beneath the surface and extending down as far as 15 cm (6 in.). The vesicles are small, on the order of a millimeter or so, and do not seem to be connected. When soils become saturated, air bubbles form and move toward the surface. The presence of a crust at the surface prevents the release of these air bubbles, and as the soil dries, they form small vesicles immediately below the surface. Vesicular zones are often indicative of finer-grained sediments in the crust than below the surface (Evenari et al. 1974).

The coherence of the surface crust and the vesicular horizons may be enhanced by calcium carbonate accumulation in the sediments. Concentrations of calcium carbonate are ubiquitous in semiarid soils of the western U.S. (Gile et al. 1966). Calcium carbonate in Stage I or II categories (Gile et al. 1966) forms stringers and nodules in the sediments at various depths, most common in the upper 30 cm (1 ft) of almost every hole. This often occurs adjacent to roots or root casts, where moisture is removed from the sediments, leaving the calcium carbonate behind as a precipitate. The sediments beneath the vesicular horizon were dry and very loose, blowing around in the slightest breeze, with occasional hard layers. These hard layers may be caused by an increase in calcium carbonate, although this was not visually discernible, or by an increase in the proportion of fine silt and clay, which are not distinguishable with the dry sieving technique used.

6.0 Conclusions

This study was designed to determine the physical characteristics of bergmounds and their relationships to erosion. These characteristics are summarized by the following statements.

1. The bergmounds studied have a topographic relief of up to 5 m (16 ft) (Fecht and Tallman 1978) and diameter of up to 56 m (175 ft) or more. They are roughly circular and symmetrical in shape, and have a flat top.

2. There is no visible evidence of wind or water erosion on the bergmound surfaces. However, areas between bergmounds show definite evidence of water erosion.

3. Diamicton appears to be only a thin veneer over most of the bergmounds, with rare pockets up to 0.6 m (2 ft) thick.

4. The surfaces of the bergmounds are partially graveled, with most of the gravel on the west, north, and south sides, and the least gravel on the east side.

5. The surficial sediments (excluding gravel) range in composition from silty, fine to very-fine sand to sandy silt, as do those beneath the surface. The surficial sediments often form a crust.

6. The bergmounds support a mature plant community including sagebrush, hopsage, grasses, and cryptogams.

7. Most sediments immediately beneath the surface are gravel-free and exhibit a vesicular and blocky texture indicating long, undisturbed periods.

8. Calcium carbonate is accumulating in the subsurface sediments.

The first two characteristics listed above imply that bergmounds have survived, apparently intact, for nearly 13,000 years against natural processes that are proceeding to erode sediments all around them. There is no direct evidence to prove that bergmounds have not undergone some degree of erosion in the past. The latter five characteristics listed above are all related to soil development and are thought to provide some erosion resistance; with the exception of number 4, all are found in areas between bergmounds as well. Because there is less gravel in the areas that show signs of erosion between bergmounds, it could be inferred that gravel on the bergmound surface has increased its resistance to erosion.

It was hoped that the concentrations of surface gravel would clearly indicate an equilibrium between erosive processes and the sediments on the bergmounds, i.e., only the amount of gravel necessary to prevent further wind erosion of the fine-grained sediments would be found on the surface, with the rest still below the surface. This would have allowed estimation of the amount of gravel

necessary for erosion resistance. This concept, however, was simplistic. The bergmounds exhibit a distribution of gravels over their surfaces that, at first glance, implies that processes such as wind erosion on the west, eolian deposition on the east, and freeze-thaw on the south side have caused the variations in surface gravel cover. This concept was based on the assumptions that 1) the gravel was spread randomly throughout the iceberg and 2) the iceberg was centered over the mound, causing a fairly even distribution of gravel throughout the diamicton and of diamicton across the mound. This is contradicted by the lack of gravels found beneath the surface anywhere on the bergmounds, most notably on the east side where less erosion and more deposition should have caused this evenly distributed diamicton to have remained in its nearly original form beneath a layer of windblown sand. The mechanism for the uneven distribution of gravel must, therefore, be directly related to the bergmound formation, and not to erosion or freeze-thaw activity.

It is proposed here that the bergmounds formed on the downstream side of the iceberg, affording some shelter from the floodwaters draining to the east/southeast. The topographic relief of the mound was formed by the erosive force of the draining catastrophic flood water. The top of the mound was probably slightly in front of the iceberg (Figure 6.1). As the ice melted, most of the diamicton would have been deposited as a layer on the west side of the bergmounds, thinning on the north and south, and almost nonexistent on the east side. It is coincidental that this distribution matches that expected from wind erosion and freeze-thaw processes, although these may have helped accentuate the uneven distribution by causing all of the gravels to be on the surface.

Several conclusions can be drawn from this study. First, although bergmounds do not appear to have suffered excessive erosion, there is no way to relate the amount of gravel on the surface to the amount of erosion resistance provided. This will have to be determined in other ways.

Second, there are several characteristics of bergmounds that have probably improved the resistance of the bergmounds to erosion. The graveled surface and soil development indicated by the latter five bergmound characteristics would all contribute to protection of the barrier surface and should be considered in future tests and designs. Although the larger cryoturbation processes do not seem to have occurred in the Pasco Basin, smaller scale processes such as freeze-thaw may have occurred or are continuing. Freeze-thaw could potentially bring more gravel to the surface of the protective barrier than is desired, affecting the evapotranspiration rate of the topsoil.

Third, the surfaces of the bergmounds generally appear to have reached long-term stability with respect to erosion, based on the development of the cryptograms and soil textures. This implies that the analogous protective barrier surfaces will also reach a long-term stability after some period of erosion and weathering of the surface.

Finally, although the point-intercept method was not able to provide an adequate estimate of the percent gravel cover of bergmounds, calculating the number of grid intersections per frame and/or the number of replications required per sampling location will show that this method can provide accurate estimates for percent gravel cover. This method could be a valuable tool for nondestructive time-efficient measurements of percent cover.

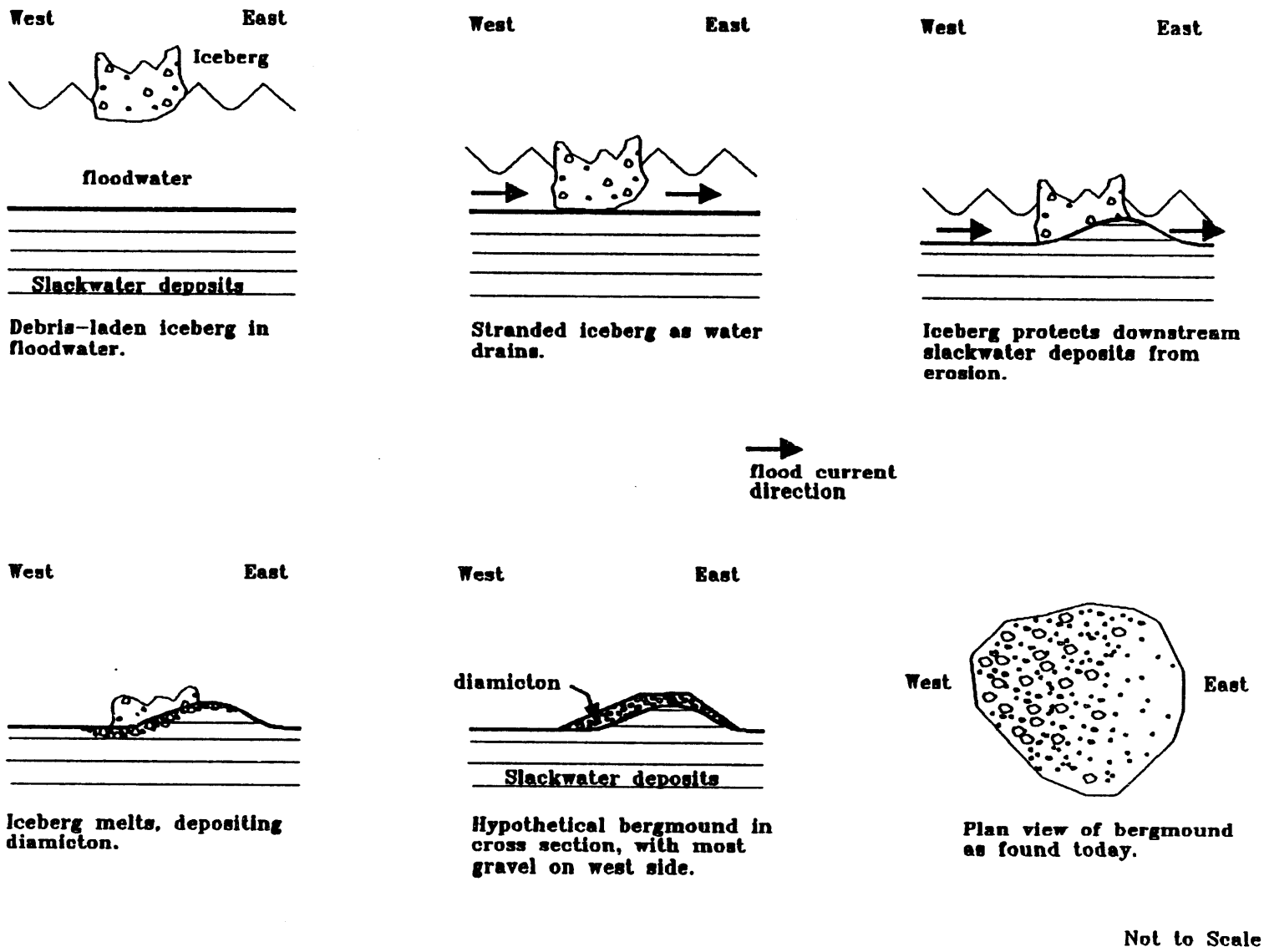

Figure 6.1. Hypothetical Bergmound Formation

7.0 Recommendations

One purpose of this report is to make recommendations for possible future studies. Since this study was unable to evaluate quantitatively the bergmounds' resistance to erosion and its causes, their use in future erosion studies is not recommended.

There are other ways in which bergmounds and the information collected from bergmounds can be valuable in the effort to perfect the protective barrier design. One way would be to take those bergmound characteristics thought to be a factor in erosion resistance and test them in a wind tunnel. Ligotke (1993) has performed tests with various amounts of gravel in a wind tunnel. By testing other bergmound characteristics in various combinations, the optimal protective features necessary for a barrier can be determined. Different combinations of bergmounds characteristics listed below would be an excellent beginning for such tests.

- Crusty sandy silt
- Sandy silt (not crusty)
- Cryptogams
- Mature vegetation

It should be possible to find geographic areas where these combinations of desired characteristics occur naturally. Sections of these areas can then be excavated and transported relatively undisturbed to the test facility. Other similar studies on wind erosion (Chepil 1953) have used this method successfully. This would be especially important in studying the effects of cryptogams and some plants, since they require relatively long periods of time to reach maturity.

Other characteristics could be simulated in the test facility, such as repeated wetting and drying to produce a crust on the sandy silt. Winds at various speeds can be blown across these surfaces, providing measures of amount and size of sediments eroded per unit time. Such simulations could be invaluable in testing the barrier topsoil design.

Waugh et al. (in press) have investigated evapotranspiration of moisture from test plots of fine sediments mixed with varying amounts of gravel. However, there has been insufficient time for fully mature, deep-rooted plants to become established. Bergmounds could be useful in studying the changing sediment moisture profile with depth using neutron probes to evaluate evapotranspiration on a mature analog to the conceptual protective barrier. This would provide information on the effects of mature plants, animal burrows, and graveled and ungraveled surfaces on moisture in the sediment at various depths, and would indicate whether the barrier design will allow adequate evapotranspiration under ambient climatic conditions. There are even bergmounds found at elevations up to 61 m (200 ft)

higher than those used for this study, which would provide information on the same features under slightly cooler, slightly moister conditions, which could occur at lower elevations during a 1000-year time-span.

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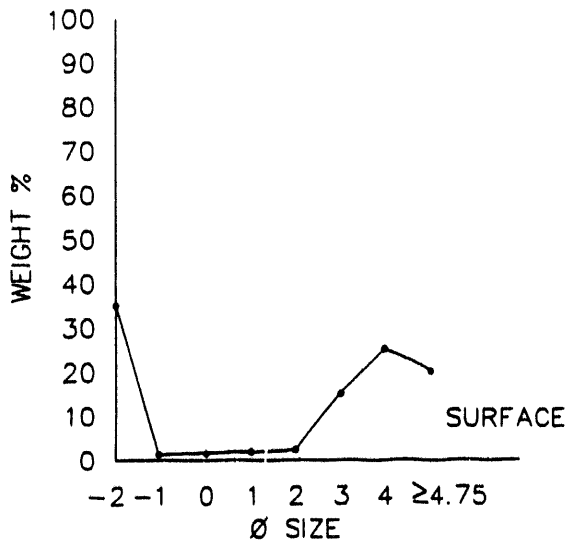
Appendix

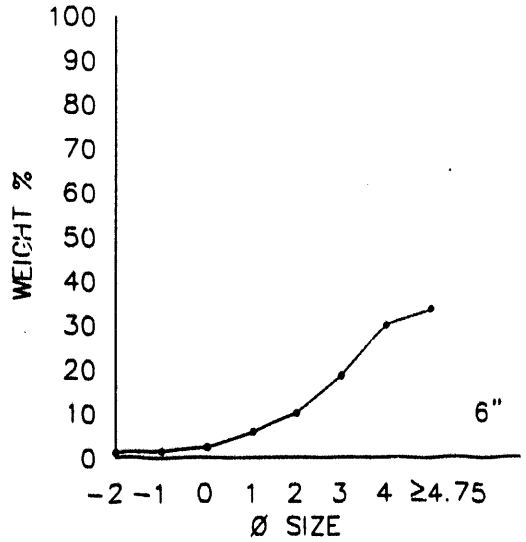
Plots of Sieve Data from Surface and Various Depths of Bergmounds

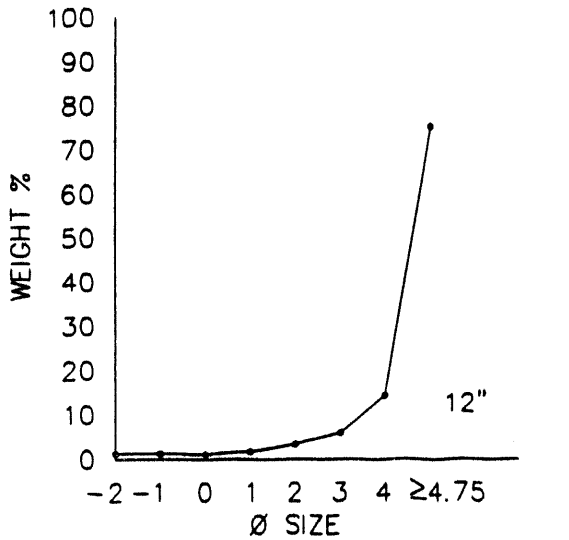
Grain Size Scales
Modified Wentworth Scale

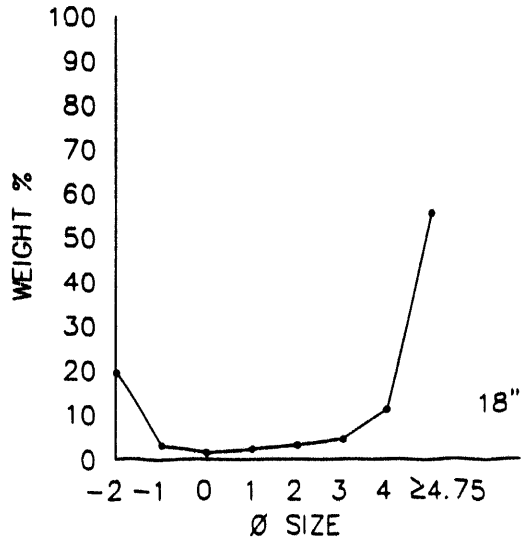
phi	Grade Limits mm	mm	Inches	Standard Sieve Series	U.S. Grade Name		
-12	4096		161.3				
					Very large		
-11	2048		80.6				
					Large		
-10	1024		40.3			Boulders	
					Medium		
-9	512		20.2				
					Small		
-8	256		10.1				
					Large		
-7	128		5.0			Cobbles	
					Small		GRAVEL
-6	64		2.52	63mm			
					Very coarse		
-5	32		1.26	31.5mm			
					Coarse		
-4	16		0.63	16mm			
					Medium	Pebbles	
-3	8		0.32	8mm			
					Fine		
-2	4		0.16	No. 5			
					Very fine		
-1	2		0.08	No. 10			
					Very coarse		
0	1		0.04	No. 18			
					Coarse		
+1	1/2	0.500		No. 35			
					Medium	Sand	SAND
+2	1/4	0.250		No. 60			
					Fine		
+3	1/8	0.125		No. 120			
					Very fine		
+4	1/16	0.062		No. 230			
					Coarse		
+5	1/32	0.031					
					Medium		
+6	1/64	0.016				Silt	
					Fine		
+7	1/128	0.008					
					Very fine		
+8	1/256	0.004					MUD
					Coarse		
+9	1/512	0.002					
					Medium		
+10	1/1024	0.001				Clay	
					Fine		
+11	1/2048	0.0005					
					Very fine		
+12	1/4096	0.00025					

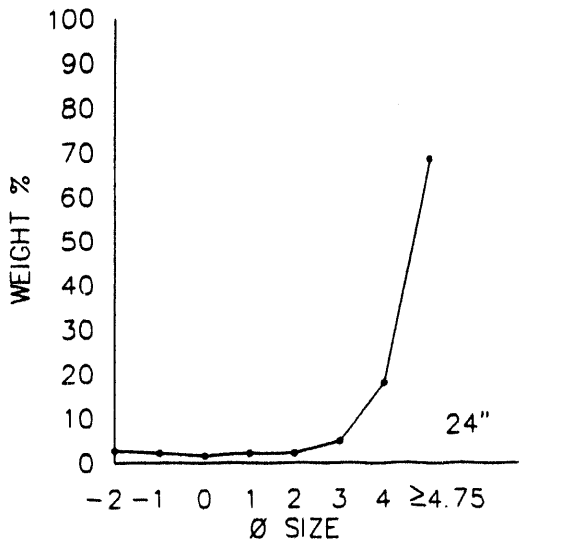
BERGMOUND 1, HOLE 1

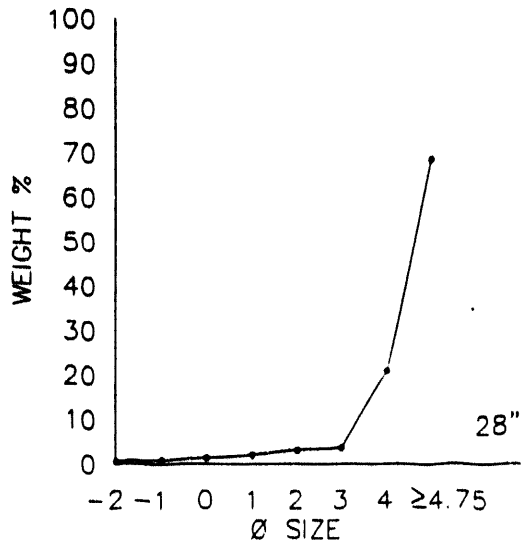












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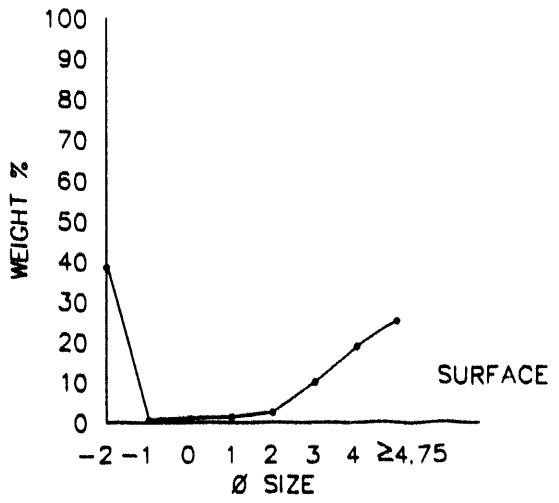

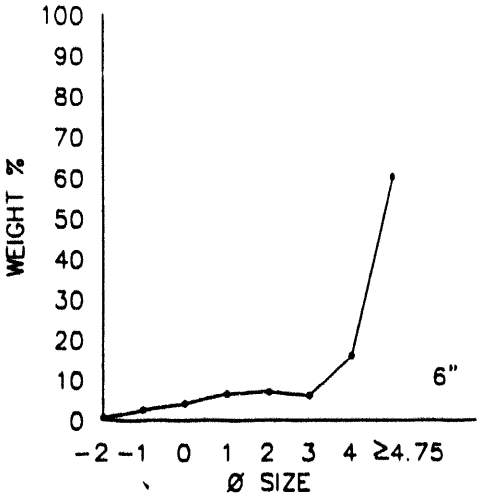

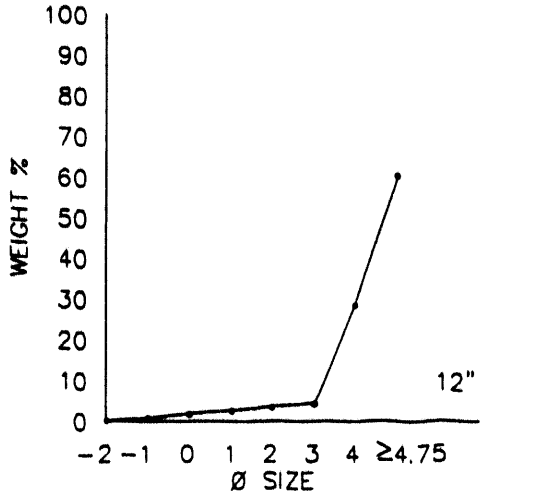

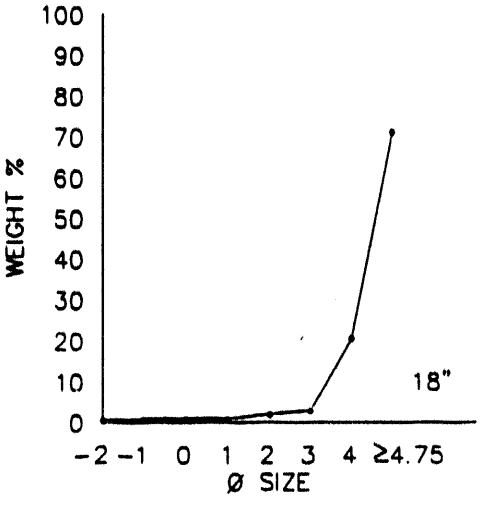

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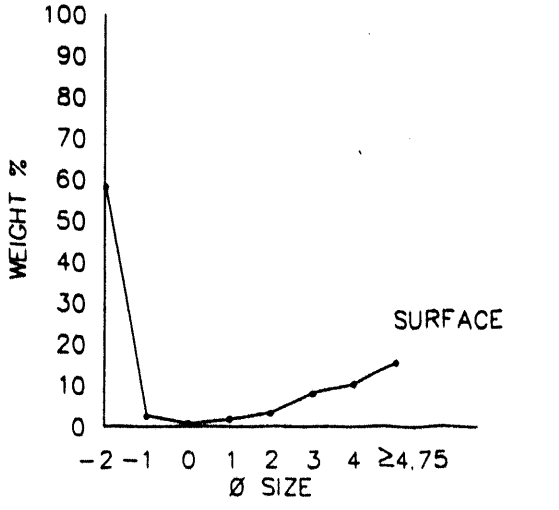

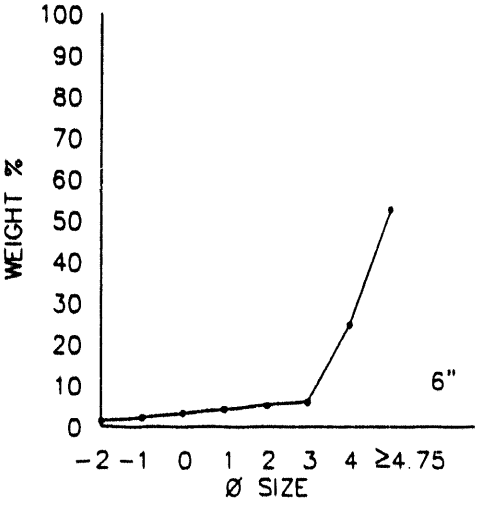

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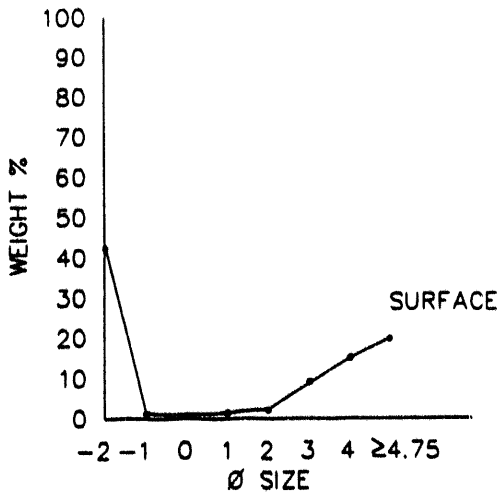

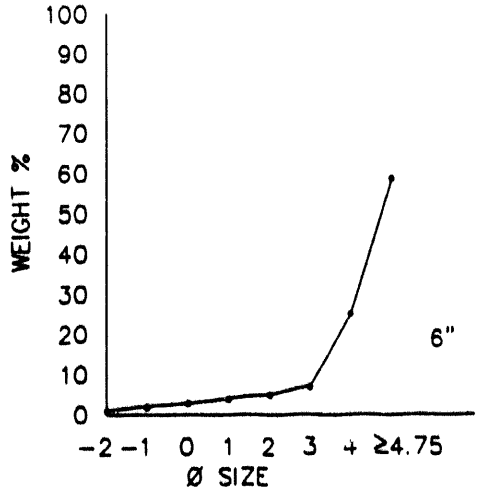

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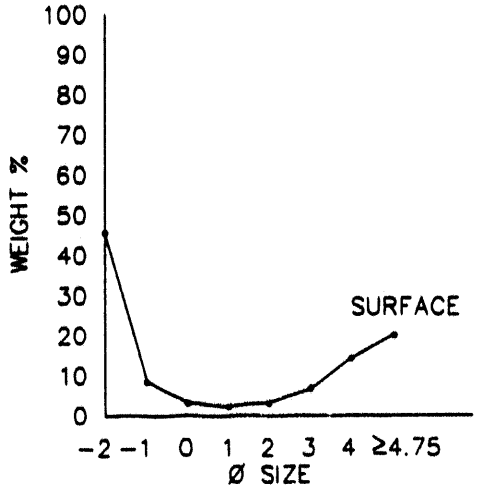

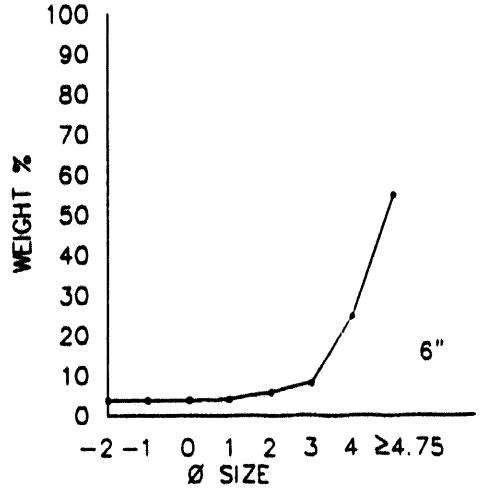

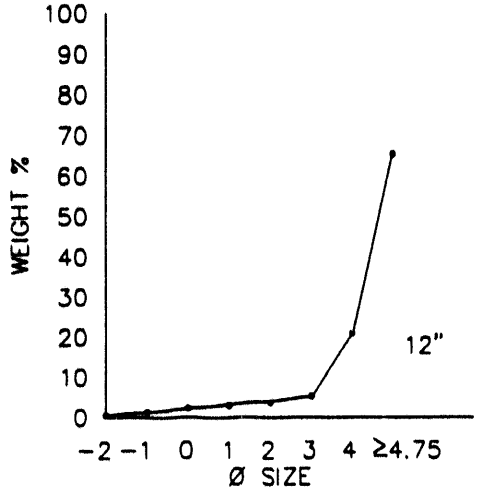

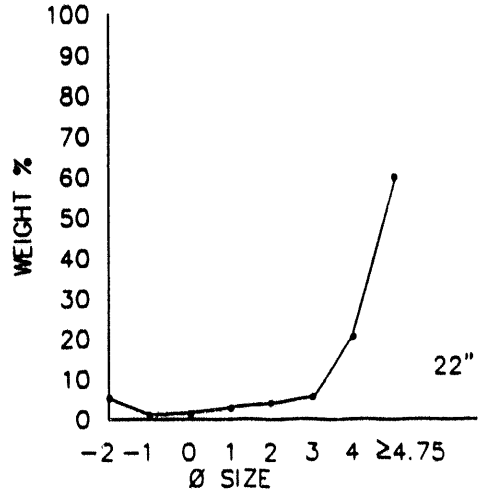

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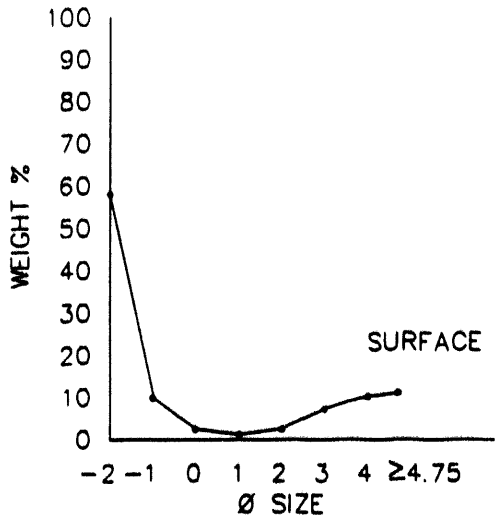

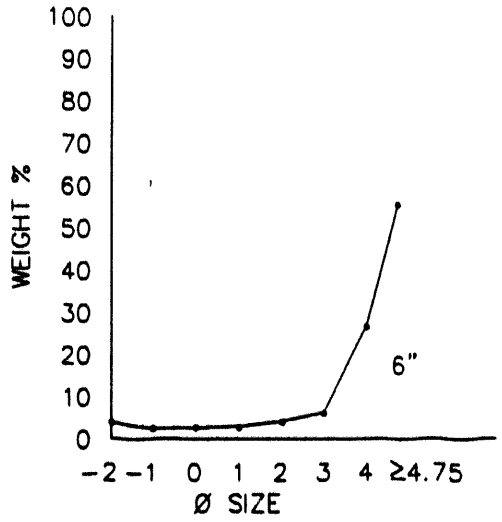

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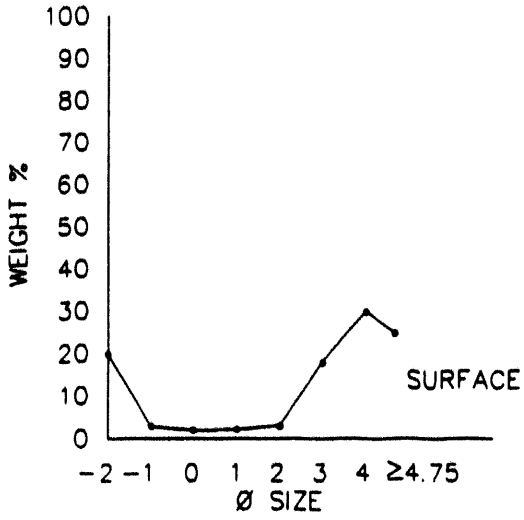

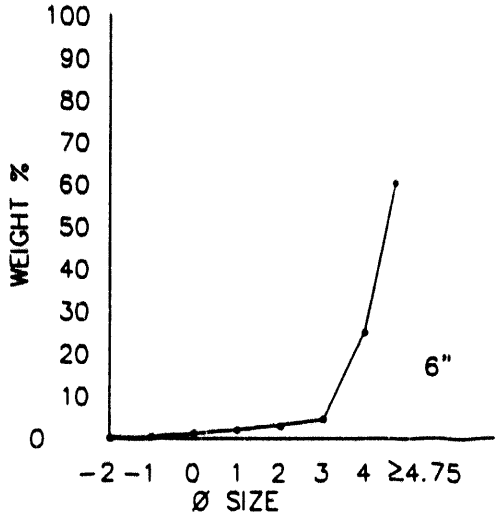

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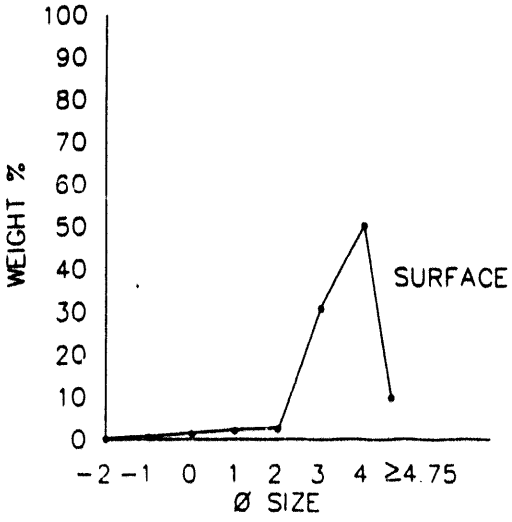

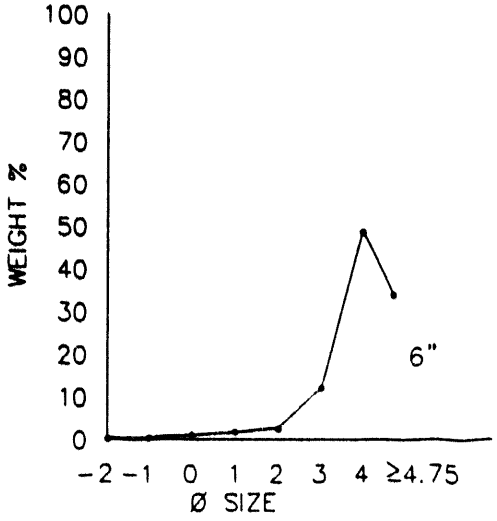

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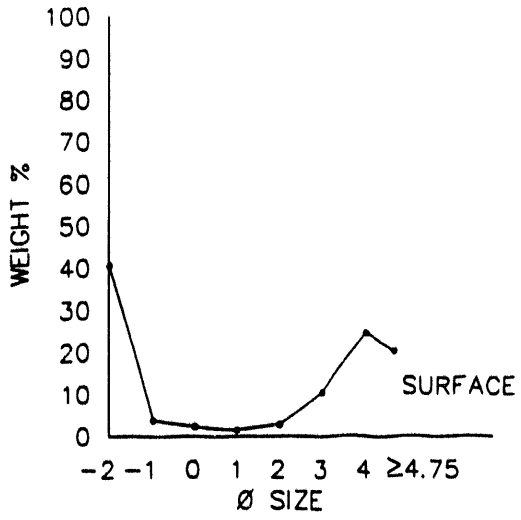

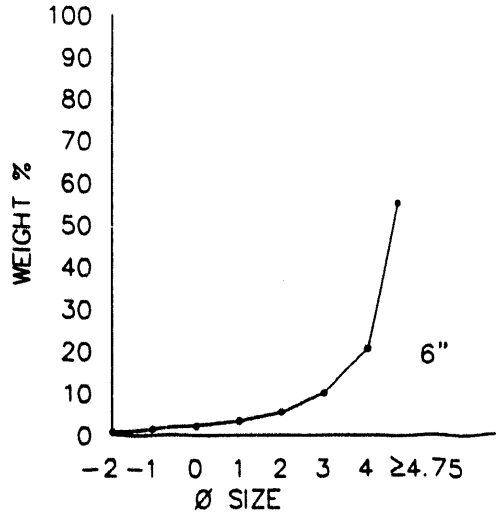

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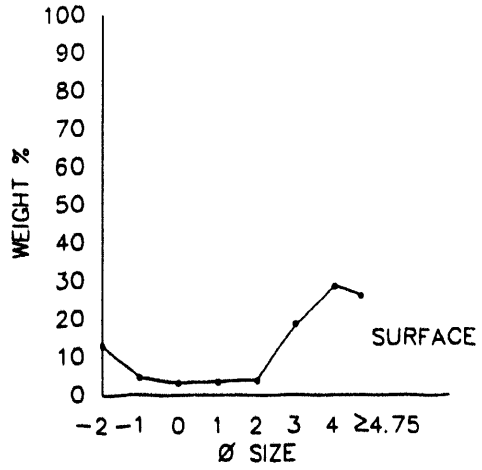

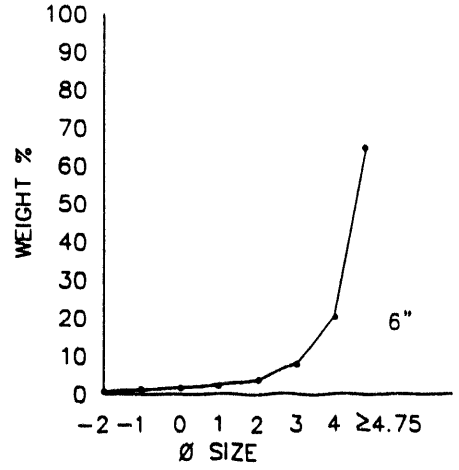

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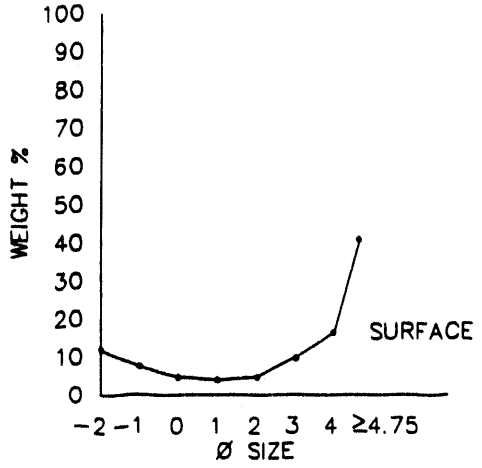

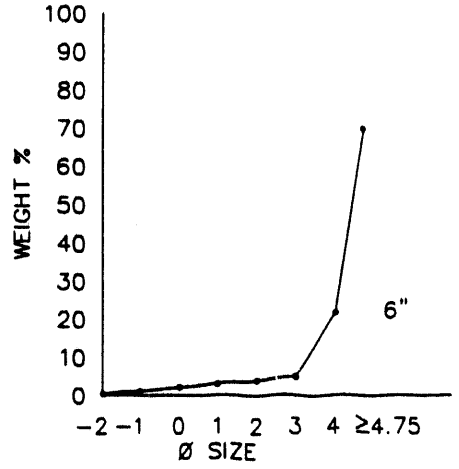

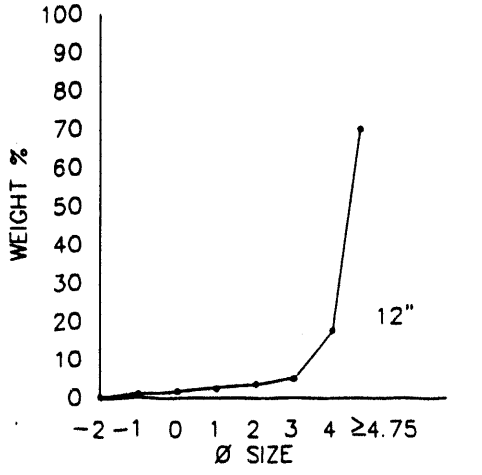

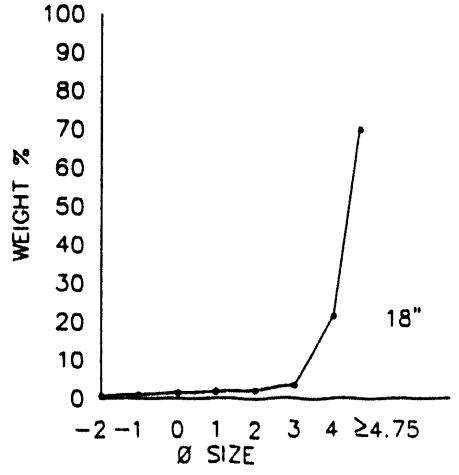

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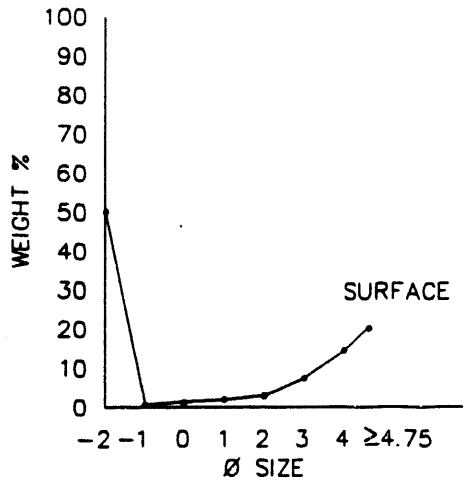

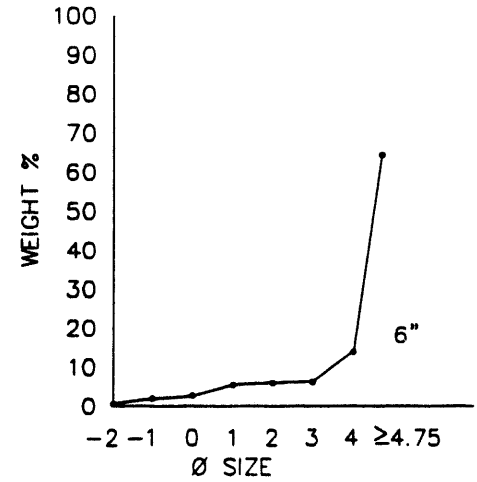

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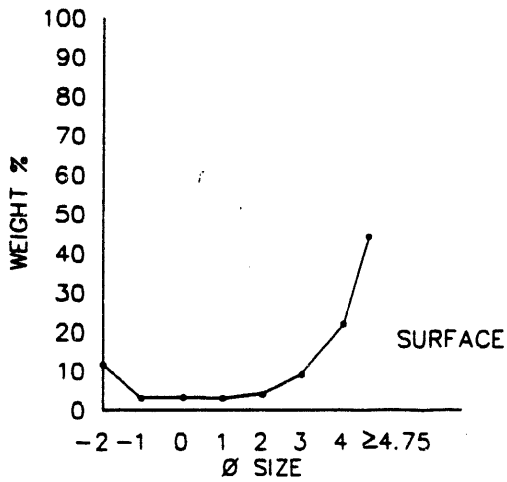

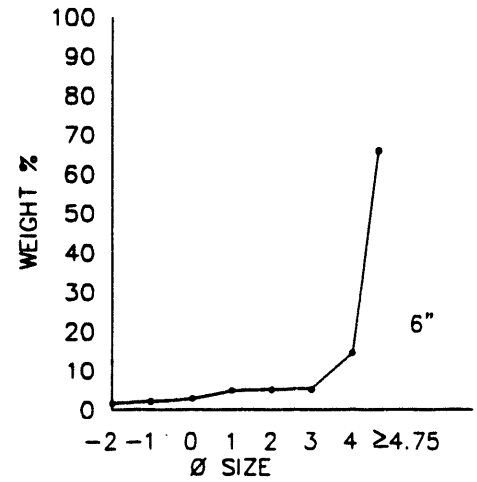

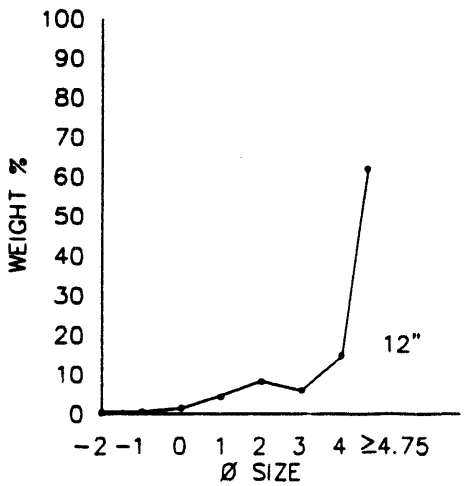

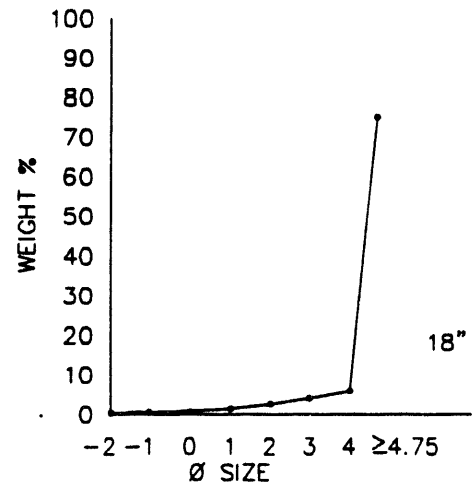

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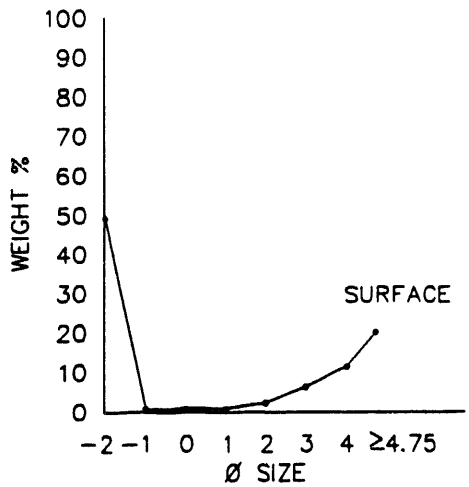

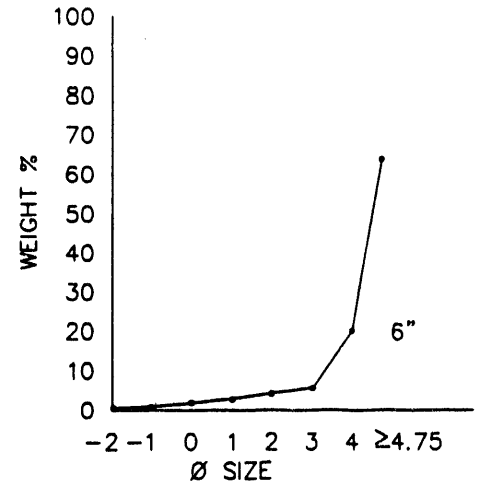

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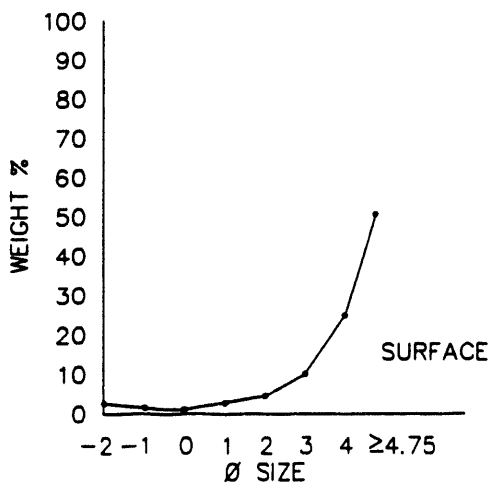

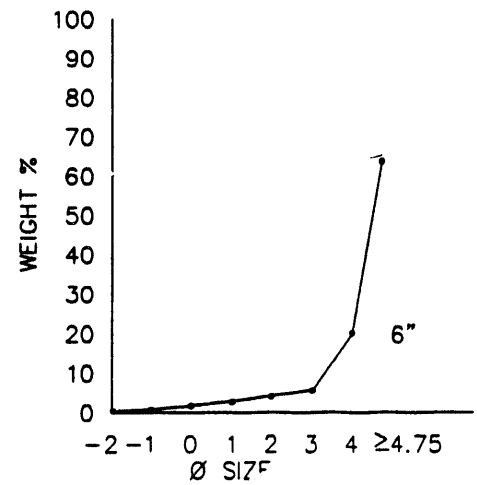

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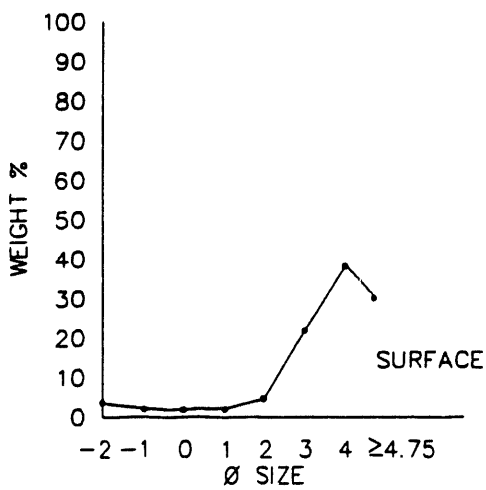

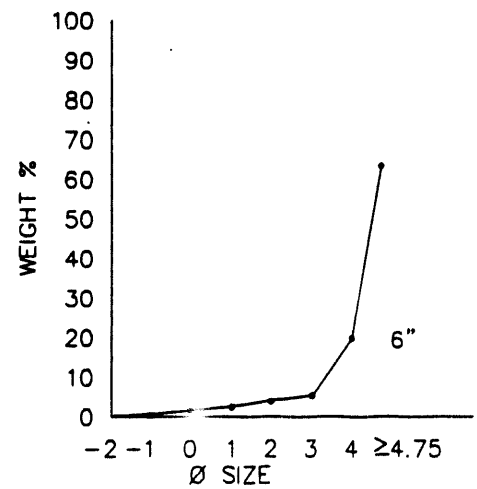

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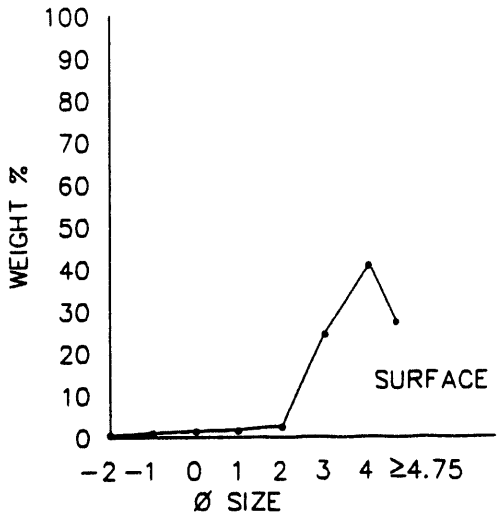

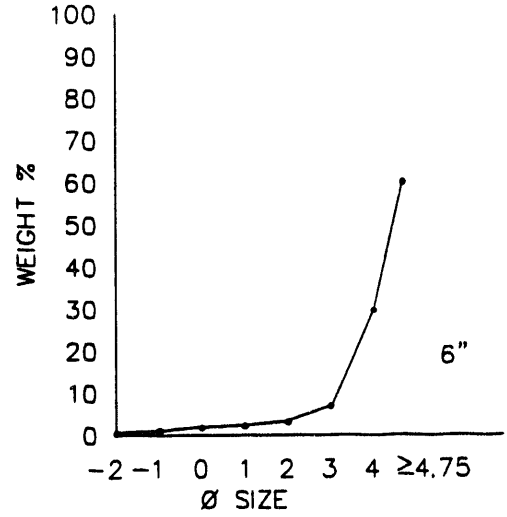

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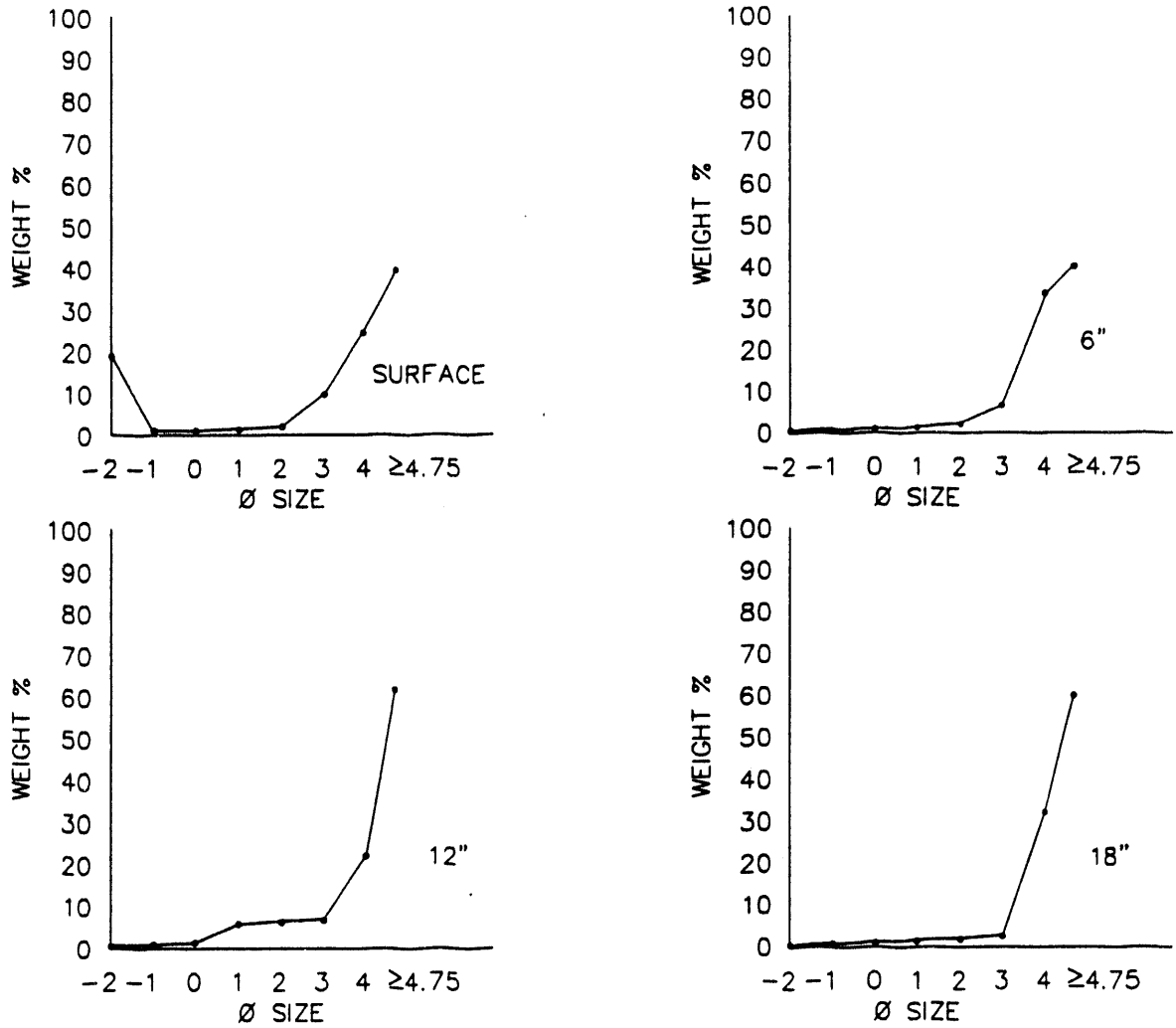

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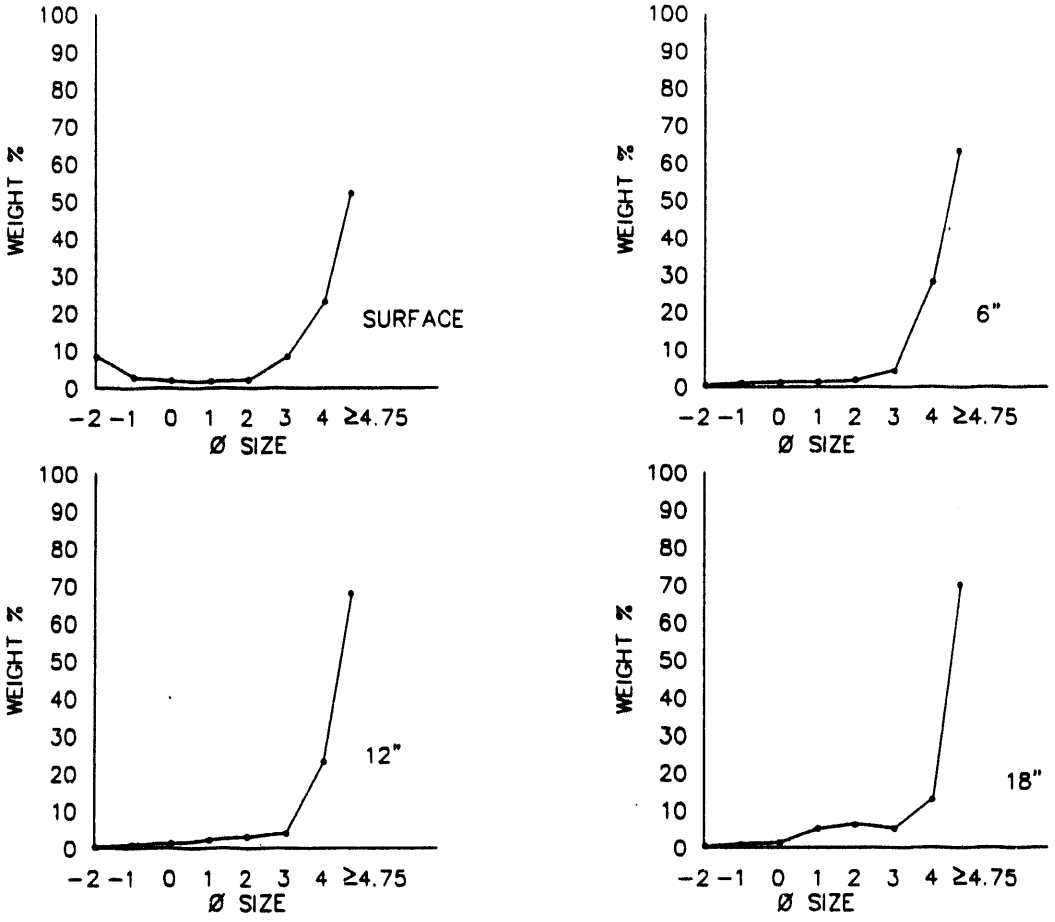

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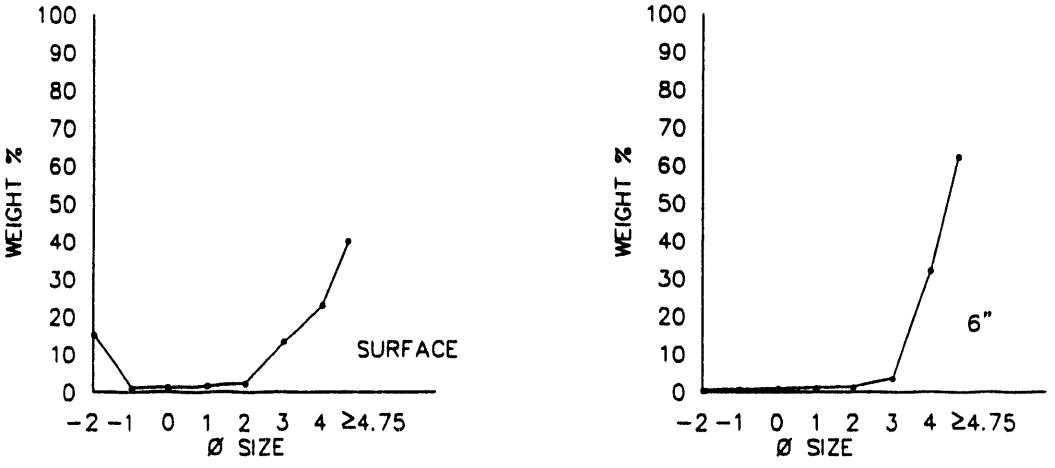

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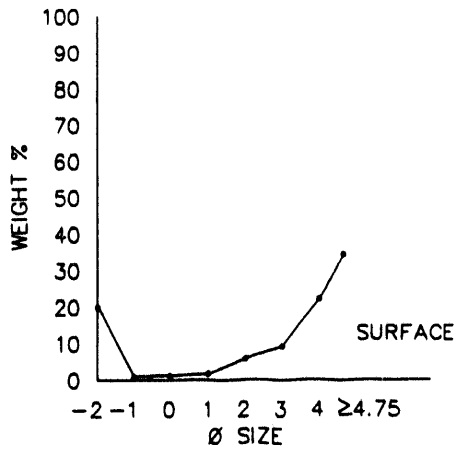

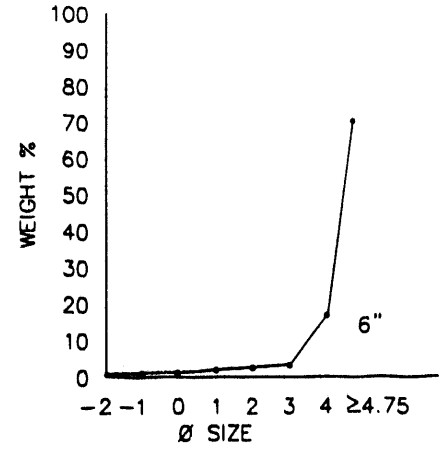

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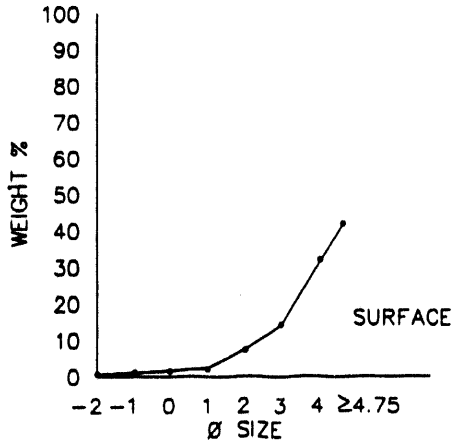

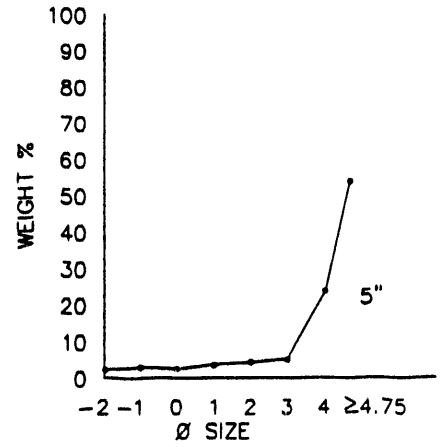

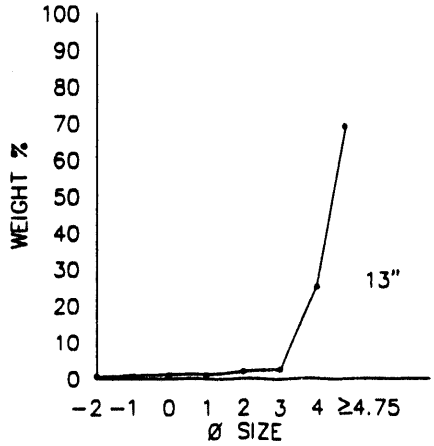

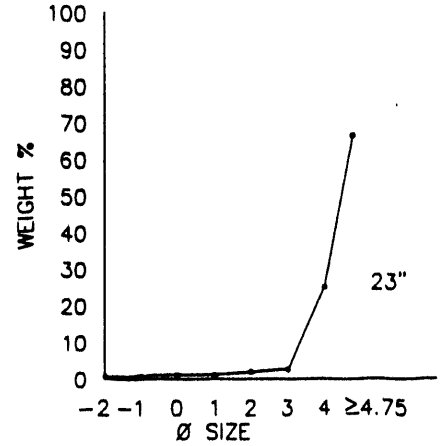

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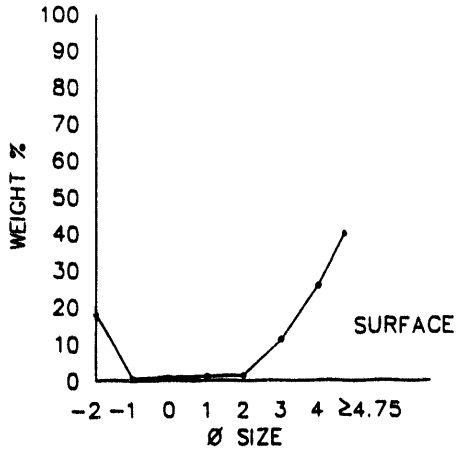

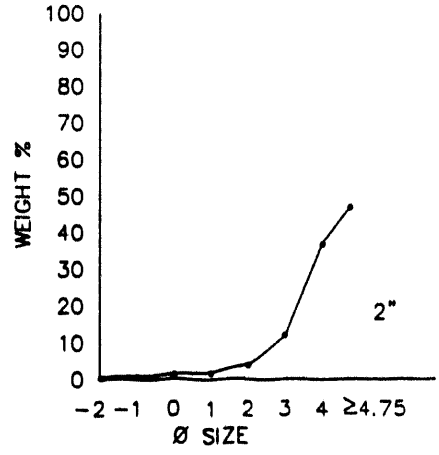

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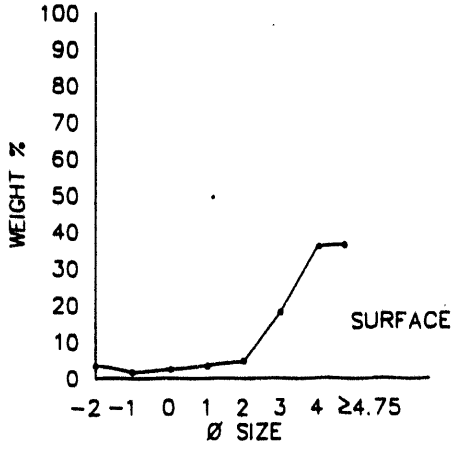

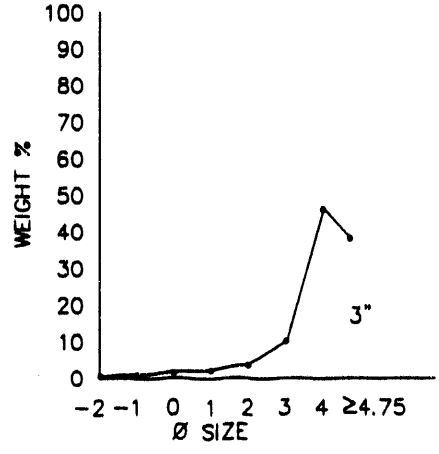

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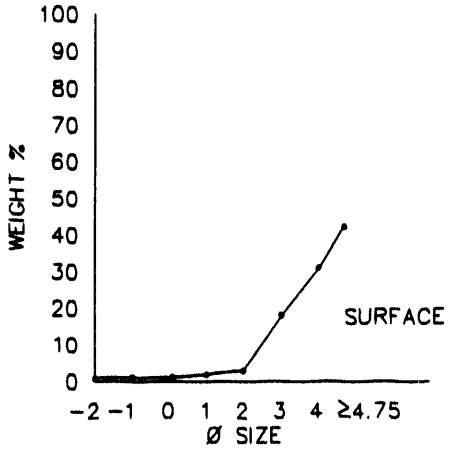

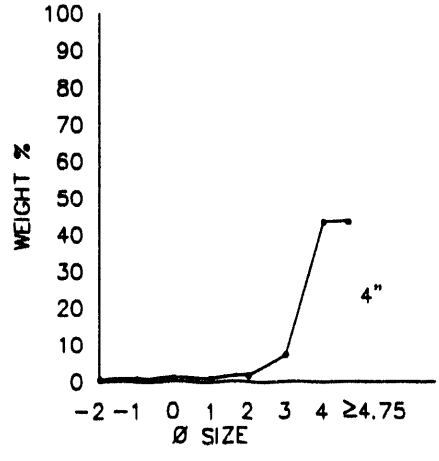

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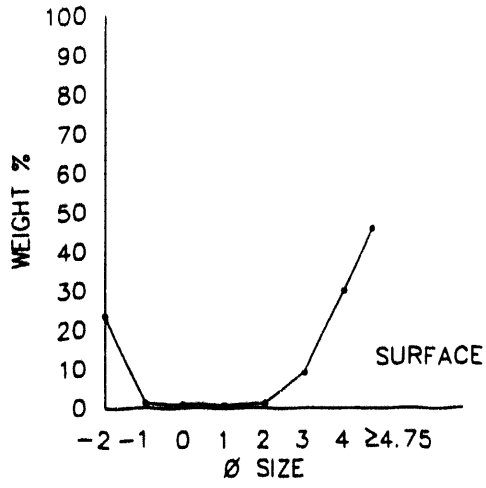

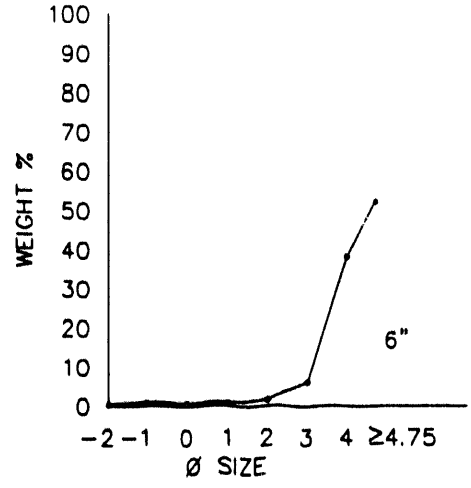

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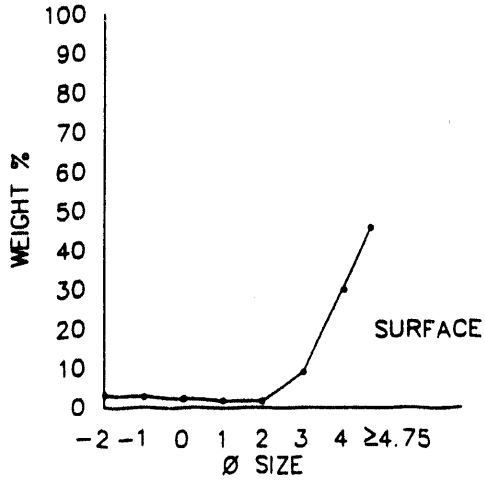

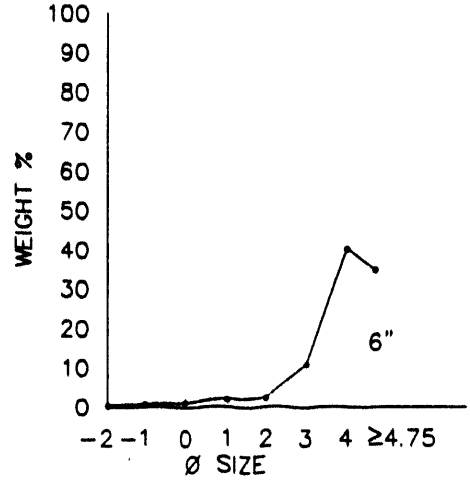

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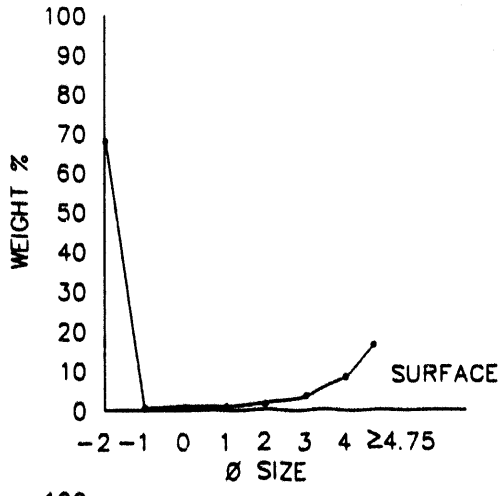

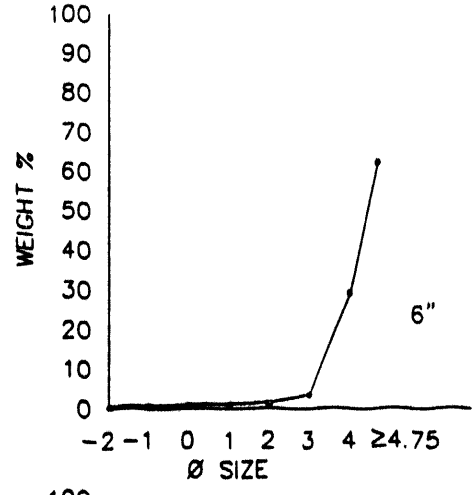

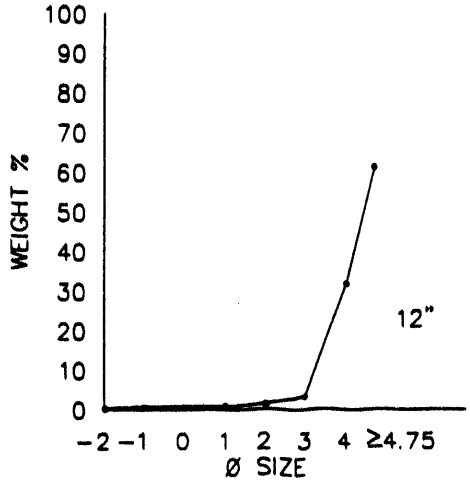

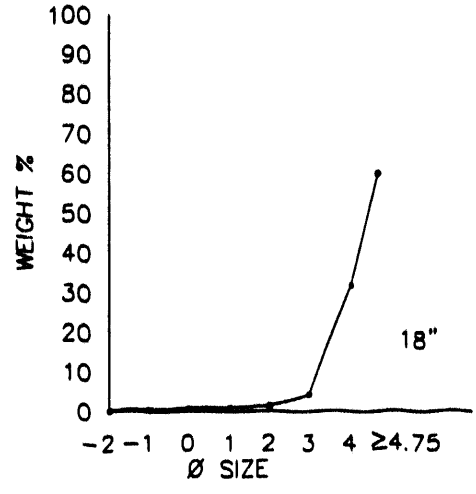

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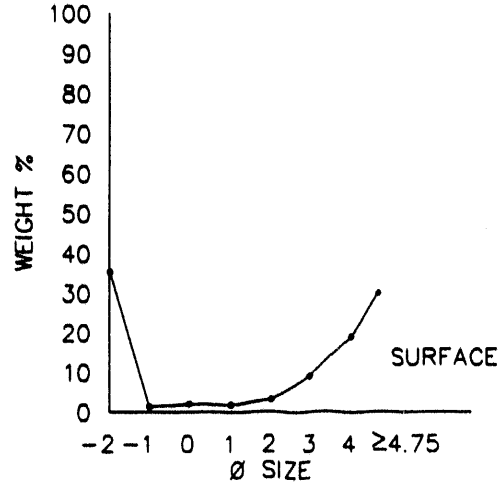

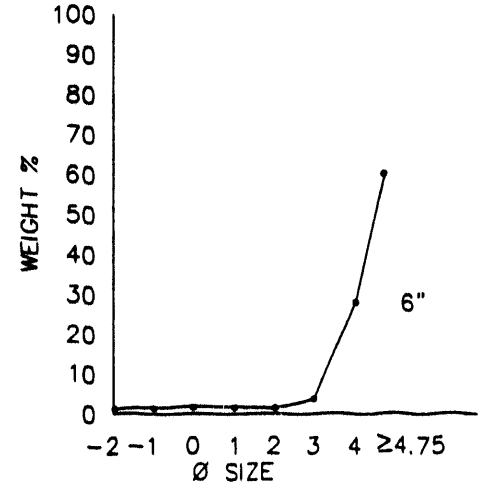

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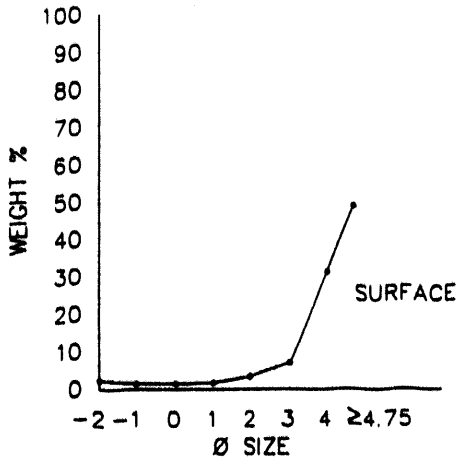

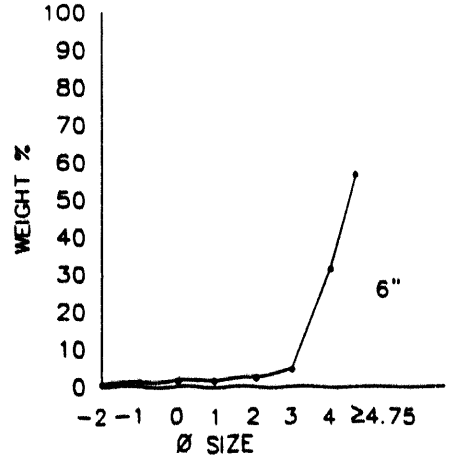

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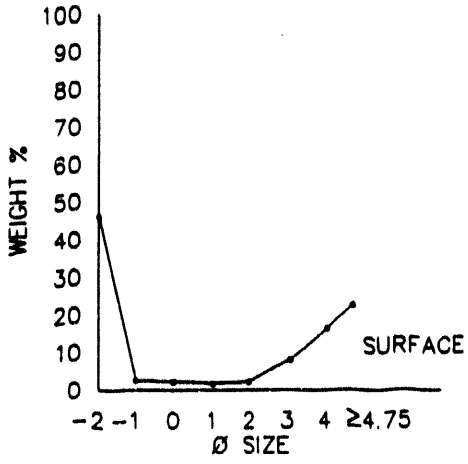

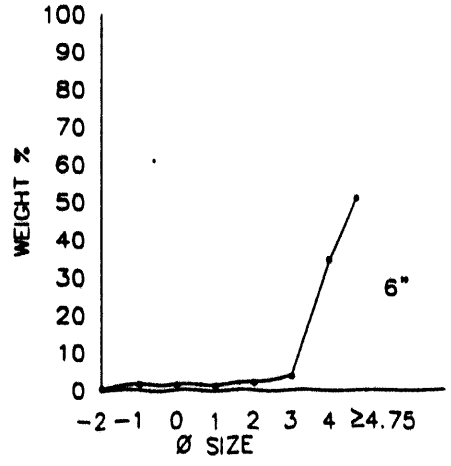

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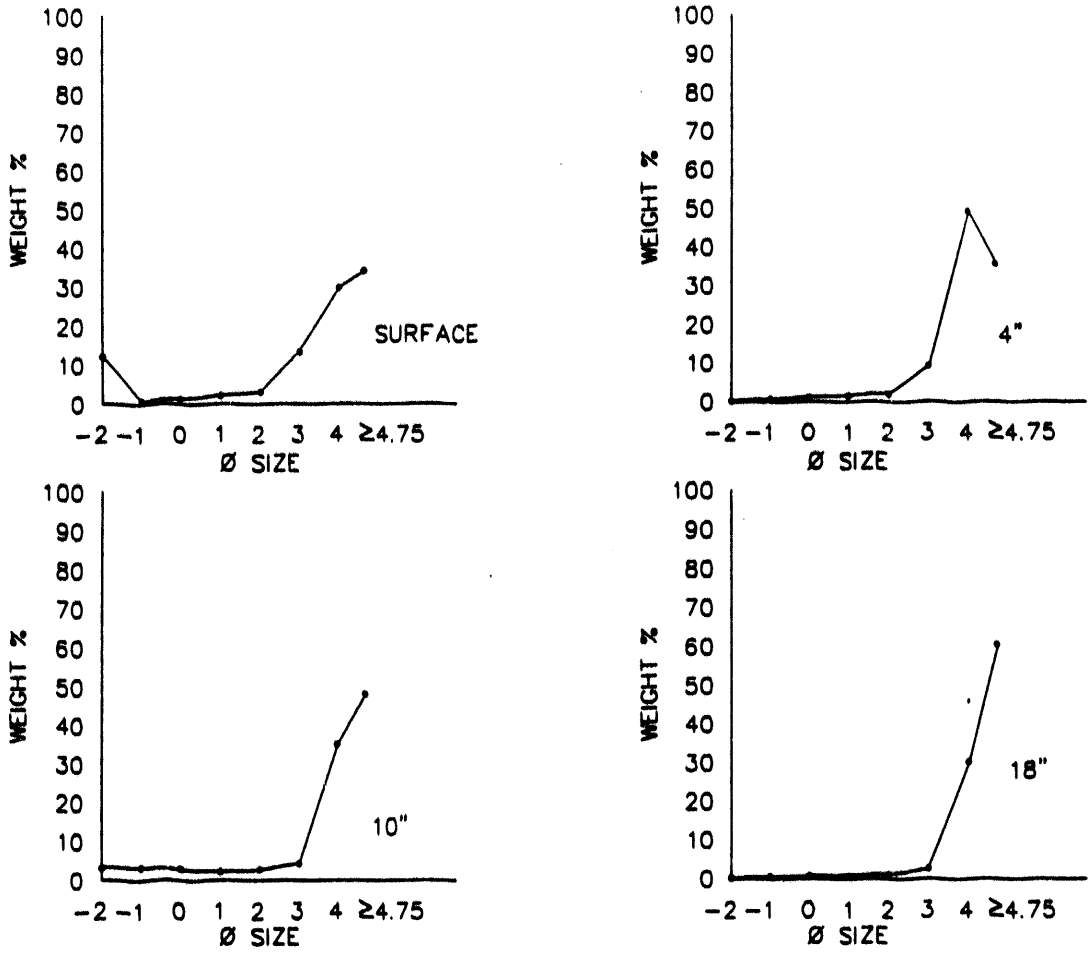

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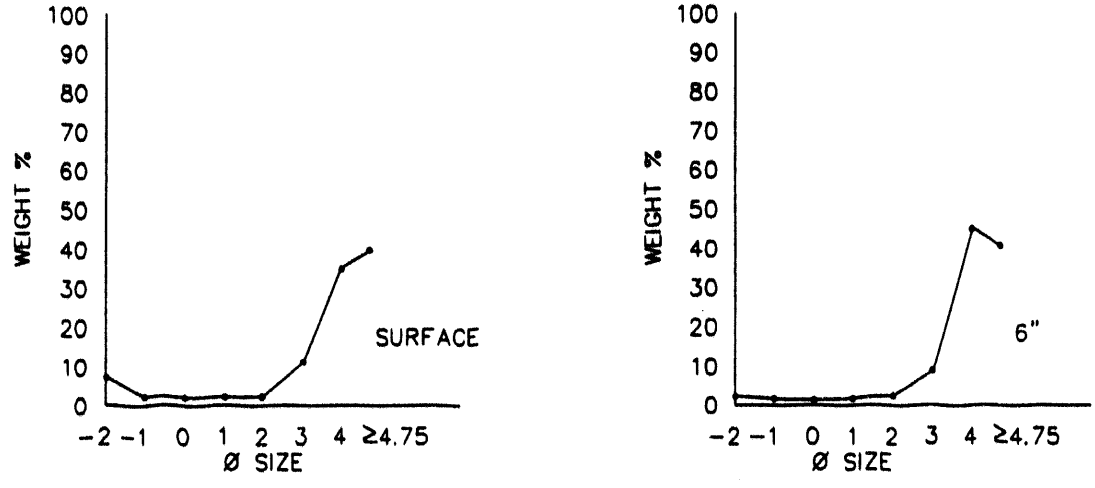

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