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ES 102

An Analysis of Slide Areas at Pine Cobble Development

Introduction

As the number of residents in the Williams College owned Pine Cobble development begins to grow, glaring erosion problems still plague the new subdivision. Built on the south and westward facing slopes of East Mountain, the southern terminus of which is Pine Cobble, this housing development is built on steep terrain that was previously a forested region adjacent to the Clarksburg State Forest. Since the clearing of this land for development the immediate area has been subject to severe erosion. Initially, a major problem was sediment runoff. Much topsoil was lost during rains occurring immediately after the area was cleared of vegetation in early 1990. Figure 1 is a graph showing sediment discharge at the base of the Pine Cobble development. Of particular interest is the amount of discharge in the rain storm of May 23, 1990. Little was done to immediately alleviate the problem of lost sediment. After the development's single loop road was completed sediment runoff diminished when grass was planted on exposed slopes.

Since the road's completion a new, and potentially very costly, problem has developed. Two major mass movements of earth appeared on the upper slopes of the road. A map of the development with these slide locations is included as Figure 2. Major Slide A occurred on what was designated as a lot for housing. On this site a major slump developed. This area was engineered extensively since the area above it is now occupied by a new house. The slope is currently considered stable. The other slide, shown as Major Slide B in Figure 2, is somewhat more damaging. This slide is located between the development road and the access road to the development's water tank. This slide is currently active and is visibly undercutting the water tank access roadway. Work with vegetation and drainage is underway in an attempt to stabilize this slide before the water access road is entirely destroyed.

These slides have developed for several reasons, all of which are part of a simple equation which governs the shear strength of a slope.

This equations is: $C+(W\cos a-m)\tan\emptyset$=shear strength of slope

In this equation C represents the soil cohesion, due primarily to plant roots, W is the weight of the soil mass, a is the slope angle, m is the water pressure, and Ø is the internal friction of the soil particles.

These factors were affected in several ways by the cutting of the road bed. Principally, the road bed was cut into the mountain side, which increased the slope angle at the major slide sites. The variable C was also affected by the removal of vegetation. Tree and shrub roots that had previously stabilized the slope were removed, leaving the soil with little in the way of cohesion. Water pressure was also affected by the removal of vegetation since precipitation directly eroded away at the slope, rather than being buffered by plants.

These principles were also demonstrated in some of the minor slides that are currently active in the development. These are shown in blue by Figure 2. These slides were the focus of this experiment which attempted to characterize the causes of these mass movements. Specifically, an attempt was made to identify the causes of individual slides when adjacent areas consisted of stable slopes.

Methods and Materials

Initially, the Pine Cobble development area was roughly surveyed to locate sites that showed the effects of mass movements. Specifically, smaller slides, which may not have caused any serious damage, were identified. Again, these slides can be seen in Figure 2. From these identified slide regions, several were chosen as sites to be analyzed in this experiment. At these slides, pits were dug in the soil at various locations within the individual slide. Samples were collected from every horizon and the depths of each horizon were measured. At most sites these pits were dug straight through the scarp-like region of the slide. However, at one location, pits were dug above the head scarp, through the scarp region, and at the base of the slide. This was sufficient to determine a viable model for the cross-section of the slide. Similar pits were dug at a non-slide location. Again, soil horizons were sampled and depth measurements taken.

The collected samples were analyzed primarily for particle size. Each layer was sieved to determine the percentage of various sizes of soil particles. This was done for the samples from both the slide and inactive areas. The sieving technique broke the particles down into seven different size categories. These categories were particles with a phi value of less than -1, -1-0, 0-1, 1-2, 2-3, 3-4, and above 4. (translate to mm for the non-geologist!)

At each site vegetation and other pertinent factors, such as groundwater seepage, and obvious human influences were also observed.

Data

Cross-sections of two slide areas can be seen in Figure 3. These two slide areas show the diversity of the slide regions studied. The first cross-section, Slide 1, shows a slide occurring over a groundwater seep. The second slide, Slide 2, shows a slide over a relatively dry slope.

The following table shows percentages of soil particle sizes for these two slides:

phi	Slide 1-A	Slide 1-B	Slide 1-BC	1 Mixed Layer	Slide 2-A	Slide 2-B
≤-1	3.5±2	13.7±2	1.4±2	4.6±2	16.6±2	36.5±2
-1-0	22.3±2	20.9±2	28.7±2	28.9±2	27.7±2	11.1±2
0-1	25.0±2	20.6±2	26.6±2	24.8±2	20.8±2	12.4±2
1-2	20.3±2	16.9±2	18.7±2	17.8±2	13.8±2	9.5±2
2-3	14.7±2	13.1±2	11.4±2	11.9±2	13.4±2	8.3±2
3-4	12.5±2	13.0±2	10.9±2	10.1±2	6.8±2	3.8±2
>4	1.7±2	1.7±2	2.4±2	2.2±2	.9±2	7.5±2

The following table is similar data from a non-slide area:

phi	A	B
≤-1	18.8±2	30.0±2
-1-0	17.3±2	16.6±2
0-1	14.5±2	14.7±2
1-2	10.6±2	11.5±2
2-3	8.6±2	8.8±2
3-4	18.0±2	11.6±2
>4	16.5±2	6.8±2

Discussion

One of the first discoveries made during this experiment was that the slides on Pine Cobble are caused by no single action. Nor is it immediately possible to ascertain whether or not a given action shown to cause a slide at one site will have the same ~~a~~effects on another, similar appearing site. All of the slides studied in this project were caused by a lessening of the shear strength of the soil through some human action that affected the variables in the formula: $C+(W\cos a\text{-}m)\tan\emptyset$=shear strength.

One human impact that is, to some degree, a cause of each slide is the steepening of slopes along the road embankment. As is shown by Figure 2, the major slides each occur in areas where already steep slopes were made even steeper when the road grade was cut. The areas of minor slides occur where the road bed runs parallel to the slope contours. The slides occur in these areas because embankment slopes are simply steepened extensions of the natural slope. These areas are slide prone since runoff and groundwater from the natural slope all flow over the steepened embankment. Embankments at road curves cut do not share this problem. The road bed cuts perpendicular to the contours of the slope at these locations, thus the embankment is steepened at an angle to the natural slope. Because of this, drainage down the embankment is not a problem. This principle is shown in Figure 2 since sections of the roadway cut parallel to the slope all show active slides, whereas road sections angling up the slope are largely inactive.

Water pressure (the variable m) also seemed to be a key factor in determining active slide sites. One slide (occurring in both lots 43 and 44 on Figure 2, and shown in cross section as Slide 1 in Figure 3) shows the effects of both groundwater and surface runoff on a steepened slope. This slope has very little vegetation over its surface. As the area above it is thickly forested, we can assume that this slope was once forested as well before the housing project was developed. This lack of vegetation not only lowers soil cohesion, but also yields a surface that is especially prone to surface runoff (an increase in the variable m) since the slope is not directly protected by vegetation. Groundwater also plays an important key in this particular slide. Over the entire length of the slide (approximately 75 m) groundwater seepage occurred just below the slump. In addition, the slide area did not extend past the area of seepage. On the day that pits were dug at this site the water table occurred approximately 32 cm below the base of the slide. It was, however evident that this changed somewhat as several days later the table was a few centimeters higher. Despite this fluctuation in elevation the erosion patterns caused by this seepage showed that the water table had not recently risen above the level of the base of the slide. From this we can conclude that by cutting an embankment through the water table a slope failure was induced. The slide was, however, controlled to some degree by the aquifer, since the slide did not extend below the water table at any point.

The slides appearing in Lots 55 and 56 and at site S-5 are more difficult to explain. There is no water seepage coming from the embankment at these locations, and no water table was encountered when soil pits were dug. In addition, the area is covered with grassy vegetation. Complicating the issue is the fact that the entire slope was not active, rather isolated patches showed active slides. Initially, vegetation was analyzed at the slide sites. There was little difference between the active and inactive regions. It appeared that the entire area had been seeded with grass. Thus, species composition and density were relatively uniform over the entire area.

Only one of the four slides in this area showed an obvious cause. At the base of this slide (on the boundary of Lots 55 and 56) was a box of electrical equipment that was anchored into the ground with a large cement mounting. In order to make room for this structure an area of the slope was leveled, thus increasing the slope angle directly above the equipment to an even greater degree. At the other slide areas, however, there was no such obvious disturbance. The entire face slopes at approximately the same angle, yet slides only occurred in certain locations.

Analysis of slide and non-slide sites showed that soil particle size was the cause of the differentiation between slide and non-slide areas. Figures 4, 5 and 6 are graphs showing the particle sizes over soil horizons in two slide areas and in one non-slide area. These graphs show that uniformity of particle sizes through the horizons at a single site is not a factor in determining the likelihood of slope failure. Figure 4 shows a relatively uniform distribution of particle sizes over the three soil layers that were a part of the slide. Figure 5, however, shows a different slide region in which the particle sizes are not uniform at all over soil horizons. Finally, Figure 6, shows that particle sizes in a non-slide area are only somewhat uniform. Thus, it was determined that particle size uniformity over soil horizons is not an important factor in determining the likelihood of slope failure.

It was evident in the soil cross sections that the actual translational motion occurred in the B soil horizon. Thus particle sizes through the B layer of two slide sites and a single non-slide site were analyzed. Figure 7 shows the compositions of these B layers by particle sizes. Very little correlation was determined from this graph. A similar graph showing A layers instead of B layers can be seen in Figure 8. This graph showed an interesting trend. In the non-slide area the A horizon showed substantially higher amounts of fine silt and clay sized particles than shown to exist in the A horizons of slide sites. This is an important factor in determining which sites will develop mass movements. The increased levels of clay in non-slide sites helps to make the A layers more impermeable to water. Thus water is retained in the A layer where it is eventually used by plants or simply evaporates. In slide areas, the A horizon contains very little clay, thus the water seeps directly into the B horizon of the soil. As was shown in the slide that was controlled by the elevation of the water table, ground water is an important factor in controlling slope failure. These slides that occurred in Lots 55 and 56 have higher levels of water pressure (m values) than the adjacent areas that are protected by clay in the A horizon.

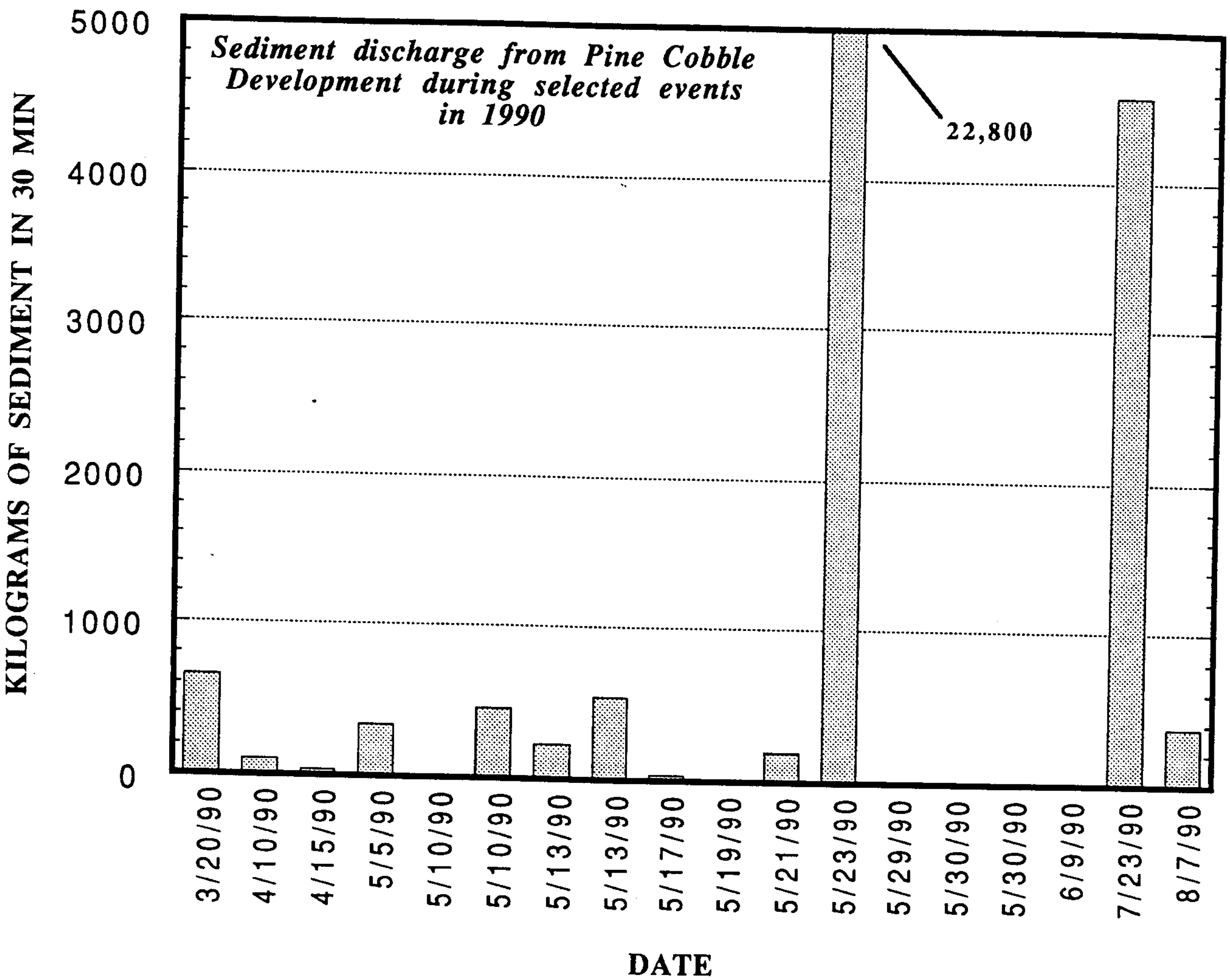
This analysis showed that no single cause can determine whether or not a slide will occur in a given area. Rather, each sloping region had its own unique set of circumstances that determined whether or not the slope would fail. The only thing common to these slopes is that the likelihood of a slide has been greatly exacerbated due to the over-steepening of the slope by human construction. Given the range of factors that cause each individual slide, there is little that can be done to the entire development to make future slope failure less likely. Rather, precautions should be taken in to limit building in hazardous areas of potential failure. Slides that do develop must be dealt with on a case by case basis in order to determine the factors responsible for that particular slide. Only then can strengthening measures such as planting vegetation, increasing drainage, or covering with other protective material be taken with confidence that they will aid in increasing the shear strength of the slope. Since the development has already been built, these are the only preventative actions that can be taken. In the future, however, developers should realize that perhaps housing projects do not belong on the sides of mountains.

Background in information was taken from the following sources:

Kellar, Edward A. Environmental Geology, Macmillan Publishing Company, New York: 1992. pp. 112-135

Class notes from Geology 103. Professor David Dethier. November 6, 8, 11, 1993.

Figure 1



Provided as class handout by Prof. Dethier in Geology 103 on Nov. 8, 1993.

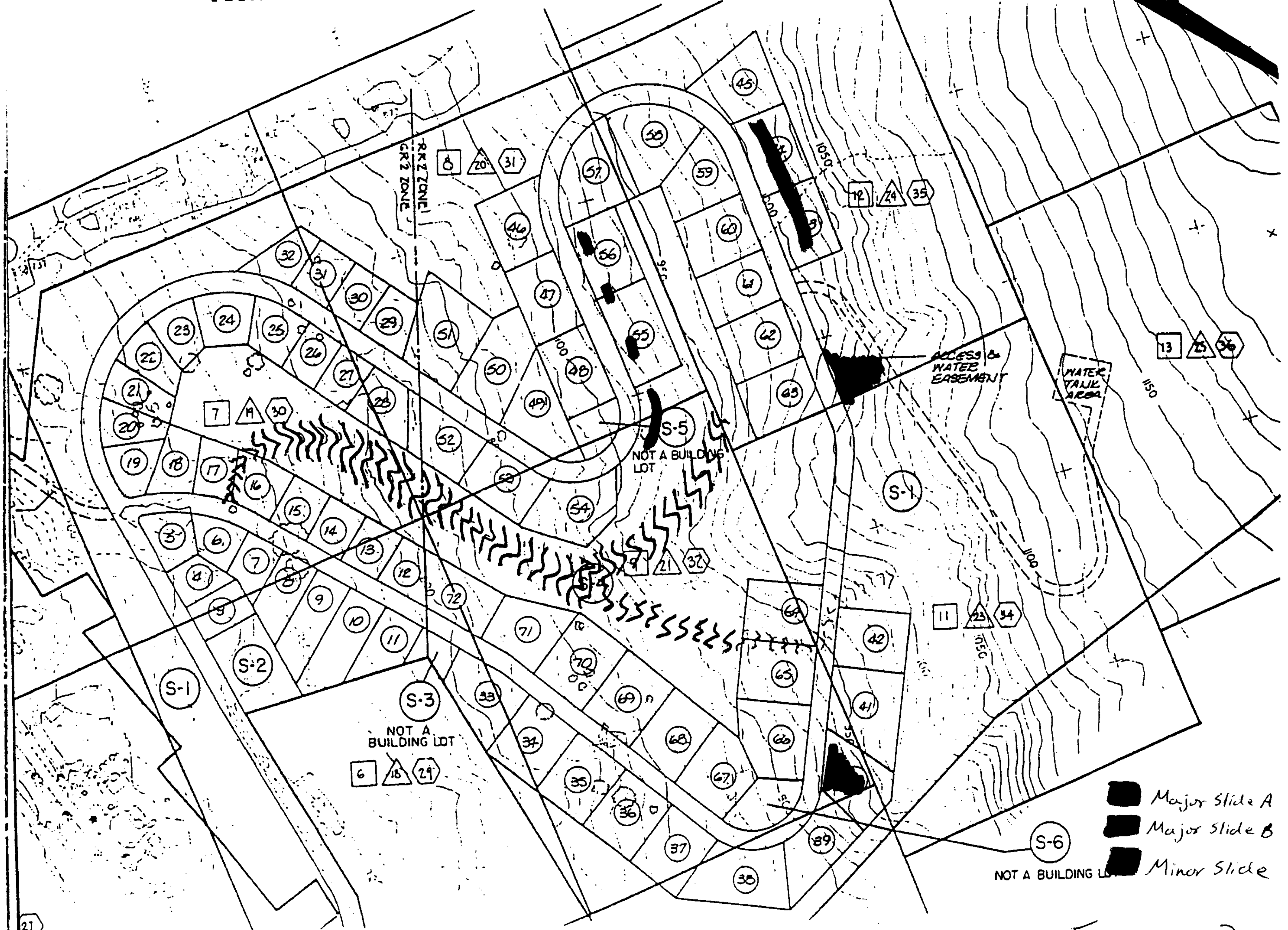
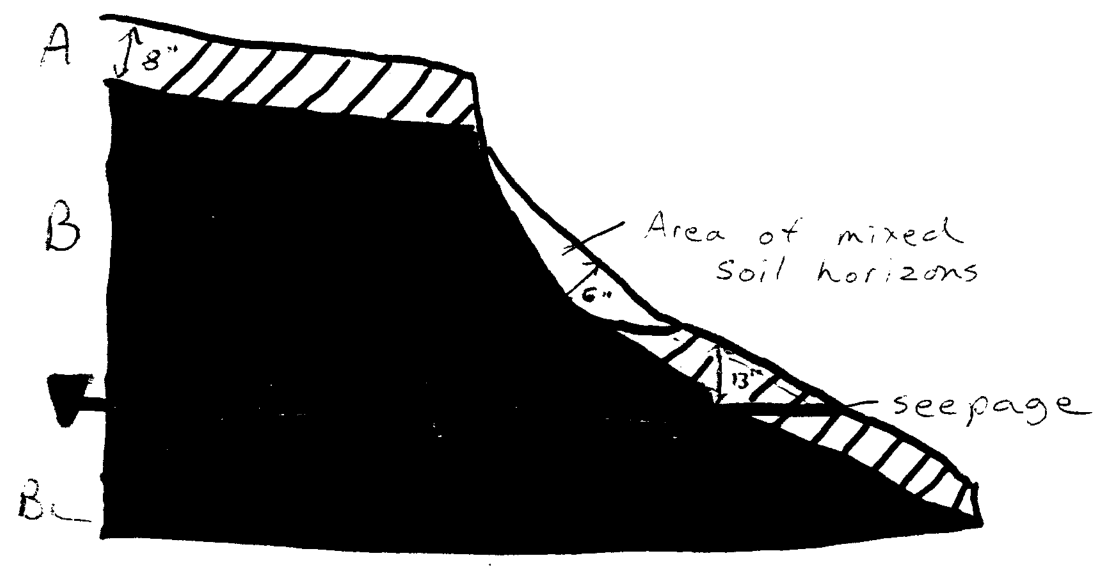


Figure 2

base map provided by David Dethier

Figure 3

Slide 1



Slide 2

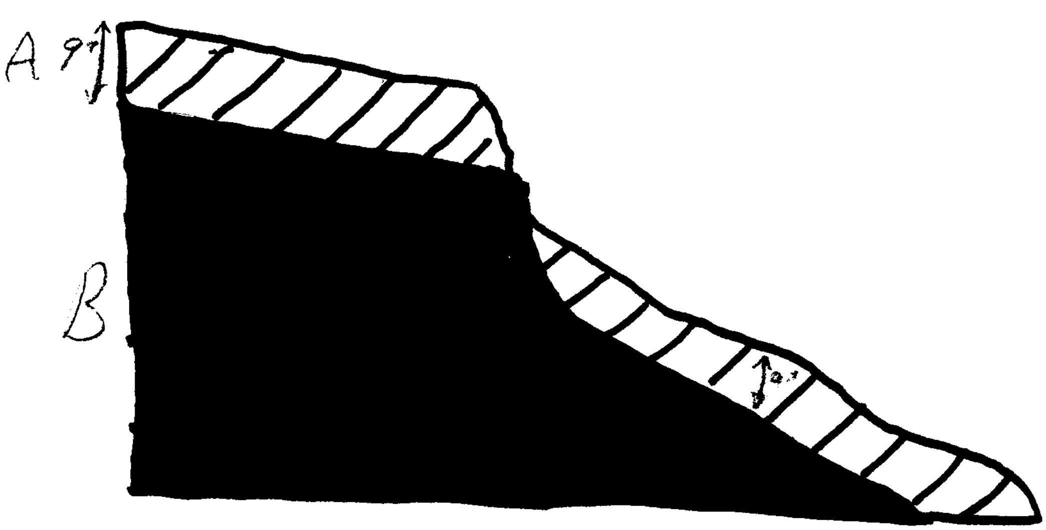


Figure 4

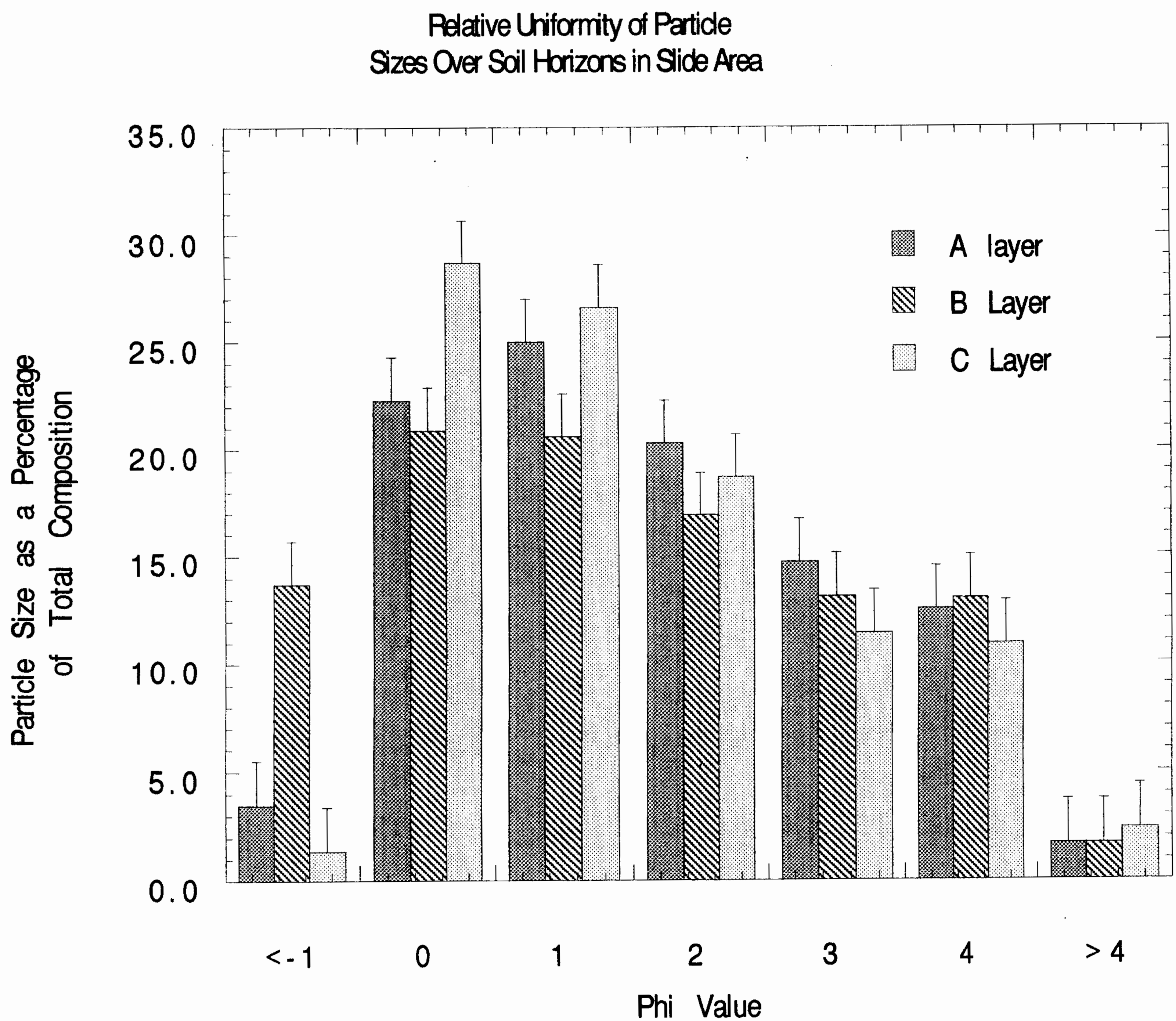
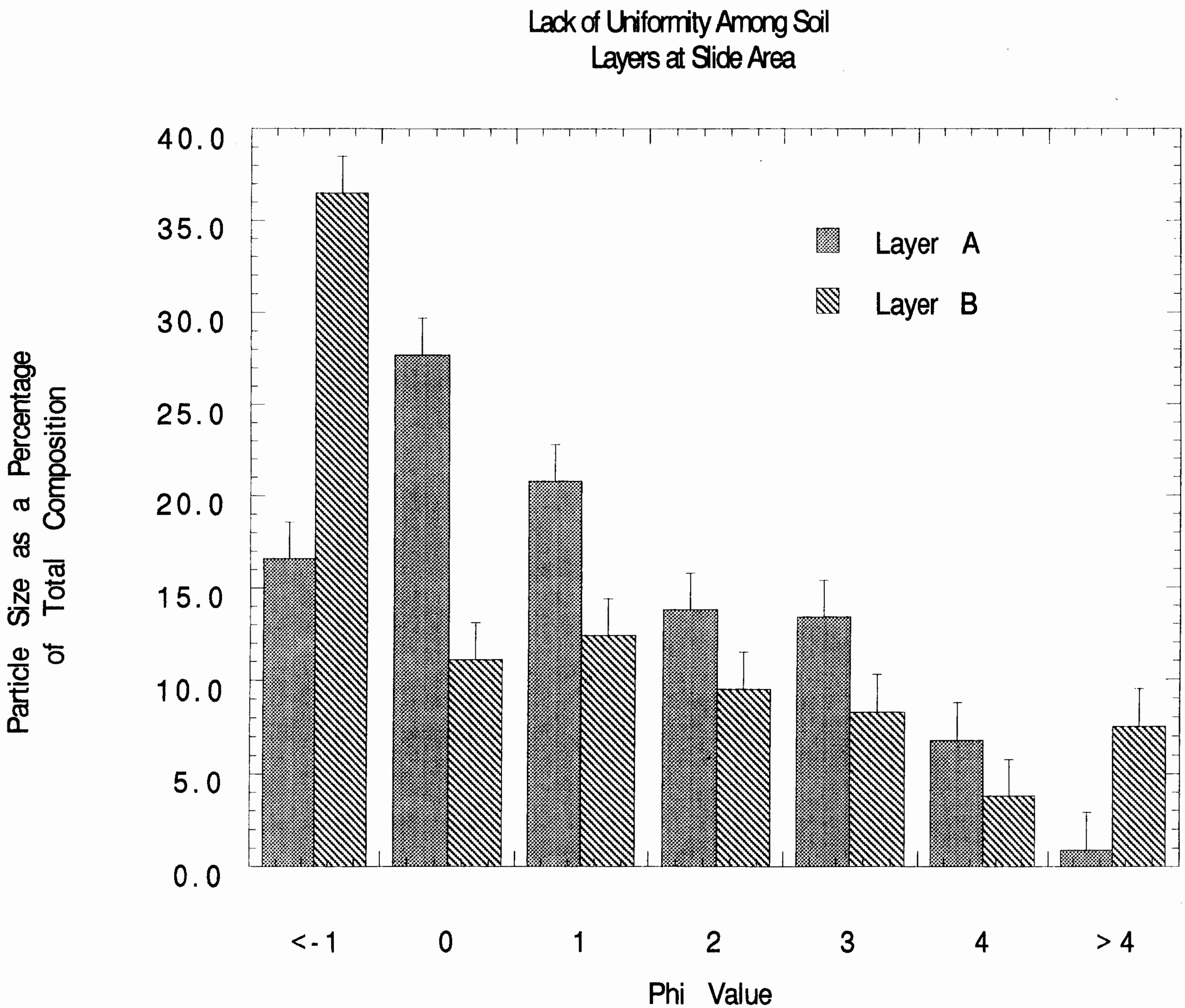
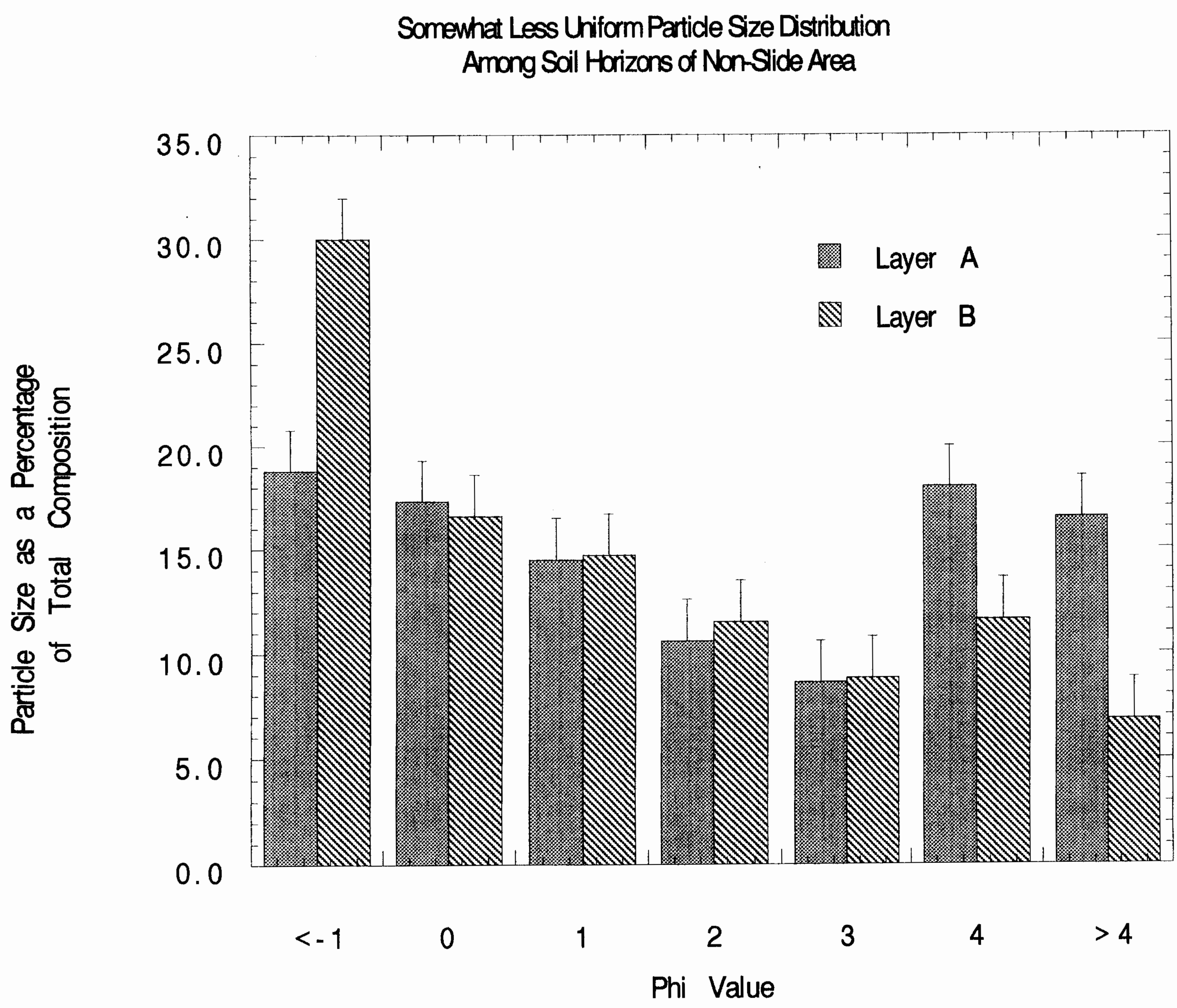

Relative Uniformity of Particle
Sizes Over Soil Horizons in Slide Area
Particle Size as a Percentage
of Total Composition
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
A layer
B Layer
C Layer
< -1
0
1
2
3
4
> 4
Phi Value

Figure 5



Lack of Uniformity Among Soil Layers at Slide Area
Layer A
Layer B
Particle Size as a Percentage of Total Composition
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
<-1
0
1
2
3
4
>4
Phi Value

Figure 6



Somewhat Less Uniform Particle Size Distribution
Among Soil Horizons of Non-Slide Area
Particle Size as a Percentage of Total Composition
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
Layer A
Layer B
< -1
0
1
2
3
4
> 4
Phi Value

Figure 7

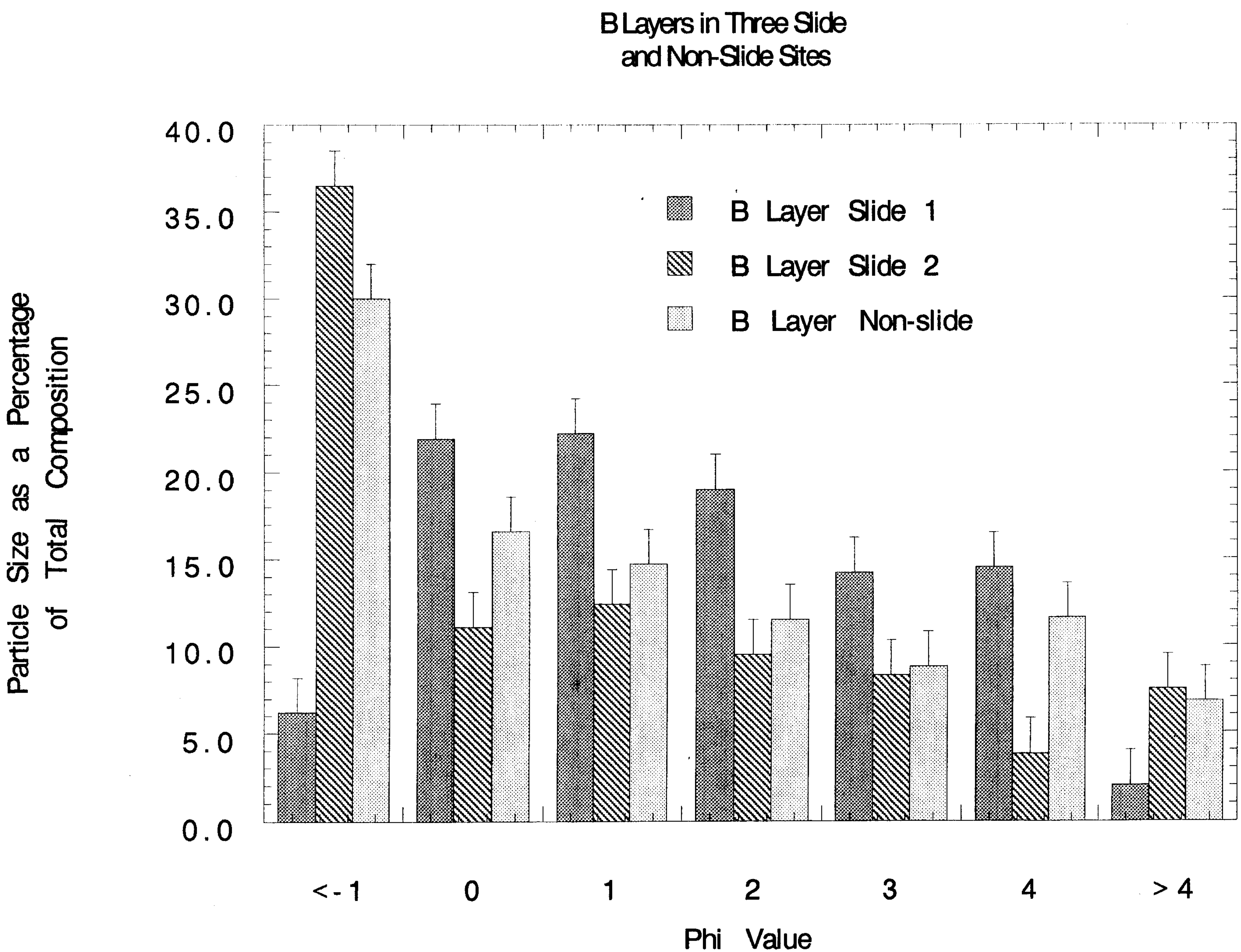
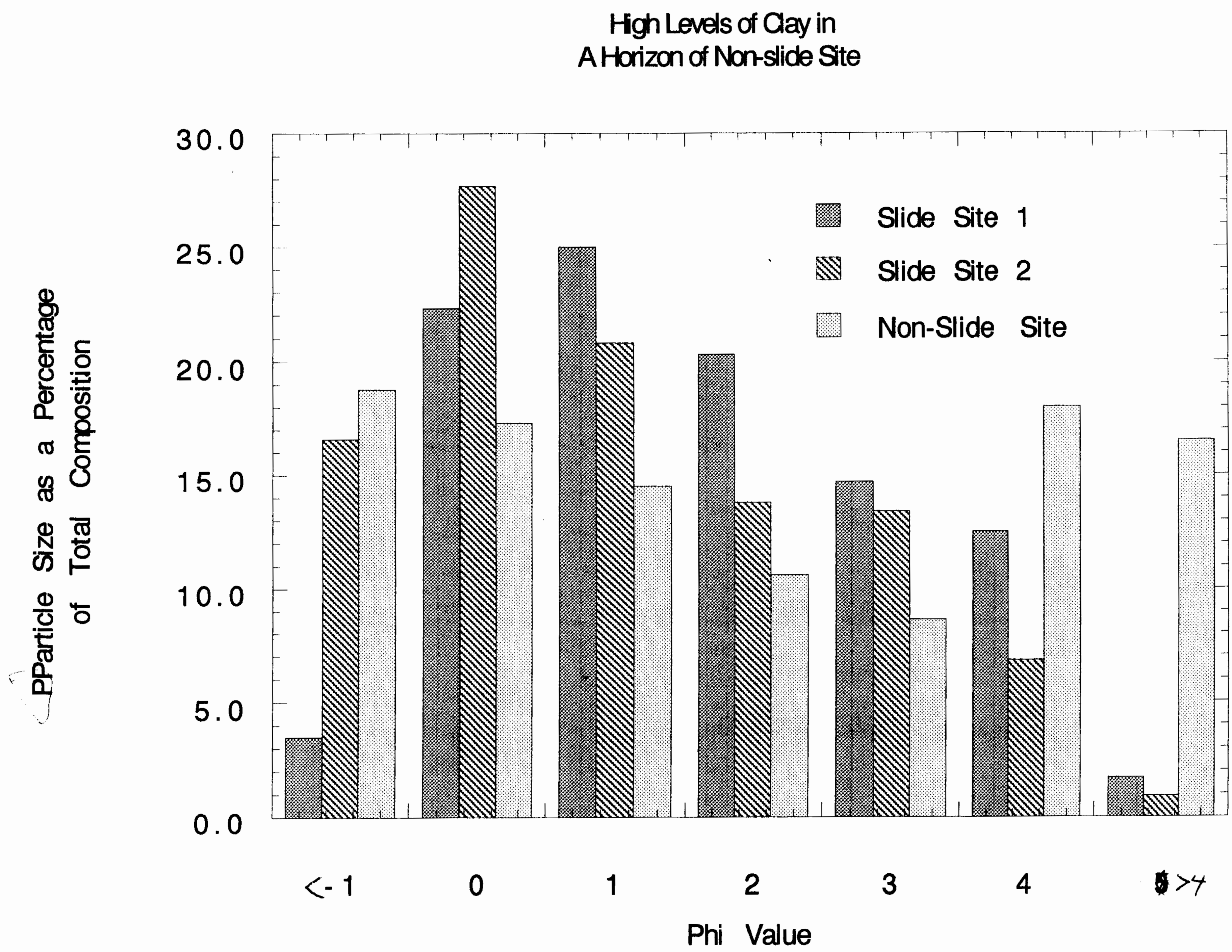

B Layers in Three Slide
and Non-Slide Sites
B Layer Slide 1
B Layer Slide 2
B Layer Non-slide
Particle Size as a Percentage
of Total Composition
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
< -1
0
1
2
3
4
> 4
Phi Value

Figure 8


High Levels of Clay in
A Horizon of Non-slide Site
Slide Site 1
Slide Site 2
Non-Slide Site
PParticle Size as a Percentage
of Total Composition
30.0
25.0
20.0
15.0
10.0
5.0
0.0
<- 1
0
1
2
3
4
>4
Phi Value