# Laboratory Characterization of Immediate Floor Strata Associated with Coal Seams in Illinois

by
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Illinois Mine Subsidence Research Program

cooperating agencies

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## FOREWORD

This study was initiated under a research contract from the Illinois Department of Energy and Natural Resources and the Illinois State Geological Survey for the Illinois Mine Subsidence Research Program. This final report presents the results of studies conducted during the period June, 1985 to May 30, 1986.

The primary objective of the study was to generate data on engineering index properties and laboratory strength deformation characteristics of the immediate floor strata associated with coal seams in Illinois. These data will be utilized by mine operators to estimate in-place strength (bearing capacity) and deformation characteristics of immediate floor strata. The data are required for effective design of mine workings (mine openings and coal pillars) for optimum mine stability and resource extraction under planned and unplanned subsidence options. An additional objective was to develop a computerized data base of the available and project generated index properties and strength-deformation characteristics of immediate floor strata on a IBM-PC/XT microcomputer. The data base will be eventually made available to Illinois mine operators upon request.

Weak floor strata associated with coal seams currently being mined in Illinois are one of the more significant factors contributing to mine subsidence. Unfortunately, pertinent data on physical properties and strength-deformation characteristics of floor strata required for efficient and effective design of mine workings are sparse in the literature. It is expected that the data included in the report will lead to more efficient design of mine workings with controlled and predictable amounts of mine subsidence in mining underneath prime agricultural lands in Illinois.

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# I. INTRODUCTION

## Background and Statement of the Problem

Stability of mine workings and surface subsidence resulting from underground mining of stratified deposits (such as coal) depends upon interaction of roof, pillar, and floor. Overburden strata (roof) loads are transmitted to the floor through pillars that are left to support overburden (figure 1). Instability of any one of the three structural elements can lead to overall instability of the mine workings that may eventually lead to surface subsidence. The effects of roof and pillar elements have been extensively studied in the past. However, very limited research has been done on the immediate floor (weak underclay and the competent strata immediately below the surface of the coal) because its importance was not fully recognized until the early 1970s. The floor acts as a foundation for the mine structure and must be designed to adequately carry the loads imposed on it. An inadequate floor element may cause floor heave, squeeze, pillar punching and pillar sloughing, and roof falls leading to surface subsidence. The load-carrying capacity of the floor largely depends upon its thickness and engineering index properties, such as particle size, Atterberg limits, natural moisture content, specific gravity, clay mineralogy, and mechanical behavior of immediate floor strata associated with the coal seam.

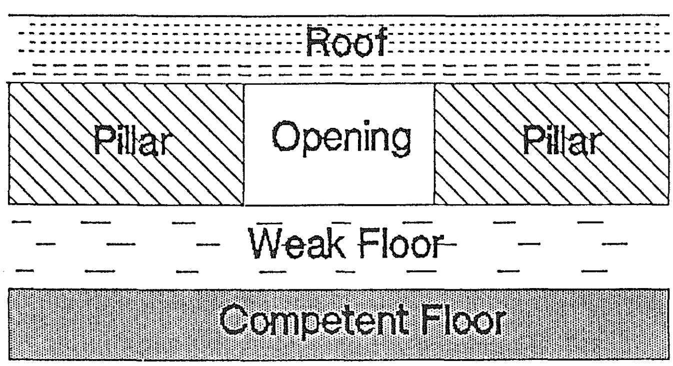


Figure 1. Interaction of mine roof, pillar, and floor.

Mine stability considerations (design of mine openings and coal pillars) and surface subsidence in a large number of active Illinois underground mines are controlled primarily by weak (100-500 psi compressive strength) and relatively thick (2 to 7 ft) underclays. Unfortunately, very limited data are available on the nature and strength-deformation properties of immediate floor strata associated with these seams. These data could be used by mine operators to estimate the bearing capacity of the floor for effective design of mine openings and coal pillars. Once the strength-deformation characteristics of weak floor strata are determined, standard soil mechanics and foundation design equations may be utilized for estimation of the ultimate bearing capacity of floors underneath pillars. A significant portion of the currently available data was generated by the author in the last 2 to 3 years in working with coal companies in Illinois to fulfill the permitting requirements of the Surface Mining Control and Reclamation Act of 1977 and regulations thereunder. Some data were also collected previously by Ganow (1975) and Rockaway and Stephenson (1979) under a U.S. Bureau of Mines contract, and by the Illinois State Geological Survey (White, 1954, 1956).

On the basis of a review of available literature (Chapter II), I feel there is an <u>urgent</u> need to characterize the strength and deformation characteristics of immediate floor strata using engineering index properties described earlier. Therefore this study was specifically directed toward this objective. This report summarizes such data for two underground coal mines in the state of Illinois: one located in southern Illinois and the other in central Illinois. Both mine the Springfield (No. 5) Coal member, one at a depth of about 900 ft and the other at about 300 ft.

## Goals

The ultimate goals of this project were twofold:

1) Estimate in-place strength and deformation characteristics of immediate floor strata on the basis of laboratory-determined engineering index properties and strength-deformation characteristics.

2) Develop a computerized data base incorporating pertinent laboratory and field properties of immediate floor strata for design of mine workings and subsidence control.

The first goal requires determination of a) engineering index properties and laboratory strength-deformation characteristics of immediate floor strata samples taken at different depths, b) in-place strength-deformation characteristics of immediate floor strata, and c) correlation of properties. All three aspects will be addressed in the overall research program. However, this research study was specifically directed to item "a" and correlation between the laboratory-determined engineering index properties and strength-deformation characteristics. Specific tasks for this research study are outlined below.

1) Develop a computerized data base of the available and project-generated physical properties and laboratory or field-determined strength-deformation characteristics of underclays associated with coal seams in Illinois and the stratum immediately below the underclay.

2) Drill about twenty 2 1/8-in.-diameter core holes below the coal seam to a suitable depth at selected locations in two mines to study floor lithology and obtain core samples of the underclay and 1 to 2 ft of the competent stratum below it.

3) Study the core samples for their index and laboratory strength-deformation properties at different depths under unconfined and confined compressive loading conditions. The properties include natural water content, particle size analysis, Atterberg limits, clay mineralogy, and total clay content. Strength deformation characteristics were to be determined for four confining stresses under unconsolidated, undrained conditions to determine failure strength, angle of internal friction, and moduli of deformation at 50 and 100 percent of the failure strength.

4) Develop statistical correlations of index properties of underclays and their strength deformation characteristics.

This report presents the methodology and results obtained for the specific tasks 1, 2, and 3. Bearing capacity tests in the field and in situ shear strength tests of underclays using a borehole shear tester were also carried out at the sites where the corings were made. However, these in situ studies were conducted as a part of a separate research contract (J0256002) with the U.S. Bureau of Mines to determine the in-place strength-deformation characteristics of immediate floor strata in some of the same mines and at the same sites where cores of floor strata were taken for laboratory characterization. These studies were reported in the U.S. Bureau of Mines Open File Report (OFR 16-87) "In-Situ Strength Characteristics of Coal Mine Floor Strata in Illinois." "Mine 1" in OFR 16-87 represents the same mine as "mine 1" in this report. "Mine 2" in the OFR and "mine 3" in this report are two separate mines, although similar testing took place at each mine.

## Overall Approach

The research was subdivided into five parts: 1) review of pertinent literature and available data, 2) development of a computerized data base, 3) drilling and core sampling of immediate floor strata, 4) laboratory studies for determination of index properties and strength-deformation characteristics of core samples, and 5) statistical analysis.

Available information in the open literature on immediate floor strata associated with coal seams in Illinois was reviewed. A computerized data base was developed on an IBM/PC-XT microcomputer using the dBase III software. The data base consisted of five separate files; each file representing a set of properties of immediate floor strata. A computer program was developed for storage and retrieval of data. The variables selected for inclusion in these files were decided after discussions with several researchers knowledgeable in the field. Statistical analyses of the data were conducted using ASYST (statistical data analysis program) software.

NX-size continuous core sampling of immediate floor strata was done with a portable hydraulic drill at 18 locations in two active mines in Illinois. Drilling was done with compressed air using a diamond bit and a double-tube core barrel. The cores were logged for core recovery, rock quality designation (RQD), and natural fractures. The entire core was immediately wrapped in two layers of plastic to minimize loss of natural moisture. The cores were carefully boxed and transported to SIUC for laboratory studies. The weak underclay cores were carefully logged for lithology upon arrival in the laboratory. Index and strength-deformation properties were determined utilizing ASTM standards or procedures recognized by professional societies.

The data obtained on properties in this study were incorporated in the developed computerized data base. ASYST was used to perform descriptive statistics, and linear regression analysis.

Mining geometry at each drill site, along with any indications of weak-floor-related problems (heave, pillar sloughing at the bottom, pillar punching, etc.), were carefully noted. These observations will be eventually related to values of laboratory and field-determined properties of immediate floor strata.

Chapter II of this report presents a brief review of pertinent studies conducted in the past. Chapter III discusses experimental procedures utilized and data base development. Chapter IV presents results obtained in the study and Chapter V summarizes the study.

# II. REVIEW OF RELATED LITERATURE

## Introduction

Very few studies have been conducted that attempt to relate strength and deformation characteristics of underclays to their index properties. Research by Rockaway and Stephenson (1979) of underclay samples from a few mines in Illinois may represent the only available data in this area. Several other researchers have collected limited data on selected properties of underclay but have not attempted correlations among them.

The following sections 1) discuss the nature of underclays associated with Illinois Basin coal seams and 2) review pertinent studies on selected properties of underclays.

**Nature of Underclays**

The term "underclay" is commonly used to refer to claystones lying immediately beneath beds of coal. In Illinois, they are sometimes referred to as Pennsylvanian underclays. Grim and Allen (1938) described their lithology and occurrence in some depth. The following paragraphs were taken directly from their paper.

> "The material is usually grey, occasionally carbonaceous, occasionally calcareous, and varying from nongritty to distinctly sandy. It is particularly distinctive because of the presence of many small, discontinuous slickensided fracture surfaces along which the clay breaks readily. The slickensided fractures are limited to the clay and are not continuous into overlying or underlying beds. Underclays are generally unbedded and nonlaminated, although occurrences are known in which clay showing a layered character occurs with the underclays or in the position of underclay in the cyclothem. Underclays vary in thickness from less than a foot to about 20 feet.
>
> Many underclays contain fresh-water limestone either as continuous beds or as discontinuous nodular masses. The limestone usually has no fossils but at times contains forms indicating a fresh-water or brackish-water environment of accumulation.
>
> The relative position of the underclay with respect to the other sediments of the Pennsylvanian system is shown by the following typical sequence of beds in a Pennsylvanian cyclothem as given by Wanless and Weller (1932) and by Weller (1930).
>
> 8. Shale, containing "ironstone" bands in upper part and thin limestone layers in lower part
> 7. Limestone
> 6. Calcareous shale
> 5. Black "fissile" shale
> 4. Coal
> 3. Underclay, not uncommonly containing concretionary or bedded fresh-water limestone
> 2. Sandy and micaceous shale
> 1. Sandstone unconformity
>
> The succession of beds at any particular locality or in any particular cyclothem may be incomplete. Consequently, although underclays are usually immediately overlain by coal, they are occasionally overlain directly by another higher member of the cyclothem or by a member

of a succeeding cyclothem. The contact between the underclay and the underlying beds is at times gradational, whereas the contact with the overlying bed is usually sharp. The large areal extent of members of some cyclothems has been emphasized by Wanless and Weller (1932). The underclays may be grouped into (1) noncalcareous, and (2) calcareous or calcareous grading upward into noncalcareous. Underclays which are noncalcareous throughout are particularly prominent beneath coal No. 2 and older coals. They outcrop in northern, western, and southern Illinois around the margin of the Pennsylvanian outcrop area. In Grundy and La Salle Counties, northern Illinois, underclays of this kind are particularly well known. They are well known also in western Illinois where several noncalcareous underclays beneath the Seahorne limestone constitute the Cheltenham clay horizon near the base of the Pennsylvanian system. The clays are believed by Wanless (1931) to represent several cyclothems; members other than the clays being absent.

With few exceptions underclays beneath coals younger than coal No. 2 are calcareous or calcareous grading upward to noncalcareous. Such underclays outcrop in the central part of the coal basin in Illinois--in the eastern and central part of the State.

The available subsurface data suggest that the characteristics of the underclays shown at the outcrop are retained when the material is not exposed."

## Index Properties

**Particle size distribution** Particle size distribution may be used to 1) classify underclays, 2) determine their total clay content, and 3) predict their deformational behavior. Wilson (1965) found that the fine-grained underclays contained numerous slickensides. These provide easy paths along which movement and deformation can take place. Nelson (1947) thought that the occurrence of these irregular fractures or planes of weakness imparted "pseudo-plastic" properties to the underclay. Dulaney (1960) and White (1956) observed that moisture significantly reduced strength of an underclay when it had over 40 percent total clay content. White (1956) conducted grain size analysis of underclays obtained from different mines in Illinois. He found that for underclays below the Herrin (No. 6) coal member in the Lumaghi Coal Co. mine, the particle size of the samples taken from the squeeze area was generally smaller than those taken from nonsqueeze areas. The clay size fraction (2 microns or less) ranged from 20.4 to 35.1 percent for squeeze areas and 17.6 to 28.4 percent for nonsqueeze areas. The underclays contained considerable amounts of the expandable clay mineral, montmorillonite: but he pointed out that if total clay content was greater than 45 percent, the clay might be unstable regardless of the clay minerals present. Over the last five years, the author has determined total clay content for over 50 samples of underclay from Illinois coal mines and found the clay content to range between 20 and 50 percent. These data have been incorporated in the data base developed during this study.

**Specific gravity** Specific gravity of a rock depends on its mineral composition and the degree of compaction. The heavier the minerals present and the greater the degree of compaction, the higher the specific gravity. Specific gravity is a fundamental physical property and gives an idea about the likely mechanical response when the rock is stressed. Within the sedimentary rocks also, clays have generally a lower specific gravity (2.35 to 2.64) compared with harder rocks like sandstone (2.59 to 2.72) and limestone (2.68 to 2.84). Rockaway and Stephenson (1979) did not find a good correlation between the triaxial compressive strength of underclays at 300 psi confining stress and specific gravity. Very few other previous studies involved determination of the specific gravity.

**Clay mineral analysis** Kaolinite, illite, chlorite, and montmorillonite are the primary clay minerals usually present in underclays with the possibility of some mixed layers. Of these, montmorillonite has considerably more surface area along which slippage can take place. It can also absorb the largest amount of water and can significantly swell in the process.

Grim and Allen (1938) studied the petrology of the Pennsylvanian age underclays of Illinois. They determined the mineralogical composition, base-exchange capacity values, and textural characteristics. They differentiated between two types of underclays. The completely noncalcareous underclays generally occurring beneath No. 2 and older coals were composed largely of kaolinite. Different amounts of illite and quartz were also present in these underclays. The second type included calcareous underclays and those grading from noncalcareous to calcareous clays. These occurred beneath younger coals and contained illite as the major clay mineral constituent. Dulaney (1960) and White (1956) observed that moisture significantly reduced strength of an underclay when it contained 5 to 10 percent montmorillonite.

White (1954) pointed out that even small amounts of montmorillonite increased plastic behavior greatly out of proportion to their weight percentages. On the other hand, kaolinite, good crystalline illites and chlorite could generally be considered as stable. In another study, White (1956) found that montmorillonite was the dominant clay mineral (50 to 70 percent) in the clay fraction of the underclay in samples from squeeze areas and was less abundant (40 to 50 percent) in samples from nonsqueeze areas. Grim (1948) showed that montmorillonite produced sensitive clay even when it was present in small percentages (10 percent). Krishna and Whittaker (1973) and Ganow (1975) also considered the presence of montmorillonite to be important in defining strength properties of underclay.

Wilson (1965) studied the lithological and petrological characteristics of the underclays from South Wales in the United Kingdom. X-ray diffraction analysis was used to determine the clay mineralogy, and he found that the underclays of upper coal measures generally contained more chlorite and illite and less kaolinite than those of the lower and middle coal measures. No montmorillonite was found in both cases. The change from kaolinitic to illitic underclays was explained by a relatively drier climate favorable for formation of illite in the upper coal measures depositional period.

Rockaway and Stephenson (1979) analyzed clay mineral composition for several underclay samples associated with No. 6 and No. 5 coal members of Illinois. Though they could not establish any statistically significant relationship between clay mineralogy and underclay strength, several trends were discernible. Illite content was found to have the highest positive relationship ($r = 0.66$) with triaxial strength, whereas montmorillonite content had a negative relationship with strength ($r = -0.79$). Percentage of the mixed-layer minerals and kaolinite had apparently no relationship with strength values. The author conducted clay mineral analyses on over 100 samples of underclays from Illinois Basin mines. Except in three or four samples, no free montmorillonite was observed. Illite and kaolinite were the primary clay minerals observed. Mixed-layer content varied from 20 to 60 percent. These data have been incorporated in the computerized data base.

**Natural water content** Hall (1909) pointed out that the strength of underclays was reduced when acted upon by water and air. Therefore, there may be progressive deterioration of floor with time and the pillar failure in turn may also be time-dependent. White (1956) found that the underclay samples obtained from squeeze areas had generally a higher natural water content as compared to those obtained from nonsqueeze areas.

Dulaney (1960) observed that moisture significantly decreased strength of underclays containing over 40 percent total clay content. Rockaway and Stephenson (1979) found an association between water content and floor lithology. The water content was higher for the underclays compared with claystones and limestones. An increase in water content was also observed where a shear zone could be identified. A negative correlation coefficient between strength and water content was also observed for underclays and claystones with triaxial strength less than 400 psi.

The following equation best describes the relationship for samples from Zeigler mines:

$$r = 0.91, \log (TR300) = 4.01 - 0.175 (WC) \qquad (1)$$

where TR300 is triaxial compressive strength at a confining pressure of 300 psi, and WC is natural water content (percent), and r is correlation coefficient.

Speck (1981) reported that severe floor heave occurred at those sites where natural water contents of underclays and claystones were highest. In a recent study on highly anisotropic sediments of the Illinois Basin, Bauer (1984) also confirmed the negative relationship between strength and water content. For Energy Shale, he found the following relationship:

$$UCS = -66.3 (\log WC) + 71 \quad (2)$$

where UCS is normalized uniaxial compressive strength (MPa).

The author has also conducted several studies for Illinois mine operators that involved determination of the natural moisture content and unconfined compressive strength of underclays. His observations are very similar to those of Bauer (1984).

**Atterberg limits** Atterberg limits define water contents at which clay changes consistency. The two important limits are the plastic limit and the liquid limit and define respectively the moisture content at which a soil starts to behave plastically and like a liquid. These limits depend upon the soil texture, particle size distribution, total clay content, and clay minerals present in the soil or rock. Rockaway and Stephenson (1979) tried to correlate Atterberg limits and several parameters derived from these limits with triaxial strength. For samples from the River King mine, the most significant correlations existed between triaxial strength and plastic limit (PL), and triaxial strength and PL/WC (figure 2).

The following equations represent the best-fit lines:

$$r = 0.97, \ TR300 = 105 (PL) + 1090 (PL/WC) \quad (3)$$

and

$$r = 0.91, \ \log (TR300) = -1410 + 799 (PL/WC) \quad (4)$$

The author has also studied Atterberg limits of immediate floor materials but has not correlated them with their compressive strength. The data have been incorporated in the data base developed during this study. Atterberg limits provide information on the plastic behavior of immediate floor based on its natural moisture content and how the addition of water from any source may affect its behavior.

**Unconfined and confined compressive strength** Unconfined and confined compressive strengths are considered most important parameters, since these can be directly used to calculate ultimate bearing capacity based on soil mechanics principles. Unfortunately, the RQD of underclay cores is generally so low that samples with adequate L:D ratios cannot be obtained for compressive strength tests. Bieniawski (1983) suggested the use of integral sampling technique to get good samples of underclay cores.

Rockaway and Stephenson (1979) reported that the typical values of unconfined compressive strength for the floor rocks of No. 5 and 6 seams of Illinois coalfield might be taken as <400 psi for underclays, 800 to 1,000 psi for claystone, and 5,000 to 10,000 psi for limestones. Hunt, Bauer, and DuMontelle (1981) have reported an unconfined compressive strength for Illinois coal floors ranging from about 200 to 1200 psi based on records of the Illinois State Geological Survey rock mechanics data base.

The triaxial strengths determined by Rockaway and Stephenson (1979) and summarized in figure 3 varied widely (31 to 2267 psi). Lower values were thought to be more representative of underclays. Specimens with values of 800 psi or above might have contained limestone nodules or might have been claystone. Correlation of triaxial strength with index properties was attempted, and some of these attempts were discussed earlier.

The following additional relationship was developed involving four index properties:

$$r = 0.91, \qquad (5)$$

$$\log (TR300) = 1.27 + 0.260 (PL/WC) + 1.81 * 10^{-2} (PI)$$

$$-5.78 * 10^{-2} (WC) + 5.75 * 10^{-5} (PPARA)$$

where PPARA is P-wave velocity parallel to the bedding plane (inches per second).

**Tensile strength** If the floor consists of a hard layer lying above a softer layer, failure can occur because of buckling. The ultimate failure of the upper layers may be in tension, and the tensile and flexural strength of the hard layer then become important. Though there are several methods of 20 tensile strength determination, the Brazilian or indirect tension test is the simplest and most commonly used. This test allows the use of shorter samples which may not be suitable for compressive strength tests. For No. 5 and 6 coal seam underclays, Rockaway and Stephenson (1979) reported tensile strength values of 100 psi for underclays, 100 to 200 psi for claystones and 500 to 1400 psi for limestones. The tensile strength was found to have a good correlation with P-wave velocity parallel to the bedding plane.

**Ultrasonic velocity** Longitudinal or P-wave velocity tests have been used by many investigators to estimate strength, elastic properties, discontinuities, and internal structure of rocks. P-wave velocity is dependent on the density, elastic constants and continuity of the material. A higher velocity is indicative of a sound intact structure, whereas a lower velocity might indicate the presence of voids, fractures or other planes of weakness. Rockaway and Stephenson (1979) determined the P-wave velocity of underclay samples from No. 5 and 6 coal members of Illinois in directions parallel and perpendicular to the bedding plane. Velocities were found to have good correlation with tensile strength, water content, and secant modulus of elasticity at peak strength. As the P-wave velocity increased, tensile strength increased, but the expected Young's modulus and water content decreased. It was thought that a decrease in water content signified a high degree of consolidation of the geologic material, thereby resulting in an increase in the value of P-wave velocity. The ratio of P-wave velocity parallel and perpendicular to the bedding plane also provides information about the anisotropic properties of underclays.

## Conclusions

The above review led to the following conclusions:

The available information on the index properties of subcoal strata associated with Illinois coal seams is very limited.

Rockaway and Stephenson (1979) were the first to initiate studies relating index properties to strength of underclays. Their results were found to be applicable to particular mines only. A generalized equation with one or two index property variables did not give good coefficient of correlation, and the inclusion of more variables cast serious limitations on the utility of the equations.

Variation of index properties with depth below coal seam has not been studied to any large extent.

To obtain some meaningful correlations of a general nature, the data base must be considerably increased. Additional studies must be carried out for those index properties that have not been adequately studied.

A computerized data base including most of the index properties will be very helpful to the mining industry and may facilitate data analysis on a larger scale. Such a data base may lead to reasonably accurate predictions based on equations involving even a large number of variables.

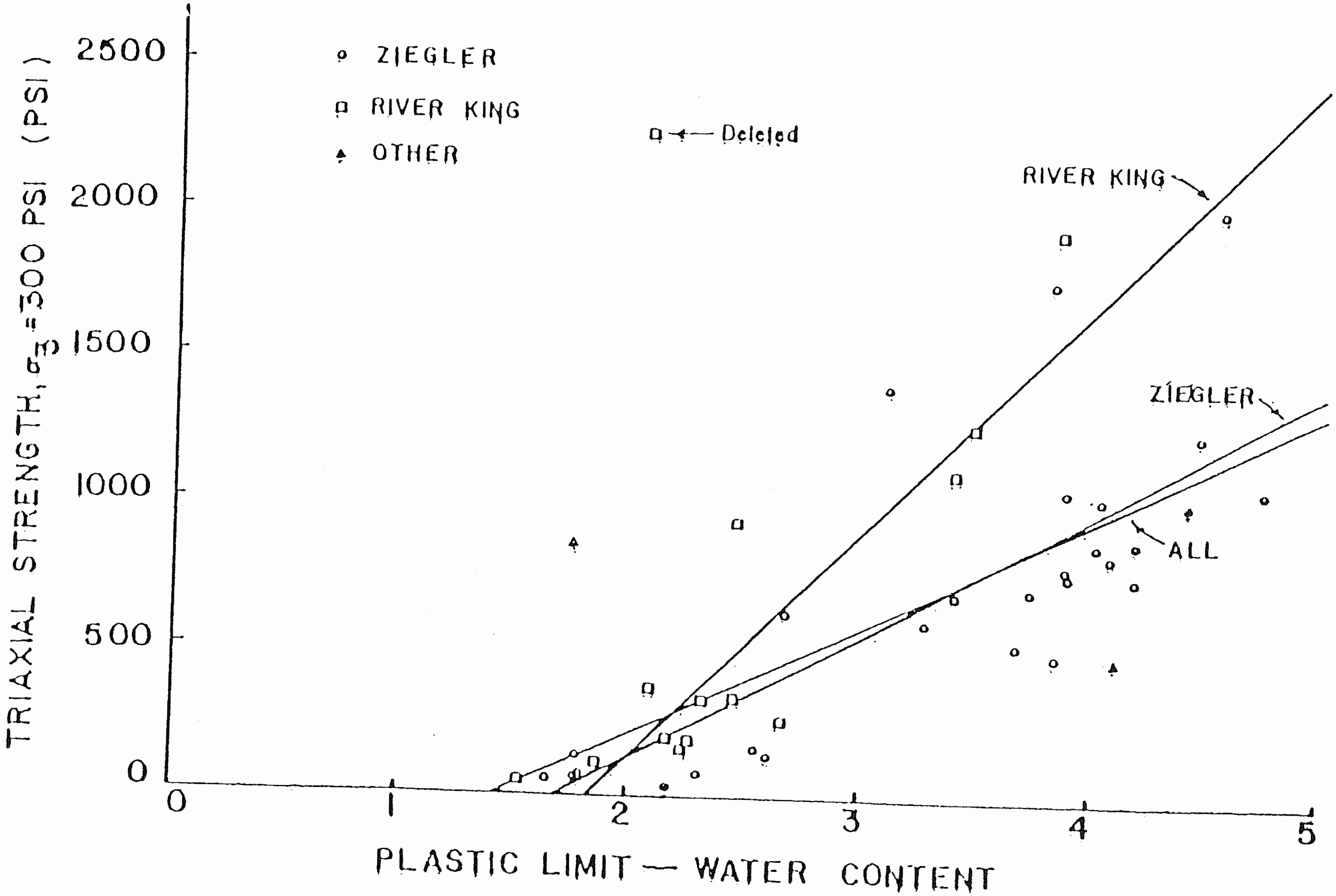


Figure 2. Variation of triaxial strength with plastic limit/water content (after Rockaway and Stephenson, 1979).

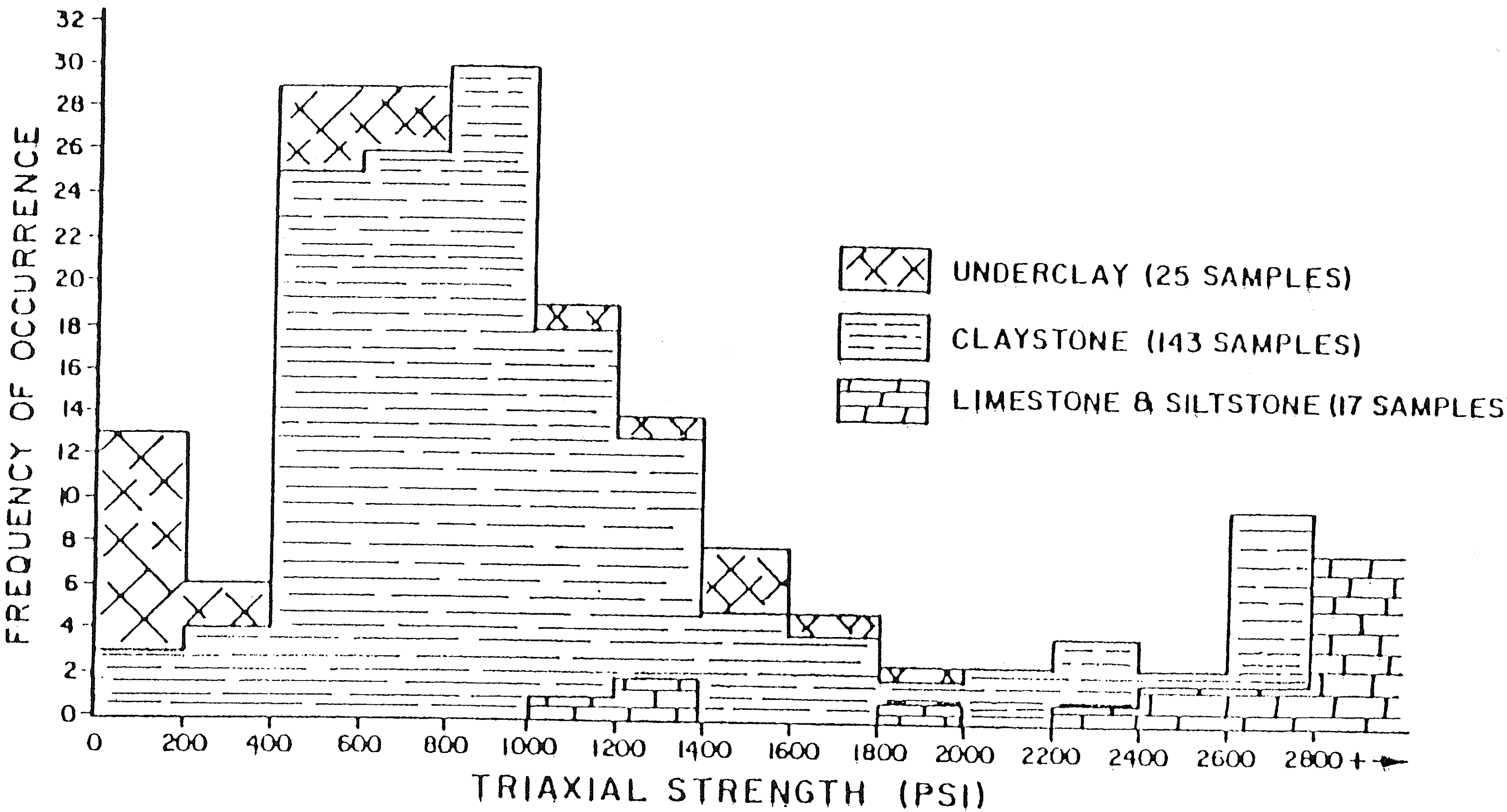


Figure 3. Distribution of triaxial strength values with respect to lithology; (185 samples), 1 PSI = 6895 PA, (Rockaway and Stephenson, 1979).

## III. GEOTECHNICAL STUDIES AND DATA BASE DEVELOPMENT

### Geotechnical Studies--An Overview

Detailed geotechnical studies for floor strata were conducted in two mines in Illinois: one located in southern Illinois (mine 1) and the other in central Illinois (mine 3). Mining depths for mine 1 and mine 3 were 950 feet and 250 feet respectively; both mined the Springfield (No. 5) coal member. Factors affecting selection of mines included willingness and support of the mining company management, and ground control problems associated with immediate floor strata. Ten sites in mine 1 and eight sites in mine 3 were core sampled for immediate floor strata: average sampling depths for mine 1 and mine 3 were 8 ft and 20 ft. For each drill site, two sampling sites were completed in close vicinity of each other (15 to 20 ft) so that there was adequate core for conducting all laboratory tests planned in this study. Sampling sites were generally decided by researchers in cooperation with mine management. The factors considered in site selection were mining plans, variation in underclay thickness, and the time period over which the area had been open after mining. Field observations on ground conditions at each sampling site were also made.

### Core Drilling and Sampling

Laboratory work in this study required samples of sufficient size and continuity for analysis. Cores were needed for unconfined and confined compressive strength and tensile strength tests. A portable hydraulic drill for core sampling was designed and fabricated by LEBCO, Inc., with input from the SIUC research staff. The hydraulic power from a scoop or a roofbolter is used by one ram and two motors of the drill. The ram forms the mast of the drill and secures or "stabs" the drill vertically against the floor and roof of the entry. One hydraulic motor mounted on the mast is used for drill stem rotation. Another hydraulic motor provides for the thrust or feed. Compressed air is utilized to blow cuttings out of the drill hole. Supporting equipment for the drill includes a large air compressor (approximately 100 CFM, at 40 to 60 psi) and a scoop or a roof bolter for hydraulic power. These were supplied by participating mines.

An NX-size double-tube core barrel was utilized in this study which permitted core sampling up to depths of 30 ft. The use of a double-tube core barrel significantly increased the speed of drilling. Both carbide and industrial diamond tipped bits were utilized with the double-tube core barrel. The finished diameter of the drilled hole was slightly greater than 3 in. This permitted measurement of in-place shearing strength using a borehole shear tester in the same hole. The maximum length of core obtainable in a single core run with the drill was approximately 13 in.

Each run of core was wrapped and sealed in 2-ft plastic bags to prevent moisture loss. A slip of paper inserted into every bag identified the mine, date of drilling, site number, and the position of the core in the hole, e.g., 24 to 48 in. below the coal seam. Basic lithologies, discontinuities, and sections of the missing core (blown out by air) were also included on these slips. Cores were shipped to the SIUC laboratory on the same day as they were obtained. A more detailed logging of the core for lithology was conducted in the laboratory before laboratory tests were carried out.

### Site Observations for Ground Control Problems

Observations on ground (roof, coal pillar, and floor) conditions were made at each site where floor sampling studies were conducted. This was done to assist in relating the laboratory strength properties of immediate floor strata to observed ground control problems, if any. A suitable form, shown in Table 1, was developed and completed at each site by researchers.

### Laboratory Studies

This section describes procedures for geotechnical studies on core samples, including lithologic descriptions, laboratory experimental procedures, and data analysis.

**Lithologic description** The core samples were carefully taken out of the wooden boxes and laid on a table and core was removed from the plastic tubing. Samples for moisture content, at approximately 6-in. intervals, were immediately removed. Care was taken to obtain these samples from the inner portions of the core and not from the surface of the core where moisture may have been lost. Photographs of the core were then taken. A log of the drill core was prepared. The field notes from the drilling and sampling crew were also incorporated in these descriptions. This included information such as loss of core, depth, date of drilling, top and bottom of cores, site number, and lithologic descriptions in some instances.

A detailed core description included relative wetness, relative weight density, presence of slickensides, limestone nodules, pyrite nodules, and general calcite content of the rock at different horizons. Natural tension cracks were distinguished from breakage due to drilling and photographed where appropriate. Lithologies were distinguished as shale, coal, underclay, or limestone. Horizons with fissile shale and granular nature of the strata--sometimes representing transition zones between rock types--were described. Rock quality designation (RQD) and core loss for each lithologic unit were noted. RQD was also calculated based on the length of the core run, which was approximately 12 in.

During the core description and rock classification process, core samples were separated out in plastic bags for different laboratory geotechnical tests.

Table 1. A form for conducting field observations at sampling sites.

| |
|---|
| Background information<br>Name of mine:<br>Location of mine:<br>Seam height:<br>Nature of roof:<br>Width of entries:<br>Size of the pillar:<br>Date of observation:<br>Person making observation:<br>Period for which area has been opened: |
| Presence of moisture<br>a. From roof strata<br>b. From coal pillar<br>c. From floor strata |
| Observed roof control problems (indicate slips, slickensides, joints, cracks in roof, roof falls in the vicinity, cracks along rib lines) |
| Observed floor control problems (indicate floor heave, amount of floor heave, approximate profile of heaved floor, position of cracks in the floor, preferred orientation of floor heave if any) |
| Observed coal pillar problems (indicate rib spalling; indicate whether it is at the top, middle, or bottom; pillar punching if any, signs of differential pillar settlement, major cracks in pillars) |
| Additional Comments |

**Test procedures** Several tests utilized either standard ASTM procedures or procedures outlined by the International Society for Rock Mechanics (ISRM) as listed below. Natural moisture content, grain size analysis, specific gravity, Atterberg limits, indirect tensile strength, and slake durability tests were conducted precisely according to the standards specified and are therefore not discussed any further.

| Type of test | Standard utilized |
|---|---|
| Natural moisture content | ASTM D2216 |
| Particle size analysis | ASTM D422, D-1140 |
| Specific gravity | ASTM D854 |
| Atterberg limits | ASTM D4318 |
| Unconfined compressive strength | ASTM D2938 |
| Confined compressive strength | ASTM D2664 |
| Indirect tensile strength | ASTM D3967 |
| Swelling strain index | ISRM, Brown (1978) |
| Slake durability | ISRM, Brown (1978) |

The other tests were slightly modified and pertinent comments on each are summarized below.

Unconfined swelling strain test. The unconfined swelling strain test was performed on core samples to measure the strains developed when the sample is immersed in water. The samples for this test were prepared in a manner similar to those prepared for unconfined compression test with end faces parallel and perpendicular to the axis. For some chunk floor samples obtained throughout the mine, an alternative procedure was adopted. Largest possible cubes were cut out of the chunk samples and ends were ground parallel. The main precaution observed in preparing these cubical samples was to have a set of faces approximately parallel and perpendicular to the natural bedding plane. Chunk samples represented immediate floor strata to a depth of 12 in.

Experimental procedures recommended by ISRM (Brown, 1978) and later modified by Chugh, Okunola, and Hall (1981) were utilized for measurement of unconfined swelling strain. Earlier studies using the test procedures recommended by the ISRM revealed two problems. One problem was formation of cracks around the glass slide glued to the specimen. Second, swelling strain was being measured over a small area in the center, which was not undergoing as much swelling as the surrounding area because of a coating of glue. The ISRM-recommended test procedure for measuring unconfined swelling strain was modified as follows (Chugh, Okunola, and Hall 1981):

> "Bonding glass slides with cement or glue was completely eliminated. Instead, a thin aluminum disc perforated with a large number of small holes and of the same size and shape as the specimen, was placed on the upper and lower faces of the specimen. The swelling strains were measured across the faces of aluminum discs using dial gages capable of reading

to within 0.001 in. This permitted the entire specimen surface to be exposed to an ambient environment and the measured swelling strains represented average strains over the entire surface."

These simple modifications proved very successful, and the procedure was utilized for all tests in this study.

Clay mineralogy. This analysis was performed mostly on the underclay specimens to analyze amounts of clay constituents such as illite, chlorite, kaolinite, smectite, mixed layers, and smectite-to-illite ratio. The data were obtained using standard X-ray diffraction techniques. The total clay in the sample was also determined using ASTM procedure D 422-63. These analyses were done by the Department of Geology at SIUC.

Point Load Index. This index may be used to calculate approximate values of unconfined compressive strength. This method is simple, rapid and inexpensive, and irregular or roughly cut rock lumps (1- to 4-in. size) may be used as samples. The point load test consists of applying compressive load to a test sample through two standard conical shaped platens until failure. The point-load strength index, as defined by the International Society for Rock Mechanics, is then computed using the following formula:

$$Rs = \frac{P}{D^2} \tag{6}$$

where P is force required to cause splitting of sample (pounds), D is original distance between the points of loading (inches), and Rs is point load strength index (pounds per square inch).

Rs values may be multiplied by an experimentally-determined multiplication factor for NX-size cores to estimate unconfined compressive strength. However, this factor may vary somewhat from region to region. Rs may be determined for loading along (diametral) or across (axial) the bedding planes. The multiplication factors for loading along and across the bedding planes are different. Bauer (1984) observed that for highly anisotropic sedimentary rocks from Illinois Coal Basin, axial point load index determined by the T500 index correlated well with the unconfined compressive strength.

Density. The density or "unit weight" of a rock is its specific weight and is measured in pounds per cubic foot. The dry density of a rock may be calculated from its wet density from the following relationship:

$$\gamma dry = \frac{\gamma wet}{1 + W} \tag{7}$$

where w represents the water content of rock on a dry weight basis.

The density of rock as presented in this report is the $\gamma_{wet}$ value and was calculated by weighing a cylindrical sample to the nearest 0.01 g. and dividing it by the volume of the specimen.

Unconfined and Confined Compressive Strength Tests. In compressive strength tests, axial and lateral deformations were monitored using linear variable differential transformers (LVDT). In general, six LVDTs (three axial and three lateral) were utilized to monitor deformations. The average of the three LVDT values was used to calculate deformation moduli as defined in Appendix A.

Confined compressive strength tests were conducted in a 10,000-psi triaxial cell at three confining stresses: 100, 300, and 500 psi. Axial and lateral deformations were monitored using LVDTs mounted externally: three axial and three lateral LVDTs were most commonly utilized. Deformation moduli were computed taking into account the confining stress. Shrink tubing was utilized for jacketing the samples. Mohr circle plots were prepared and cohesive strength was estimated on the basis of confined compressive strength tests only and an assumed linear failure envelope.

**Development of a Computerized Data Base for Geotechnical Properties**

One objective of this study was to develop a computerized management information system for available geotechnical properties data related to immediate roof and floor strata and coal seams. The developed data base will eventually allow compilation of all data on geotechnical properties.

This computerized data base was developed on an IBM-PC/XT micro-computer using the dBase III software. Before the data base was created, different variables were listed that could possibly be used by any mine operator for a variety of different purposes, such as planning and design of ground control activities, permitting, and research. This list was extremely large, so the variables were subdivided into five basic categories (table 2):

(1) General and geological information,
(2) Engineering index properties,
(3) In situ strength-deformation properties,
(4) Laboratory strength-deformation properties, and
(5) Clay mineralogy

Variables in each category constitute a separate file.

Since index and laboratory strength properties were to be determined at different depths below the coal seam in a single borehole, forming a single table of all the variables would have involved a lot of common information that would unnecessarily use up computer memory. Therefore, in the developed data base, the first file has most of the common information associated with each data set. The remaining variables were subdivided into four files for data inputting purposes. Internally, however, the computer has only two major files: one with general and geological information and the other with the remaining four files.

The developed data base permits data retrieval within the limits of certain coordinates, for a mine or for a region, or for a single borehole. This approach best suits the purposes of a mine operator. Data may be retrieved only for selected or for a group of properties. User-friendly programs were developed to facilitate the job of inputting or updating the data base. Editing of the data base, preparing files for analysis using another microcomputer software package ASYST, and backing up of borehole data has been entirely automated. A menu format developed during the study guides the user through data analysis with the ASYST package. It is expected that the developed data base can be expanded in the future to include data from all mines in Illinois.

**Linkage of Data Base to ASYST**

This intermediate step is simply a means to create files that can be used by ASYST for data analysis. A separate program in dBase III was written to handle this aspect, because the files in dBase III could not be used without modification for data analysis with ASYST (Henderson and Dhawan, 1985). The program does not in any way limit the versatility of creating a file that will contain the desired data. Thus, one could create a file, for analysis purposes, that includes data for a limited number of boreholes, including depth and even lithology or data values.

**Data Analysis Procedures**

The prepared files from dBase III can be conveniently used for both numerical and graphical data analysis. Numerical analysis includes simple linear regression and multiple regression analysis, non-linear regression, correlations, developing confidence intervals, computing means and standard deviations and many other useful statistical analyses. Graphical data analysis procedures include drawing bar charts, pie charts, and other X-Y plots to study trends and relationships.

In this study, all laboratory test data from mines 1 and 3 (except compressive strength, point load index, and swelling strain) were entered into the mainframe computer at SIUC. The Statistical Analysis System (SAS) package (Ray et al., 1982) was used for data analysis. The correlation matrix for the set of variables was generated both for overall data at a mine and by sites. Sitewise correlation matrices

Table 2. Variables in different files.

| 1. General and geological information | 2. Engineering index properties | 3. In situ strength-deformation properties |
|---|---|---|
| Borehole number or ID number<br>State<br>County<br>X and Y coordinates<br>Name of mine<br>Date of sampling<br>Depth of sampling<br>Nature of sampling<br>Coal seam number<br>Nonbedrock thickness<br>Bedrock thickness<br>Coal seam thickness<br>Underclay thickness<br>Depth of coring below seam<br>Stratigraphic description<br>Description of underclay<br>Elevation of top of borehole<br>Source of data | Borehole number or ID number<br>Depth of sample<br>Rock type<br>Density of sample<br>Moisture content<br>Sand content<br>Clay content<br>Silt content<br>Clay and silt content<br>Coarse fragments (>2mm)<br>Liquid limit<br>Plastic limit<br>Plasticity index<br>Shrinkage limit<br>Unified soil classification<br>Grain size analysis results | Borehole number or ID number<br>Depth of sampling<br>Test number<br>Rock type<br>Plate shape and size<br>Bearing capacity<br>Applied pressure<br>Borehole shear strength<br>Cohesive strength<br>Angle of internal friction |

| 4. Laboratory strength-deformation properties | 4. Continued. | 5. Clay mineralogy |
|---|---|---|
| Borehole number or ID number<br>Depth of sampling<br>Rock type<br>Shape of sample<br>Length of sample<br>Width of sample<br>Height of sample<br>Length to diameter ratio<br>Compressive strength<br>Adjusted compressive strength<br>Code for confined or unconfined compressive strength<br>Confining stress<br>Failure strain<br>Stress-strain data availability<br>Drained or undrained test<br>Angle of internal friction | Applied normal stress<br>Tensile strength<br>Code for direct or indirect tensile strength<br>Slake durability (single cycle)<br>Slake durability (double cycle)<br>Residual strength<br>Maximum displacement at failure<br>Swelling strain<br>Direct shear strength | Borehole number or ID number<br>Depth of sampling<br>Rock type<br>Illite content<br>Kaolinite content<br>Smectite content<br>Mixed-layer content<br>Ratio of smectite to illite in mixed-layer<br>Chlorite content<br>Total clay content |

were used to judge the consistency of relationships. Overall vertical and horizontal bar charts were also drawn to study the distribution of data. After the correlation matrices and bar charts were studied, simple linear regression analyses were conducted on highly correlated variables.

## IV. RESULTS AND DISCUSSION

### Lithologic Description of Floor Strata

Mine 1

A lithologic log from a site is presented in Figure 4; similar descriptions for other cores are included in Appendix C. The immediate floor stratum is generally grey shale with varying amounts of calcite content: underclay is generally absent or very thin (less than 12 in.). Generally, the shale is highly slickensided within the first 20-30 in. below the coal seam, and RQD values are generally less than 20 percent in this zone. In several cases grey shale is underlain by interbedded limestone, calcareous shale, sandy shale or sandstone. RQD values in the lower portions of the floor strata (below 30 in.) are generally much higher (>80%), although thin zones (6-10 in.) of very low RQD values are commonly encountered. In a few holes, presence of water was encountered at depths ranging from 3 to 8 ft.

Mine 3

Figure 5 shows a lithologic log of immediate floor strata from a site: similar logs from other sampling sites are included in Appendix C. Underclay thickness in this mine varied from 3 to 7 ft. at sampling sites. The underclay is generally underlain by interbedded mudstone, claystone, and silty or sandy shale. Limestone nodules varying in size from 0.25 to 2.0 in. in diameter are commonly encountered and generally increase in size and quantity with increasing depth below the coal seam. Generally, the underclay is highly slickensided, up to 60 in. below the coal seam: RQD values in this zone are generally less than 20%. Below a depth of 60 in., RQD values increase somewhat but are still less than 50 percent in most cases. Water at about 10 psi was encountered in most of the boreholes at a depth of 23 to 27 feet. Water pressure was estimated by the distance that the water rose in a borehole from the depth at which it was intercepted.

### Particle Size Distribution

Mine 1

Data for all sites and at different depths for each site are presented in table 3. Mean and standard deviation values for each size fraction are also presented in the table. Plots of data for two samples from different sites are shown in figures 6 and 7. Particle size distribution data for all samples at 0 to 3 ft and over 3 ft below the coal seam were plotted on the standard textural classification for soils charts and are shown in figure 8. Some comments are:

1) Total clay size particle content (<0.005 mm) varies considerably from site to site and at different depths. Mean and standard deviation values for these variables were 29.9 and 11.9 percent, based on data from all sites.

2) Total clay size particle content is generally higher in the immediate floor up to about 30 in. below the coal seam. Below this depth, total clay content is relatively constant or decreases slightly with depth.

3) Total silt content (0.005 to 0.074 mm) constitutes about 50 percent of the total sample in most cases.

4) Over 80 percent of the samples in the 0- to 3-ft depth range may be classified as silty clay or clay silty loam (figure 8).

5) Most of the samples in the 3- to 10-ft depth range below the coal seam may be designated as loam and sandy loam.

6) For 39 samples from this mine, a statistically significant negative correlation ($r = -0.505$) was observed between total clay size particle content and depth below the coal seam. The equation of the linear line is given by:

$$Y = 32.84 - 0.166\ X \tag{8}$$

where Y is total clay content (percent), and X is depth below the coal seam (inches).

## Mine 3

Particle size distribution data for samples from this mine are summarized in table 4; 48 samples were studied.

1) Clay and silt size particles constitute over 90 percent of the sample except in three samples. Particle size distribution curves for two samples are shown in figures 9 and 10.

2) Average values of total clay and total silt content vary from site to site and at different depths. The average values of these variables, based on all samples, were 43.8 and 52.2 percent.

3) Total clay particle size content is generally higher in the upper portions of the immediate floor. However, in several boreholes, layers of high clay content were also observed at greater depths.

4) Particle size distribution data for samples at 0-3 ft and over 3 ft below the coal seam were plotted on the standard textural classification for soils and are shown in figure 12. Almost all samples in the 0- to 3-ft range may be classified as clay or silty clay.

5) Samples below a 3-ft depth may be classified as silty clay, silty clay loam, or silt loam.

6) Based on 48 samples from this mine, there appears to be a negative correlation ($r = -0.341$) between the total clay content and depth below the coal seam. The equation of the line is given by:

$$Y = 49.64 - 0.054X \tag{9}$$

where Y is total clay content (percent), and X is depth below coal seam (inches).

**Apparent Specific Gravity**

Mine 1

Specific gravity data for different samples from various sites are summarized in table 5. On the basis of 55 observation points, the mean and standard deviation values for this variable are 2.676 and 0.0828. Linear regression of the specific gravity data with depth gave an equation of the form below:

$$Y = 2.647 + 0.000846X \tag{10}$$

where Y is specific gravity at any depth, and X is depth below the coal seam (inches).

Equation 10 implies a slight increase in specific gravity with increasing depth. The correlation coefficient for this regression was 0.2747, which is significant for 95 percent confidence level.

Mine 3

Specific gravity data for eight sites from mine 3 are summarized in table 6. No correlation was observed for variation of apparent specific gravity with depth below the coal seam based on a total of 53 observations. Mean values of specific gravity and standard deviation were determined to be 2.7505 and 0.11 based on all samples.

**Clay Mineral Composition**

Mine 1

Semiquantitative data for various samples from 10 different sites and at various depths are presented in table 7. Histogram plots of selected variables are included in Appendix C.

1) In the clay content of the immediate floor strata, average illite, kaolinite, and mixed-layer clay contents based on all samples were 43.3, 30.1, and 25.8 percent.

2) Illite and kaolinite are the primary clay minerals constituting over 70 percent of the total clay in most cases. Mixed layers constitute the remainder of the clay mineral fraction. No free smectite and only traces of chlorite clay minerals were observed.

3) Mixed-layer clays tend to decrease with increasing depth below the coal seam, and there appears to be a significant correlation ($r = -0.249$) between the two variables (table 8).

4) No significant correlation was observed for variation of illite clay mineral with depth below the coal seam. Similar correlation for kaolinite clay mineral was also not significant.

5) Kaolinite content varies much more widely than illite.

6) Significant correlations were found between natural moisture and kaolinite content ($r = -0.449$) and natural moisture and mixed-layer contents ($r = 0.494$) (table 8).

<u>Mine 3</u>

Similar data for mine 3 are presented in table 9 and Appendix C.

1) Average illite, kaolinite, and mixed-layer contents for the mine, based on all samples, were 36.7, 23.4, and 40.5 percent.

2) Illite and kaolinite clay minerals constitute about 60 percent of the total in most cases. Chlorite was found only in two samples. No free smectite was observed in any sample.

3) Illite, kaolinite, and mixed-layer clay mineral contents vary much more at this mine compared with mine 1.

4) Illite content appears to increase, whereas mixed layers tend to decrease with increasing depth below the coal seam. These relationships are statistically significant (table 8).

5) Natural moisture content tends to increase with increasing mixed-layer content.

## Natural Moisture Content and Atterberg Limits

<u>Mine 1</u>

Atterberg limits and natural moisture content data for samples at different depths are presented in table 10. Histogram plots of selected variables are presented in Appendix C. The results of selected correlation tests between different variables are summarized in table 11. Atterberg limits data plotted on the Casagrande's plasticity chart are shown in figure 12. Some important observations are given below.

1) Atterberg limits appear to vary randomly with changes in depth below the coal seam.

2) Natural moisture content tends to decrease with increasing depth below the coal seam and there appears to be a highly significant correlation between them (table 11).

3) A strong correlation was observed between total clay size particles and natural moisture content and total clay size particles and plastic limit (table 11). This observation is important, since natural moisture content is very easily determined compared with plastic limit or total clay size particle content. These correlations will be investigated eventually on data from all mines.

4) Natural moisture content also appears to be correlated with liquid limit and plasticity index.

5) Almost all of the samples may be classified in the M, CL-ML, and CL ranges based on the Unified Soil Classification System. Most of the samples within 3 ft of the coal seam are CL, whereas samples below 3 ft are M or CL-ML.

<u>Mine 3</u>

Similar data for mine 3 are summarized in table 12 and Appendix C. Results of selected correlation tests between different variables are presented in table 11. Atterberg limits data plotted on the plasticity chart for mine 3 are also shown in figure 12.

1) Plastic and liquid limits appear to decrease with depth (table 11).

2) Natural moisture content tends to decrease with depth below the coal seam, and there is a significant correlation between them. A more appropriate relationship is stair-step. The natural moisture content is approximately constant up to about 55 in. below the coal seam. Below this depth, there is a sudden decrease in moisture content, but again it is relatively constant.

3) Moisture content appears to be linearly correlated with plastic limit, liquid limit, and plasticity index.

4) About 50 percent of the samples may be classified as CL and the other 50 percent as CH, based on the Unified Soil Classification System.

5) Most of the samples in the 0- to 3-ft depth range can be classified as CH, whereas most of samples below 3 ft are classified as CL.

6) Correlations were not significant between moisture content and total clay size particles and plastic limit and total clay size particles.

## Indirect Tensile Strength

Data for selected samples from mine 1 and mine 3 are presented in tables 10 and 12. On the basis of limited available data, tensile strength for immediate floor strata in mine 1 was considerably higher than in mine 3. In both mines, tensile strength values appear to increase with increasing depth below the coal seam.

## Point Load Index

Point load index was determined for samples from mine 3 only, since the RQD of core samples was very low (generally less than 30 percent), and reasonable L:D ratio samples could not be obtained for compressive strength tests. The index was determined only for compressive load applied across the bedding planes (axial point load test). Values of the index for selected samples are presented in table 12.

## Unconfined and Confined Compression Tests

### Mine 1

Data on unconfined and confined compression strength for samples from various sites are summarized in table 13. Mohr circle diagrams for two sets of samples are shown in figure 13. Similar diagrams for samples from other sites are included in Appendix C. Cohesive strength values ranged from 900 to 1700 psi, and angle of internal friction ranged from 45 to 60 degrees. Axial modulus of deformation and lateral deformation ratio, as defined in Appendix A, ranged from (0.42 to 1.33) x $10^6$ psi and 0.13 to 1.19 at 50 percent of the ultimate failure stress.

A correlation was investigated for linear relationship between unconfined compressive strength and ratio of plastic limit to natural moisture content for samples at depths in the 0- to 3-ft depth range below the coal seam and classified as silty clay (figure 8) based on the textural classification system. Linear regression line ($r = 0.76$) and 95 percent confidence intervals are shown in figure 14. The equation of the best-fit line is given by:

$$Y = -104 + 956\ PL/WC \tag{11}$$

where Y is unconfined compressive strength (psi x 1000).

Mine 3

Similar data for mine 3 are summarized in table 14. Mohr circle diagrams for two sets of samples are presented in figure 15. Additional diagrams for sets of samples from other sites are included in Appendix C. Undrained cohesion and angle of internal friction values ranged from 800 to 1842 psi and 35 to 36 degrees. Mean and standard deviation values for axial deformation modulus at 50 percent of the failure stress were $0.963 \times 10^6$ and $0.292 \times 10^6$ psi. Similar values of lateral deformation ratio could not be obtained, because the LVDTs malfunctioned. No correlation was observed between the intact sample axial deformation modulus and depth below the coal seam.

Since unconfined compressive strength data was limited, an attempt was made to correlate axial point load index with PL/WC ratio for samples within 0 to 6 ft. below the coal seam and with clay or silty-clay texture (figure 12). Linear regression line ($r = 0.50$) and 95 percent confidence intervals are shown in figure 16. The equation of the best-fit line is given by

$$Y = 6.11 + 85.99(PL/WC) \tag{12}$$

where Y is point load index (psi).

Points lying beyond $\pm\ 2\sigma$ (standard deviation) were deleted in the analysis. The outlying points are primarily due to the presence of limestone nodules.

## Field Observations of Geotechnical Problems at Sampling Site

Results of observations for mine 1 and mine 3 are summarized in tables 15 and 16. Some pertinent comments are given below.

1) Most of the sampling sites had been mined less than 4 weeks before observations. Therefore, observed ground conditions may not represent a long-term condition. Similar observations should be conducted later at these sites at regular intervals to determine progressive changes in ground conditions and their relationship to the nature of immediate roof and floor strata and coal.

2) The ground conditions observed in mine 1 are probably related to the weakness of immediate roof strata.

3) Slight floor heave and other observed ground conditions in mine 3 appear to be related mostly to weak floor strata and presence of water, and to a lesser extent to immediate roof strata.

**Analysis of Geotechnical Property Data from the Developed Data Base**

The computerized data base developed during the study was used to conduct descriptive statistics and linear regression analyses with the ASYST software package. Geotechnical properties for roof and floor strata associated with the coal seam and coal seam itself are included in the data analyzed here. Selected bar charts for natural moisture content, adjusted unconfined compressive strength for L:D = 1, illite, kaolinite, and mixed-layer clays are shown in figures 17 to 19.

Additional analyses for specific lithologies will be conducted in future years after supplemental data have been incorporated in the data base.

## V. SUMMARY

This report presents results of laboratory studies conducted on immediate floor strata samples from two underground coal mines in Illinois. Data on engineering index properties and strength-deformation properties of immediate floor strata are developed in this study. These can be utilized by mine operators to estimate in-place strength (bearing capacity) and deformation characteristics of immediate floor strata. The data are required for an effective design of mine workings (mine openings and coal pillars) for optimum mine stability and resource extraction. The results of this study should also benefit agricultural industry operators in Illinois to minimize loss of agricultural productivity on prime farmland after mining.

Eighteen 2 1/8-in. diameter corings were made in two active mines in Illinois to study floor lithology and to obtain core samples of the underclay and 1 to 2 ft of the competent stratum below it. Core samples at different depths were studied for natural moisture content, grain size analysis, Atterberg limits, clay mineralogy, total clay size particle content, and unconfined and confined compressive strength. Analysis included statistical correlation of strength characteristics of immediate floor strata with their engineering index properties. In addition to laboratory studies, field observations of ground conditions and ground behavior at sampling sites were also made and their results are included in this report.

A computerized data base of available and project generated engineering index properties and laboratory or field determined strength-deformation characteristics of immediate floor strata was developed on an IBM-PC/XT microcomputer. The developed data base has been interfaced with the ASYST software package for statistical analysis. Limited analysis of data was conducted in the present study, and results are included in the report. More detailed analyses are planned in the future after all data have been incorporated in the data base. The data base will eventually be made available to Illinois mine operators upon request.

Some of the more important results of this study are summarized below.

1) Good lithologic and geotechnical descriptions of immediate floor strata can aid in assessing ground stability problems due to weak floor. In Illinois, evaluation of immediate floor strata is as important as evaluation of immediate roof strata.

2) On the basis of limited analyses of laboratory properties data from two mines, the following correlations appear significant:

   (a) Natural moisture and total clay contents
   (b) Natural moisture content and depth below the coal seam
   (c) Unconfined compressive strength and natural moisture content
   (d) Unconfined compressive strength or point load index and ratio of plastic limit to natural moisture content for specific rock types
   (e) Depth below the coal seam and mixed-layer clay content
   (f) Natural moisture content and mixed-layer content
   (g) Natural moisture content and plastic limit
   (h) Natural moisture content and plasticity index
   (i) Natural moisture content and liquid limit
   (j) Total clay content and depth below the coal seam.

3) Textural classification for soils and plasticity chart may be used to classify immediate floor strata.

4) Localized confined aquifers may be present in the immediate floor strata which may affect ground stability. Mine operators should be urged to obtain cores of immediate floor strata during exploration to a depth of at least 20 ft below the coal seam. Where appropriate, injection tests may be required so as to obtain data on water pressure and quantity.

5) Field observations made in this study of ground control problems due to weak floor should be considered only as base line data, since most of the sampling sites had been mined less than 4 weeks before observations were made. Similar observations and some measurements should be planned at regular intervals for the next 2 to 3 years to delineate progressive change in ground conditions and role of weak floor in causing these changes.

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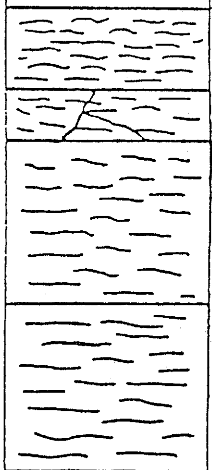
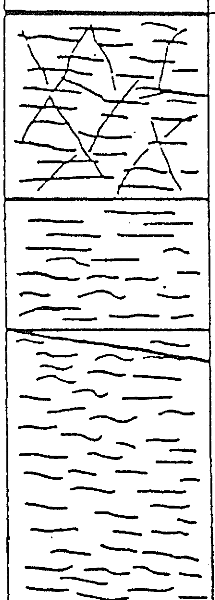
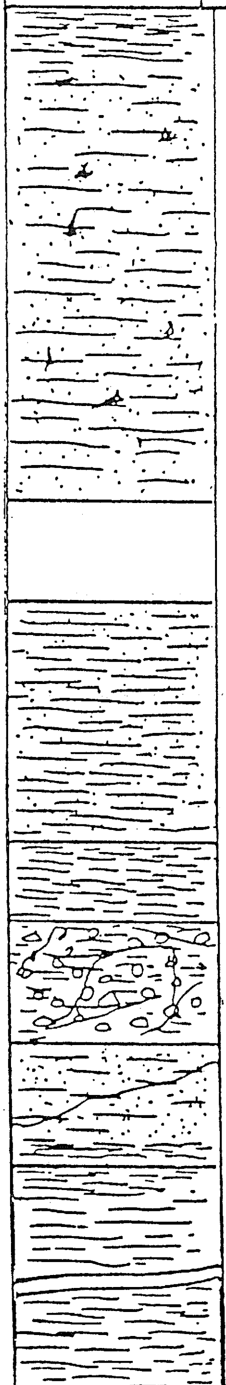
Figure 4. Lithologic description for site 1 and 2 (mine 1).

| Core Log | Depth (in) | Core Description | RQD (%) Lithologic Unit | RQD (%) (Core Run) |
|---|---|---|---|---|
|  | 0 | Hard grey shale, no calcite present. | 0 | 7 |
| | 5 | Grey shale, tension fractures. No slickensides. | 0 | |
| | 8 | Hard grey shale, no calcite present. | 21 | |
| | 18 | Grey shale, no calcite present. Slickensides present between 18 in to 19.5 in. | 48 | 35 |
| | 28 | | | |
| | | Site #2 | | |
|  | 0 | Grey shale. No calcite present. Tension fracture. Black shale nodules. | 0 | 8 |
| | 11 | Grey shale. No calcite present. | 100 | 80 |
| | 19 | Grey shale. No calcite present. Slickensides present between 19 in to 21 in. | 53 | 53 |
| | 36 | | | |

Scale 1 in = 12 in

Figure 5. Lithologic description for site 6 (mine 3).



| Core Log | Depth (in) | Core Description | RQD (%) Lithologic Unit | RQD (%) (Core Run) |
|---|---|---|---|---|
| | | Moist limey grey underclay. Calcite content decreases with depth. Few slickensides found. The first few inches of core is shaly. Most of the cores were cracked and broken along bedding planes. Some pyrite nodules found. 3 in core lost. | 17 | 17<br>17<br>17<br>17<br>17 |
| | 60 | Core lost. | | |
| | 72 | Light grey shaly underclay. Probably representing transition to shale. Lime present. Has relatively less moisture, but more dense. Lime decreases to zero at bottom. | 33 | 33<br>33 |
| | 101 | Light grey shale with no calcite. High density and competent. | | 33 |
| | 110 | Wet mudstone. Black in color. Calcite present. Pyrite found along broken sufaces. Small slickensides. | 40 | 37 |
| | 126 | Underclay of lesser density with distinct slickensides across the cores. Pyrite nodules. Bottom portions shaly. | 60 | 48<br>60 |
| | 141 | Grey shale (probably transition). Becomes denser with depth. Quartz grains found towards bottom. Bottom part is denser, but broken. Pyrite patches present; which become less with increasing depth. Bottom two inches more competent shale. | 41 | 41<br>41 |
| | 175 | | | |

Scale 1 in = 24 in

Table 3. Particle size distribution data (mine 1).

| Site no. | Depth (in)* | Percent finer by weight | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Size (mm) | | | | | | | | | | | | | |
| | | 0.0015 | 0.002 | 0.003 | 0.005 | 0.007 | 0.009 | 0.010 | 0.020 | 0.040 | 0.074 | 0.105 | 0.125 | 0.250 | 0.425 |
| 1 | 9.0 | 12.2 | 14.8 | 19.8 | 28.4 | 34.1 | 39.8 | 42.9 | 59.3 | 79.5 | 97.6 | 98.9 | 99.1 | 99.6 | 100.0 |
| | 26.0 | 11.9 | 13.6 | 17.9 | 25.6 | 32.2 | 38.4 | 40.6 | 59.2 | 79.5 | 96.7 | 98.6 | 98.7 | 99.5 | 100.0 |
| MEAN | | 12.0 | 14.2 | 18.9 | 27.0 | 33.2 | 39.1 | 41.7 | 59.3 | 79.5 | 97.1 | 98.8 | 98.9 | 98.9 | 100.0 |
| STANDARD DV | | 0.21 | 0.91 | 1.35 | 1.96 | 1.40 | 1.05 | 1.60 | 0.06 | 0.0 | 0.64 | 0.25 | 0.27 | 0.06 | 0.0 |
| 2 | 4.0 | 12.2 | 14.3 | 18.7 | 27.4 | 34.0 | 40.6 | 42.9 | 60.1 | 80.4 | 96.4 | 97.9 | 98.6 | 99.2 | 100.0 |
| | 15.5 | 12.3 | 14.5 | 19.3 | 27.8 | 34.1 | 39.5 | 42.1 | 62.4 | 81.0 | 96.5 | 97.2 | 97.3 | 98.1 | 100.0 |
| MEAN | | 12.3 | 14.4 | 19.0 | 27.6 | 34.1 | 40.0 | 42.5 | 61.2 | 80.7 | 96.5 | 97.5 | 97.9 | 98.6 | 100.0 |
| STANDARD DV | | 0.12 | 0.21 | 0.46 | 0.31 | 0.09 | 0.80 | 0.53 | 1.63 | 0.44 | 0.09 | 0.51 | 0.90 | 0.77 | 0.0 |
| 3 | 1.0 | 13.9 | 17.0 | 23.5 | 36.9 | 45.4 | 54.1 | 57.0 | 73.7 | 85.0 | 83.7 | 85.4 | 86.4 | 92.1 | 100.0 |
| | 30.5 | 15.0 | 19.1 | 27.8 | 42.6 | 54.3 | 62.5 | 65.4 | 78.5 | 86.9 | 96.2 | 97.7 | 97.9 | 98.8 | 100.0 |
| | 39.5 | 14.9 | 18.8 | 26.8 | 38.9 | 48.5 | 56.1 | 59.6 | 72.2 | 79.5 | 94.9 | 97.9 | 98.4 | 99.6 | 100.0 |
| | 49.0 | 15.0 | 19.3 | 30.0 | 44.2 | 56.1 | 64.5 | 67.8 | 80.1 | 88.9 | 98.6 | 99.3 | 99.6 | 100.0 | 100.0 |
| MEAN | | 14.7 | 18.5 | 27.0 | 40.6 | 51.1 | 59.3 | 62.5 | 76.1 | 85.1 | 93.3 | 95.1 | 95.6 | 97.6 | 100.0 |
| STANDARD DV | | 0.54 | 1.06 | 2.73 | 3.32 | 4.99 | 4.99 | 4.99 | 3.78 | 4.04 | 6.64 | 6.50 | 6.14 | 3.72 | 0.09 |
| 4 | 23.5 | 18.3 | 23.8 | 34.7 | 52.7 | 65.4 | 73.2 | 76.5 | 91.7 | 96.0 | 99.6 | 100.0 | 100.0 | 100.0 | 100.0 |
| | 44.5 | 17.6 | 21.0 | 28.0 | 41.2 | 52.0 | 61.0 | 64.5 | 79.6 | 87.4 | 95.8 | 96.9 | 97.5 | 98.5 | 100.0 |
| | 57.0 | 11.7 | 15.3 | 23.2 | 32.7 | 41.4 | 48.2 | 50.3 | 59.1 | 69.7 | 85.6 | 89.2 | 90.3 | 95.3 | 100.0 |
| | 71.8 | 13.5 | 14.9 | 19.0 | 26.8 | 34.0 | 39.8 | 42.3 | 61.1 | 76.5 | 94.7 | 97.2 | 98.5 | 99.1 | 100.0 |
| | 95.5 | 15.3 | 18.1 | 24.6 | 34.1 | 42.7 | 49.6 | 52.1 | 66.6 | 77.6 | 90.0 | 94.5 | 97.3 | 100.0 | 100.0 |
| MEAN | | 15.3 | 18.6 | 25.9 | 37.5 | 47.1 | 54.4 | 57.1 | 71.6 | 81.8 | 93.1 | 95.6 | 96.7 | 98.6 | 100.0 |
| STANDARD DV | | 2.76 | 3.80 | 5.91 | 9.90 | 12.09 | 12.95 | 13.46 | 13.79 | 11.02 | 5.43 | 4.04 | 3.76 | 1.97 | 0.16 |
| 5 | 0.5 | 27.5 | 31.8 | 41.2 | 53.6 | 62.0 | 69.5 | 73.2 | 83.4 | 90.2 | 96.7 | 97.9 | 98.6 | 100.0 | 100.0 |
| | 11.0 | 23.7 | 27.2 | 33.9 | 45.0 | 52.9 | 59.2 | 62.0 | 78.1 | 86.2 | 93.1 | 95.2 | 96.5 | 97.9 | 100.0 |
| | 21.0 | 16.9 | 20.5 | 27.3 | 37.0 | 44.6 | 51.1 | 53.5 | 69.5 | 81.0 | 90.0 | 92.4 | 93.8 | 96.4 | 100.0 |
| | 30.5 | 19.9 | 24.5 | 33.9 | 46.5 | 56.6 | 64.5 | 67.5 | 80.6 | 88.8 | 95.5 | 97.8 | 99.2 | 99.5 | 100.0 |

* Depth below coal seam (inches)

Table 3. Continued.

| Site no. | Depth (in)* | Percent finer by weight | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Size (mm) | | | | | | | | | | | | | |
| | | 0.0015 | 0.002 | 0.003 | 0.005 | 0.007 | 0.009 | 0.010 | 0.020 | 0.040 | 0.074 | 0.105 | 0.125 | 0.250 | 0.425 |
| 5 | 40.5 | 8.4 | 10.9 | 16.8 | 24.9 | 32.0 | 36.2 | 36.9 | 45.7 | 53.5 | 73.8 | 89.8 | 90.4 | 94.4 | 100.0 |
| | 52.5 | 7.9 | 9.3 | 13.9 | 21.4 | 26.5 | 30.5 | 32.4 | 46.1 | 58.0 | 71.6 | 80.7 | 86.5 | 92.1 | 100.0 |
| | 66.5 | 5.7 | 7.3 | 12.1 | 18.7 | 23.2 | 27.4 | 29.1 | 38.2 | 45.7 | 67.2 | 76.2 | 81.7 | 89.3 | 100.0 |
| | 77.5 | 0.4 | 3.0 | 8.3 | 14.2 | 19.7 | 22.1 | 23.8 | 34.3 | 42.8 | 55.3 | 67.1 | 74.8 | 85.3 | 100.0 |
| MEAN | | 13.8 | 16.8 | 23.4 | 32.7 | 39.7 | 45.0 | 47.3 | 59.5 | 68.3 | 80.4 | 87.1 | 90.2 | 94.4 | 100.0 |
| STANDARD DV | | 9.57 | 10.52 | 12.20 | 14.76 | 16.42 | 18.28 | 19.08 | 20.42 | 20.25 | 15.47 | 11.28 | 8.68 | 5.18 | 0.16 |
| 6 | 1.0 | 12.5 | 15.7 | 20.9 | 30.1 | 36.9 | 42.2 | 44.5 | 59.9 | 72.9 | 84.9 | 92.1 | 92.6 | 95.7 | 100.0 |
| | 18.5 | 21.6 | 25.3 | 32.1 | 43.1 | 51.5 | 58.3 | 61.4 | 75.8 | 84.2 | 94.7 | 97.3 | 97.5 | 98.5 | 100.0 |
| | 27.5 | 19.8 | 23.8 | 32.1 | 44.2 | 53.0 | 59.9 | 63.3 | 77.8 | 85.1 | 93.9 | 97.5 | 100.0 | 100.0 | 100.0 |
| | 52.0 | 8.7 | 11.6 | 16.4 | 24.0 | 28.4 | 33.5 | 35.0 | 44.1 | 51.1 | 70.3 | 86.3 | 93.3 | 96.1 | 100.0 |
| | 67.0 | 9.1 | 11.6 | 16.5 | 22.8 | 27.2 | 33.3 | 35.0 | 45.0 | 52.6 | 71.6 | 86.0 | 86.9 | 92.3 | 100.0 |
| MEAN | | 14.4 | 17.6 | 23.6 | 32.8 | 39.4 | 45.4 | 47.8 | 60.5 | 69.2 | 83.1 | 91.8 | 94.0 | 96.5 | 100.0 |
| STANDARD DV | | 6.04 | 6.56 | 7.96 | 10.24 | 12.34 | 12.98 | 13.84 | 16.13 | 16.56 | 11.74 | 5.64 | 5.04 | 2.95 | 0.19 |
| 7 | 0.8 | 11.1 | 14.7 | 18.3 | 23.8 | 29.2 | 34.6 | 35.9 | 40.8 | 46.9 | 66.8 | 94.2 | 95.4 | 100.0 | 100.0 |
| | 13.5 | 12.2 | 16.0 | 21.8 | 32.8 | 38.6 | 43.2 | 44.3 | 50.9 | 57.2 | 74.4 | 93.4 | 95.2 | 97.2 | 100.0 |
| | 30.0 | 5.1 | 8.3 | 12.0 | 18.6 | 22.0 | 22.9 | 24.0 | 30.2 | 36.3 | 56.0 | 80.2 | 81.9 | 92.5 | 100.0 |
| | 41.5 | 4.8 | 6.9 | 10.0 | 15.9 | 18.7 | 22.1 | 23.6 | 35.6 | 52.0 | 73.4 | 85.8 | 87.0 | 94.9 | 100.0 |
| | 54.8 | 8.1 | 10.6 | 15.0 | 20.5 | 24.9 | 28.7 | 30.4 | 42.2 | 55.0 | 77.5 | 86.8 | 87.6 | 92.8 | 100.0 |
| MEAN | | 8.3 | 11.3 | 15.4 | 22.3 | 26.7 | 30.3 | 31.6 | 40.0 | 49.5 | 69.6 | 88.1 | 89.4 | 95.5 | 100.0 |
| STANDARD DV | | 3.37 | 3.96 | 4.75 | 6.56 | 7.71 | 8.77 | 8.70 | 7.74 | 8.32 | 8.55 | 5.81 | 5.81 | 3.15 | 0.18 |
| 8 | 5.5 | 15.7 | 22.0 | 31.3 | 44.3 | 54.3 | 61.1 | 63.8 | 74.1 | 81.5 | 92.4 | 99.7 | 99.7 | 99.8 | 100.0 |
| | 31.3 | 5.6 | 7.8 | 11.7 | 16.2 | 21.2 | 25.1 | 26.5 | 35.3 | 49.8 | 80.8 | 90.2 | 90.8 | 94.7 | 100.0 |
| | 55.0 | 5.1 | 7.8 | 12.4 | 16.9 | 21.4 | 24.9 | 26.2 | 35.3 | 48.2 | 68.8 | 77.8 | 79.2 | 87.9 | 100.0 |
| | 67.5 | 7.5 | 11.5 | 16.5 | 21.8 | 27.4 | 32.0 | 34.4 | 49.4 | 72.8 | 91.4 | 95.8 | 96.0 | 97.7 | 100.0 |
| | 79.3 | 3.2 | 4.9 | 7.6 | 12.2 | 15.8 | 20.2 | 21.4 | 30.4 | 47.0 | 65.1 | 73.4 | 75.1 | 85.5 | 100.0 |

* Depth below coal seam (inches)

Table 3. Continued.

| Site no. | Depth (in)* | Percent finer by weight | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Size (mm) | | | | | | | | | | | | | |
| | | 0.0015 | 0.002 | 0.003 | 0.005 | 0.007 | 0.009 | 0.010 | 0.020 | 0.040 | 0.074 | 0.105 | 0.125 | 0.250 | 0.425 |
| 8 | 96.5 | 10.5 | 12.6 | 16.5 | 25.2 | 30.2 | 35.3 | 38.0 | 54.1 | 77.1 | 95.8 | 98.6 | 98.7 | 99.2 | 100.0 |
| MEAN | | 7.9 | 11.1 | 16.0 | 22.8 | 28.4 | 33.1 | 35.1 | 46.4 | 62.8 | 82.4 | 89.2 | 89.9 | 94.1 | 100.0 |
| STANDARD DV | | 4.54 | 6.02 | 8.22 | 11.48 | 13.65 | 14.75 | 15.32 | 16.36 | 16.02 | 13.02 | 11.14 | 10.44 | 6.09 | 0.19 |
| 9 | 1.5 | 21.3 | 25.3 | 33.4 | 46.7 | 55.7 | 62.1 | 64.9 | 77.6 | 85.9 | 95.4 | 98.4 | 100.0 | 100.0 | 100.0 |
| | 15.5 | 15.3 | 19.6 | 27.6 | 41.4 | 49.7 | 56.6 | 59.7 | 73.3 | 82.9 | 93.3 | 97.6 | 97.8 | 99.0 | 100.0 |
| | 30.3 | 4.3 | 6.7 | 9.8 | 16.7 | 21.4 | 26.7 | 29.3 | 40.5 | 58.5 | 81.1 | 87.3 | 88.1 | 93.0 | 100.0 |
| | 41.0 | 8.1 | 10.3 | 14.4 | 20.8 | 26.4 | 31.3 | 32.6 | 42.7 | 58.1 | 81.3 | 88.8 | 89.5 | 93.9 | 100.0 |
| | 53.3 | 11.7 | 12.9 | 17.2 | 27.7 | 36.0 | 41.9 | 44.7 | 63.8 | 75.4 | 90.3 | 95.7 | 96.0 | 97.7 | 100.0 |
| | 66.5 | 4.2 | 5.5 | 7.0 | 11.2 | 17.6 | 20.8 | 22.0 | 35.2 | 44.6 | 65.2 | 75.4 | 77.2 | 88.2 | 100.0 |
| | 89.5 | 1.8 | 2.2 | 5.5 | 7.8 | 11.2 | 13.8 | 14.8 | 21.2 | 30.7 | 59.8 | 73.3 | 75.5 | 88.9 | 100.0 |
| MEAN | | 9.5 | 11.8 | 16.4 | 24.6 | 31.2 | 36.2 | 38.3 | 50.6 | 62.3 | 80.9 | 88.1 | 89.1 | 94.4 | 100.0 |
| STANDARD DV | | 6.99 | 8.21 | 10.59 | 14.84 | 16.68 | 18.12 | 18.86 | 21.17 | 20.39 | 13.80 | 10.29 | 9.76 | 4.74 | 0.20 |
| 10 | 11.0 | 17.2 | 22.8 | 31.6 | 45.0 | 55.8 | 62.2 | 64.8 | 77.6 | 84.1 | 94.5 | 98.2 | 100.0 | 100.0 | 100.0 |
| | 19.0 | 16.0 | 21.1 | 28.9 | 42.3 | 50.4 | 56.7 | 59.6 | 73.5 | 80.7 | 92.1 | 97.2 | 100.0 | 100.0 | 100.0 |
| | 36.5 | 8.9 | 9.7 | 13.7 | 20.2 | 24.5 | 29.4 | 31.0 | 42.7 | 58.8 | 81.9 | 88.7 | 89.4 | 93.8 | 100.0 |
| | 49.5 | 8.9 | 10.2 | 16.1 | 24.0 | 30.9 | 36.0 | 37.9 | 49.8 | 61.1 | 79.7 | 88.1 | 88.8 | 93.5 | 100.0 |
| MEAN | | 12.8 | 16.0 | 22.6 | 12.9 | 40.4 | 46.1 | 48.3 | 60.9 | 71.2 | 87.0 | 93.0 | 94.6 | 96.8 | 100.0 |
| STANDARD DV | | 4.43 | 6.95 | 8.95 | 12.58 | 15.09 | 15.83 | 16.44 | 17.24 | 13.07 | 7.37 | 5.41 | 6.29 | 3.67 | 0.17 |
| OVERALL MN | | 11.9 | 14.9 | 20.8 | 29.9 | 36.9 | 42.6 | 44.8 | 57.7 | 68.9 | 84.2 | 91.1 | 92.5 | 96.0 | 100.0 |
| OVERALL DV | | 5.96 | 6.87 | 8.78 | 11.94 | 14.13 | 15.61 | 16.28 | 17.91 | 17.20 | 12.72 | 8.41 | 7.54 | 4.20 | 0.29 |

* Depth below coal seam (inches)

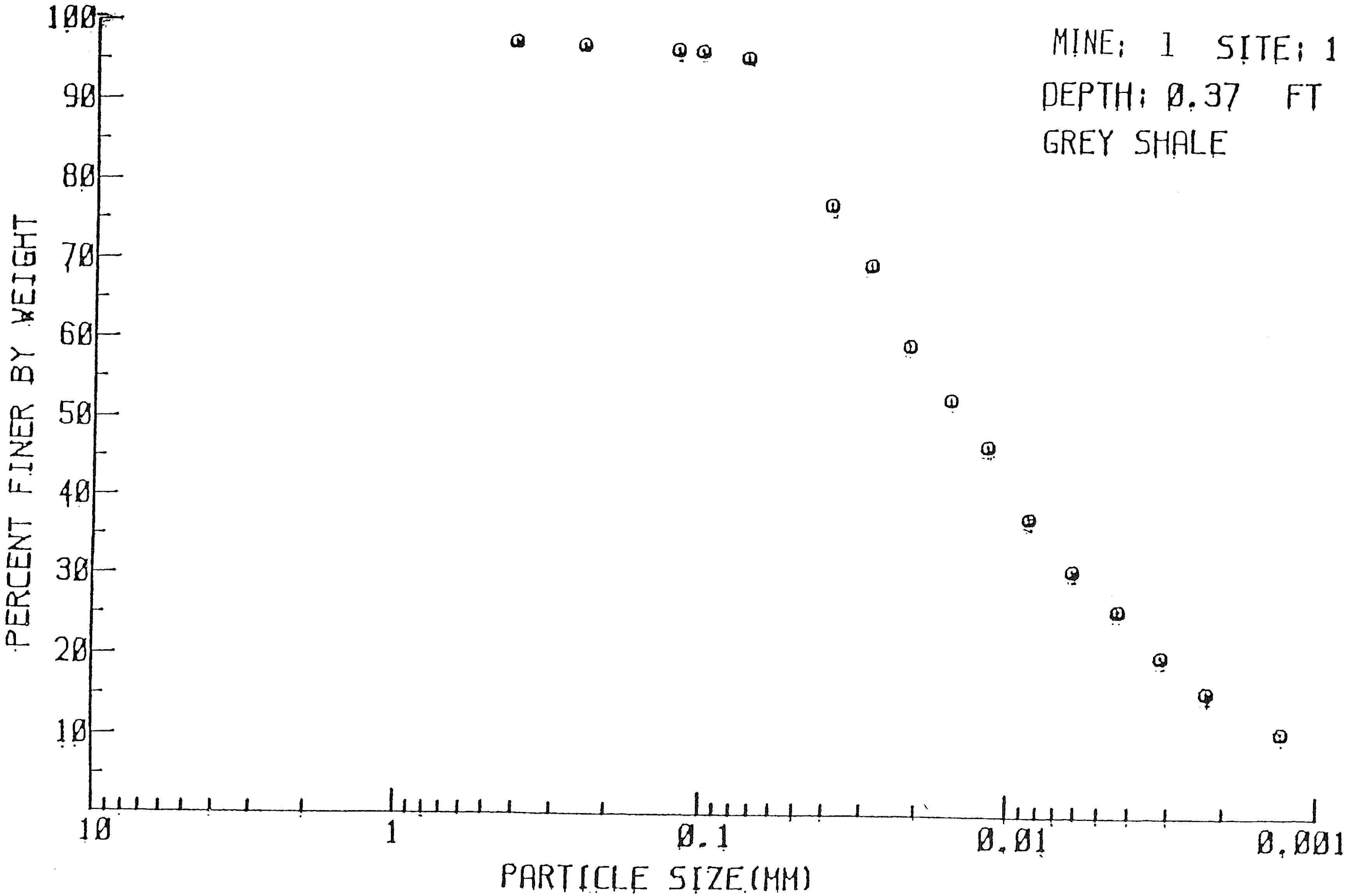



Figure 6. Particle size distribution curve (mine 1, site 1).

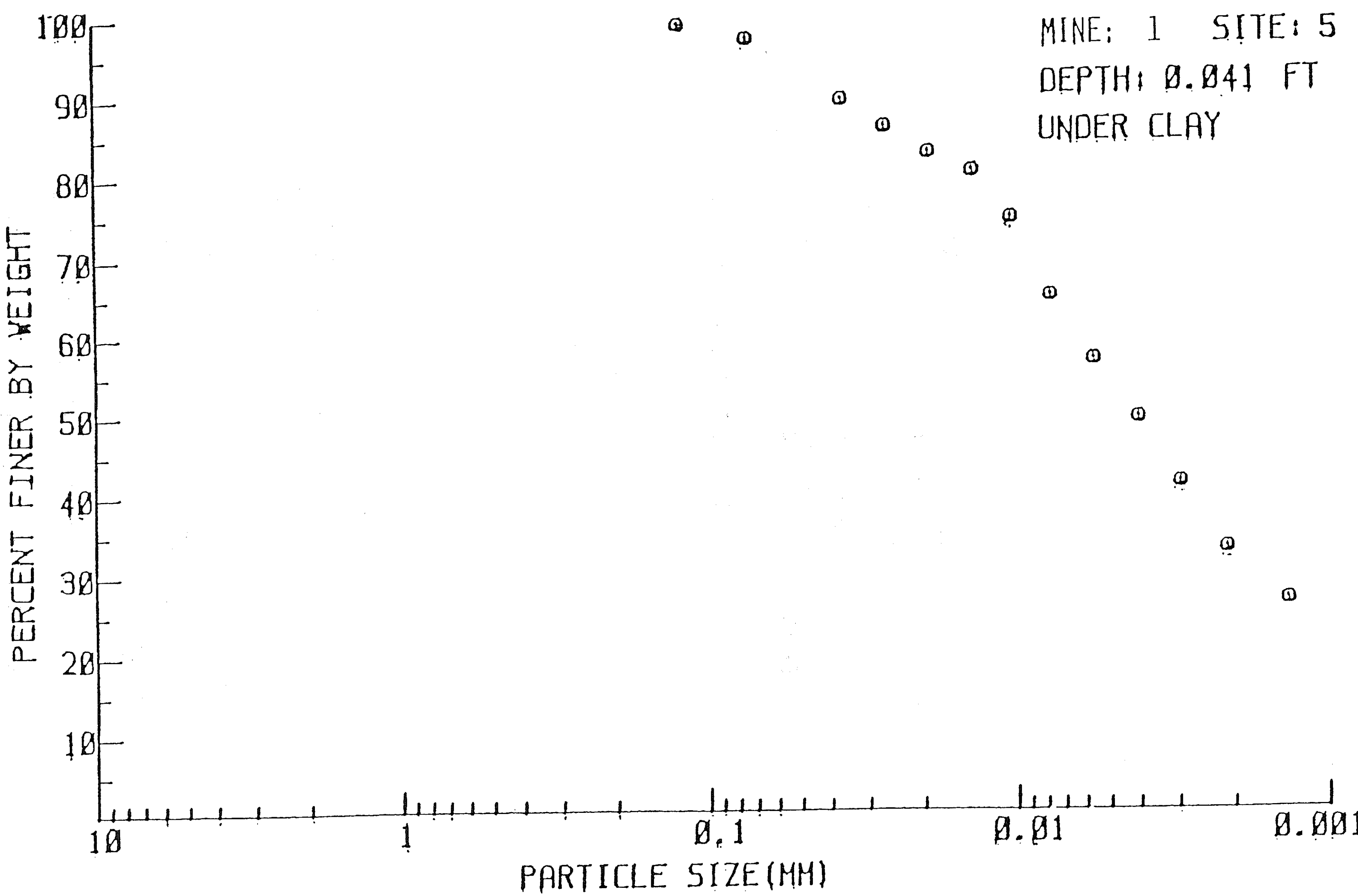



Figure 7. Particle size distribution curve (mine 1, site 5).

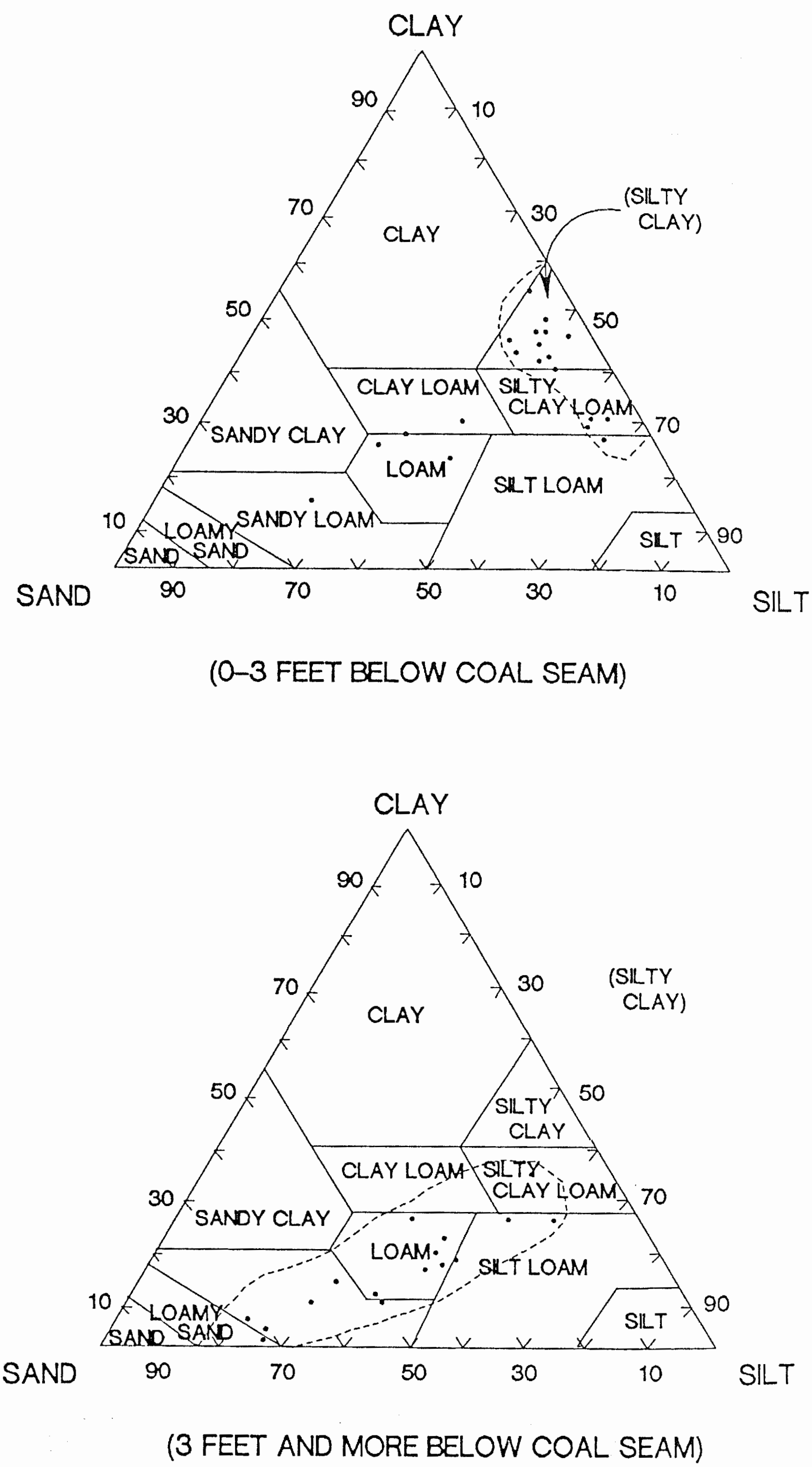



Figure 8. Textural classification of immediate floor strata (mine 1).

Table 4. Particle size distribution data (mine 3).

| Site no. | Depth (in)* | Percent finer by weight | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Size (mm) | | | | | | | | | | | | | |
| | | 0.0015 | 0.002 | 0.003 | 0.005 | 0.007 | 0.009 | 0.010 | 0.020 | 0.040 | 0.074 | 0.105 | 0.125 | 0.250 | 0.425 |
| 1 | 3.0 | 0.6 | 0.8 | 1.2 | 2.0 | 9.9 | 33.8 | 49.9 | 79.7 | 89.4 | 97.1 | 97.5 | 97.5 | 98.6 | 100.0 |
| | 11.5 | 23.5 | 32.5 | 49.3 | 65.3 | 74.1 | 80.6 | 82.5 | 91.3 | 93.4 | 98.1 | 100.0 | 100.0 | 100.0 | 100.0 |
| | 17.0 | 17.7 | 24.5 | 36.8 | 55.6 | 67.5 | 74.6 | 77.6 | 88.9 | 92.1 | 96.4 | 96.8 | 96.9 | 97.9 | 100.0 |
| | 23.0 | 20.5 | 27.7 | 39.0 | 54.2 | 63.2 | 71.6 | 74.6 | 86.2 | 91.2 | 98.2 | 100.0 | 100.0 | 100.0 | 100.0 |
| | 24.0 | 10.4 | 14.9 | 22.5 | 31.9 | 37.9 | 44.6 | 47.9 | 61.0 | 67.1 | 77.6 | 80.9 | 82.1 | 89.5 | 100.0 |
| | 55.0 | 20.4 | 27.3 | 37.0 | 51.6 | 62.1 | 68.9 | 71.8 | 86.2 | 90.5 | 96.6 | 100.0 | 100.0 | 100.0 | 100.0 |
| | 108.0 | 14.7 | 19.2 | 25.5 | 36.2 | 43.8 | 50.9 | 54.3 | 72.5 | 82.8 | 94.0 | 94.7 | 95.1 | 97.0 | 100.0 |
| MEAN | | 15.4 | 21.0 | 30.2 | 42.4 | 51.2 | 60.7 | 65.5 | 80.8 | 86.7 | 94.0 | 95.7 | 96.0 | 97.6 | 100.0 |
| STANDARD DV | | 7.82 | 10.64 | 15.58 | 21.25 | 22.33 | 17.58 | 14.36 | 10.79 | 9.28 | 7.35 | 6.84 | 6.41 | 3.74 | 0.14 |
| 2 | 12.0 | 0.9 | 1.2 | 1.9 | 3.1 | 5.2 | 16.7 | 36.4 | 78.6 | 91.1 | 98.9 | 100.0 | 100.0 | 100.0 | 100.0 |
| MEAN | | 0.9 | 1.2 | 1.9 | 3.1 | 5.2 | 16.7 | 36.4 | 78.6 | 91.1 | 98.9 | 100.0 | 100.0 | 100.0 | 100.0 |
| STANDARD DV | | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3 | 34.0 | 33.7 | 38.6 | 44.6 | 56.5 | 64.0 | 69.9 | 72.9 | 86.1 | 90.4 | 96.3 | 96.9 | 97.2 | 100.0 | 100.0 |
| | 54.0 | 14.6 | 18.0 | 23.0 | 32.5 | 39.5 | 45.6 | 48.5 | 67.8 | 83.8 | 97.6 | 100.0 | 100.0 | 100.0 | 100.0 |
| | 109.0 | 27.6 | 34.3 | 43.1 | 54.2 | 61.3 | 66.0 | 68.0 | 78.6 | 85.1 | 97.8 | 100.0 | 100.0 | 100.0 | 100.0 |
| | 126.0 | 0.0 | 0.0 | 0.0 | 0.0 | 5.7 | 40.3 | 45.7 | 66.3 | 84.7 | 97.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| | 157.0 | 18.6 | 25.1 | 35.6 | 49.3 | 60.8 | 68.1 | 71.1 | 84.9 | 91.6 | 97.6 | 100.0 | 100.0 | 100.0 | 100.0 |
| MEAN | | 18.9 | 23.2 | 29.3 | 38.5 | 46.3 | 58.0 | 61.2 | 76.7 | 87.0 | 97.2 | 99.4 | 99.4 | 100.0 | 100.0 |
| STANDARD DV | | 12.96 | 15.24 | 18.46 | 23.48 | 24.71 | 13.92 | 13.06 | 9.30 | 3.74 | 0.61 | 1.39 | 1.26 | 0.0 | 0.0 |
| 4 | 21.0 | 10.3 | 13.8 | 16.9 | 23.8 | 30.4 | 36.4 | 39.2 | 56.5 | 76.4 | 93.2 | 94.4 | 94.7 | 96.9 | 100.0 |
| | 24.0 | 23.2 | 27.2 | 34.9 | 46.4 | 56.3 | 62.5 | 64.9 | 75.7 | 84.1 | 95.1 | 96.2 | 96.8 | 98.1 | 100.0 |
| | 45.0 | 30.8 | 35.5 | 42.3 | 53.0 | 62.6 | 68.5 | 70.7 | 83.3 | 88.5 | 95.3 | 96.0 | 96.3 | 98.1 | 100.0 |
| MEAN | | 21.4 | 25.5 | 31.4 | 41.1 | 49.8 | 55.8 | 58.3 | 71.8 | 83.0 | 94.6 | 95.5 | 95.9 | 97.7 | 100.0 |
| STANDARD DV | | 10.32 | 10.98 | 13.08 | 15.31 | 17.06 | 17.04 | 16.79 | 13.81 | 6.14 | 1.19 | 1.02 | 1.07 | 0.70 | 0.17 |
| 5 | 12.0 | 33.2 | 38.7 | 49.2 | 64.3 | 72.6 | 77.1 | 78.6 | 85.6 | 90.1 | 97.3 | 97.6 | 97.6 | 97.9 | 100.0 |

* Depth below coal seam (inches)

Table 4. Continued.

| Site no. | Depth (in)* | 0.0015 | 0.002 | 0.003 | 0.005 | 0.007 | 0.009 | 0.010 | 0.020 | 0.040 | 0.074 | 0.105 | 0.125 | 0.250 | 0.425 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Percent finer by weight — Size (mm) | | | | | | | | | | | | | |
| 5 | 12.0 | 29.1 | 36.1 | 44.4 | 55.1 | 63.8 | 71.0 | 74.4 | 86.2 | 92.5 | 99.1 | 100.0 | 100.0 | 100.0 | 100.0 |
| | 18.0 | 16.6 | 22.6 | 32.6 | 46.6 | 57.5 | 65.8 | 69.8 | 86.7 | 92.0 | 95.8 | 96.6 | 96.8 | 98.1 | 100.0 |
| | 48.0 | 31.5 | 37.6 | 45.4 | 57.1 | 66.2 | 72.4 | 75.2 | 87.6 | 92.1 | 98.9 | 100.0 | 100.0 | 100.0 | 100.0 |
| | 96.0 | 6.1 | 11.2 | 16.2 | 22.5 | 27.7 | 33.1 | 35.6 | 54.1 | 75.1 | 93.7 | 96.2 | 96.4 | 97.9 | 100.0 |
| | 108.0 | 27.2 | 35.7 | 46.0 | 59.9 | 68.9 | 73.5 | 75.0 | 84.9 | 89.6 | 99.2 | 100.0 | 100.0 | 100.0 | 100.0 |
| | 139.0 | 30.7 | 36.9 | 45.0 | 55.3 | 61.5 | 66.0 | 68.1 | 77.2 | 85.3 | 97.8 | 100.0 | 100.0 | 100.0 | 100.0 |
| | 156.0 | 7.4 | 11.4 | 16.0 | 23.0 | 29.3 | 35.8 | 38.8 | 61.5 | 79.5 | 98.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| | 198.0 | 9.9 | 13.2 | 16.3 | 22.0 | 28.4 | 34.7 | 37.6 | 61.2 | 81.0 | 93.9 | 95.3 | 95.6 | 97.4 | 100.0 |
| MEAN | | 21.3 | 27.1 | 34.6 | 45.1 | 52.9 | 58.8 | 61.4 | 76.1 | 86.3 | 97.1 | 98.4 | 98.5 | 99.0 | 100.0 |
| STANDARD DV | | 11.22 | 12.30 | 14.52 | 17.57 | 18.81 | 18.56 | 18.35 | 13.39 | 6.44 | 2.13 | 1.98 | 1.86 | 1.15 | 0.09 |
| 6 | 5.0 | 0.0 | 0.0 | 19.8 | 48.9 | 58.3 | 64.9 | 68.0 | 81.9 | 89.9 | 99.4 | 100.0 | 100.0 | 100.0 | 100.0 |
| | 8.0 | 22.4 | 27.9 | 39.9 | 56.8 | 66.7 | 75.0 | 78.3 | 91.9 | 95.7 | 98.4 | 100.0 | 100.0 | 100.0 | 100.0 |
| | 29.2 | 23.6 | 28.9 | 38.7 | 53.0 | 61.6 | 68.6 | 72.0 | 83.8 | 89.8 | 97.3 | 97.7 | 97.9 | 98.8 | 100.0 |
| | 30.0 | 3.5 | 4.6 | 6.9 | 19.6 | 52.5 | 62.8 | 67.0 | 84.3 | 90.8 | 96.6 | 97.3 | 100.0 | 100.0 | 100.0 |
| | 52.0 | 0.0 | 0.0 | 0.0 | 11.3 | 43.9 | 55.7 | 59.3 | 75.5 | 86.1 | 96.9 | 97.7 | 100.0 | 100.0 | 100.0 |
| MEAN | | 9.9 | 12.3 | 21.1 | 37.9 | 56.6 | 65.4 | 68.9 | 83.5 | 90.5 | 97.7 | 98.5 | 99.6 | 99.8 | 100.0 |
| STANDARD DV | | 12.07 | 14.85 | 18.11 | 20.91 | 8.77 | 7.12 | 6.98 | 5.84 | 3.43 | 1.17 | 1.34 | 0.95 | 0.57 | 0.13 |
| 7 | 18.0 | 1.9 | 21.6 | 34.3 | 46.5 | 54.7 | 61.8 | 65.2 | 80.0 | 87.4 | 97.2 | 97.9 | 98.1 | 98.9 | 100.0 |
| | 27.0 | 23.6 | 29.7 | 38.2 | 55.2 | 66.5 | 73.4 | 76.2 | 88.2 | 91.7 | 98.1 | 100.0 | 100.0 | 100.0 | 100.0 |
| | 39.0 | 25.4 | 32.2 | 40.9 | 56.4 | 66.0 | 73.6 | 76.6 | 87.9 | 93.0 | 98.3 | 100.0 | 100.0 | 100.0 | 100.0 |
| | 70.0 | 17.1 | 19.6 | 25.9 | 35.2 | 43.0 | 50.0 | 53.2 | 70.8 | 81.8 | 94.5 | 96.2 | 96.4 | 97.9 | 100.0 |
| | 108.0 | 29.1 | 35.7 | 48.0 | 61.9 | 69.7 | 74.4 | 76.2 | 84.0 | 90.3 | 99.2 | 100.0 | 100.0 | 100.0 | 100.0 |
| | 135.0 | 29.0 | 35.3 | 44.7 | 55.0 | 61.3 | 65.6 | 67.0 | 76.2 | 84.7 | 98.8 | 100.0 | 100.0 | 100.0 | 100.0 |
| | 158.0 | 21.6 | 26.1 | 35.9 | 44.2 | 50.6 | 56.1 | 58.7 | 71.1 | 84.6 | 97.2 | 100.0 | 100.0 | 100.0 | 100.0 |
| | 163.0 | 23.1 | 28.4 | 39.8 | 56.8 | 69.2 | 76.1 | 78.0 | 85.4 | 90.8 | 97.8 | 100.0 | 100.0 | 100.0 | 100.0 |

* Depth below coal seam (inches)

Table 4. Continued.

| Site no. | Depth (in)* | 0.0015 | 0.002 | 0.003 | 0.005 | 0.007 | 0.009 | 0.010 | 0.020 | 0.040 | 0.074 | 0.105 | 0.125 | 0.250 | 0.425 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Percent finer by weight — Size (mm) | | | | | | | | | | | | | |
| 7 | 209.0 | 7.7 | 9.6 | 14.6 | 20.7 | 26.7 | 31.7 | 34.2 | 50.0 | 67.1 | 80.5 | 82.2 | 83.1 | 97.7 | 100.0 |
| | 213.0 | 10.4 | 12.3 | 18.6 | 25.3 | 31.8 | 37.3 | 39.4 | 59.7 | 77.6 | 93.2 | 94.0 | 94.2 | 96.7 | 100.0 |
| | 220.0 | 9.5 | 12.2 | 15.9 | 23.6 | 30.1 | 35.8 | 38.5 | 57.6 | 71.5 | 81.4 | 82.1 | 82.9 | 87.6 | 100.0 |
| MEAN | | 18.0 | 23.9 | 32.4 | 43.7 | 51.8 | 57.8 | 60.3 | 73.7 | 83.7 | 94.2 | 95.7 | 95.9 | 98.1 | 100.0 |
| STANDARD DV | | 9.31 | 9.46 | 11.81 | 15.10 | 16.50 | 16.82 | 16.73 | 13.16 | 8.51 | 6.81 | 6.97 | 6.64 | 3.66 | 0.08 |
| 9 | 3.0 | 34.8 | 37.4 | 42.9 | 55.3 | 62.0 | 68.6 | 72.2 | 85.6 | 93.0 | 98.4 | 100.0 | 100.0 | 100.0 | 100.0 |
| MEAN | | 34.8 | 37.4 | 42.9 | 55.3 | 62.0 | 68.6 | 72.2 | 85.6 | 93.0 | 98.4 | 100.0 | 100.0 | 100.0 | 100.0 |
| STANDARD DV | | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 10 | 3.0 | 37.1 | 42.0 | 51.7 | 66.0 | 74.6 | 79.9 | 81.6 | 90.7 | 95.0 | 98.8 | 100.0 | 100.0 | 100.0 | 100.0 |
| MEAN | | 37.1 | 42.0 | 51.7 | 66.0 | 74.6 | 79.9 | 81.6 | 90.7 | 95.0 | 98.8 | 100.0 | 100.0 | 100.0 | 100.0 |
| STANDARD DV | | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 11 | 3.0 | 39.4 | 44.7 | 54.2 | 68.4 | 76.0 | 82.0 | 84.1 | 92.6 | 95.1 | 98.7 | 100.0 | 100.0 | 100.0 | 100.0 |
| MEAN | | 39.4 | 44.7 | 54.2 | 68.4 | 76.0 | 82.0 | 84.1 | 92.6 | 95.1 | 98.7 | 100.0 | 100.0 | 100.0 | 100.0 |
| STANDARD DV | | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 12 | 3.0 | 33.5 | 37.0 | 43.7 | 55.5 | 65.9 | 71.5 | 73.9 | 85.9 | 90.8 | 95.4 | 96.1 | 96.4 | 100.0 | 100.0 |
| MEAN | | 33.5 | 37.0 | 43.7 | 55.5 | 65.9 | 71.5 | 73.9 | 85.9 | 90.8 | 95.4 | 96.1 | 96.4 | 100.0 | 100.0 |
| STANDARD DV | | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 13 | 3.0 | 0.0 | 0.0 | 0.0 | 52.8 | 67.1 | 71.5 | 73.4 | 87.1 | 94.8 | 97.9 | 100.0 | 100.0 | 100.0 | 100.0 |
| MEAN | | 0.0 | 0.0 | 0.0 | 52.8 | 67.1 | 71.5 | 73.4 | 87.1 | 94.8 | 97.9 | 100.0 | 100.0 | 100.0 | 100.0 |
| STANDARD DV | | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 14 | 3.0 | 44.8 | 49.8 | 57.8 | 70.0 | 75.9 | 82.0 | 83.6 | 91.2 | 94.4 | 99.2 | 100.0 | 100.0 | 100.0 | 100.0 |
| MEAN | | 44.8 | 49.8 | 57.8 | 70.0 | 75.9 | 82.0 | 83.6 | 91.2 | 94.4 | 99.2 | 100.0 | 100.0 | 100.0 | 100.0 |
| STANDARD DV | | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| OVERALL MN | | 19.1 | 23.8 | 31.4 | 43.8 | 53.1 | 60.6 | 64.0 | 78.5 | 87.1 | 96.0 | 97.5 | 97.7 | 98.8 | 100.0 |
| OVERALL DV | | 12.20 | 13.62 | 16.15 | 18.67 | 18.93 | 16.72 | 15.30 | 11.45 | 7.06 | 4.62 | 4.56 | 4.34 | 2.44 | 0.11 |

* Depth below coal seam (inches)

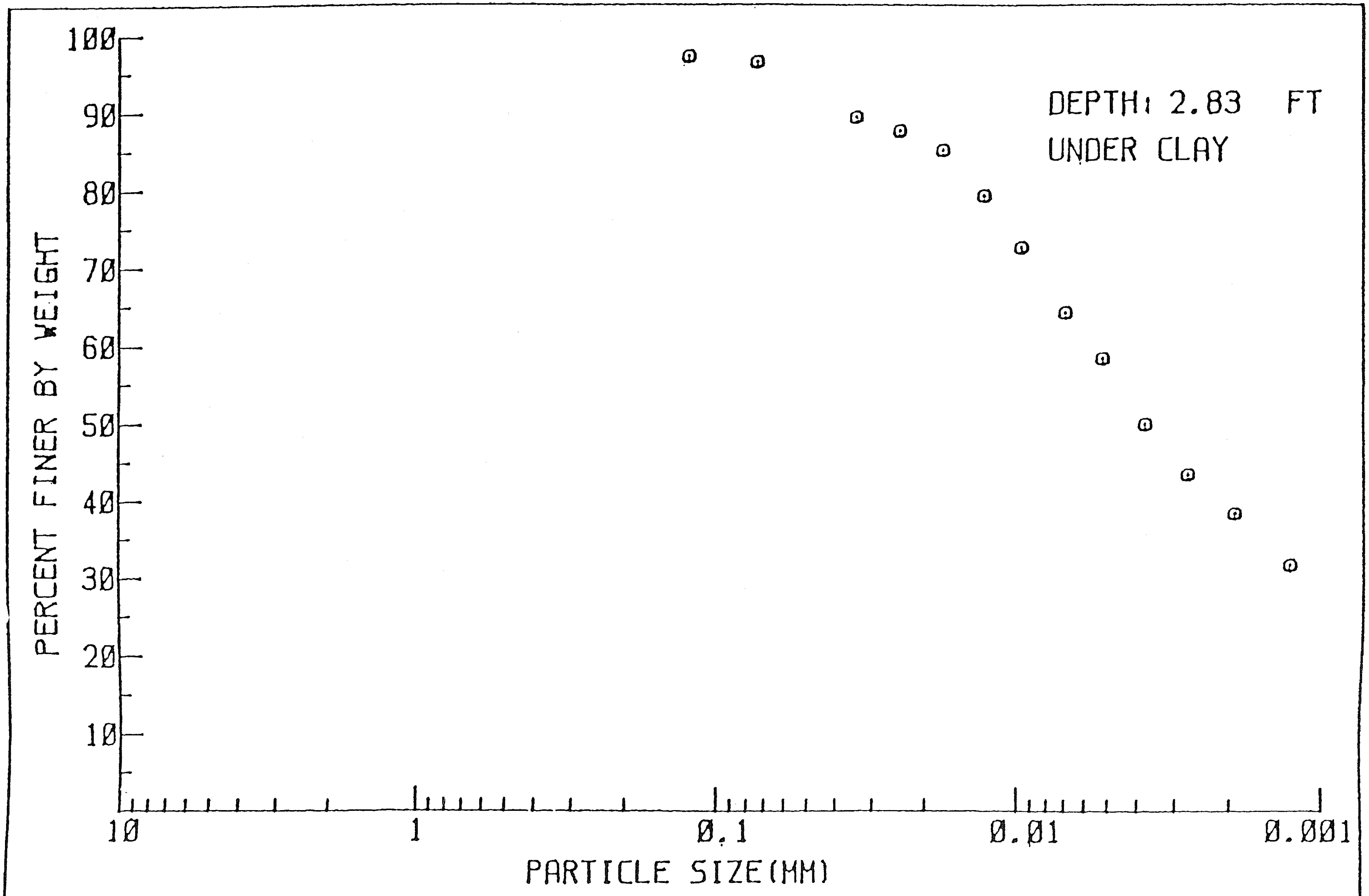



Figure 9. Particle size distribution curve (mine 3, site 3).

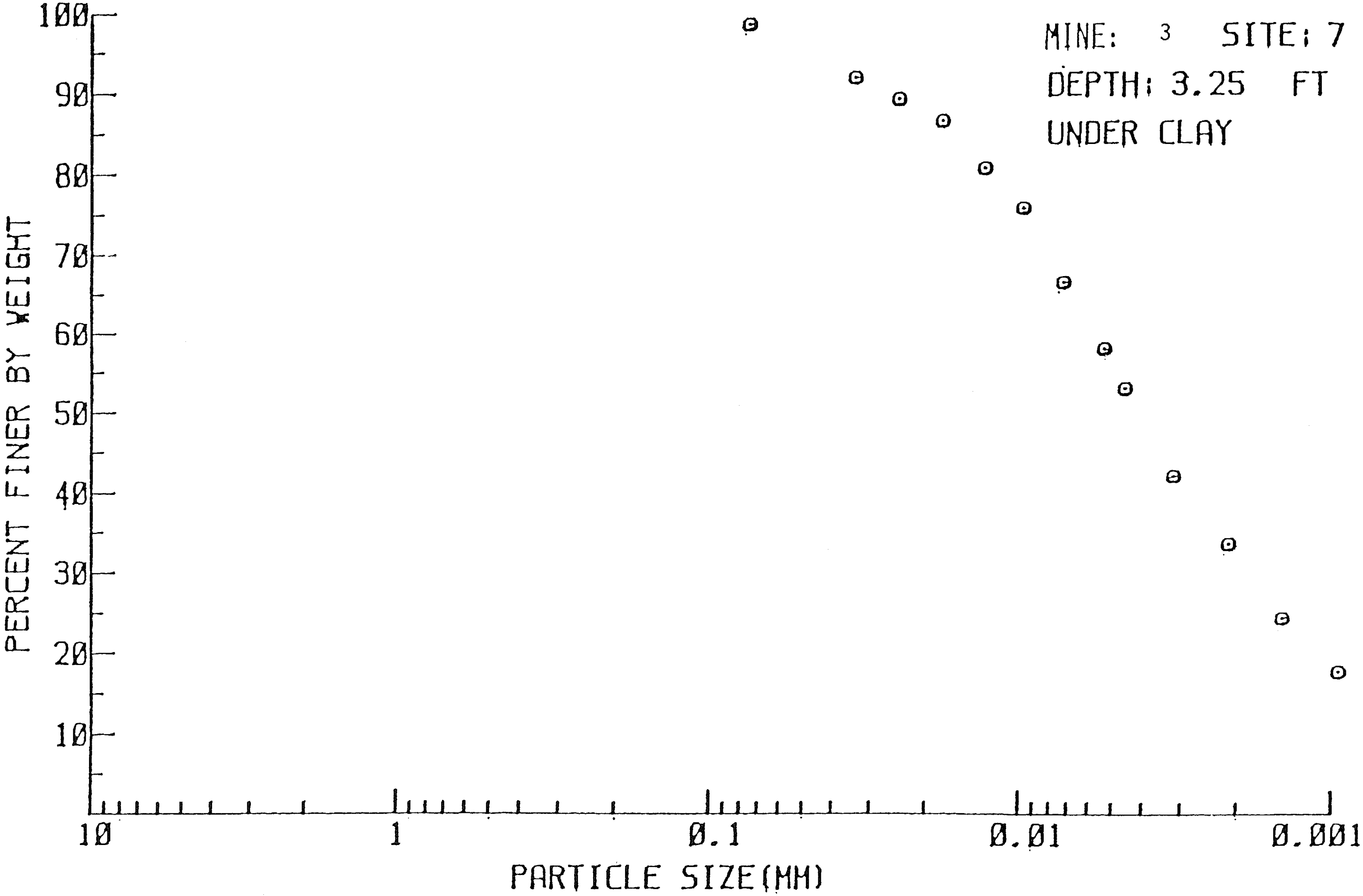



Figure 10. Particle size distribution curve (mine 3, site 7).

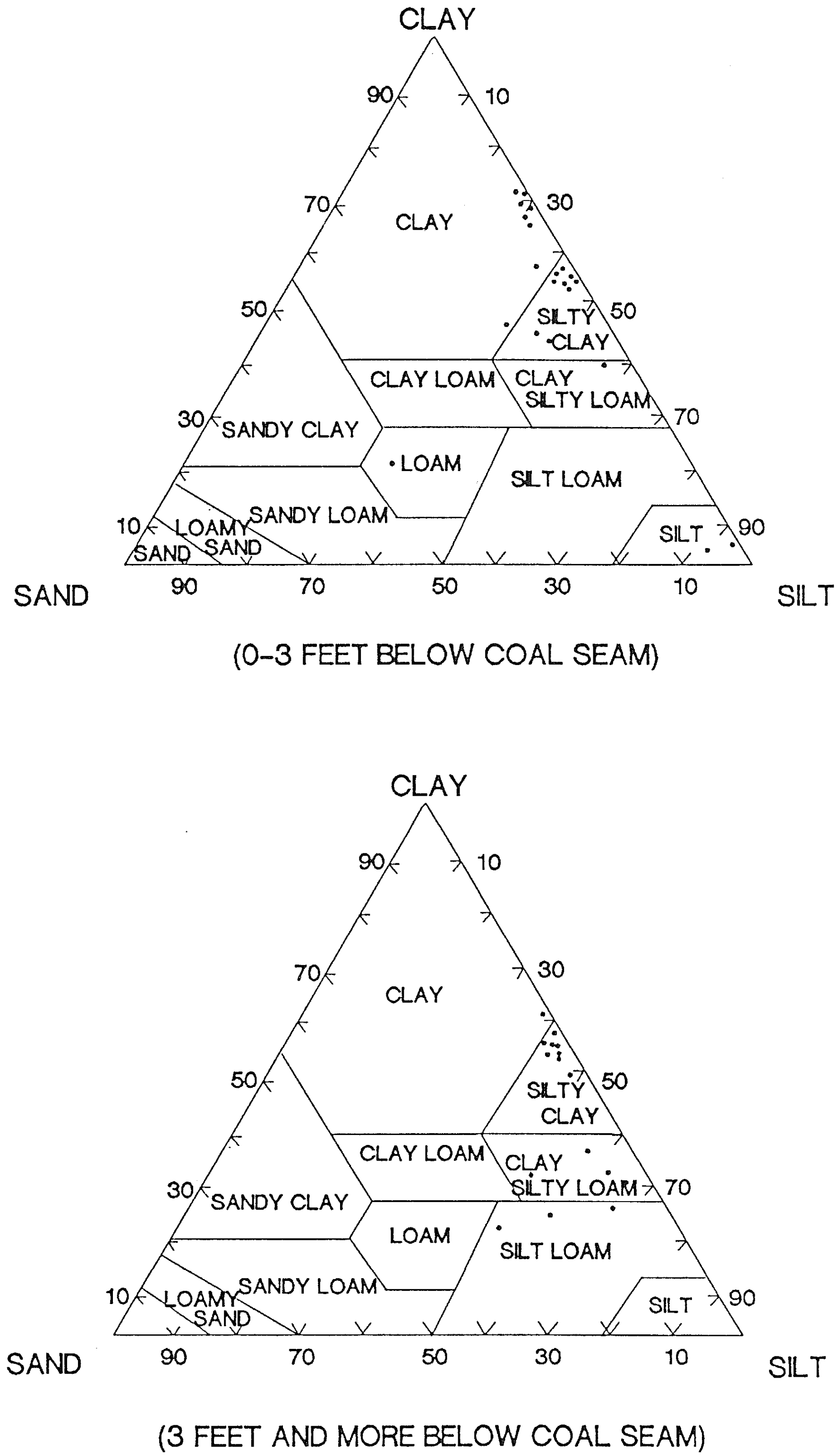



Figure 11. Textural classification of immediate floor strata (mine 3).

Table 5. Apparent specific gravity data (mine 1).

| Site | Depth below coal seam (in.) | Type of rock | Specific gravity |
|---|---|---|---|
| 1 | 1-3 | Grey shale | 2.50 |
| | 9 | Grey shale | 2.64 |
| | 13-15 | Grey shale | 2.62 |
| | 26 | Grey shale | 2.54 |
| 2 | 13-18 | Shale | 2.75 |
| 3 | 3-5 | Limestone | 2.55 |
| | 18-19 | Limestone | 2.73 |
| | 30-31 | Grey shale | 2.61 |
| | 39-40 | Grey shale | 2.61 |
| | 49 | Grey shale | 2.60 |
| 4 | 0-2 | Limestone | 2.55 |
| | 16-18 | Limestone | 2.72 |
| | 23-24 | Limestone | 2.74 |
| | 30-32 | Grey shale | 2.58 |
| | 35-37 | Grey shale | 2.59 |
| | 50-52.5 | Grey shale | 2.72 |
| | 57 | Grey shale | 2.57 |
| | 70.5-73 | Sandy shale | 2.59 |
| | 93-98 | Sandy shale | 2.73 |
| 5 | 0-1 | Underclay | 2.59 |
| | 10-12 | Underclay | 2.59 |
| | 20-22 | Underclay | 2.59 |
| | 30-31 | Underclay | 2.59 |
| | 38-43 | Grey shale | 2.72 |
| | 52-53 | Grey shale | 2.72 |
| | 66-67 | Sandy shale | 2.61 |
| | 77-78 | Sandstone | 2.73 |
| 6 | 0-2 | Underclay | 2.66 |
| | 18-19 | Grey shale | 2.74 |
| | 27-28 | Grey shale | 2.71 |
| | 51-53 | Sandy grey shale | 2.68 |
| | 66-68 | Sandy grey shale | 2.70 |

Table 6. Apparent specific gravity data (mine 3).

| Site | Depth below coal seam (in.) | Type of rock | Specific gravity |
|---|---|---|---|
| 1 | 34 | Underclay | 2.72 |
| | 54 | Underclay | 2.80 |
| | 109 | Grey shale | 2.54 |
| | 126 | Underclay | 2.62 |
| | 157 | Grey shale | 2.76 |
| 2 | 21 | Underclay | 2.75 |
| | 24 | Underclay | 2.85 |
| | 45 | Underclay | 2.76 |
| 3 | 8-12 | Underclay | 2.67 |
| | 12 | Underclay | 2.76 |
| | 18 | Underclay | 2.69 |
| | 48 | Underclay | 2.75 |
| | 96 | Sandy shale | 2.74 |
| | 108 | Claystone | 2.66 |
| | 139 | Black shale | 2.63 |
| | 156 | Grey shale | 2.78 |
| | 180-216 | Grey shale | 2.73 |
| 4 | 5 | Underclay | 2.76 |
| | 8 | Underclay | 2.68 |
| | 29 | Underclay | 2.73 |
| | 30 | Underclay | 2.54 |
| | 52 | Underclay | 2.79 |
| 5 | 18 | Underclay | 2.83 |
| | 27 | Underclay | 2.71 |
| | 39 | Underclay | 2.74 |
| | 70 | Underclay | 2.82 |
| | 108 | Mudstone | 2.84 |
| | 135 | Mudstone | 2.73 |
| | 158 | Grey shale | 2.81 |
| | 163 | Grey shale | 2.79 |
| | 200 | Grey shale | 2.77 |
| | 209 | Grey shale | 2.83 |
| | 213 | Grey shale | 2.75 |
| | 220 | Grey shale | 2.77 |

Table 6. Continued.

| Site | Depth below coal seam (in.) | Type of rock | Specific gravity |
|---|---|---|---|
| 6 | 6-8 | Underclay | 2.72 |
| | 20-21 | Underclay | 2.81 |
| | 30-32 | Underclay | 2.81 |
| | 43-46 | Underclay | 2.82 |
| | 51-53 | Underclay | 2.90 |
| | 74-77 | Underclay | 2.85 |
| | 93-94 | Underclay | 2.85 |
| | 119-121 | Black mudstone | 2.26 |
| | 136-138 | Black mudstone | 2.76 |
| | 144-146 | Grey shale | 2.85 |
| | 156-162 | Grey shale | 3.01 |
| 7 | 3 | Underclay | 2.87 |
| | 9.0-11.5 | Underclay | 2.65 |
| | 13-17 | Underclay | 2.67 |
| | 18-24 | Underclay | 2.66 |
| | 23 | Underclay | 2.84 |
| | 55 | Underclay | 2.72 |
| | 108 | Claystone | 2.76 |
| 8 | 6-12 | Underclay | 2.87 |

Table 7. Clay mineral composition for immediate floor strata (mine 1).

| Site no. | Depth below coal seam (in) | Illite (I) (percent) | Kaolinite (percent) | Chlorite (percent) | Smectite (S) (percent) | * Mixed layer (percent) | ** Ratio S:I | Total clay (percent) |
|---|---|---|---|---|---|---|---|---|
| 1 | 5 - 6 | 49.0 | 29.0 | - | - | 22.0 | 0.85 | 27.0 |
| | 16 - 17 | 51.0 | 32.0 | - | - | 17.0 | 0.75 | 26.0 |
| 2 | 19 - 22 | 52.0 | 30.0 | - | - | 18.0 | 0.75 | 24.0 |
| 3 | 6 - 9 | 33.0 | 51.0 | - | - | 16.0 | 0.75 | 28.0 |
| | 27 - 30 | 40.0 | 48.0 | Tr | - | 12.0 | 0.72 | 34.0 |
| 4 | 8 - 11 | 51.0 | 19.0 | - | - | 30.0 | 0.75 | 27.0 |
| | 24 - 29 | 44.0 | 27.0 | - | - | 29.0 | 0.67 | 38.0 |
| | 52.5 - 58 | 49.0 | 38.0 | Tr | - | 13.0 | 1.38 | 30.0 |
| | 83.5 - 86.5 | 48.0 | 35.0 | - | - | 17.0 | 1.38 | 26.0 |
| 5 | 4 - 6 | 53.0 | 4.0 | - | - | 43.0 | 0.61 | 46.0 |
| | 16 - 19 | 47.0 | 7.0 | - | - | 46.0 | 0.75 | 34.0 |
| | 33 - 36 | 48.0 | 7.0 | - | - | 45.0 | 0.75 | 42.0 |
| | 56 - 58 | 41.0 | 22.0 | - | - | 37.0 | 0.85 | 26.0 |
| | 74 - 76 | 48.0 | 29.0 | - | - | 23.0 | 0.75 | 20.0 |
| 6 | 9 - 17 | 51.0 | 7.0 | - | - | 42.0 | 0.67 | 44.0 |
| | 59 - 62 | 44.0 | 32.0 | - | - | 24.0 | 0.75 | 20.0 |
| 7 | 1.5 - 4.5 | 32.0 | 46.0 | - | - | 22.0 | 0.61 | 19.0 |
| | 20 - 22 | 35.0 | 41.0 | - | - | 24.0 | 0.75 | 18.0 |
| | 33.5 - 36 | 36.0 | 39.0 | - | - | 25.0 | 0.75 | 20.0 |
| | 45.5 - 48 | 42.0 | 39.0 | - | - | 19.0 | 0.75 | 18.0 |
| | 60.5 - 62.5 | 39.0 | 32.0 | Tr | - | 29.0 | 0.43 | 19.0 |
| 8 | 2 - 5 | 41.0 | 19.0 | - | - | 40.0 | 0.47 | 24.0 |
| | 6 - 10 | 38.0 | 37.0 | Tr | - | 25.0 | 0.75 | 42.0 |
| | 16 - 18 | 36.0 | 37.0 | 7.0 | - | 22.0 | 0.75 | 22.0 |
| | 28.5 - 31.0 | 41.0 | 27.0 | 10.0 | - | 22.0 | 0.75 | 20.0 |
| | 45 - 48 | 37.0 | 35.0 | 3.0 | - | 25.0 | 0.67 | 20.0 |
| | 55.5 - 59.5 | 42.0 | 30.0 | 4.0 | - | 24.0 | 0.67 | 19.0 |
| | 68.0 - 70.5 | 44.0 | 36.0 | - | - | 20.0 | 0.75 | 19.0 |
| | 75.5 - 78.5 | 46.0 | 34.0 | - | - | 20.0 | 0.67 | 21.0 |
| | 84.5 - 87.5 | 39.0 | 39.0 | - | - | 22.0 | 0.67 | 23.0 |
| 9 | 5 - 14 | 37.0 | 15.0 | - | - | 48.0 | 0.67 | 37.0 |
| | 25 - 29 | 39.0 | 35.0 | - | - | 26.0 | 0.61 | 31.0 |
| | 37.5 - 40.0 | 42.0 | 25.0 | - | - | 33.0 | 0.75 | 23.0 |

* Percent of mixed layer smectite/illite present

Table 7. Continued.

| Site no. | Depth below coal seam (in) | Illite (I) (percent) | Kaolinite (percent) | Chlorite (percent) | Smectite (S) (percent) | * Mixed layer (percent) | ** Ratio S:I | Total clay (percent) |
|---|---|---|---|---|---|---|---|---|
| 9 | 48.0 - 50.5 | 50.0 | 25.0 | - | - | 25.0 | 0.72 | 25.0 |
| | 62.5 - 68.0 | 44.0 | 32.0 | Tr | - | 24.0 | 0.75 | 17.0 |
| | 84 - 87 | 46.0 | 33.0 | - | - | 21.0 | 0.85 | 23.0 |
| 10 | 0 - 10 | 45.0 | 45.0 | - | - | 10.0 | 0.47 | 46.0 |
| | 27 - 30 | 46.0 | 37.0 | - | - | 17.0 | 0.47 | 27.0 |
| | 54.5 - 57.0 | 44.0 | 28.0 | - | - | 28.0 | 0.67 | 17.0 |

* Percent of mixed layer smectite/illite present
** Ratio of smectite to illite within the mixed layer fraction
*** Unable to obtain total clay percentage due to severe flocculation

Table 8. Correlation analysis results for selected clay mineral composition variables.

Mine 1

| Test | X variable | Y variable | No. of points | Correlation coefficient (r *) | Linear regression equation |
|---|---|---|---|---|---|
| 2 | Depth (in.) | Mixed layers (%) | 39 | -0.249 | Y = 29.14 + 0.09X |
| 4 | Moisture content | Mixed layers (%) | 36 | 0.494 | Y = 17.53 + 3.04 X |
| 5 | Moisture content | Kaolinite (%) | 36 | -0.499 | Y = 40.82 - 3.797X |

Mine 3

| Test | X variable | Y variable | No. of points | Correlation coefficient (r *) | Linear regression equation |
|---|---|---|---|---|---|
| 1 | Depth (in.) | Illite (%) | 21 | 0.448 | Y = 27.76 + 0.168X |
| 2 | Depth (in.) | Mixed layers (%) | 22 | -0.657 | Y = 52.81 - 0.219X |
| 4 | Moisture content | Mixed layers (%) | 21 | 0.471 | Y = 14.13 + 3.76 X |

* See Appendix B for test values of correlation coefficients.

Table 9. Clay mineral composition for immediate floor strata (mine 3).

| Site no. | Depth below coal seam (in) | Illite (I) (percent) | Kaolinite (percent) | Chlorite (percent) | Smectite (S) (percent) | * Mixed layer (percent) | ** Ratio S:I | Total clay (percent) |
|---|---|---|---|---|---|---|---|---|
| 1 | 6 | 35.0 | 4.0 | - | - | 61.0 | 0.92 | 33.0 |
| | 51 | 48.0 | 11.0 | - | - | 41.0 | 0.85 | 26.0 |
| | 100 | 54.0 | 6.0 | - | - | 40.0 | 0.67 | 23.0 |
| | 138 | 46.0 | 5.0 | - | - | 49.0 | 0.67 | 32.0 |
| 2 | 10 | 2.0 | 31.0 | - | - | 67.0 | 1.20 | 38.0 |
| | 33 | 34.0 | 6.0 | - | - | 60.0 | 1.20 | 31.0 |
| | 45 | 1.0 | 95.0 | - | - | 4.0 | 0.67 | 47.0 |
| 3 | 9 | 12.0 | 55.0 | 3.0 | - | 30.0 | 0.54 | 42.0 |
| | 48 | 47.0 | 11.0 | - | - | 42.0 | 0.61 | 35.0 |
| 4 | 4 | 36.0 | 3.0 | - | - | 61.0 | 0.85 | 47.0 |
| | 14 | 42.0 | 11.0 | - | - | 47.0 | 0.85 | 41.0 |
| | 16 | 9.0 | 33.0 | - | - | 58.0 | 1.04 | 51.0 |
| 5 | 27 | 46.0 | 8.0 | - | - | 46.0 | 0.92 | 40.0 |
| | 54 | 33.0 | 16.0 | - | - | 51.0 | 0.85 | 42.0 |
| | 113 | 50.0 | 17.0 | - | - | 33.0 | 0.75 | 43.0 |
| | 171 | 31.0 | 57.0 | - | - | 12.0 | 0.75 | 36.0 |
| 6 | 26 | 41.0 | 13.0 | - | - | 46.0 | 1.56 | 50.0 |
| | 87 | 53.0 | 16.0 | 3.0 | - | 28.0 | 0.75 | 30.0 |
| | 105 | 57.0 | 8.0 | - | - | 35.0 | 0.92 | 51.0 |
| | 131 | - | 88.0 | - | - | 12.0 | 0.75 | 42.0 |
| [illegible] | 22 | 42.0 | 8.0 | - | - | 50.0 | 0.75 | 54.0 |
| | 55 | 41.0 | 13.0 | - | - | 46.0 | 0.75 | 51.0 |
| | 114 | 56.0 | 6.0 | - | - | 38.0 | 0.82 | 59.0 |

* Percent of mixed layer smectite/illite present
** Ratio of smectite to illite within the mixed layer fraction
*** Unable to obtain total clay percentage due to severe flocculation

Table 10. Selected index properties of immediate floor strata (mine 1).

| Site no. | Depth below coal seam (in) | Rock type | Moisture content (percent) | Density (pfc) | Atterberg limits | | | Tensile strength (psi) |
|---|---|---|---|---|---|---|---|---|
| | | | | | LL[1] | PL[2] | PI[3] | |
| 1 | 2 | Grey shale | 2.63 | 159 | - | - | - | 339 |
| | 5-6 | Grey shale | 2.63 | - | - | - | - | - |
| | 7 | Grey shale | 2.70 | - | 24.17 | 13.82 | 10.35 | - |
| | 10 | Grey shale | 2.70 | 165 | - | - | - | 315 |
| | 14 | Grey shale | 2.73 | 158 | - | - | - | 298 |
| | 16-17 | - | 2.42 | - | - | - | - | - |
| | 19 | Grey shale | 2.42 | 160 | - | - | - | 400 |
| | 23 | Grey shale | - | 158 | 23.50 | 15.98 | 7.52 | 514 |
| | 27 | Grey shale | 2.47 | - | - | - | - | - |
| 2 | 1 | Grey shale | 1.61 | - | - | - | - | - |
| | 5-9 | Grey shale | 2.24 | - | 23.96 | 15.01 | 8.95 | - |
| | 15 | Grey shale | 2.30 | - | - | - | - | - |
| | 18 | Grey shale | - | 165 | - | - | - | 200 |
| | 19-22 | Grey shale | 2.41 | - | 23.75 | 16.88 | 6.87 | - |
| | 29 | Grey shale | 2.21 | - | - | - | - | - |
| | 34-36 | Grey shale | 2.43 | 160 | 22.16 | 15.96 | 6.62 | 762 |
| 3 | 3 | Limestone | 0.24 | - | - | - | - | - |
| | 6-9 | Limestone | 0.43 | - | - | - | - | - |
| | 12 | Limestone | 0.43 | - | - | - | - | - |
| | 14-18 | Limestone | 2.41 | - | 17.15 | 12.21 | 4.94 | - |
| | 21 | Limestone | 0.93 | 164 | - | - | - | 63 |
| | 24 | Grey shale | 4.28 | 158 | - | - | - | 541 |
| | 27-30 | Grey shale | 3.98 | - | - | - | - | - |
| | 32 | Grey shale | 3.68 | 163 | - | - | - | 377 |
| | 33-36 | Grey shale | 3.71 | - | - | 17.35 | - | - |

[1] Plastic Limit, [2] Liquid Limit, [3] Plasticity Index
Slake durability values are for two cycles of wetting and drying ($Id_2$)
Point Load Index values are for loading across bedding planes

Table 10. Continued.

| Site no. | Depth below coal seam (in) | Rock type | Moisture content (percent) | Density (pfc) | Atterberg limits | | | Tensile strength (psi) |
|---|---|---|---|---|---|---|---|---|
| | | | | | LL[1] | PL[2] | PI[3] | |
| 3 | 37 | Grey shale | 3.71 | - | - | - | - | - |
| | 41 | Grey shale | 2.81 | - | - | - | - | - |
| | 48 | Grey shale | 2.88 | - | - | - | - | - |
| | 52-56 | Grey shale | 2.88 | 26.95 | 16.31 | 10.64 | - | - |
| 4 | 1 | Limestone | 2.36 | - | - | - | - | - |
| | 2-8 | Limestone | 2.86 | 20.82 | 13.73 | 7.09 | - | - |
| | 8-10 | Limestone | 2.32 | - | - | - | - | - |
| | 11 | Limestone | 1.78 | - | - | - | - | - |
| | 17 | Limestone | 0.31 | 171 | - | - | - | 1152 |
| | 20 | Limestone | 0.67 | - | - | - | - | - |
| | 24-31 | Grey shale | 7.96 | 159 | - | - | - | 270 |
| | 32-34 | Grey shale | 3.54 | - | 28.96 | 19.34 | 9.62 | - |
| | 36 | Grey shale | 3.54 | 159 | - | - | - | 218 |
| | 44 | Grey shale | 3.41 | 153 | - | - | - | 200 |
| | 46-50 | Grey shale | 2.74 | 162 | 28.96 | 23.46 | 5.52 | 379 |
| | 51 | Shale | - | 160 | - | - | - | 405 |
| | 52.5-58.0 | Shale | 4.01 | 160 | - | - | - | 392 |
| | 58.5-63.0 | Shale | 2.75 | - | 26.45 | 20.01 | 6.44 | - |
| | 64 | Sandy shale | - | 163 | - | - | - | 335 |
| | 70 | Sandy shale | - | 162 | - | - | - | 421 |
| | 73.0-77.5 | Sandy shale | 2.63 | - | 24.90 | 16.60 | 8.30 | - |
| | 83.5-86.5 | Sandy shale | 2.37 | - | - | - | - | - |
| | 86.0-90.5 | Sandy shale | 2.07 | - | - | - | - | 410 |
| | 95 | Sandy shale | 2.02 | - | - | - | - | - |

[1] Plastic Limit, [2] Liquid Limit, [3] Plasticity Index
Slake durability values are for two cycles of wetting and drying ($Id_2$)
Point Load Index values are for loading across bedding planes

Table 10. Continued.

| Site no. | Depth below coal seam (in) | Rock type | Moisture content (percent) | Density (pfc) | Atterberg limits | | | Tensile strength (psi) |
|---|---|---|---|---|---|---|---|---|
| | | | | | LL[1] | PL[2] | PI[3] | |
| 5 | 0-2 | Underclay | 4.97 | - | 29.60 | 20.55 | 9.05 | - |
| | 4-6 | Underclay | 5.04 | - | - | - | - | - |
| | 10-17 | Underclay | 4.71 | - | 20.62 | 14.27 | 6.35 | - |
| | 14 | Underclay | - | 164 | - | - | - | 176 |
| | 16-19 | Underclay | 4.80 | - | - | - | - | - |
| | 23-26 | Underclay | 4.98 | - | 29.90 | 15.24 | 14.66 | - |
| | 30-33 | Underclay | 6.42 | - | 31.10 | 16.24 | 14.86 | - |
| | 33-36 | Underclay | 4.99 | - | - | - | - | - |
| | 43-46 | Grey shale | 3.05 | - | 22.66 | 13.62 | 9.04 | - |
| | 51 | Grey shale | 1.80 | - | - | - | - | - |
| | 54-56 | Grey shale | 0.97 | - | 28.12 | 15.58 | 12.54 | - |
| | 56-59 | Grey shale | 0.97 | 173 | - | - | - | 470 |
| 5 | 64 | Sandy shale | 1.62 | - | - | - | - | - |
| | 69 | Sandy shale | 1.86 | 160 | - | - | - | 289 |
| | 74-76 | Sandy shale | 1.73 | - | - | - | - | - |
| | 78 | Sandstone | 1.22 | - | - | - | - | - |
| | 81-84 | Sandstone | 1.96 | - | 17.25 | 14.55 | 2.70 | - |
| 6 | 1 | Grey shale | 4.25 | - | - | - | - | - |
| | 2-9 | Grey shale | 3.34 | - | 28.55 | 19.83 | 8.72 | - |
| | 9-17 | Grey shale | 5.05 | 163 | - | - | - | 313 |
| | 18 | Grey shale | 3.34 | - | - | - | - | - |
| | 20-27 | Grey shale | 5.44 | - | 28.83 | 17.84 | 11.04 | - |
| | 51 | Sandy shale | 2.43 | - | - | - | - | - |
| | 54-58 | Sandy shale | 2.07 | 158 | 21.10 | 14.83 | 6.27 | 484 |
| | 59-62 | Sandy shale | 2.21 | - | - | - | - | - |
| | 68-72 | Sandy shale | 1.77 | - | 19.20 | 13.75 | 5.45 | 451 |

[1] Plastic Limit, [2] Liquid Limit, [3] Plasticity Index
Slake durability values are for two cycles of wetting and drying ($Id_2$)
Point Load Index values are for loading across bedding planes

Table 10. Continued.

| Site no. | Depth below coal seam (in) | Rock type | Moisture content (percent) | Density (pfc) | Atterberg limits | | | Tensile strength (psi) |
|---|---|---|---|---|---|---|---|---|
| | | | | | LL[1] | PL[2] | PI[3] | |
| 7 | 1.0-4.5 | Grey shale | 2.50 | - | - | - | - | - |
| | 4.5-8.5 | Grey shale | 2.12 | - | 16.78 | 14.05 | 2.73 | - |
| | 14-18 | Sandy shale | 2.21 | - | 15.29 | 12.70 | 2.59 | - |
| | 19 | Sandy shale | 2.09 | 163 | - | - | - | 429 |
| | 20-22 | Sandy shale | 2.09 | - | - | - | - | - |
| | 28 | Sandy shale | 2.18 | 162 | - | - | - | 363 |
| | 31-33 | Sandy shale | 1.60 | - | 17.62 | 14.52 | 3.10 | - |
| | 33.5-36.0 | Sandy shale | 1.60 | - | - | - | - | - |
| | 38 | Sandy shale | 2.39 | - | - | - | - | - |
| | 42-45 | Sandy shale | 2.41 | 160 | 19.36 | 16.39 | 2.97 | 349 |
| | 45-48 | Sandy shale | 2.41 | - | - | - | - | - |
| | 53 | Sandy shale | 2.04 | - | - | - | - | - |
| | 56-60 | Sandy shale | 2.11 | 20.60 | 14.58 | 6.02 | - | - |
| | 60.5-62.5 | Sandy shale | 2.11 | - | - | - | - | - |
| 8 | 1 | Dark grey shale | 2.65 | 158 | - | - | - | 330 |
| | 2-5 | Dark grey shale | 3.65 | - | - | - | - | - |
| | 6-10 | Dark grey shale | 4.09 | 154 | - | - | - | 186 |
| | 15-18 | Dark grey shale | 3.98 | - | - | - | - | - |
| | 22-26 | Sandy shale | 2.44 | - | 18.70 | 15.44 | 3.26 | - |
| | 27 | Sandy shale | 2.32 | 161 | - | - | - | 392 |
| | 28.5-31.0 | Sandy shale | 2.32 | - | - | - | - | - |
| | 33-40 | Sandy shale | 2.66 | 157 | 15.52 | 12.15 | 3.37 | 317 |
| | 45-49 | Grey shale | 1.44 | 166 | - | - | - | 414 |
| | 52.5-54.5 | Grey shale | 2.11 | - | 18.90 | 17.76 | 1.14 | - |

1 Plastic Limit, 2 Liquid Limit, 3 Plasticity Index
Slake durability values are for two cycles of wetting and drying ($Id_2$)
Point Load Index values are for loading across bedding planes

Table 10. Continued.

| Site no. | Depth below coal seam (in) | Rock type | Moisture content (percent) | Density (pfc) | Atterberg limits | | | Tensile strength (psi) |
|---|---|---|---|---|---|---|---|---|
| | | | | | LL[1] | PL[2] | PI[3] | |
| | 55.5-61.0 | Grey shale | 2.25 | 165 | - | - | - | 370 |
| | 63-67 | Sandy shale | 2.19 | - | 20.31 | 14.50 | 5.81 | - |
| | 68.0-78.5 | Sandy shale | 2.13 | 161 | - | - | - | 775 |
| | 84.0-87.5 | Sandy shale | 1.86 | - | - | - | - | - |
| | 87.5-89.0 | Sandy shale | 2.56 | - | 22.56 | 18.85 | 3.71 | - |
| | 95 | Sandy shale | 4.15 | 167 | - | - | - | 545 |
| | 98 | Sandy shale | - | 162 | - | - | - | 319 |
| 9 | 1-5 | Underclay | 5.64 | - | 30.12 | 18.57 | 11.55 | - |
| | 5-13 | Underclay | 6.05 | - | - | - | - | - |
| | 14 | Underclay | 5.74 | - | - | - | - | - |
| | 16-24 | Underclay | 5.55 | - | 27.88 | 20.44 | 7.44 | - |
| | 25-29 | Grey shale (Lime nodulus) | 2.88 | - | - | - | - | - |
| | 31.0-35.5 | Grey shale (Lime nodulus) | 2.22 | - | 20.94 | 16.11 | 4.83 | - |
| | 36-40 | Grey shale (Lime nodulus) | 1.89 | 167 | - | - | - | 521 |
| | 42 | Grey shale (Lime nodulus) | 1.97 | - | - | - | - | - |
| | 46.5-50.5 | Grey shale (Lime nodulus) | 1.99 | - | 22.92 | 15.61 | 7.31 | - |
| | 52 | Grey shale (Lime nodulus) | 1.66 | 173 | - | - | - | 440 |
| | 59-61 | Sandy shale | 2.08 | 164 | 18.06 | 15.55 | 2.51 | 832 |

1 Plastic Limit, 2 Liquid Limit, 3 Plasticity Index
Slake durability values are for two cycles of wetting and drying ($Id_2$)
Point Load Index values are for loading across bedding planes

Table 10. Continued.

| Site no. | Depth below coal seam (in) | Rock type | Moisture content (percent) | Density (pfc) | Atterberg limits | | | Tensile strength (psi) |
|---|---|---|---|---|---|---|---|---|
| | | | | | LL[1] | PL[2] | PI[3] | |
| 9 | 62.5-68.0 | Sandy shale | 2.02 | 161 | - | - | - | 1001 |
| | 72 | Sandy shale | 1.93 | 161 | - | - | - | 619 |
| | 76 | Sandy shale | 2.04 | - | - | - | - | - |
| | 78.5-84.0 | Sandy shale | 2.04 | - | 20.30 | 14.16 | 6.14 | - |
| | 84-87 | Sandy shale | 2.19 | - | - | - | - | - |
| | 88 | Sandy shale | 2.04 | 160 | - | - | - | 492 |
| 10 | 0-5 | Underclay | 5.98 | - | - | - | - | - |
| | 6 | Underclay | 5.68 | - | - | - | - | - |
| | 12 | Underclay | 5.82 | - | - | - | - | - |
| | 14-18 | Underclay | 5.64 | - | 30.00 | 21.57 | 8.43 | - |
| | 27-30 | Underclay | 3.52 | - | - | - | - | - |
| | 32-37 | Shale | 2.10 | - | 21.90 | 16.23 | 5.67 | - |
| | 38 | Grey shale | 1.77 | - | - | - | - | - |
| | 40 | Grey shale | - | - | - | - | - | - |
| | 42 | Grey shale | 2.05 | 165 | - | - | - | 257 |
| | 47-50 | Grey shale | 2.45 | - | 20.83 | 14.02 | 6.81 | - |
| | 53 | Grey shale | - | 170 | - | - | - | 529 |
| | 54.5-57.0 | Grey shale | 1.13 | - | - | - | - | - |

[1] Plastic Limit, [2] Liquid Limit, [3] Plasticity Index
Slake durability values are for two cycles of wetting and drying ($Id_2$)
Point Load Index values are for loading across bedding planes

Table 11. Correlation analysis results for selected Atterberg limit variables.

Mine 1

| Test | X variable | Y variable | No. of points | Correlation coefficient (r*) | Linear regression equation |
|---|---|---|---|---|---|
| 1 | Depth (in.) | Natural moisture content | 77 | -0.424 | Y = 3.785 - 0.023 X |
| 2 | Natural moisture content | Total clay | 36 | 0.746 | Y = 14.909 + 3.959X |
| 3 | Plastic limit | Total clay | 33 | 0.517 | Y = 2.077 + 1.497 X |
| 4 | Moisture content | Liquid limit | 41 | 0.615 | Y = 16.241+ 2.239 X |
| 5 | Moisture content | Plastic limit | 40 | 0.386 | Y = 13.86 + 0.736 X |
| 6 | Moisture content | Plasticity index | 40 | 0.594 | Y = 2.305 + 1.567 X |
| 7 | Liquid limit | Plasticity index | 43 | 0.832 | Y = -6.807 + 0.594X |

Mine 3

| Test | X variable | Y variable | No. of points | Correlation coefficient (r*) | Linear regression equation |
|---|---|---|---|---|---|
| 1 | Depth (in.) | Plastic limit | 62 | -0.537 | Y = 21.99 - 0.052 X |
| 2 | Depth (in.) | Moisture content | 192 | -0.600 | Y = 8.36 - 0.0311 X |
| 3 | Moisture content | Total clay | 48 | +0.340 | -- |
| 4 | Moisture content | Liquid limit | 62 | 0.481 | Y = 23.77 + 2.22 X |
| 5 | Moisture content | Plasticity index | 62 | 0.340 | Y = 11.92 + 1.218 X |
| 6 | Liquid limit | Plasticity index | 62 | 0.897 | Y= -6.606 + 0.693 X |
| 7 | Depth (in.) | Liquid limit | 62 | -0.537 | Y = 46.43 - 0.121 X |
| 8 | Moisture content | Plastic limit | 62 | 0.526 | Y = 11.73 + 1.04 X |

* See Appendix C for test values of correlation coefficients.

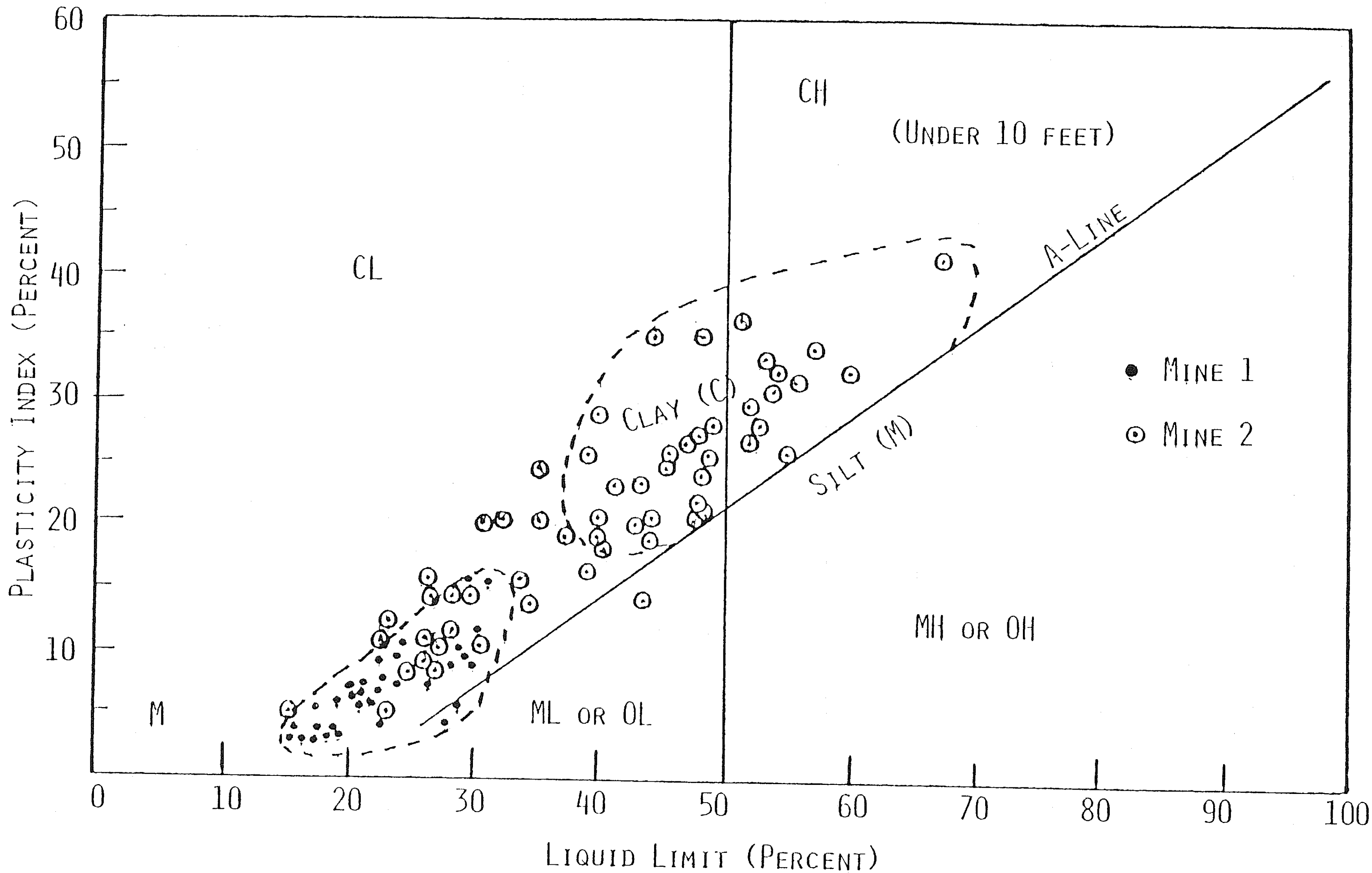



Figure 12. A plot of Atterberg limits data on plasticity chart (mines 1 and 3).

Table 12. Selected index properties of immediate floor strata (mine 3).

| Site no. | Depth below coal seam (in.) | Rock type | Moisture content (%) | Density (pcf) | Atterberg limits | | | Tensile strength (psi) | Swelling strain (%) | Slake durability (%) | Point load index (psi) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | LL[1] | PL[2] | PI[3] | | | | |
| 1 | 6 | Underclay | 8.63 | | | | | | | | |
| | 10 | Underclay | | 147.9 | 47.0 | 22.5 | 24.5 | 37.0 | | | 191.7 |
| | 12 | Underclay | 8.86 | | | | | | | | |
| | 22 | Underclay | 9.54 | | | | | | | | |
| | 30 | Underclay | 8.81 | | | | | | | | |
| | 34 | Underclay | | | 52.0 | 15.0 | 37.0 | | | | |
| | 38 | Underclay | 8.93 | | | | | | | | |
| | 44 | Underclay | 7.67 | | | | | | | | |
| | 50 | Underclay | 5.20 | | | | | | | | |
| | 54 | Underclay | | 158.1 | 29.3 | 18.8 | 10.5 | 87.8 | | 33.6 | 333.8 |
| | 58 | Underclay | 4.17 | | | | | | | | 575.7 |
| | 70 | Underclay | 4.63 | | | | | | | | |
| | 72 | Underclay | | | | | | | | | |
| | 76 | Underclay | 3.89 | | | | | | | | |
| | 86 | Underclay | 5.23 | | | | | | | | |
| | 96 | Mudstone | 5.12 | | | | | | | | |
| | 109 | Shale | 4.56 | | 45.1 | 14.0 | 35.1 | | | | |
| | 112 | Shale | | 153.6 | 41.8 | 13.7 | 28.1 | 195.8 | | | 439.4<br>443.1 |
| | 116 | Shale | 4.10 | | | | | | 18.1 | | |
| | 124 | Shale | 11.77 | | | | | | | | |
| | 126 | Shale | | | 31.9 | 11.7 | 20.2 | | | | |
| | 132 | Shale | 2.52 | | | | | | | | |
| | 145 | Shale | 1.85 | | | | | | | | |
| | 157 | Shale | 1.86 | 145.6 | 27.05 | 13.90 | 13.15 | | | | 258.6<br>673.2 |
| 2 | 8 | Underclay | 8.44 | | | | | | | | |
| | 16 | Underclay | 9.10 | | | | | | | | |
| | 21 | Underclay | | 149.2 | 48.9 | 22.2 | 26.7 | 46.8 | | | 962.7<br>547.8 |
| | 24 | Underclay | 8.31 | 149.7 | 38.6 | 22.6 | 16.0 | 62.8 | | | 334.1<br>298.1 |

Table 12. Continued.

| Site no. | Depth below coal seam (in.) | Rock type | Moisture content (%) | Density (pcf) | Atterberg limits LL[1] | PL[2] | PI[3] | Tensile strength (psi) | Swelling strain (%) | Slake durability (%) | Point load index (psi) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 32 | Underclay | 8.72 | | | | | | | | |
| | 41 | Underclay | | | | | | | 7.1 | | |
| | 42 | Underclay | 8.27 | | | | | | | | |
| | 45 | Underclay | 7.58 | | | | | | | | |
| | 54 | Underclay | 2.38 | | | | | | | | |
| | 62 | Underclay | 5.35 | | | | | | | | |
| | 70 | Underclay | | | | | | | | 63.4 | |
| | 72 | Underclay | | | | | | | 25.7 | | |
| | 74 | Underclay | 1.89 | | | | | | | | |
| 3 | 6 | Underclay | 7.17 | | 56.6 | 19.6 | 37.0 | | | | |
| | 9 | Underclay | | | 52.3 | 19.8 | 32.5 | | | | |
| | 12 | Underclay | 7.92 | | | | | | 25.71 | | |
| | 13 | Underclay | | | | | | | 20.05 | | |
| | 14 | Underclay | | | 15.75 | 12.20 | 5.55 | | | | |
| | 18 | Underclay | 8.31 | | | | | 151.6 | | | 131.9 |
| | 24 | Underclay | 8.24 | | | | | | | | |
| | 30 | Underclay | 7.61 | | | | | | | | |
| | 36 | Underclay | 7.45 | | | | | | | | |
| | 42 | Underclay | 8.41 | | | | | | | | |
| | 48 | Underclay | | | 49.2 | 21.1 | 28.1 | | | | |
| | 51 | Underclay | 1.92 | | | | | | | | |
| | 57 | Underclay | 4.21 | | | | | | | | |
| | 60 | Underclay | | | | | | 230.5 | | | 1594.8 |
| | | | | | | | | | | | 1180.5 |
| | 63 | Underclay | 3.97 | | | | | | 3.18 | | |
| | 70 | Underclay | 1.87 | | | | | | | | |
| | 75 | Sandy shale | 4.87 | | | | | | | | |
| | 81 | Sandy shale | 4.37 | | | | | | | | |
| | 90 | Sandy shale | | | | | | | 5.38 | | |
| | 93 | Sandy shale | | | | | | | 18.81 | | |
| | 96 | Sandy shale | | | | | | 386.1 | | | 878.9 |
| | | | | | | | | | | | 928.6 |

Table 12. Continued.

| Site no. | Depth below coal seam (in.) | Rock type | Moisture content (%) | Density (pcf) | Atterberg limits LL[1] | Atterberg limits PL[2] | Atterberg limits PI[3] | Tensile strength (psi) | Swelling strain (%) | Slake dura-bility (%) | Point load index (psi) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 3 | 108 | Underclay/ Claystone | | | 44.0 | 24.0 | 20.0 | | | | |
| | 137 | Black shale | | | | | | | 16.03 | | |
| | 139 | Black shale | | | | | | | 12.74 | | |
| | 156 | Grey shale | | | | | | 170.2 | | | 1024.2 |
| | | | | | | | | | | | 1017.9 |
| | 168 | Grey shale | | | | | | 841.2 | | | 511.8 |
| | | | | | | | | | | | 833.4 |
| | 180 | Grey shale | | | | | | 272.3 | | | |
| | 192 | Grey shale | | | | | | | 7.99 | | |
| | 198 | Grey shale | | | 24.5 | 18.31 | 6.19 | | | | |
| 4 | 4 | Underclay | 8.32 | | | | | | | | |
| | 10 | Underclay | 8.24 | | | | | | 15.10 | | |
| | 16 | Underclay | 7.67 | | | | | | | | |
| | 22 | Underclay | 7.83 | | | | | | | | |
| | 28 | Underclay | 7.69 | | | | | | | | |
| | 30 | Underclay | | | 42.9 | 9.4 | 23.5 | | | | |
| | 37 | Underclay | | | | | | | 14.17 | | |
| | 38 | Underclay | 6.58 | | | | | | | | |
| | 44 | Underclay | 5.18 | | | | | | | | |
| | 50 | Underclay | 5.62 | | | | | | | | |
| | 52 | Underclay | | | 32.9 | 16.4 | 16.5 | | 10.21 | | |
| | 56 | Underclay | 4.55 | | | | | | | | |
| | 60 | Underclay | | | 54.0 | 19.6 | 34.4 | | | | |
| 5 | 2 | Underclay | 8.26 | | | | | | | | |
| | 3 | Underclay | | | | | | | | | 810.6 |
| | 6 | Underclay | 8.73 | 146.6 | | | | 111.6 | 16.5 | | |
| | 12 | Underclay | 7.95 | | 45.6 | 21.10 | 24.6 | | | | |
| | 18 | Underclay | 5.52 | | 52.5 | 22.8 | 29.7 | | | | |
| | 24 | Underclay | 7.75 | | | | | | | | |
| | 30 | Underclay | 7.89 | | | | | | 13.8 | | |
| | 36 | Underclay | 8.82 | | 47.7 | 21.1 | 26.6 | | | | |
| | 42 | Underclay | 8.73 | | | | | | | | |

Table 12. Continued.

| Site no. | Depth below coal seam (in.) | Rock type | Moisture content (%) | Density (pcf) | Atterberg limits | | | Tensile strength (psi) | Swelling strain (%) | Slake dura-bility (%) | Point load index (psi) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | LL[1] | PL[2] | PI[3] | | | | |
| 5 | 48 | Underclay | 8.73 | | | | | | | | |
| | 56 | Underclay | | | 41.2 | 21.6 | 19.6 | | | | |
| | 60 | Underclay | 5.52 | | | | | | | | |
| | 62 | Underclay | | | | | | | | | 350.6 |
| | 65 | Underclay | | | | | | | 18.9 | | |
| | 66 | Underclay | 4.37 | 158.2 | | | | 340.2 | | | |
| | 71 | Underclay | | | | | | | | | 850.3 |
| | 72 | Underclay | 4.09 | | | | | | | | |
| | 78 | Underclay | 3.62 | | | | | | | | |
| | 84 | Underclay | 4.63 | | | | | | | | |
| | 90 | Silty shale | 1.13 | 160.2 | | | | 376.7 | | | |
| | 99 | Silty shale | | | 37.1 | 16.2 | 20.9 | | | | 438.3 |
| | 100 | Silty shale | 4.49 | 159.1 | | | | 211.7 | | | |
| | 106 | Black mudstone | 7.72 | | | | | | | | |
| | 107 | Black mudstone | | | | | | | 9.5 | | |
| | 110 | Black mudstone | | | 42.7 | 23.1 | 19.6 | | | | |
| | 112 | Black mudstone | 10.67 | | | | | | | | |
| | 118 | Black mudstone | 4.82 | 172.2 | | | | 216.9 | | | 800.5 |
| | | | | | | | | | | | 1118.8 |
| | 124 | Black mudstone | 4.71 | | 48.9 | 14.7 | 34.2 | | | | |
| | 133 | Black mudstone | 3.33 | | | | | | | | |
| | 137 | Black mudstone | | | | | | | | | 162.8 |
| | 139 | Black mudstone | 4.08 | | | | | | | | |
| | 142 | Sandy shale | | | | | | | | | 634.9 |
| | 145 | Sandy shale | 4.26 | 144.0 | | | | 229.8 | | | |
| | 153 | Grey shale | 3.18 | | | | | | | | |
| | 157 | Grey shale | | | 35.2 | 10.3 | 24.9 | | | | |
| | 159 | Grey shale | 3.64 | 164.8 | | | | 199.6 | | | |
| | 162 | Grey shale | | | | | | | 21.0 | | |
| | 165 | Grey shale | 4.31 | | | | | | | | |
| | 171 | Grey shale | 3.89 | 157.8 | | | | 265.6 | | | |
| | 183 | Grey shale | 2.71 | | | | | | | | |

Table 12. Continued.

| Site no. | Depth below coal seam (in.) | Rock type | Moisture content (%) | Density (pcf) | Atterberg limits LL[1] | PL[2] | PI[3] | Tensile strength (psi) | Swelling strain (%) | Slake dura-bility (%) | Point load index (psi) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 187 | Grey shale | | | | | | | 18.9 | | |
| | 189 | Grey shale | 2.23 | | | | | | | | |
| | 190 | Grey shale | | | | | | | | | 1014.2 |
| | 200 | Grey shale | | | | | | | 95.2 | | |
| 6 | 1 | Limy underclay | 4.20 | | | | | | | | |
| | 6 | Limy underclay | 5.07 | 150.6 | | | | 86.3 | | | |
| | 12 | Limy underclay | 7.87 | | | | | | | | |
| | 14 | Limy underclay | | | 53.4 | 21.0 | 32.4 | | | | |
| | 17 | Limy underclay | | | | | | | | | 69.1 |
| | | | | | | | | | | | 234.8 |
| | 18 | Limy underclay | 8.38 | | | | | | 36.84 | | |
| | 24 | Limy underclay | 8.40 | | | | | | | | |
| | 26 | Limy underclay | 6.86 | | 55.4 | 19.3 | 26.1 | | | | 54.2 |
| | | | | | | | | | | | 330.2 |
| | 30 | Limy underclay | 7.82 | | | | | | | | 330.6 |
| | | | | | | | | | | | 481.9 |
| | 36 | Limy underclay | 7.82 | 151.4 | 47.3 | 19.7 | 27.6 | | | | 516.7 |
| | | | | | | | | | | | 645.4 |
| | 41 | Limy underclay | 8.72 | 151.4 | | | | 143.2 | 14.59 | | |
| | 43 | Limy underclay | | | | | | | | | 190.9 |
| | | | | | | | | | | | 161.7 |
| | 46 | Limy underclay | | | | | | | 6.33 | | |
| | 48 | Limy underclay | 7.91 | | | | | | | | |
| | 49 | Limy underclay | 7.91 | | 46.4 | 19.9 | 26.5 | | | | |
| | 51 | Limy underclay | | | | | | | | | 173.8 |
| | | | | | | | | | | | 143.9 |
| | 54 | Limy underclay | 4.03 | | | | | | | | |
| | 72 | Shaly underclay | | | 24.1 | 15.5 | 8.6 | | | | 1089.0 |
| | | | | | | | | | | | 379.0 |
| | | | | | | | | | | | 586.3 |
| | 74 | Shaly underclay | 3.05 | 160.0 | | | | 331 | 3.10 | | |
| | 77 | Shaly underclay | | | | | | | | | 745.0 |
| | | | | | | | | | | | 703.6 |

Table 12. Continued.

| Site no. | Depth below coal seam (in.) | Rock type | Moisture content (%) | Density (pcf) | Atterberg limits LL[1] | PL[2] | PI[3] | Tensile strength (psi) | Swelling strain (%) | Slake durability (%) | Point load index (psi) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 6 | 79 | Shaly underclay | 3.17 | 158.4 | 25.8 | 16.1 | 9.7 | | | | |
| | 82 | Shaly underclay | | | | | | | 14.73 | | |
| | 87 | Shaly underclay | 4.83 | | | | | | | | |
| | 93 | Shaly underclay | 2.53 | | | | | | | | 367.3 |
| | | | | | | | | | | | 279.3 |
| | 99 | Grey shale | 2.32 | | | | | | | | |
| | 105 | Grey shale | | | | | | | 17.69 | | |
| | 107 | Grey shale | 6.08 | | | | | | | | |
| | 115 | Black mudstone | 7.71 | | | | | | | | |
| | 119 | Black mudstone | | | | | | | | | 284.3 |
| | | | | | | | | | | | 271.9 |
| | 121 | Black mudstone | 6.22 | | 40.2 | 19.0 | 21.2 | | | | |
| | 127 | Underclay | 4.35 | | | | | | | | |
| | 131 | Underclay | | | | | | | 20.77 | | |
| | 134 | Underclay | 3.67 | 164.5 | | | | 278.7 | | | |
| | 142 | Grey shale | 3.92 | 156.1 | | | | 147.7 | | | |
| | 146 | Grey shale | | | | | | | 15.11 | | |
| | 147 | Grey shale | 3.16 | | 37.2 | 17.7 | 19.5 | | | | |
| | 152 | Grey shale | | | | | | | 14.47 | | 524.3 |
| | | | | | | | | | | | 826.3 |
| | 157 | Grey shale | 2.62 | | | | | | | | |
| | 162 | Grey shale | | 152.7 | | | | 183.8 | | | 438.7 |
| | | | | | | | | | | | 409.3 |
| | 164 | Grey shale | | | 40.3 | 22.3 | 18.0 | | | | |
| | 166 | Grey shale | | | | | | | 18.08 | | |
| | 170 | Grey shale | 3.21 | | | | | | | | |
| 7 | 5 | Underclay | 8.98 | | 39.1 | 23.3 | 15.8 | | | | |
| | 9 | Underclay | 9.66 | 146.46 | | | | | | | |
| | 12 | Underclay | 8.75 | | 48.3 | 25.6 | 22.7 | | | | |
| | 18 | Underclay | 9.67 | | 43.5 | 25.1 | 18.4 | | | | |
| | 22 | Underclay | 9.83 | | 43.7 | 29.4 | 14.3 | | | | |
| | 29 | Underclay | 9.84 | | 32.8 | 18.8 | 14.0 | | | | |

Table 12. Continued.

| Site no. | Depth below coal seam (in.) | Rock type | Moisture content (%) | Density (pcf) | Atterberg limits | | | Tensile strength (psi) | Swelling strain (%) | Slake durability (%) | Point load index (psi) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | LL[1] | PL[2] | PI[3] | | | | |
| 7 | 36 | Underclay | | | 48.7 | 28.9 | 19.8 | | | | |
| | 40 | Underclay | 8.74 | | | | | | | | |
| | 44 | Underclay | | | 37.6 | 19.5 | 18.1 | | | | |
| | 48 | Underclay | 9.35 | 147.75 | | | | | | | |
| | 50 | Underclay | | | 45.7 | 22.0 | 23.7 | | | | |
| | 55 | Underclay | 9.18 | | 45.8 | 26.5 | 19.3 | | | | |
| | 60 | Underclay | 5.68 | 158.30 | 35.2 | 15.7 | 19.5 | | | | |
| | 67 | Underclay | 4.84 | | | | | | | | |
| | 70 | Underclay | | | 24.3 | 16.0 | 8.3 | | | | |
| | 72 | Underclay | 4.39 | 160.67 | | | | | | | |
| | 76 | Limestone | | | 24.6 | 12.6 | 12.0 | 144.68 | | | |
| | 78 | Limestone | 3.53 | 157.03 | | | | | | | |
| | 84 | Limestone | 4.69 | 161.30 | 27.0 | 17.1 | 9.9 | | | | |
| | 90 | Hard claystone | | | 27.6 | 16.0 | 11.6 | 90.30 | | | |
| | 92 | Hard claystone | 4.36 | | | | | | | | |
| | 96 | Hard claystone | 5.87 | | 28.2 | 16.3 | 11.9 | | | | |
| | 102 | Hard claystone | 5.03 | | 31.0 | 19.8 | 11.2 | | | | |
| | 108 | Hard claystone | | | 30.0 | 16.2 | 13.8 | 111.74 | | | |
| | 110 | Underclay | 9.62 | | | | | | | | |
| | 114 | Underclay | 10.34 | | 27.5 | 12.8 | 14.7 | | | | |
| 8 | 9 | Underclay | 9.91 | | | | | | | | |
| | 86 | Hard underclay | 4.24 | | | | | | | | |
| | 87 | Hard underclay | | | 23.4 | 12.4 | 11.0 | 253.82 | | | |
| | 90 | Hard underclay | 3.78 | 146.47 | | | | | | | |
| | 93 | Hard underclay | | | 22.4 | 11.1 | 11.3 | 209.07 | | | |
| | 94 | Hard underclay | 3.97 | | | | | | | | |
| | 100 | Hard underclay | | 159.47 | 22.7 | 10.3 | 12.4 | | | | |
| | 104 | Hard underclay | 4.78 | | | | | | | | |
| | 106 | Grey shale | | 158.27 | | | | | | | |
| | 108 | Grey shale | 4.16 | | 26.7 | 11.4 | 15.3 | 230.22 | | | |
| | 111 | Grey shale | | | | | | 218.67 | | | |
| | 112 | Grey shale | 4.77 | | 28.3 | 17.6 | 10.7 | | | | |

Table 12. Continued.

| Site no. | Depth below coal seam (in.) | Rock type | Moisture content (%) | Density (pcf) | Atterberg limits LL[1] | PL[2] | PI[3] | Tensile strength (psi) | Swelling strain (%) | Slake dura-bility (%) | Point load index (psi) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 8 | 116 | Grey shale | | | 28.9 | 17.6 | 11.3 | | | | |
| | 119 | Grey shale | | | | | | 162.15 | | | |
| | 120 | Grey shale | 5.07 | 160.06 | 28.1 | 15.9 | 12.2 | | | | |
| | 125 | Grey shale | | | | | | 186.02 | | | |
| | 126 | Grey shale | 5.03 | | 26.2 | 13.5 | 12.7 | | | | |
| | 133 | Grey shale | | | | | | 448.65 | | | |
| | 134 | Grey shale | 3.43 | | 16.9 | 7.8 | 9.1 | | | | |

[1]Plastic Limit, [2]Liquid Limit, [3]Plasticity Index
Slake durability values are for two cycles of wetting and drying ($Id_2$)
Point Load Index values are for loading across bedding planes

Table 13. Compressive strength-deformation properties of immediate floor strata (mine 1).

| Site no. | Depth below coal seam (in.) | Rock type | Moisture content (%) | Confining stress ($\sigma_3$, psi) | Axial stress ($\sigma_1$,psi) | Axial deformation modulus (X $10^6$ psi) | | Lateral deformation ratio * ($\epsilon_x/\epsilon_y$) | Cohesion (C,psi) | Friction angle ($\Phi$, deg.) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | at 50% of $\sigma_1$ | at 100% of $\sigma_1$ | | | |
| 1 | 12-16 | Grey shale | 2.73 | 0 | 4178.0 | 0.62 | 0.44 | 0.68 | | |
| 2 | 13-18 | Grey shale | 2.30 | 0 | 5633.1 | 0.82 | 0.53 | 0.45 | | |
| | 24-28 | Grey shale | 2.31 | 100 | 5025.4 | 0.68 | 0.28 | 0.26 | 1000 | 45.0 |
| | 28-34 | Grey shale | 2.21 | 300 | 7450.0 | | | | | |
| 3 | 33-36 | Grey shale | | 0 | 4653 | 0.52 | 0.12 | 0.46 | 900 | 45.0 |
| | 43-58 | Grey shale | 2.88 | 300 | 6244.6 | | | | | |
| 4 | 37.5-41 | Grey shale | 3.54 | 100 | 4808.2 | 0.65 | 0.56 | 1.19 | | |
| | 58.5-63 | Sandy shale | 2.75 | 0 | 5272.0 | 0.70 | 0.69 | 0.40 | 900 | 54.0 |
| | 65.5-70 | Sandy shale | 2.20 | 300 | 8361.2 | 0.90 | 0.61 | 0.21 | | |
| | 78-83 | Sandy shale | 2.63 | 500 | 10230.0 | | | | | |
| 5 | 23-26 | Underclay | 4.98 | 0 | 6836.0 | 0.42 | 0.44 | 0.27 | | |
| | 38-43 | Grey shale | 3.05 | 100 | 4855.1 | 0.75 | 0.92 | 0.54 | 1300 | 49.0 |
| | 47-51 | Grey shale | 1.80 | 300 | 7935.9 | 1.12 | 0.89 | 0.92 | | |
| 6 | 54-58 | Sandy grey shale | | 0 | 7387.0 | 1.04 | 0.79 | 0.19 | | |
| | 62-66 | Sandy grey shale | 2.32 | 100 | 8289.1 | | | | | |
| | 68-72 | Sandy grey shale | | 0 | 8029.0 | 1.26 | 1.06 | 0.45 | 1375 | 58.0 |
| 7 | 4.5-8.5 | Grey shale | 2.12 | 0 | 7876.0 | 1.06 | 1.20 | 0.78 | | |
| | 9-13 | Grey shale | 2.21 | 100 | 10759.2 | 1.20 | 0.88 | | | |
| | 14-18 | Sandy shale | 2.21 | 0 | 6528.0 | 1.14 | 0.68 | 0.42 | 1700 | 57.5 |

* 50% failure stress

Table 13. Continued.

| Site no. | Depth below coal seam (in.) | Rock type | Moisture content (%) | Confining stress ($\sigma_3$, psi) | Axial stress ($\sigma_1$,psi) | Axial deformation modulus (X $10^6$ psi) at 50% of $\sigma_1$ | at 100% of $_1$ | Lateral deformation ratio * ($\epsilon_x/\epsilon_y$) | Cohesion (C, psi) | Friction angle ($\Phi$, deg.) |
|---|---|---|---|---|---|---|---|---|---|---|
| 7 | 22-26.5 | Sandy grey shale | 2.18 | 300 | 11786.2 | 1.53 | 1.24 | 0.71 | | |
| | 48-53 | Sandy grey shale | 2.04 | 500 | 13304.3 | 1.32 | 1.15 | 0.99 | | |
| | 56-60 | Sandy grey shale | 2.11 | 0 | 9926 | 0.96 | 1.00 | | 1300 | 60.0 |
| | 62.5-66 | Sandy grey shale | 2.11 | 100 | 11671.9 | 1.16 | 1.00 | 0.22 | | |
| 8 | 63-67 | Sandy shale | 2.19 | 0 | 9136.0 | 1.33 | 0.72 | 0.48 | | |
| | 70.5-75 | Sandy shale | 2.13 | 100 | 9980.9 | | | | 1700 | 47.0 |
| | 79.5-84 | Sandy shale | 1.84 | 300 | 10669.4 | 0.89 | 0.66 | 0.51 | | |
| | 89-93.5 | Sandy shale | 2.25 | 500 | 12391.6 | 1.10 | 0.89 | 0.15 | | |
| 9 | 42-46.5 | Grey shale | 1.97 | 100 | 8407.5 | 0.94 | 0.44 | 0.13 | | |
| 10 | 43.5-47 | Grey shale | 2.45 | 0 | 7835.0 | 0.76 | 0.67 | 0.34 | 1300 | 52.0 |
| 9 | 54-58.5 | Grey shale | 1.66 | 300 | 10331.8 | 1.36 | 1.09 | 0.68 | | |

* 50% failure stress

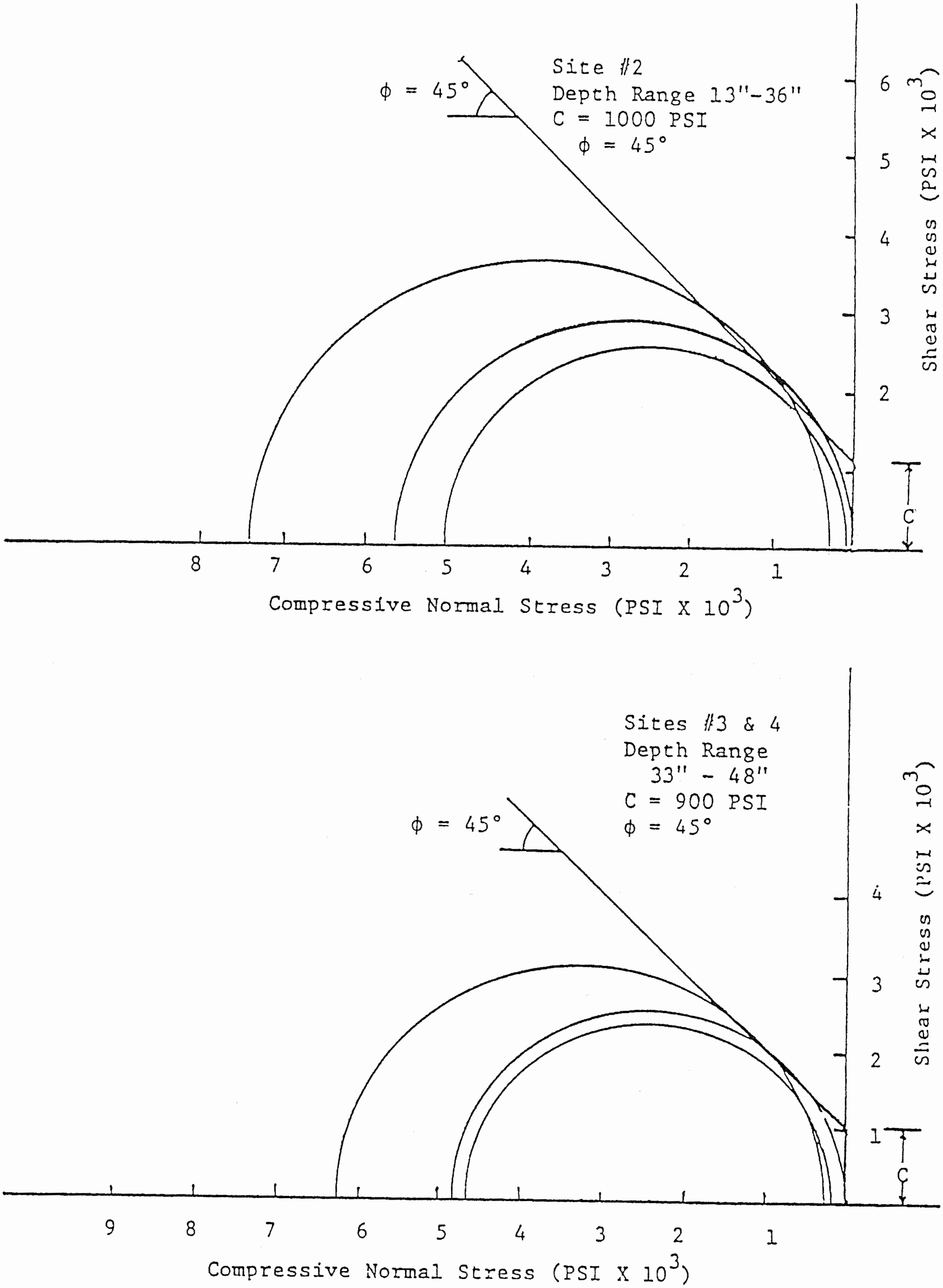



Figure 13. Mohr-circle diagrams for compressive strength data (mine 1).

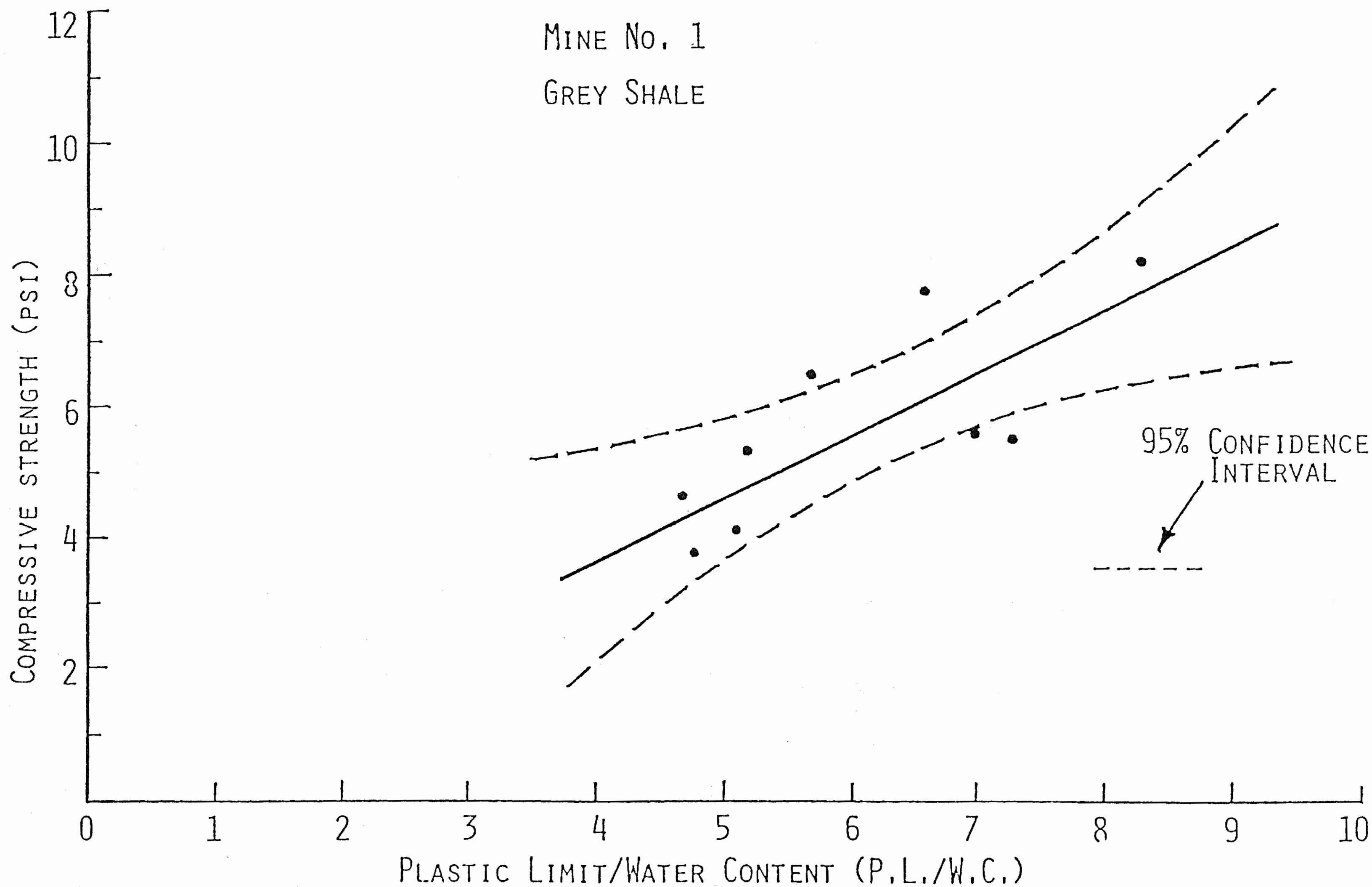
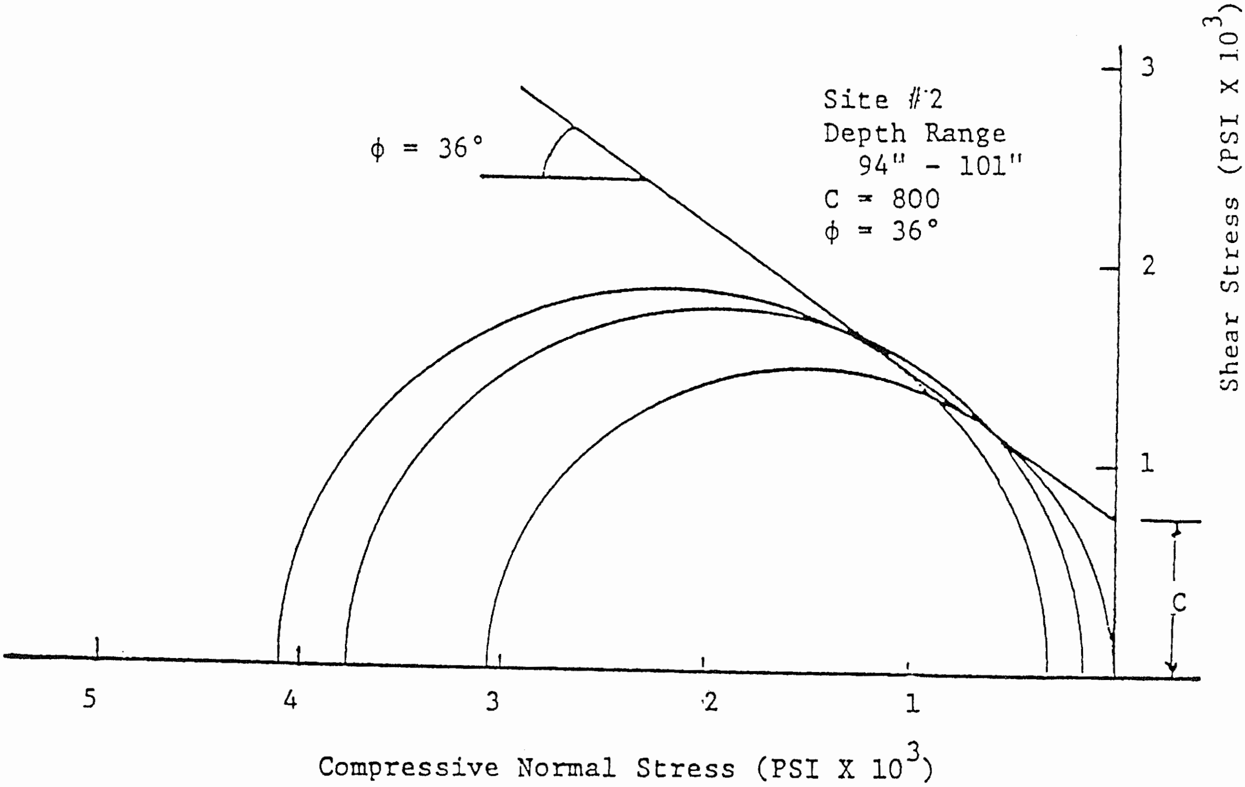



Figure 14. Variation of unconfined compressive strength with the ratio of PL/WC (mine 1).

Table 14. Compressive strength-deformation properties of immediate floor strata (mine 3).

| Site no. | Depth below coal seam (in.) | Rock type | Moisture content (%) | Confining stress ($\sigma_3$, psi) | Axial stress ($\sigma_1$, psi) | Axial deformation modulus (X $10^6$ psi) at 50% of $\sigma_1$ | at 100% of $\sigma_1$ | Lateral deformation ratio * ($\epsilon_x/\epsilon_y$) | Cohesion (C, psi) | Friction angle ($\Phi$, deg.) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 50 | Underclay | 5.20 | 0 | 3487.00 | 0.292 | 0.088 | - | 1842 * | - |
| | 3-6 | Underclay | 8.63 | 500 | 3883.27 | 0.268 | 0.278 | - | - | - |
| 2 | 99 | Underclay | 6.91 | 0 | 3033.17 | 0.373 | 0.376 | - | - | - |
| | 86-93 | Underclay | 5.23 | 100 | 3781.01 | - | - | - | 800 | 36 |
| | 97-101 | Mudstone | 9.16 | 300 | 4097.34 | 0.352 | 0.311 | - | - | - |
| | 94-97 | Underclay | 5.12 | 500 | 4256.00 | 0.498 | 0.390 | - | - | - |
| 3 | 147 | Grey Shale | - | 0 | 3279.43 | 0.462 | 0.127 | - | - | - |
| | 132-136 | Black Shale | - | 100 | 3525.73 | 0.331 | 0.277 | - | 1793 * | - |
| | 124-127 | Black Shale | - | 300 | 3483.29 | 0.349 | 0.256 | - | - | - |
| | 139 | Black Shale | - | 500 | 4055.90 | 0.296 | 0.297 | - | - | - |
| 4 | 173-183 | Grey Shale | - | 0 | 743.37 | 0.230 | 0.003 | - | - | - |
| | 197 | Grey Shale | - | 100 | 2993.00 | 0.393 | 0.494 | - | 1442 * | - |
| | 173-183 | Grey Shale | - | 300 | 2777.90 | 0.459 | 0.428 | - | - | - |
| 5 | 208 | Grey Shale | - | 0 | 2890.05 | 0.350 | 0.443 | - | - | - |
| | 180-216 | Grey Shale | 2.17 | 100 | 1958.07 | 0.421 | 0.324 | - | 800 | 35 |
| | 180-216 | Grey Shale | 2.17 | 300 | 4559.16 | 0.490 | 0.429 | - | - | - |
| | 180-216 | Grey Shale | 2.23 | 500 | 4757.39 | 0.487 | 0.614 | - | - | - |

* High cohesion values were obtained because friction angle was assumed to be zero.



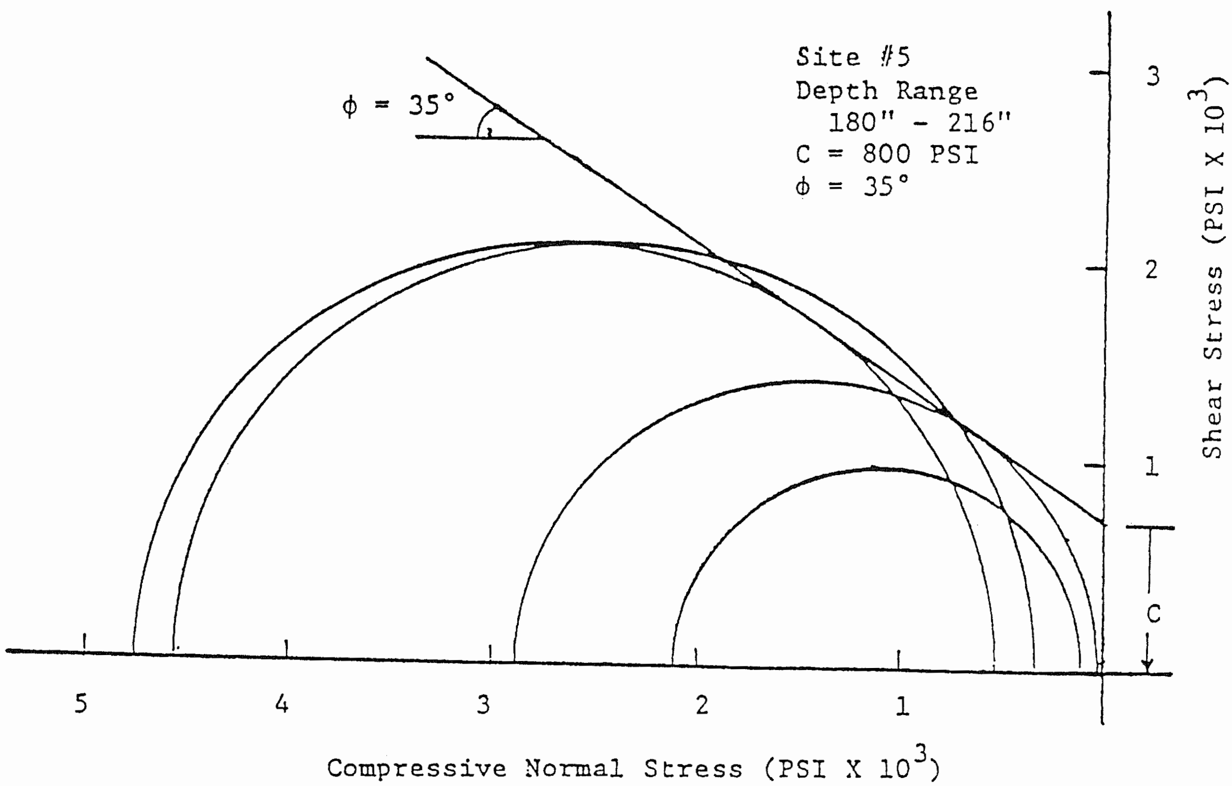




Figure 15. Mohr-circle diagrams for compressive strength data (mine 3).

Table 15. Summary of observations on ground control problems at sampling sites (mine 1).

| Site no. | Location | Period site open | Width and height of entry (ft) | Pillar size (ft) | Presence of water | Ground control problems | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | Roof | Coal pillar | Floor |
| 1, 2 | NE-2R | 4 wk | 18 x 7.3 | 75 x 75 | None | Fractured grey shale | Sloughing in middle and top | None |
| 3, 4 | NE-mains | 3 wk | 18 x 6.0 | 85 x 110 | None | Thinly bedded fractured grey shale | Sloughing towards top | None |
| 5, 6 | West-mains | 2 yr | 18 x 5.2 | 85 x 100 | 8 ft below coal seam | Thinly bedded fractured grey shale | Sloughing towards top | None |
| 7, 8 | SW-submains | 8 wk | 18 x 5.2 | 85 x 100 | None | Relatively competent grey shale | None | None |
| 9, 10 | 5L panel of West Mains | 4 wk | 18 x 5.2 | 85 x 75 | None | Thinly bedded grey shale | None | None |

Table 16. Summary of observations on ground control problems at sampling sites (mine 3).

| Site no. | Location | Period site open | Width and height of entry (ft) | Pillar size (ft) | Presence of water | Ground control problems | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | Roof | Coal pillar | Floor |
| 1 | 2R 1E | | 20 X 5.5 | | | | | |
| 2 | 2R 1E | | 20 X 5.5 | | | | | |
| 3, 4 | 4L-1W | 2-3 wk | 20 X 5.5 | 70 X 70 | Roof, coal, and floor | Black shale-limestone, looks stable | Sloughing in upper and lower portions, cracks in pillars | < 1 " floor heave |
| 5, 6 | 4L-1W | 1-2 wk | 20 X 6.0 | 55 X 55 | Bottom portion of coal pillar | Same as above 1-ft clay dike, looks stable | Same as above | < 0.5 " floor heave |
| 7, 8 | 4L-1W | 1-2 wk | 20 X 5.5 | 55 X 55 | None | Black shale-limestone, localized falls | Sloughing in upper portion | 1" floor heave, cracks in center of roadway |

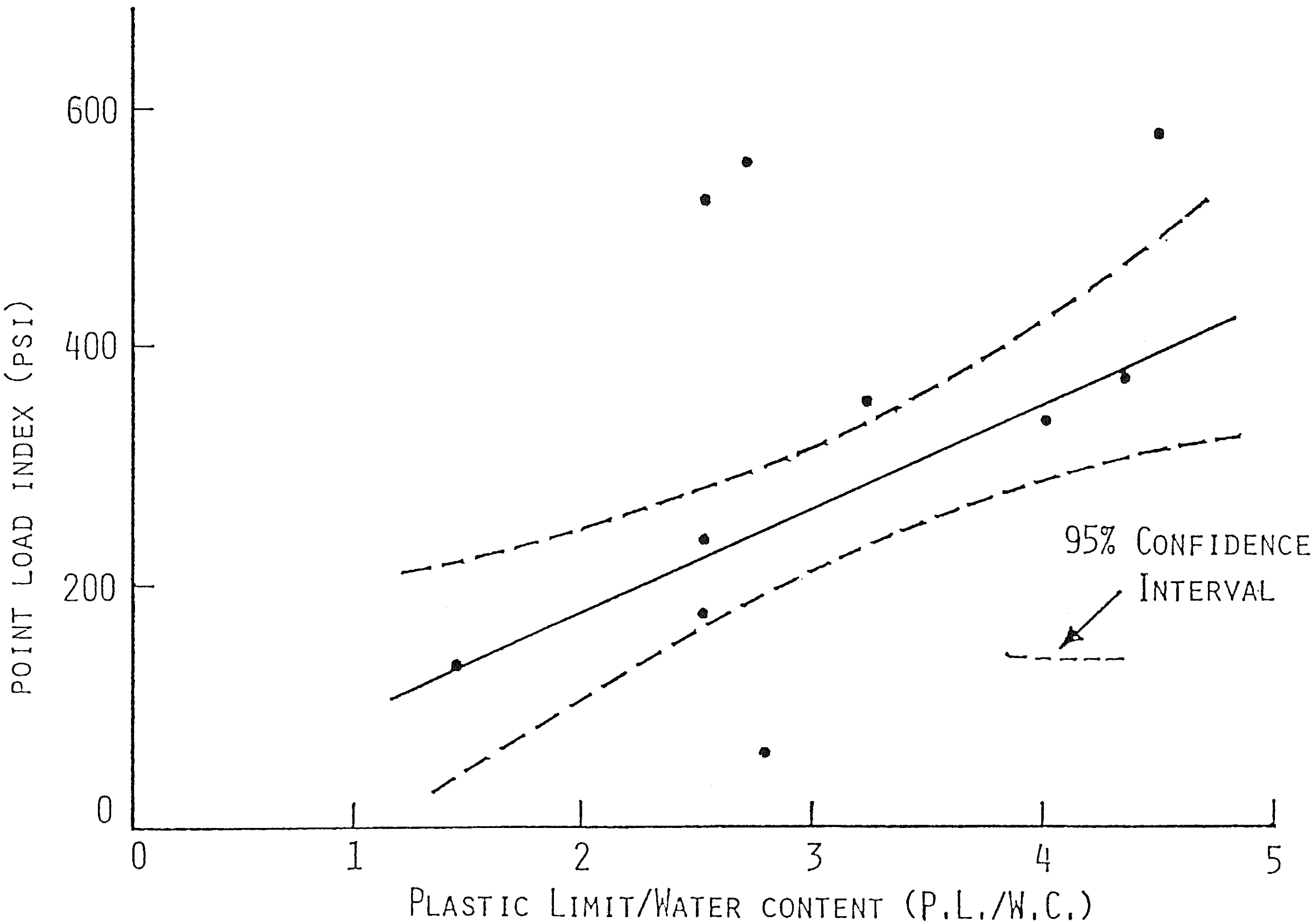
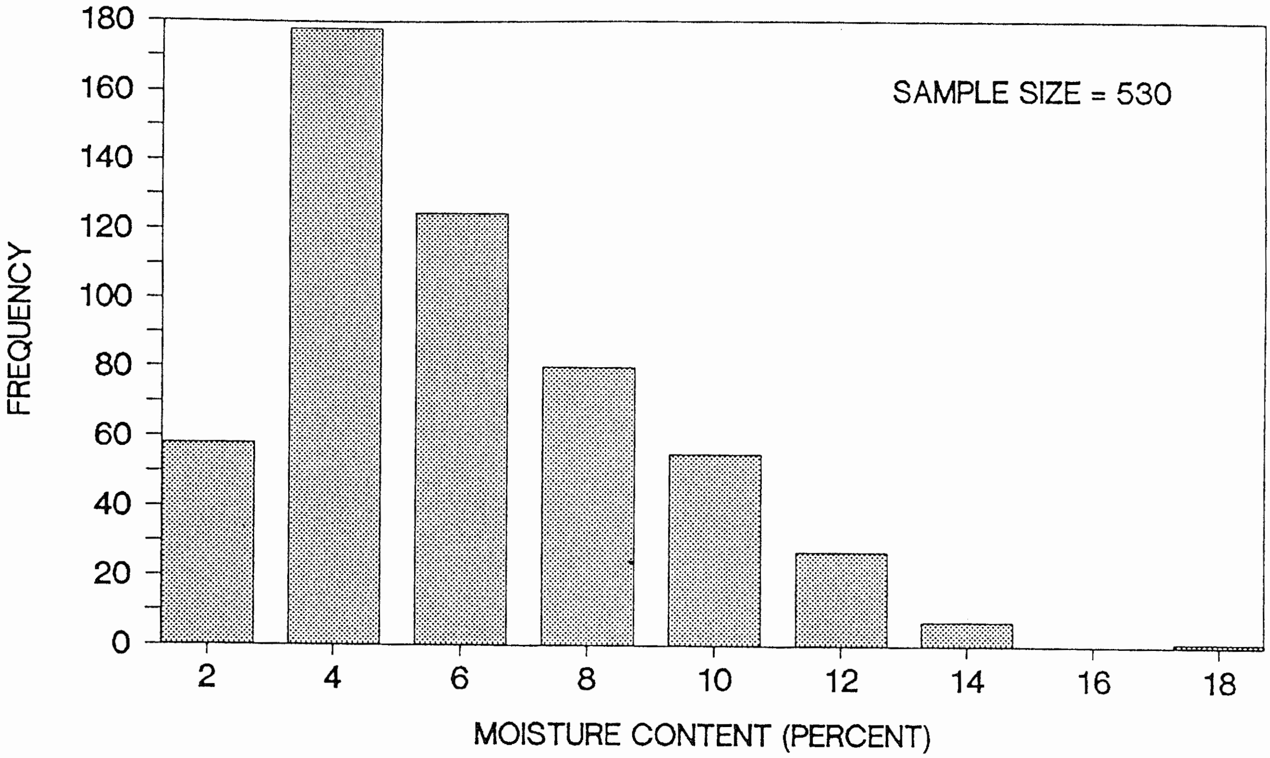



Figure 16. Correlation of point load index with the ratio of PL/WC (mine 3).



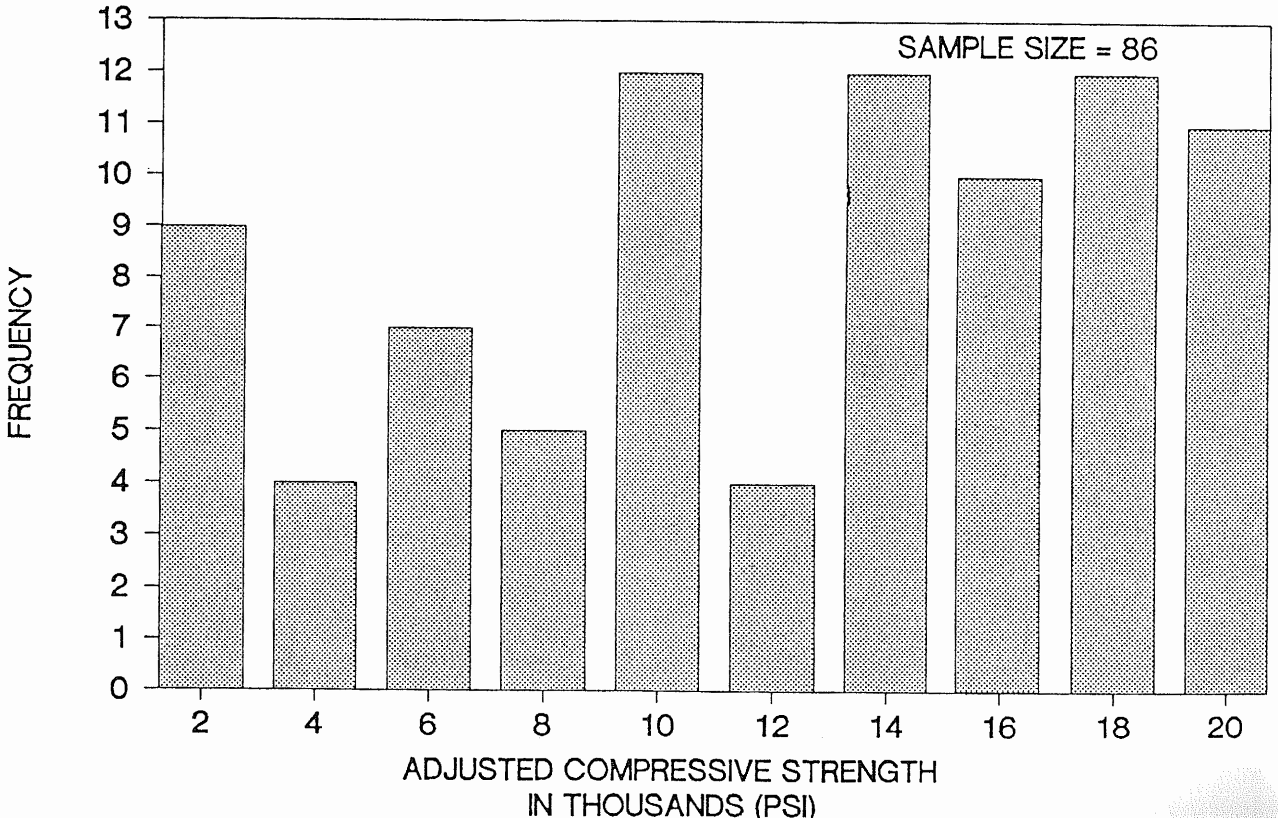




Figure 17. Histogram plots for natural moisture content and unconfined compressive strength.

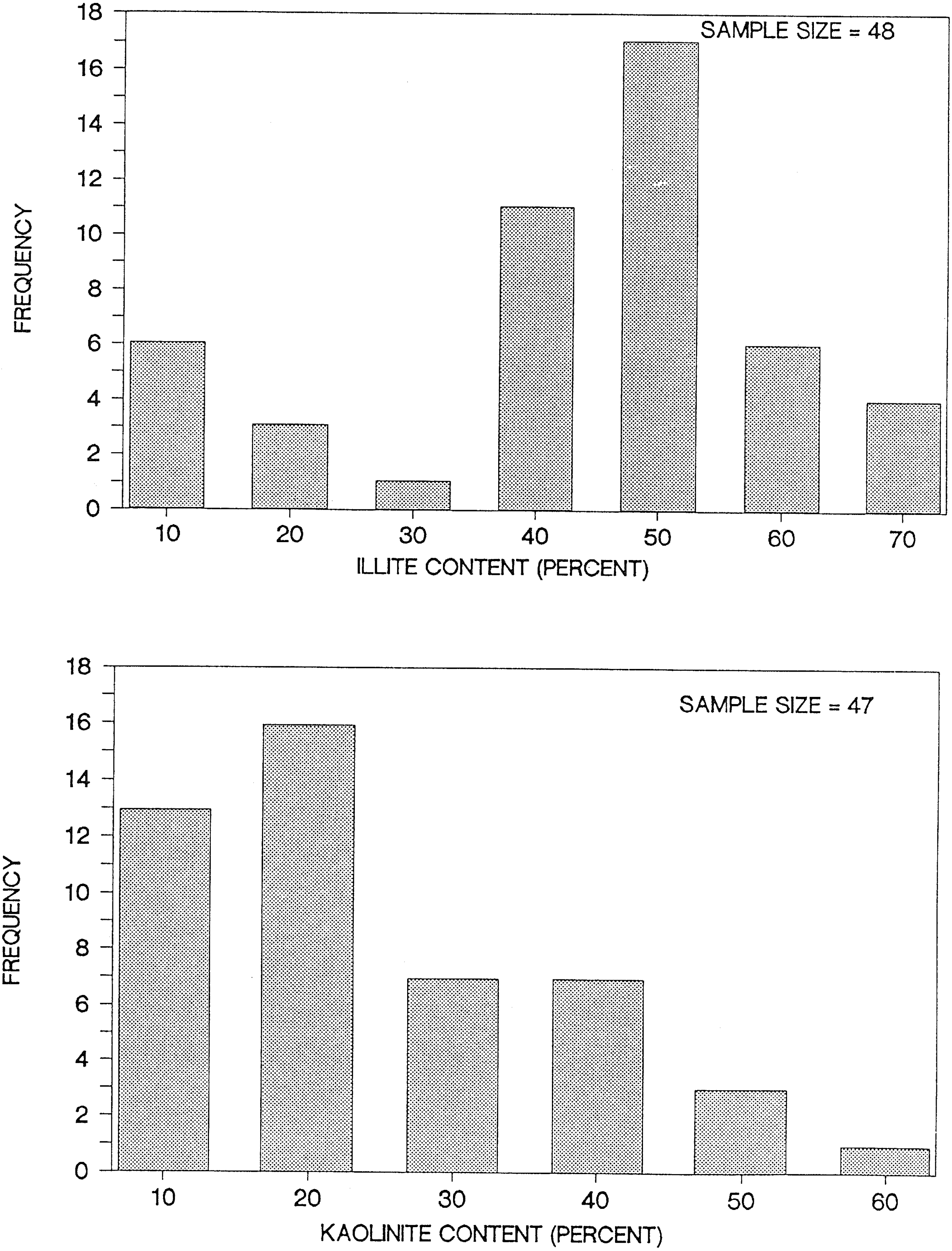



Figure 18. Histogram plots for illite and kaolinite contents.

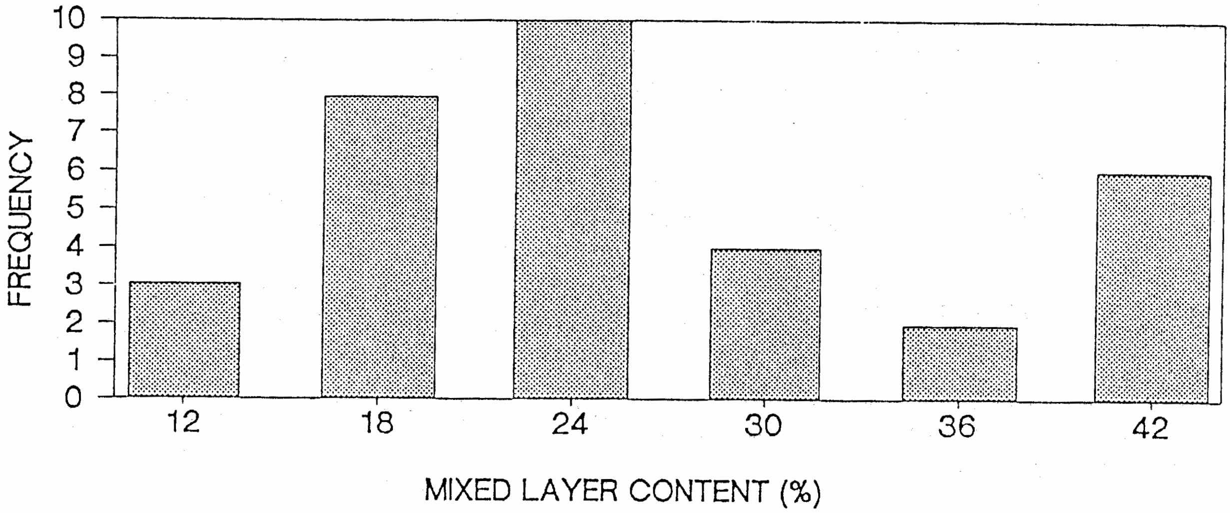



Figure 19. Histogram plot for mixed-layers content.

## APPENDIX A. DEFORMATION MODULI FOR DISCONTINUOUS ROCK MASSES

Classical definitions of the modulus of elasticity and Poisson's ratio apply to an elastic continuum only. A discontinuous rock mass, such as an underclay associated with a coal seam, behaves very differently when subjected to stress. Typical stress-axial strain and stress-lateral strain curves for such a rock are shown in figure A.1. The following comments are pertinent:

1) Both curves are S-shaped and are characterized by low slope values at low and high stresses. Linear portions of the curve may or may not exist.

2) None or only a portion of the strains, particularly lateral strains, may be recoverable at any stress level.

3) The ratio of lateral to axial strains at any point along the curve may be larger than 0.5, which violates the definition of a continuum.

The above comments make the definition of deformation moduli by terms Modulus of Elasticity and Poisson's ratio improper. Therefore, the following terms were used in this report to define moduli of deformation.

$$\text{Axial Deformation Modulus} = \frac{\text{Axial Stress}}{\text{Axial Strain}}$$

$$\text{Lateral Deformation Ratio} = \frac{\text{Lateral Strain}}{\text{Axial Strain}}$$

Tangent or secant values of these moduli of deformation may be calculated.

Although, these terms correspond to definitions of the modulus of elasticity and Poisson's ratio for an elastic continuum, they can be used for continuous and discontinuous rock masses as well as for nonelastic rock masses.

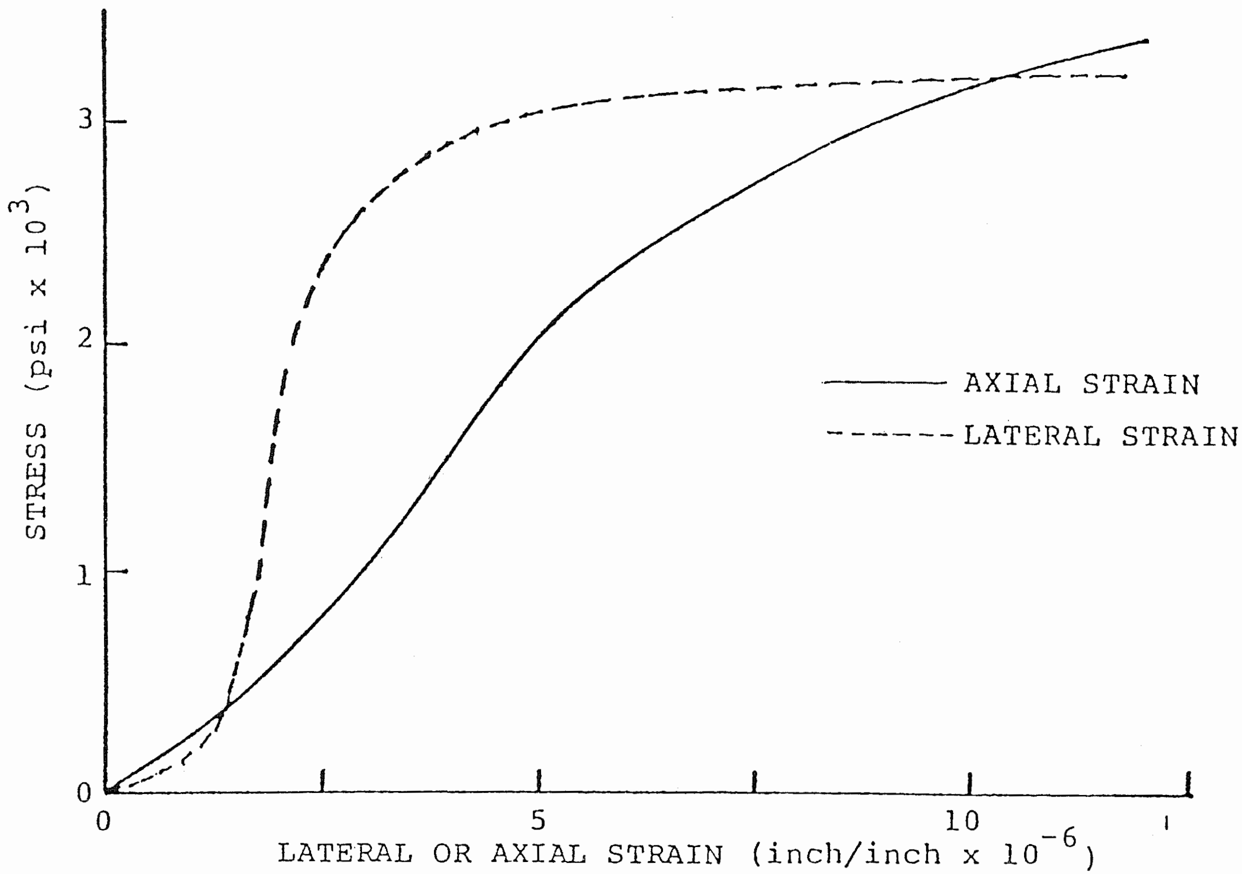



Figure A.1. Typical axial stress-axial strain and axial stress-lateral strain curves for a discontinuous rock mass.

## APPENDIX B. TEST VALUES FOR CORRELATION COEFFICIENTS

This table is used to determine the level of significance for the calculated correlation coefficient between two variables (Whitstitt et al., 1986). For a given number of observations (samples), the test values of correlation coefficients for selected levels of significance between 80 and 99.9 percent are supplied below. The calculated correlation coefficient may be compared with the test values in the table to estimate the level of significance of a correlation.

Table B.1. Test values for correlation coefficients.

| Number of samples | Degrees of freedom | 80% | 90% | 95% | 99% | 99.9% |
|---|---|---|---|---|---|---|
| 3 | 1 | 0.951 | 0.988 | 0.997 | 1.000 | 1.000 |
| 4 | 2 | 0.800 | 0.900 | 0.950 | 0.990 | 0.999 |
| 5 | 3 | 0.687 | 0.805 | 0.878 | 0.959 | 0.991 |
| 6 | 4 | 0.608 | 0.729 | 0.811 | 0.917 | 0.974 |
| 7 | 5 | 0.551 | 0.669 | 0.755 | 0.875 | 0.951 |
| 8 | 6 | 0.507 | 0.621 | 0.707 | 0.834 | 0.925 |
| 9 | 7 | 0.472 | 0.582 | 0.666 | 0.798 | 0.898 |
| 10 | 8 | 0.443 | 0.549 | 0.632 | 0.765 | 0.872 |
| 11 | 9 | 0.419 | 0.521 | 0.602 | 0.735 | 0.847 |
| 12 | 10 | 0.398 | 0.497 | 0.576 | 0.708 | 0.823 |
| 13 | 11 | 0.380 | 0.476 | 0.553 | 0.684 | 0.801 |
| 14 | 12 | 0.365 | 0.457 | 0.532 | 0.661 | 0.780 |
| 15 | 13 | 0.351 | 0.441 | 0.514 | 0.641 | 0.760 |
| 16 | 14 | 0.338 | 0.426 | 0.497 | 0.623 | 0.742 |
| 17 | 15 | 0.327 | 0.412 | 0.482 | 0.606 | 0.725 |
| 18 | 16 | 0.317 | 0.400 | 0.468 | 0.590 | 0.708 |
| 19 | 17 | 0.308 | 0.389 | 0.456 | 0.575 | 0.693 |
| 20 | 18 | 0.299 | 0.378 | 0.444 | 0.561 | 0.679 |
| 21 | 19 | 0.291 | 0.369 | 0.433 | 0.549 | 0.665 |
| 22 | 20 | 0.284 | 0.360 | 0.433 | 0.549 | 0.665 |
| 23 | 21 | 0.277 | 0.352 | 0.413 | 0.526 | 0.640 |
| 24 | 22 | 0.271 | 0.344 | 0.404 | 0.515 | 0.629 |
| 25 | 23 | 0.265 | 0.337 | 0.396 | 0.505 | 0.618 |
| 26 | 24 | 0.260 | 0.330 | 0.388 | 0.496 | 0.607 |
| 27 | 25 | 0.255 | 0.323 | 0.381 | 0.487 | 0.597 |
| 28 | 26 | 0.250 | 0.317 | 0.374 | 0.479 | 0.588 |
| 29 | 27 | 0.245 | 0.311 | 0.367 | 0.471 | 0.579 |
| 30 | 28 | 0.241 | 0.306 | 0.361 | 0.463 | 0.570 |
| 31 | 29 | 0.237 | 0.301 | 0.355 | 0.456 | 0.562 |
| 32 | 30 | 0.233 | 0.296 | 0.349 | 0.449 | 0.554 |
| 42 | 40 | 0.202 | 0.257 | 0.304 | 0.393 | 0.490 |
| 62 | 60 | 0.165 | 0.211 | 0.250 | 0.325 | 0.408 |
| 122 | 120 | 0.117 | 0.150 | 0.178 | 0.232 | 0.294 |

## APPENDIX C. SUPPLEMENTARY RESULTS

1) Lithologic descriptions. A limited number of lithologic descriptions were included in Chapter IV. Additional descriptions are included here: figures C.1. to C.8. are for mine 1 and figures C.9. to C.13. for mine 3.

2) Mohr-circle diagrams for compressive strength tests. Typical Mohr-circle diagrams for samples from mines 1 and 3 were presented in Chapter IV. Similar diagrams (figures C.14. to C.18.) for additional samples from mines 1 and 3 are presented here.

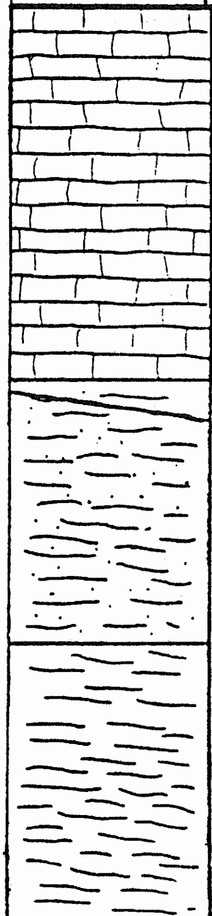
3) Histogram plots for selected variables (mine 1). Natural moisture content, plastic limit, plasticity index, illite, kaolinite, and mixed-layer contents data are presented in figures C.19. to C.24.

4) Histogram plots for selected variables (mine 3). Data for variables in 3 above for this mine are presented in figures C.25. to C.30.

5) Linear regression for selected variables (mine 1). Linear regression plots for moisture content vs total clay size content and unconfined compressive strength vs total clay size content are shown in figure C.31. and C.32.

6) Linear regression for selected variables (mine 3). Linear regression plots as in (5) above for mine 3 are shown in figures C.33. and C.34.

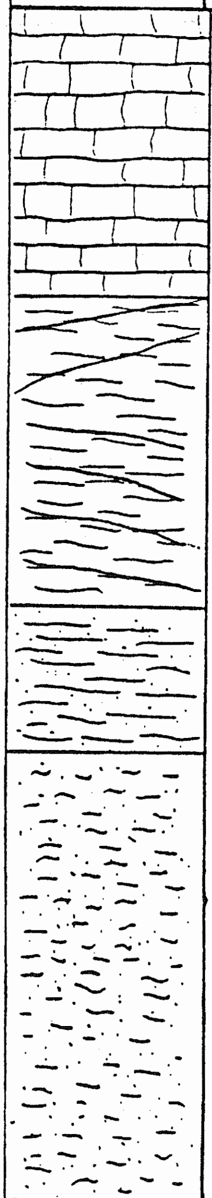
Figure C.1. Lithologic description for site 3 (mine 1).



| Core Log | Depth (in) | Core Description | RQD (%) Lithologic Unit | RQD (%) (Core Run) |
|---|---|---|---|---|
| | 0 | Limestone. | 100 | 100<br>95 |
| | 23 | Grey shale. Calcite content decreasing with depth. Slickensides present between 25 in and 25.5 in. | 41 | 41 |
| | 39 | Grey shale. No calcite present. Fractures present between 39 in and 40 in. Slickensides present between 52 in and 53 in. | 35 | 37<br>35 |
| | 56 | | | |

Scale 1 in = 12 in

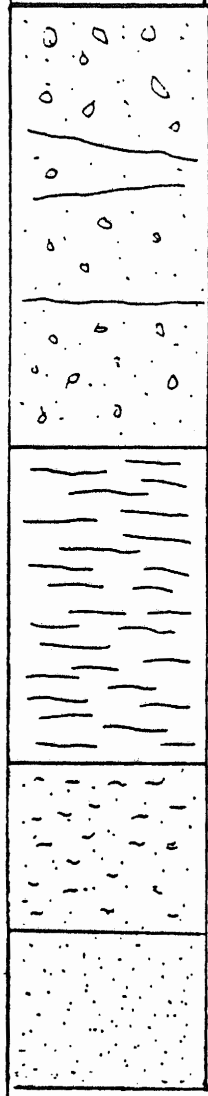
Figure C.2. Lithologic description for site 4 (mine 1).



| Core Log | Depth (in) | Core Description | RQD (%) Lithologic Unit | RQD (%) (Core Run) |
|---|---|---|---|---|
| | 0 | Limestone. | 100 | 100<br>100 |
| | 23.5 | Hard Grey Shale, no calcite present. Shear fractures present. | 0 | 0<br>0 |
| | 49 | Grey Shale with limestone nodules. | 38 | 35 |
| | 61 | Sandy Shale. No slickensides. | 95 | 90<br>95<br>95 |
| | 98 | | | |

Scale 1 in = 16 in

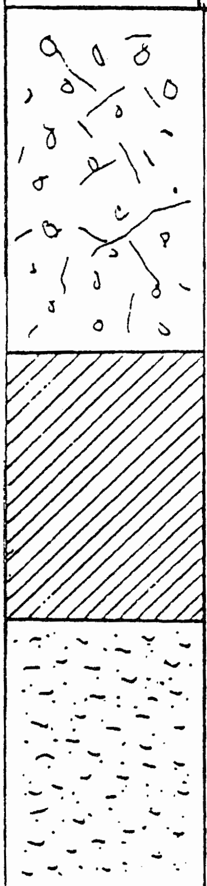
Figure C.3. Lithologic description for site 5 (mine 1).



| Core Log | Depth (in) | Core Description | RQD (%) Lithologic Unit | RQD (%) (Core Run) |
|---|---|---|---|---|
| | 0 | Underclay, broken into small pieces. No calcite present. | 0 | 0 |
| | | | | 0 |
| | | | | 0 |
| | 36 | Hard grey shale, no calcite present. | 39 | 39 |
| | | | | 39 |
| | 62 | Sandy shale with limestone nodules. Sand content increasing with depth. | 29 | 31 |
| | 76 | Sandstone. No calcite present. | 50 | 45 |
| | 88 | | | |

Scale 1 in = 16 in

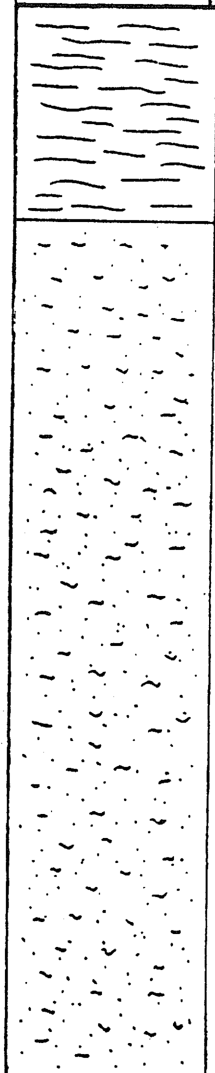
Figure C.4. Lithologic description for site 6 (mine 1).



| Core Log | Depth (in) | Core Description | RQD (%) Lithologic Unit | RQD (%) (Core Run) |
|---|---|---|---|---|
| | 0 | Dark grey shale. Rock is fractured. No calcite present. | 0 | 0<br>0 |
| | 28 | Core lost. | | |
| | 50 | Sandy grey shale. No calcite present. No slickensides. | 22 | 22<br>22 |
| | 72 | | | |

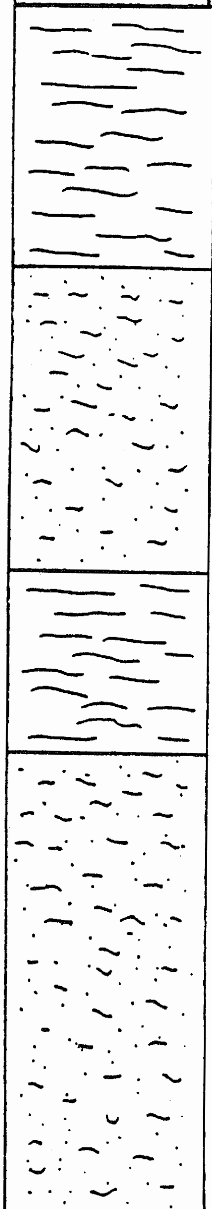
Scale 1 in = 16 in

Figure C.5. Lithologic description for site 7 (mine 1).

| Core Log | Depth (in) | Core Description | RQD (%) Lithologic Unit | RQD (%) (Core Run) |
|---|---|---|---|---|
|  | 0 | Grey shale with small amount of black shale. No calcite present. | 65 | 65 |
| | 13 | Sandy grey shale. No calcite present. No slickensides and shear fractures present. Sand content increases with increasing depth. | 93 | 91<br>93<br>93<br>93 |
| | 66 | | | |

Scale 1 in = 12 in

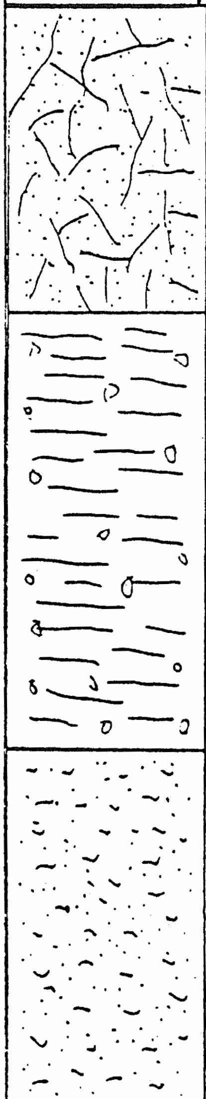
Figure C.6. Lithologic description for site 8 (mine 1).



| Depth (in) | Core Description | RQD (%) Lithologic Unit | RQD (%) (Core Run) |
|---|---|---|---|
| 0 | Dark grey shale, small particles of black shale. No calcite present. Small slickensides present between 6" to 7". No shear fractures. | 52 | 52<br>52 |
| 21 | Sandy grey shale. No calcite present. No slickensides and shear fractures | 52 | 52<br>49 |
| 46 | Light grey shale. No calcite present. | 33 | 33 |
| 61 | Sandy grey shale. Fine particles and mica present. No limestone nodules. Sand content increases with increasing depth. | 68 | 65<br>68<br>68 |
| 99 | | | |

Scale 1 in = 16 in

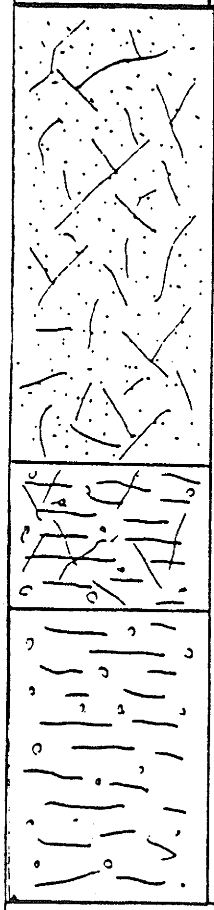
Figure C.7. Lithologic description for site 9 (mine 1).



| Core Log | Depth (in) | Core Description | RQD (%) Lithologic Unit | RQD (%) (Core Run) |
|---|---|---|---|---|
| | 0 | Underclay. Rock is fractured. No calcite present. | 0 | 0<br>0 |
| | 25 | Grey shale with lime nodules. No slickensides and shear fractures present. | 56 | 51<br>56<br>56 |
| | 61 | Sandy grey shale with small mica particles. No calcite present. | 100 | 96<br>100 |
| | 90.5 | | | |

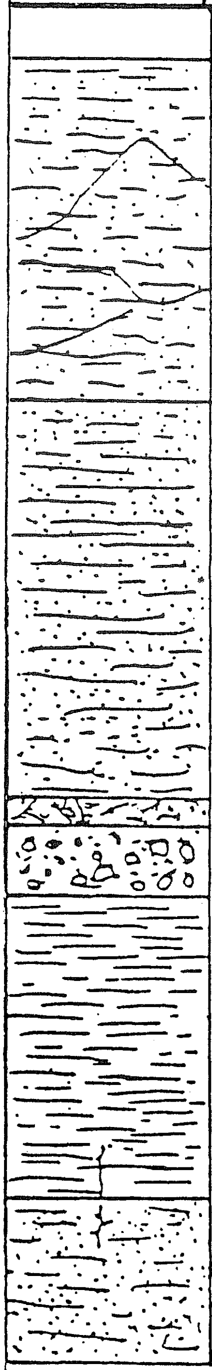
Scale 1 in = 16 in

Figure C.8. Lithologic description for site 10 (mine 1).

| Core Log | Depth (in) | Core Description | RQD (%) Lithologic Unit | RQD (%) (Core Run) |
|---|---|---|---|---|
|  | 0 | Underclay, rock is fractured, 1/2 in pieces or smaller. Dark color. No calcite present. Water content is high. | 0 | 0<br>0 |
| | 28 | Shale with lime nodules. Fracture zone at 28 in. Water content is lower than underclay. | 0 | 0 |
| | 37 | Hard grey shale with limestone nodules | 18 | 17<br>18 |
| | 55 | | | |

Scale 1 in = 12 in

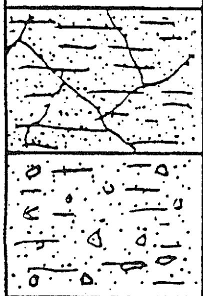
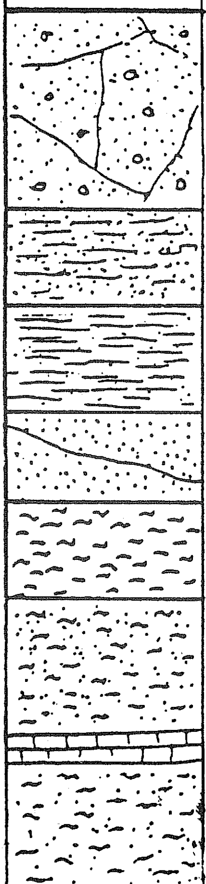
Figure C.9. Lithologic description for sites 1 & 2 (mine 3).



| Depth (in) | Core Description | RQD (%) Lithologic Unit | RQD (%) (Core Run) |
|---|---|---|---|
| | Mined out. | | 25 |
| 6 | Grey, moist underclay. Slickensided. Calcite content increases with increasing depth. | 25 | 25<br>25<br>29 |
| 48 | Grey underclay. Calcite content decreases with increasing depth. At 96 in and beyond, no calcite present. | 32 | 32<br>32<br>32<br>16 |
| 96 | Mudstone | 0 | 25 |
| 99 | Rubble of above material black in color. | 0 | |
| 108 | Light grey shale. No calcite present. Tension crack at 140 in depth. | 50 | 50<br>50<br>71 |
| 145 | Tension crack at 150 in depth. Contains quartz grains towards bottom. Phases into light-grey sandstone. | 100 | 100 |
| 165 | | | |

Scale 1 in = 24 in

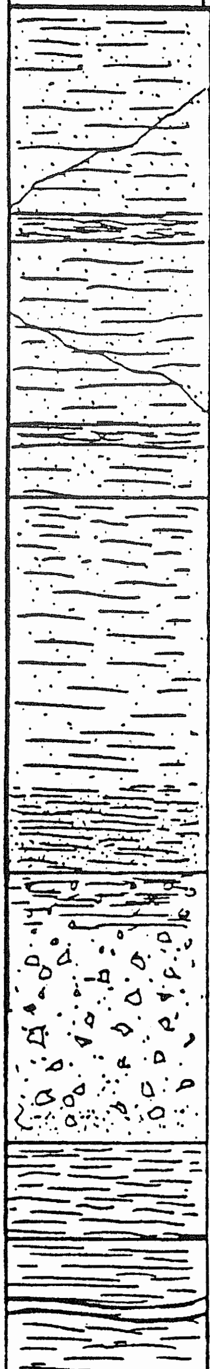
Figure C.10. Lithologic description for sites 3 & 4 (mine 3).

| Core Log | Depth (in) | Core Description | RQD (%) Lithologic Unit | RQD (%) (Core Run) |
|---|---|---|---|---|
| | | Site 3 | | |
|  | | Underclay, slickensided. Approximately 8 in core lost. Becomes more dense with increasing depth. Presence of calcite begins at about 12 in. | 0 | 0<br>0<br>0 |
| | 36 | Underclay. About 9 in core lost. Limestone nodules present. No slickensides. Bottom portions become shaly. | 0 | 0<br>0<br>0 |
| | 72 | Site 4 | | |
|  | | Underclay with limestone nodules. Slickensides present. About 5 in core lost | 0 | 0<br>0<br>0<br>0 |
| | 48 | Underclay becomes shaly with limestone nodules. 6 in - 8 in core lost. | n.a. | n.a. |
| | 71 | Sandy shale with limestone nodules. | n.a. | n.a. |
| | 98 | Slickensided wet claystone/underclay. No limestone nodules present. Calcite content increases downward. | n.a. | n.a. |
| | 120 | Black shale. Fissle. Little calcite. | n.a. | n.a. |
| | 144 | Grey shale with a limestone band of 6 in at about 14 ft depth. Small amounts of calcite in shale. | n.a. | n.a. |
| | 216 | | | |

Scale 1 in = 48 in

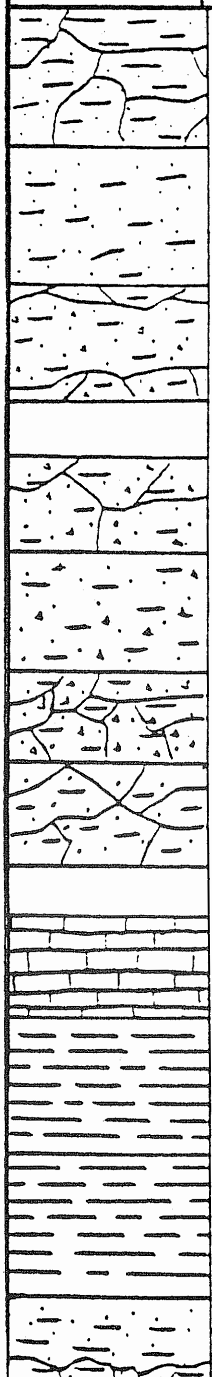
n.a. = Not available

Figure C.11. Lithologic description for site 5 (mine 3).

| Core Log | Depth (in) | Core Description | RQD (%) Lithologic Unit | RQD (%) (Core Run) |
|---|---|---|---|---|
|  | 60 | Weak wet grey underclay. Calcite present. Some slickensides observed at $60^{o}$ angles. Portions crumbled at 12 in and 25 in. Thin bands of black shale present. Some pyrite nodules found. | 0 | 0<br>0<br>0<br>0<br>0 |
| | 106 | Relatively harder light-grey underclay/claystone. Calcite present. Small amount of bottom portions phase into sandy or silty shale. Calcite content decreases with depth. | 10 | 10<br>10<br>10<br>11 |
| | 140 | Weak black mudstone. Few slickensides found. Becomes granular towards bottom. No calcite present. | 18 | 18<br>18<br>15 |
| | 152 | Dark grey sandy shale. | 10 | 23 |
| | 225 | Light grey shale. No calcite is present. More dense towards bottom. | 50 | 50 |

Scale 1 in = 24 in

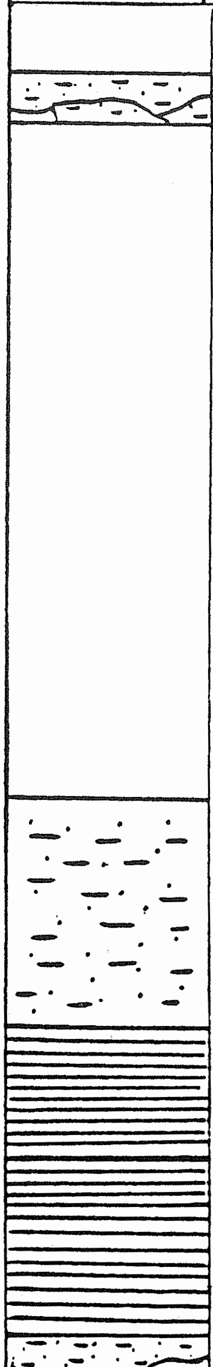
Figure C.12. Lithologic description for site 7 (mine 3).



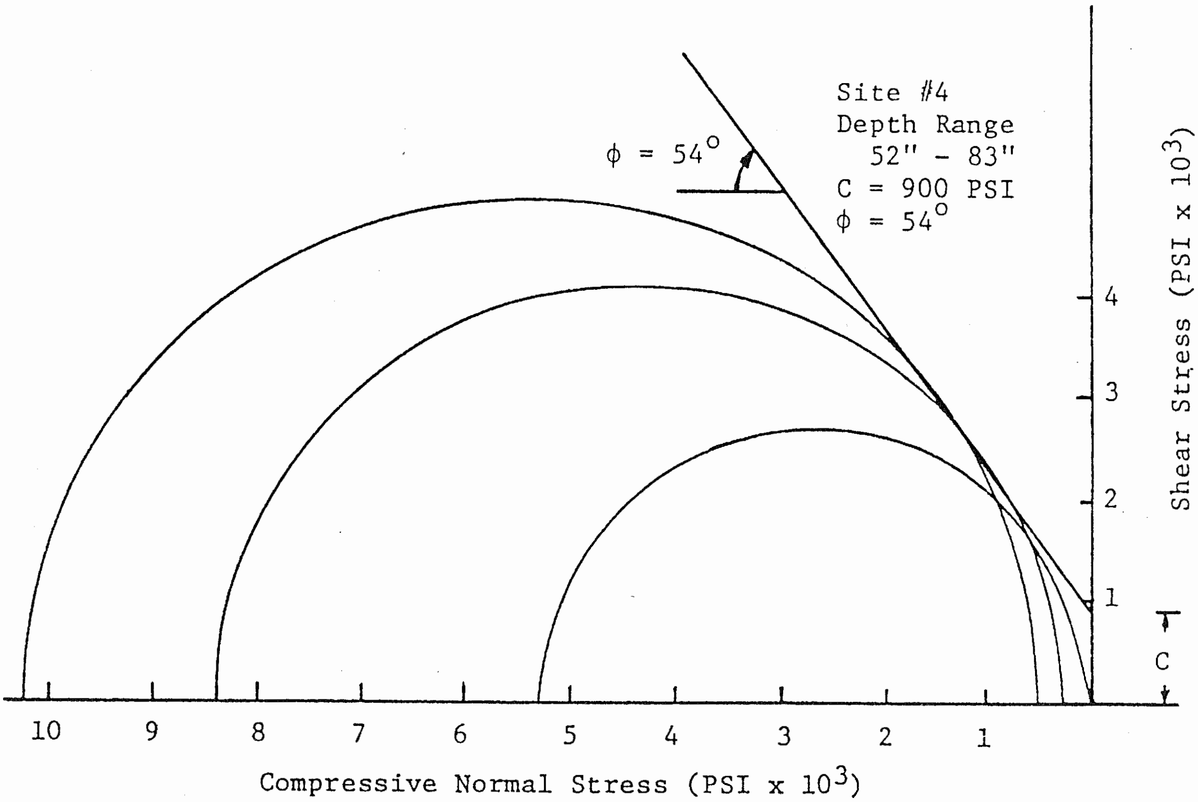
| Core Log | Depth (in) | Core Description | RQD (%) Lithologic Unit | RQD (%) (Core Run) |
|---|---|---|---|---|
| | 10 | Underclay; Abundance of slickensides. | 0 | 17 |
| | 22 | Underclay; limestone nodules present, slickensides rare. | 100 | 92 |
| | 32 | Underclay; limestone nodules present, abundance of of slickensides at top and bottom of core. | 50 | 31 |
| | 37 | Core lost. | | |
| | 45 | Underclay; abundance of limestone nodules. | 0 | 33 |
| | 55 | Underclay; limestone nodule present; joint plane at 55 in | 100 | 58 |
| | 63 | Underclay; abundance of limestone nodules. | 0 | |
| | 72 | Underclay; highly fractured. | 0 | 0 |
| | 75 | Core lost. | | |
| | 84 | Silty grey limestone. | 100 | 75 |
| | 96 | Claystone; limestone nodules present. | 100 | 100 |
| | 108 | Claystone; no limestone nodules present. | 100 | 100 |
| | 116 | Underclay; hard at top with soft green base clay. No limestone nodules present. Numerous slickenside at base. | 65 | 65 |

Scale 1 in = 16 in

Figure C.13. Lithologic description for site 8 (mine 3); size of core = 5 in.



| Depth (in) | Core Description | RQD (%) Lithologic Unit | RQD (%) (Core Run) |
|---|---|---|---|
| 0 | Core lost | | |
| 6–12 | Grey underclay; soft; moist. | 67 | 67 |
| 12–81 | Core lost | | |
| 81–104 | Underclay; bottom portion mostly shale; no calcite present; size of core = 3 in. | 100 | 100 |
| | | | 100 |
| 104–124 | Grey shale; hard; silty; size of core = 3 in. | 100 | 100 |
| 124–136 | Grey shale; stronger towards the bottom. Size of core = 3 in. | 100 | 100 |
| | | | 100 |
| 136–140 | Underclay; size of core = 3 in. | 0 | |



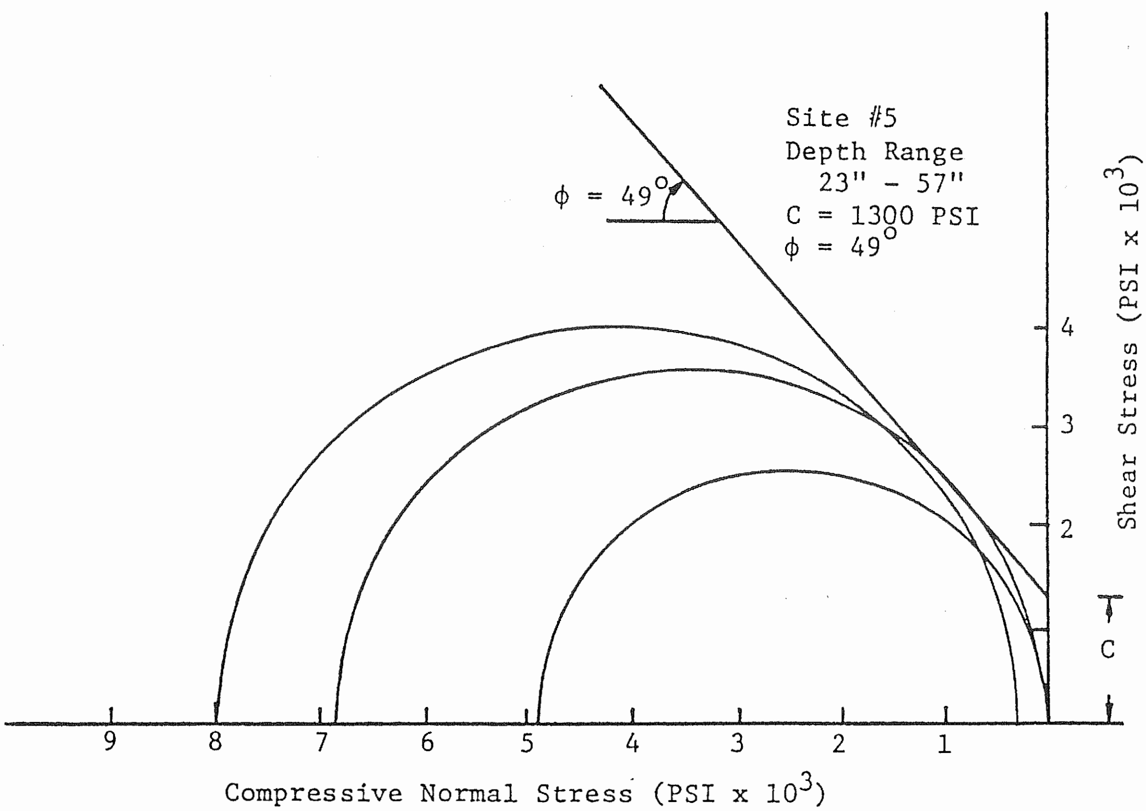




Figure C.14. Mohr circle diagrams for compressive strength data (mine 1).

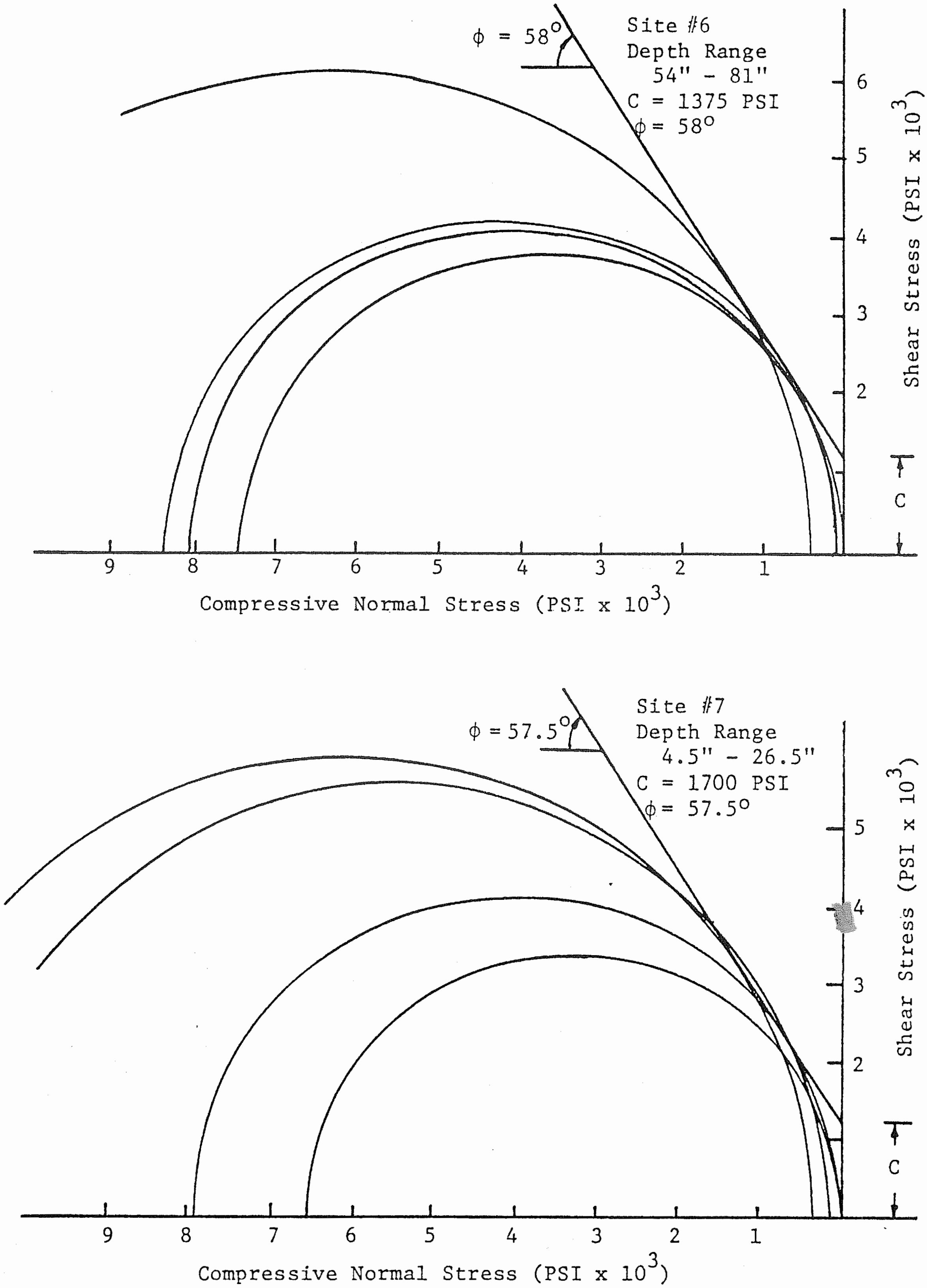
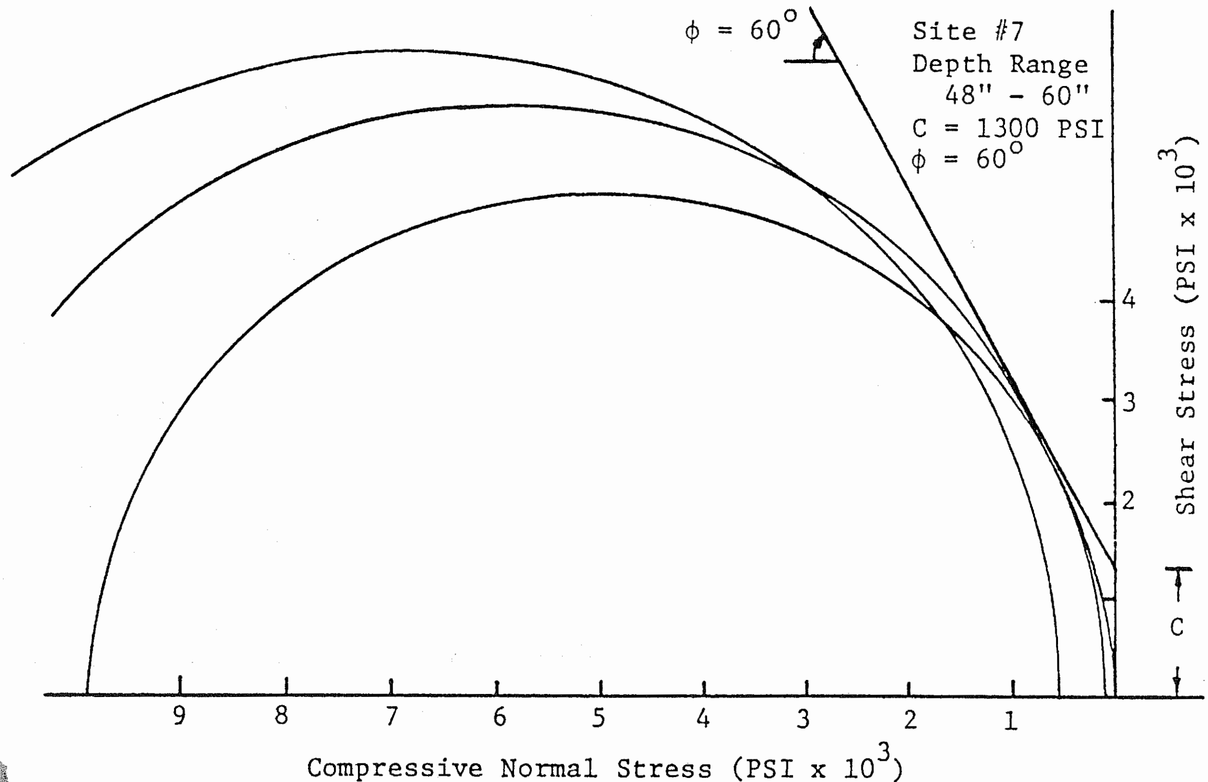



Figure C.15. Mohr circle diagrams for compressive strength data (mine 1).



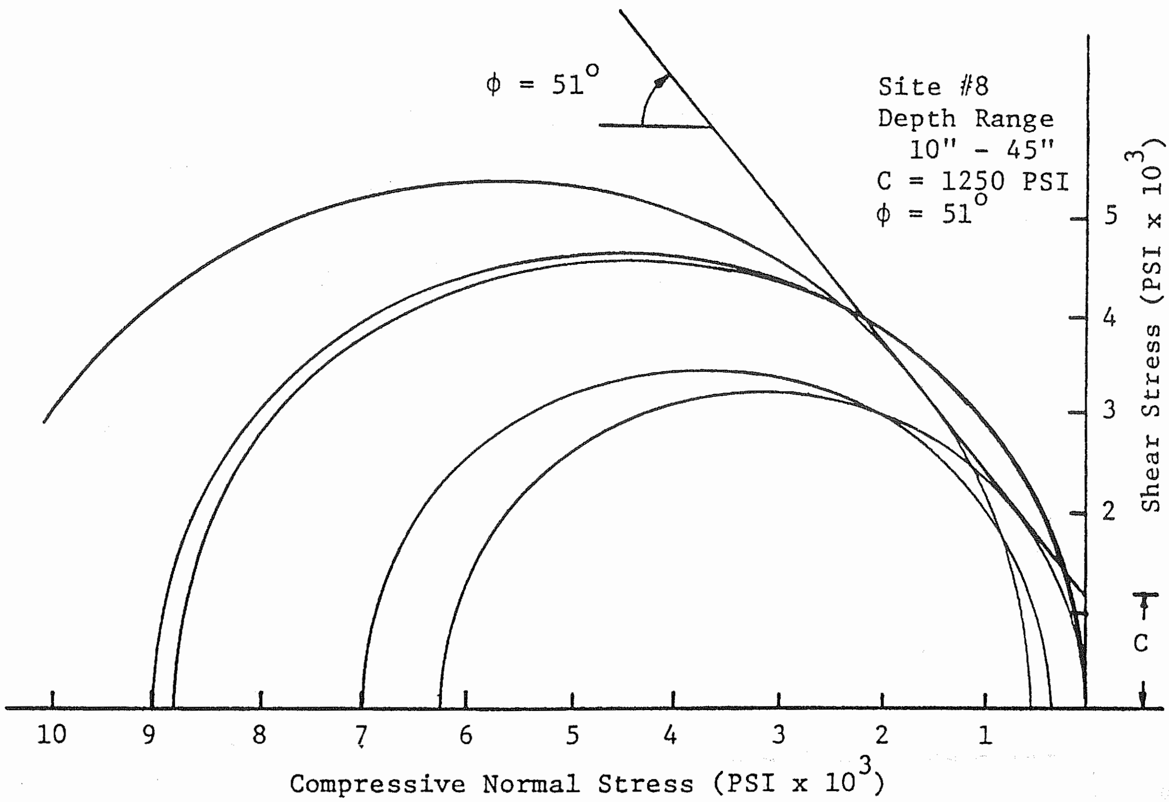
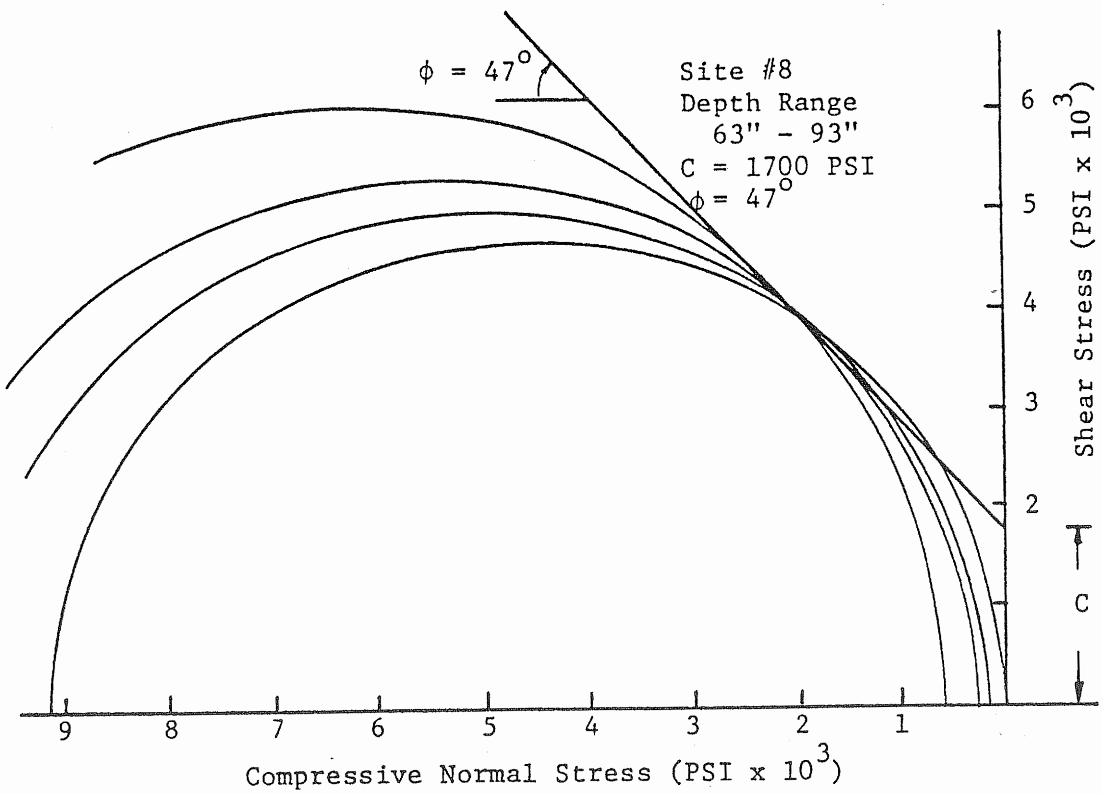




Figure C.16. Mohr circle diagrams for compressive strength data (mine 1).



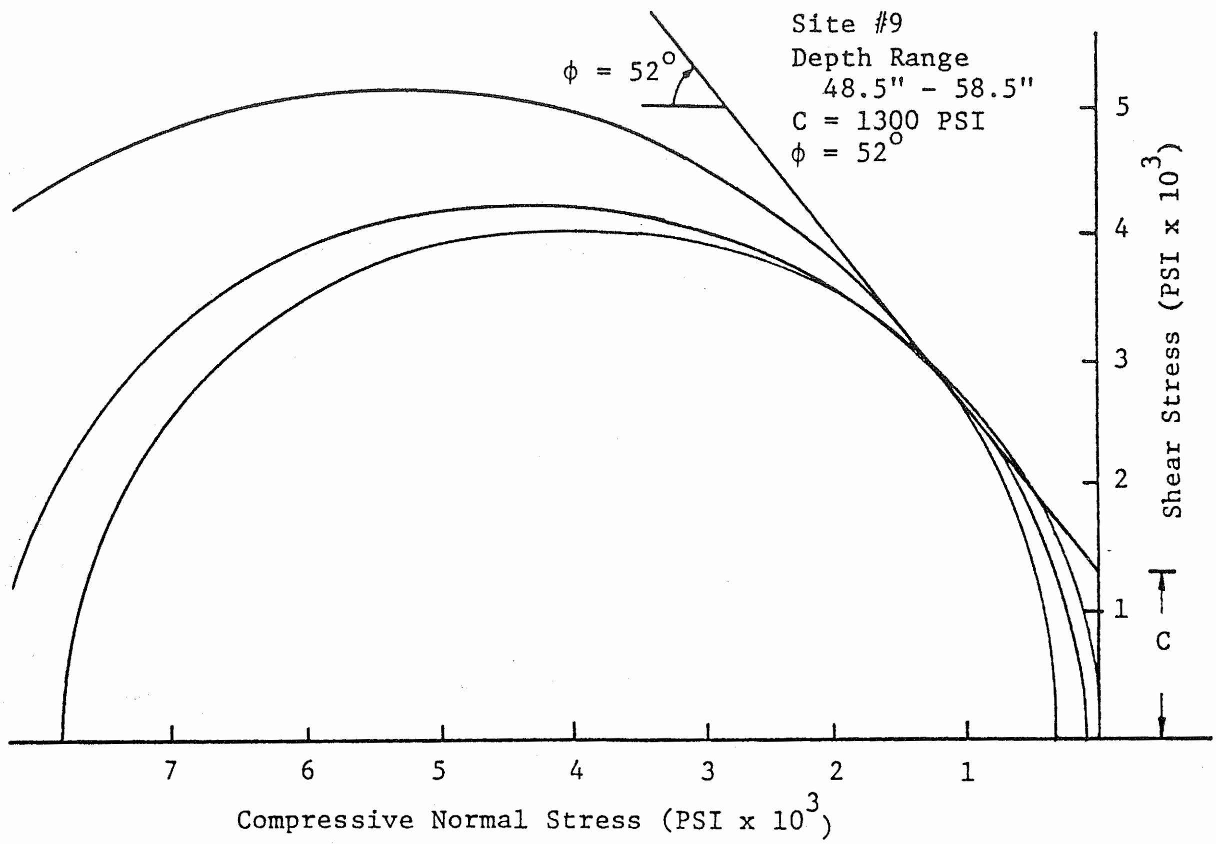




Figure C.17. Mohr circle diagrams for compressive strength data (mine 1).

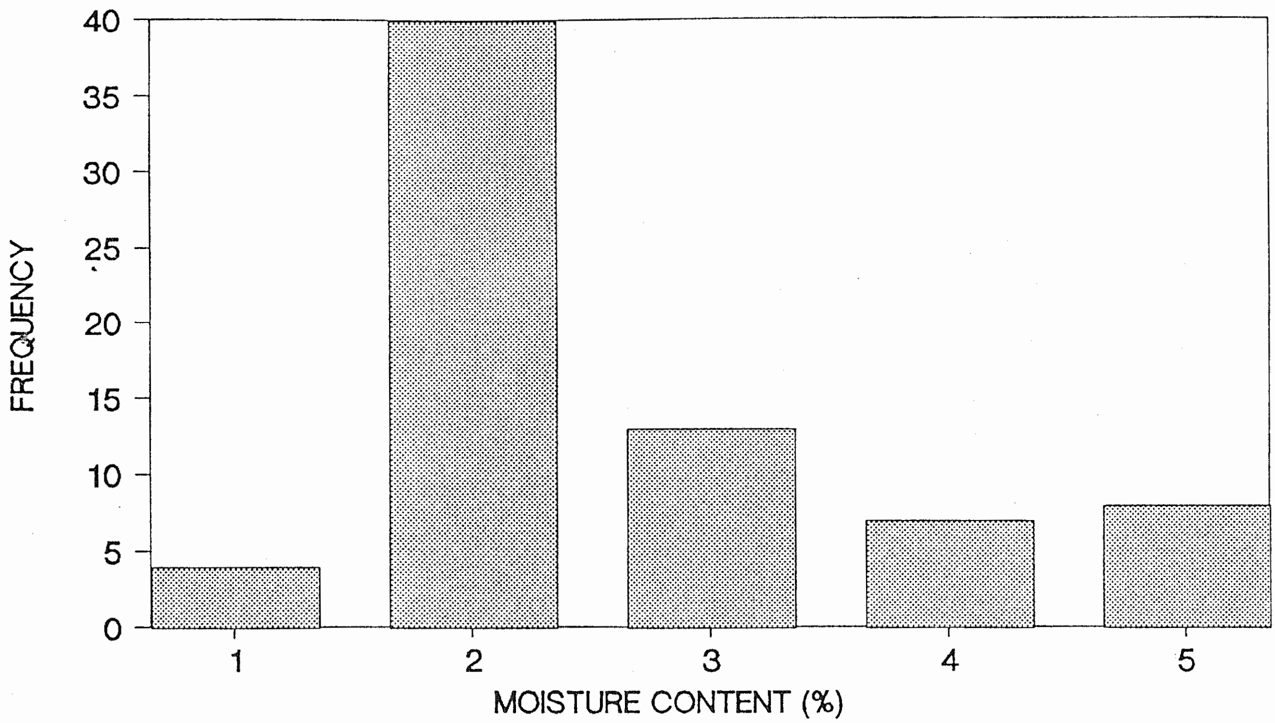



Figure C.19. Histogram plot for moisture content (mine 1).

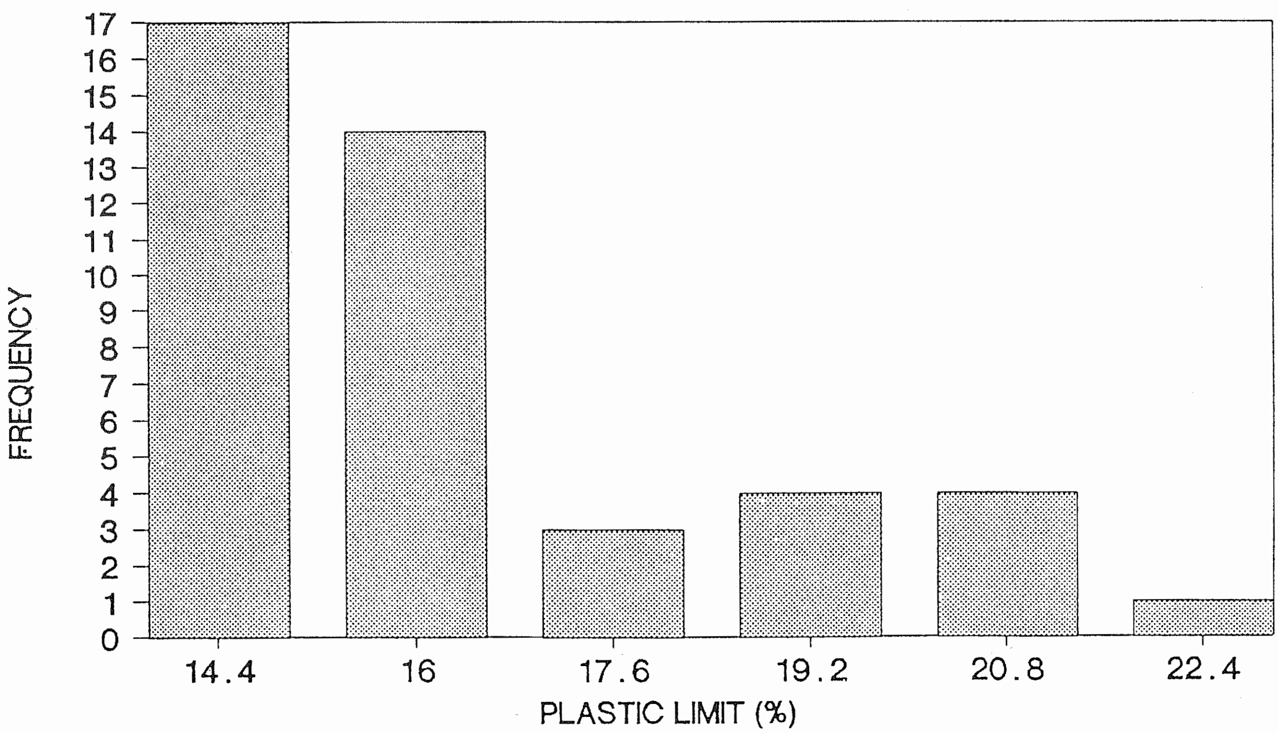



Figure C.20. Histogram plot for plastic limit (mine 1).

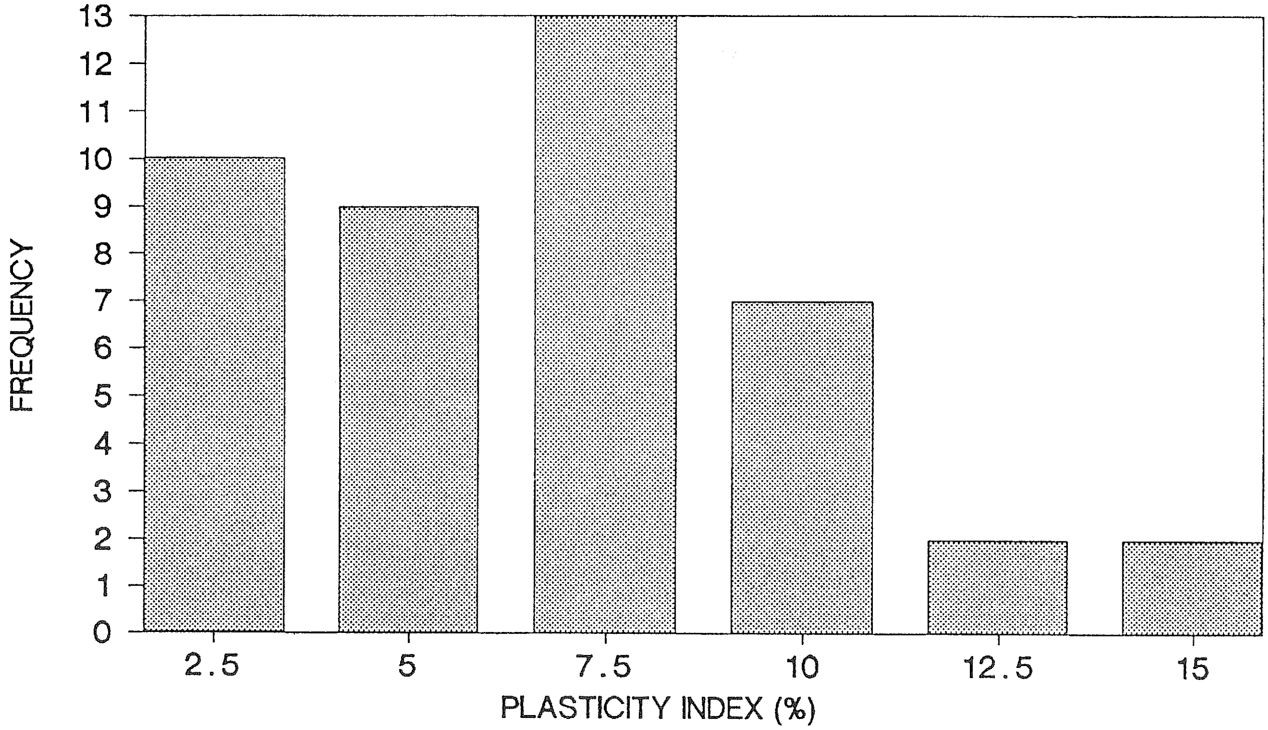



Figure C.21. Histogram plot for plasticity index (mine 1).

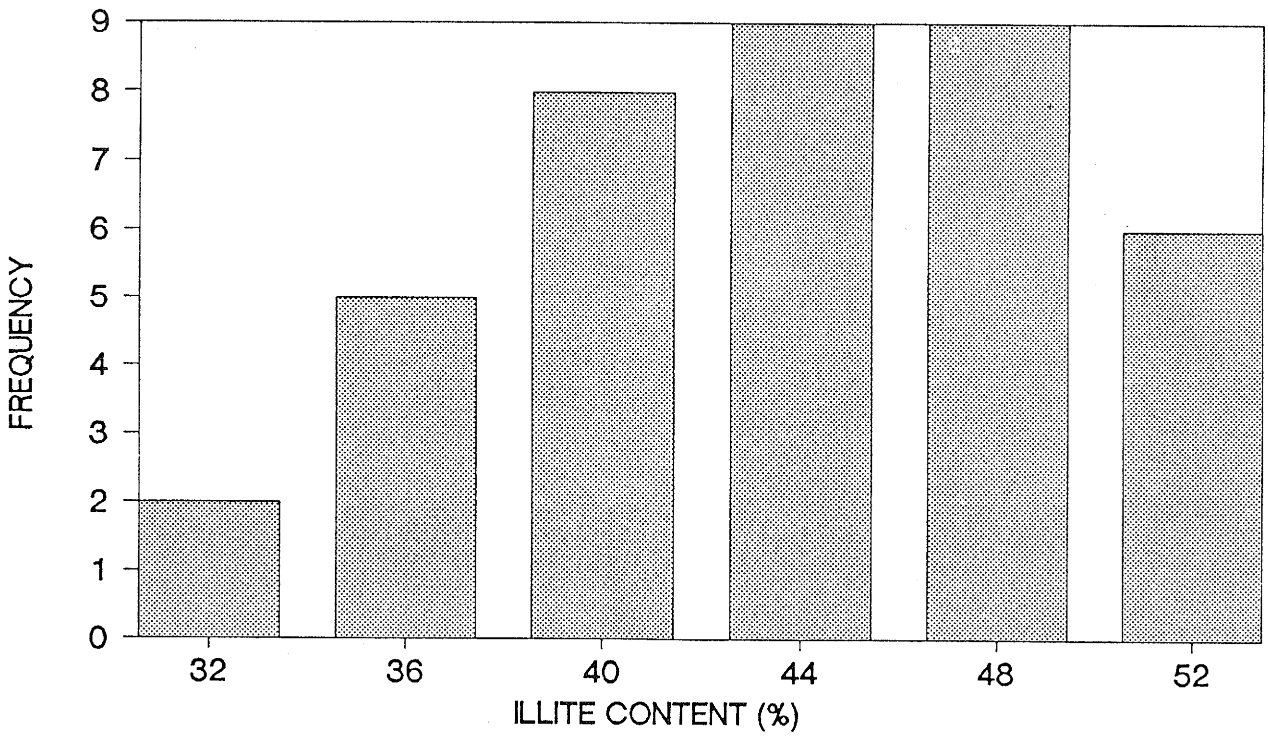



Figure C.22. Histogram plot for illite content (mine 1).

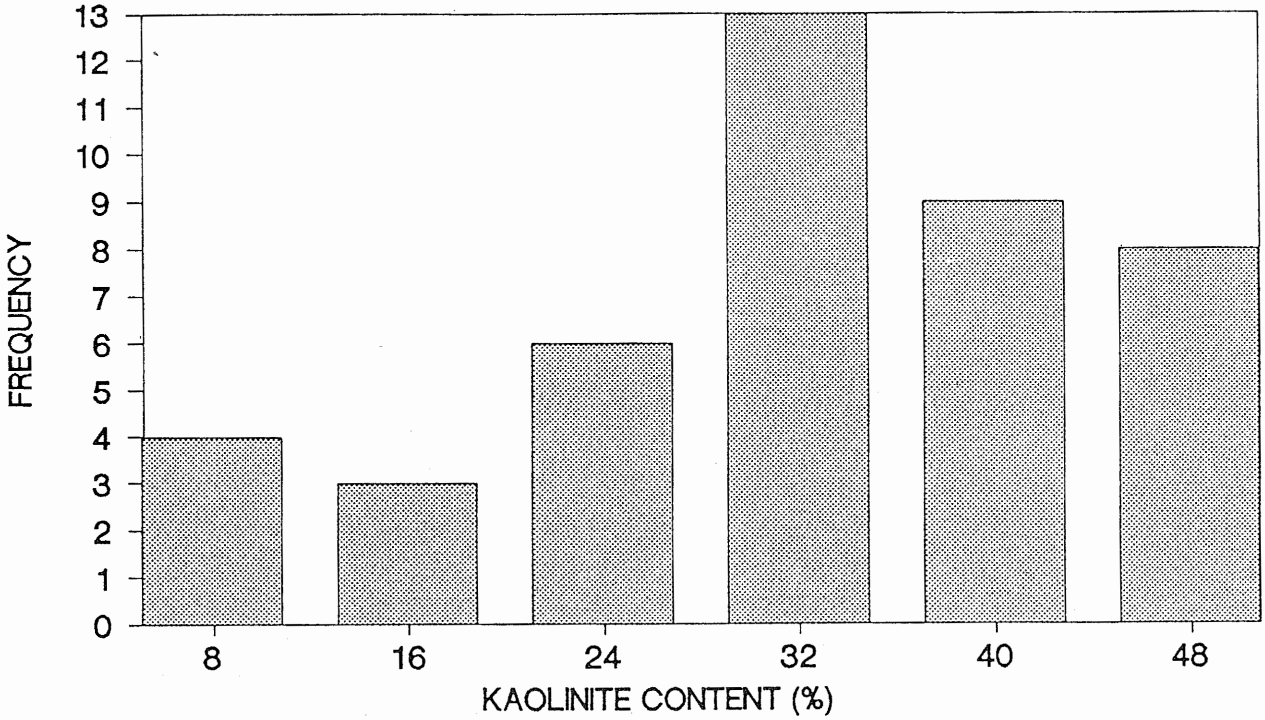



Figure C.23. Histogram plot for kaolinite (mine 1).

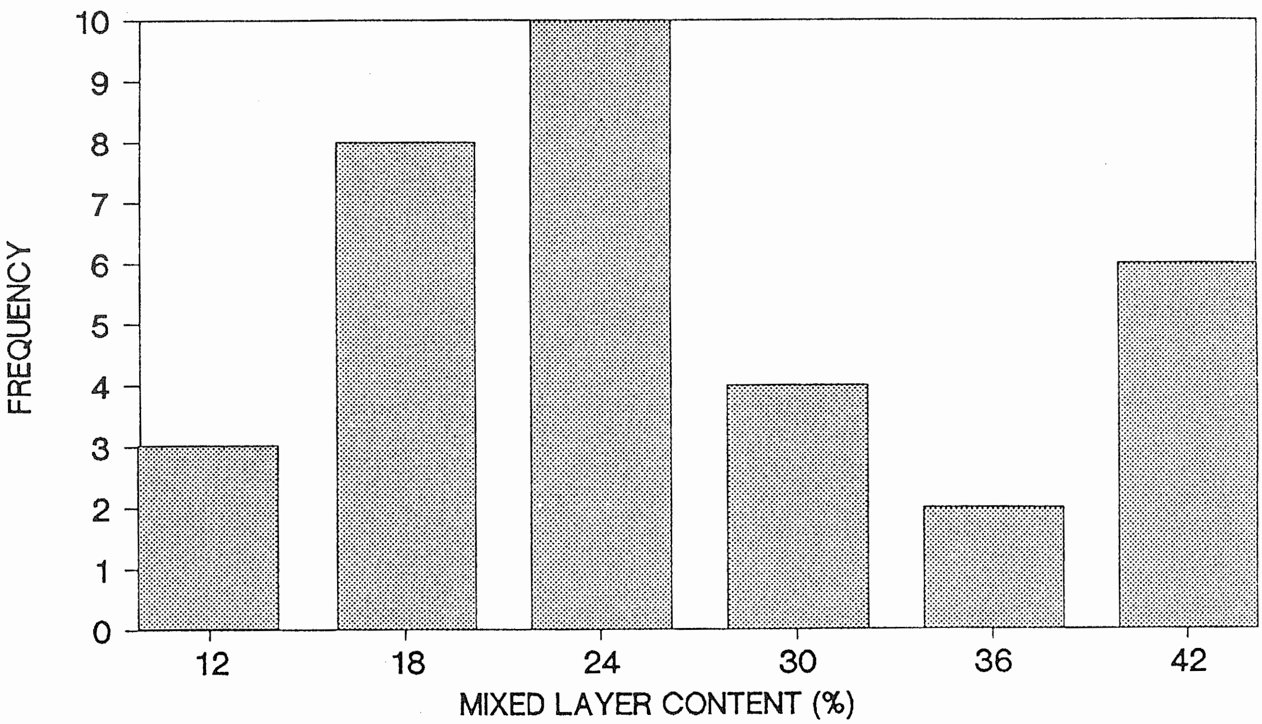



Figure C.24. Histogram plot for mixed layer (mine 1).

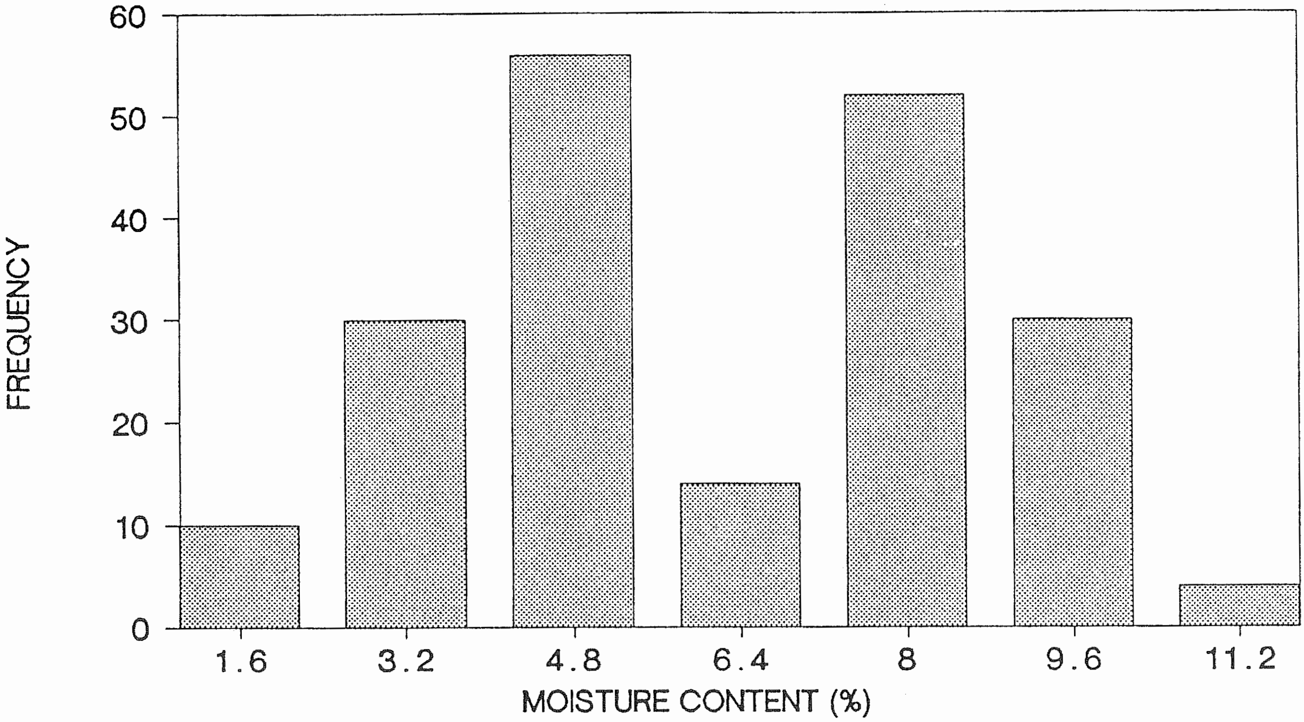



Figure C.25. Histogram plot for moisture content (mine 3).

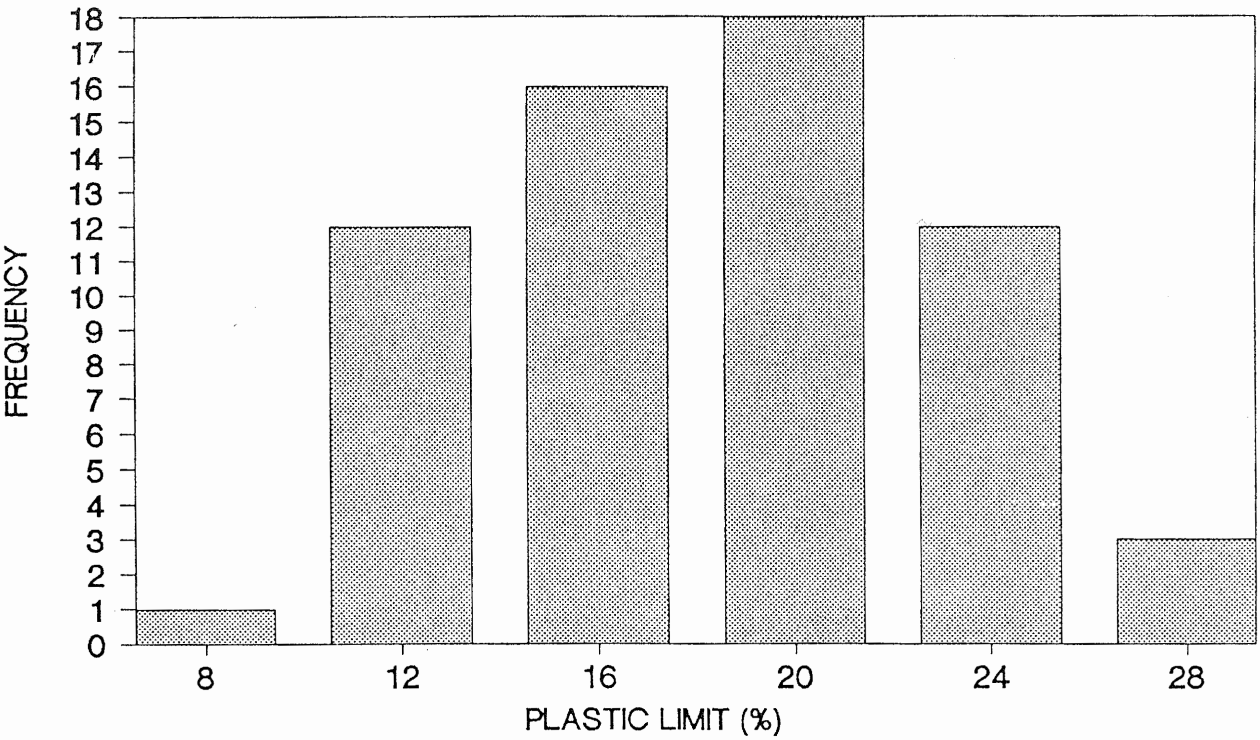



Figure C.26. Histogram plot for plastic limit (mine 3).

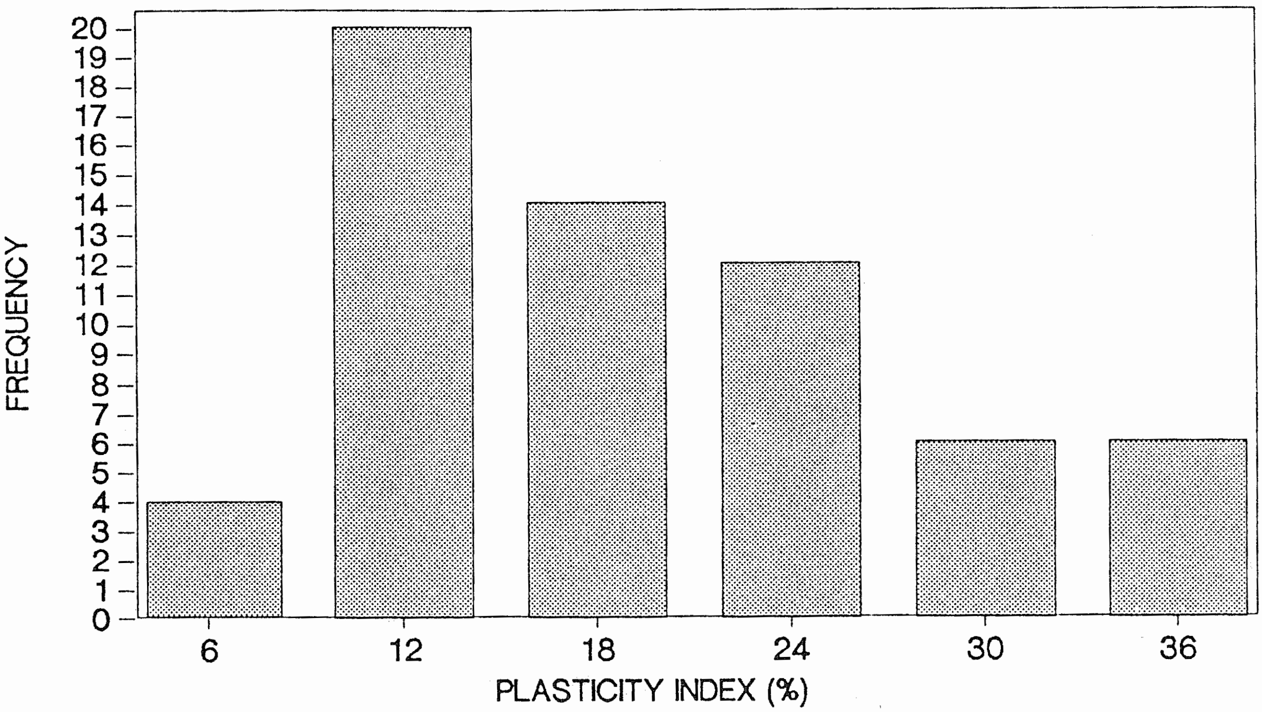



Figure C.27. Histogram plot for plasticity index (mine 3).

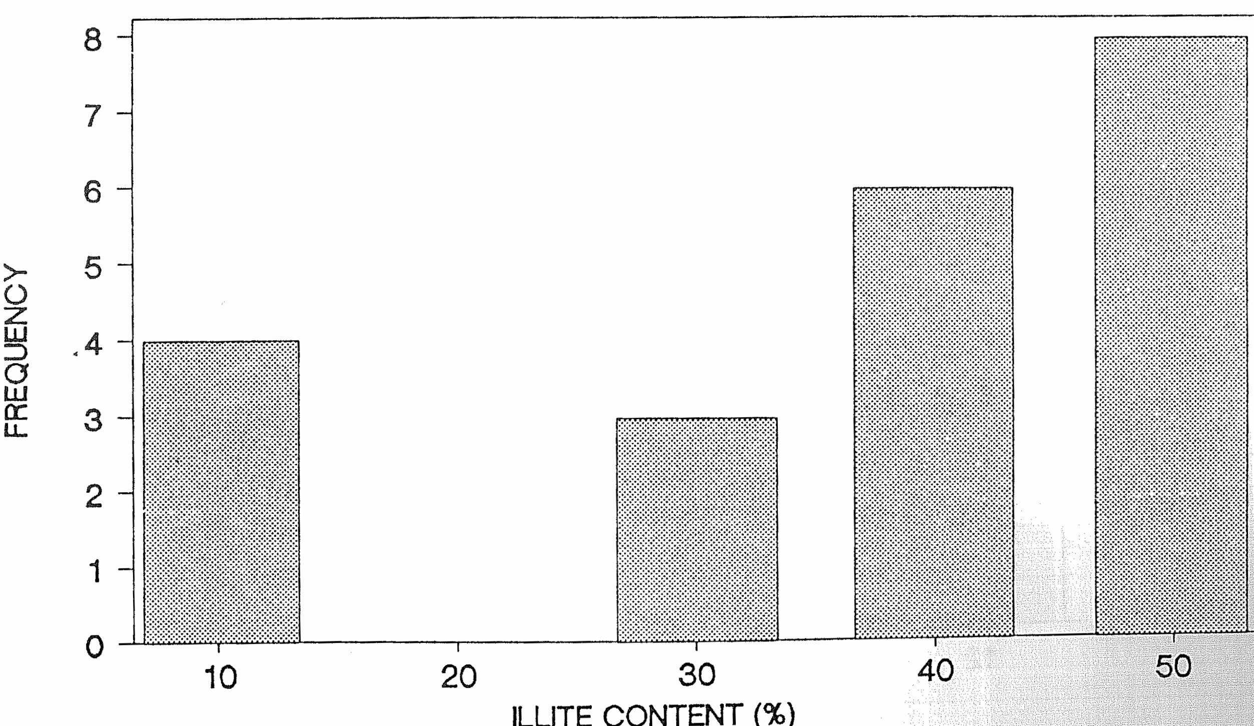



Figure C.28. Histogram plot for illite content (mine 3).

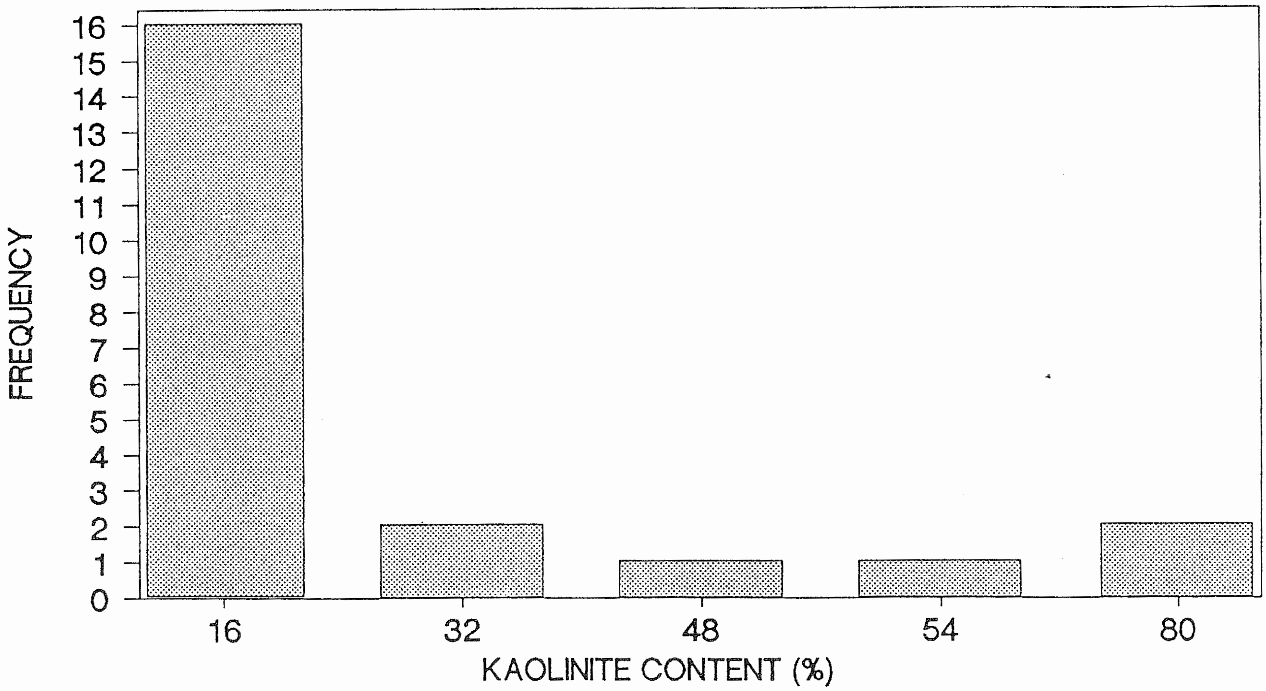



Figure C.29. Histogram plot for kaolinite (mine 3).

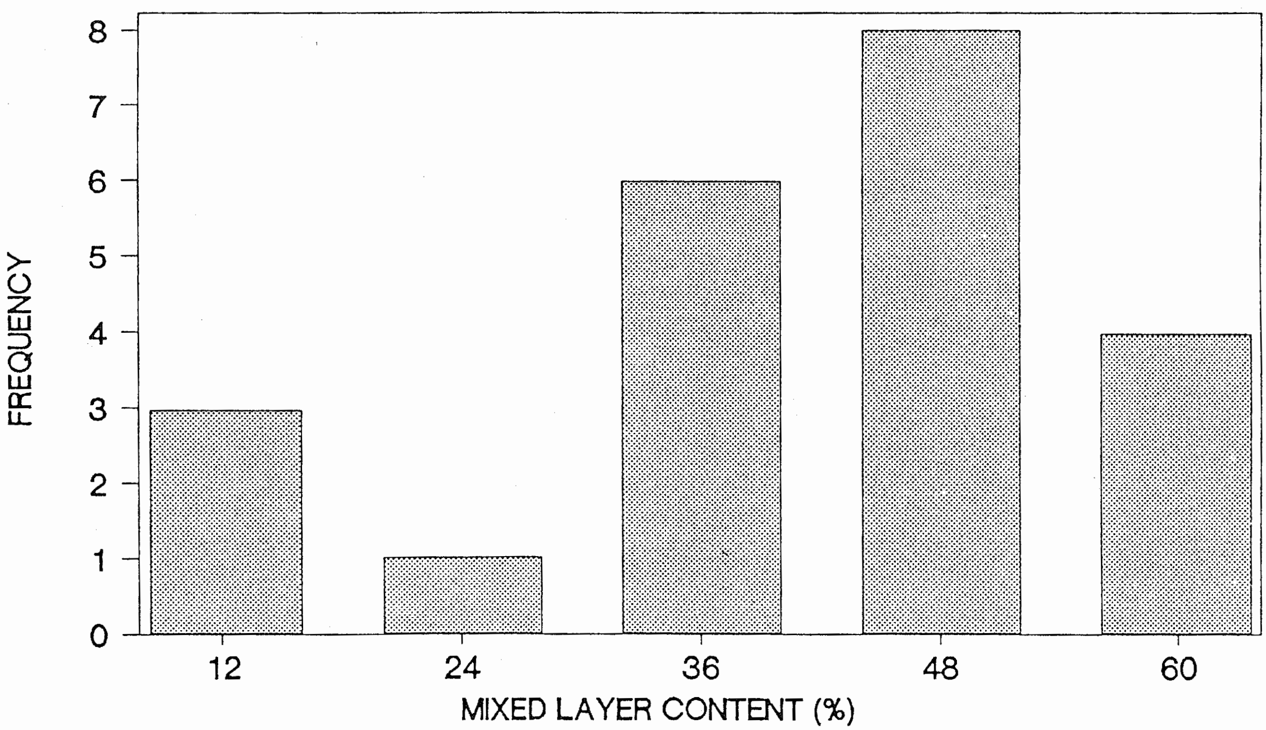



Figure C.30. Histogram plot for mixed layer (mine 3).

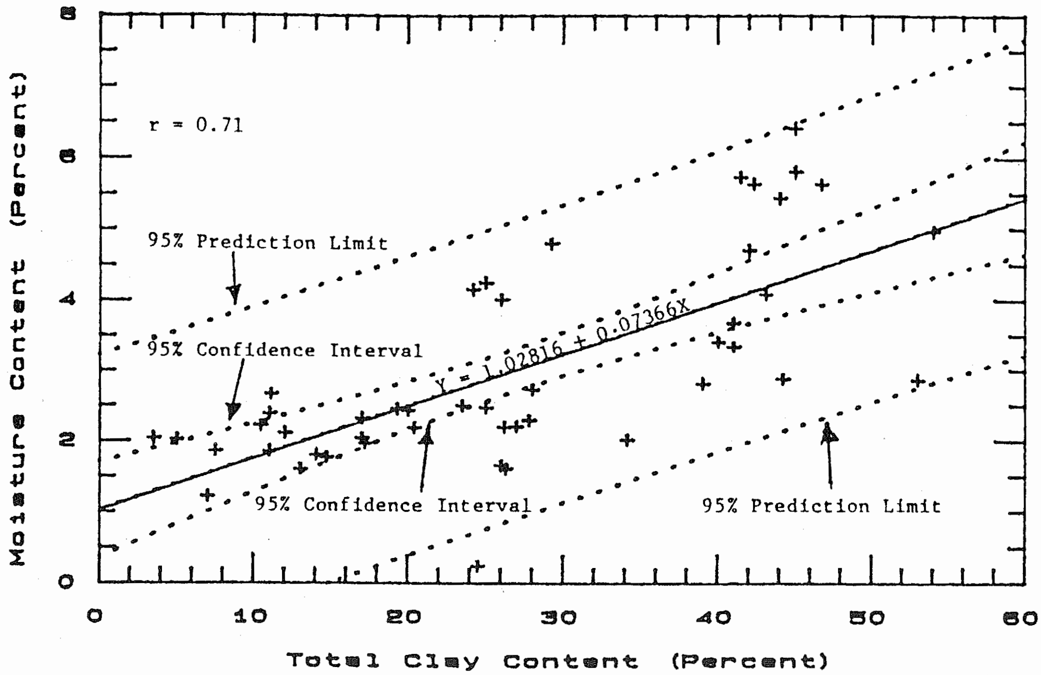



Figure C.31. Relationship between moisture content and total clay size content (mine 1).

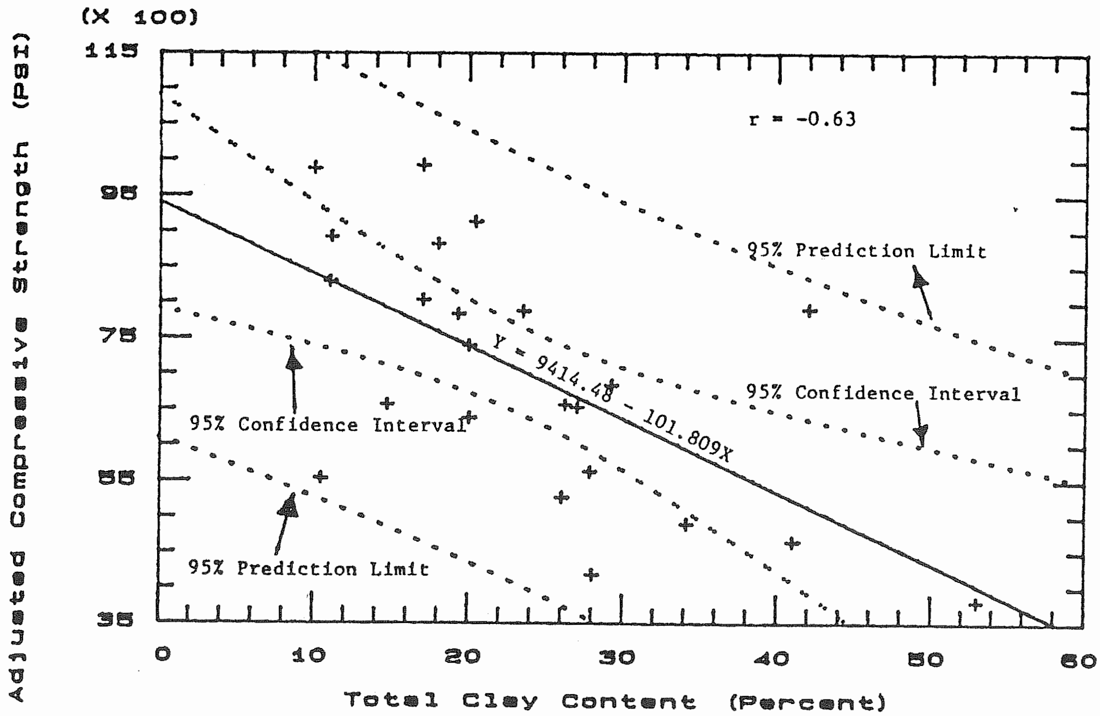



Figure C.32. Relationship between adjusted compressive strength and total clay size content (mine 1).

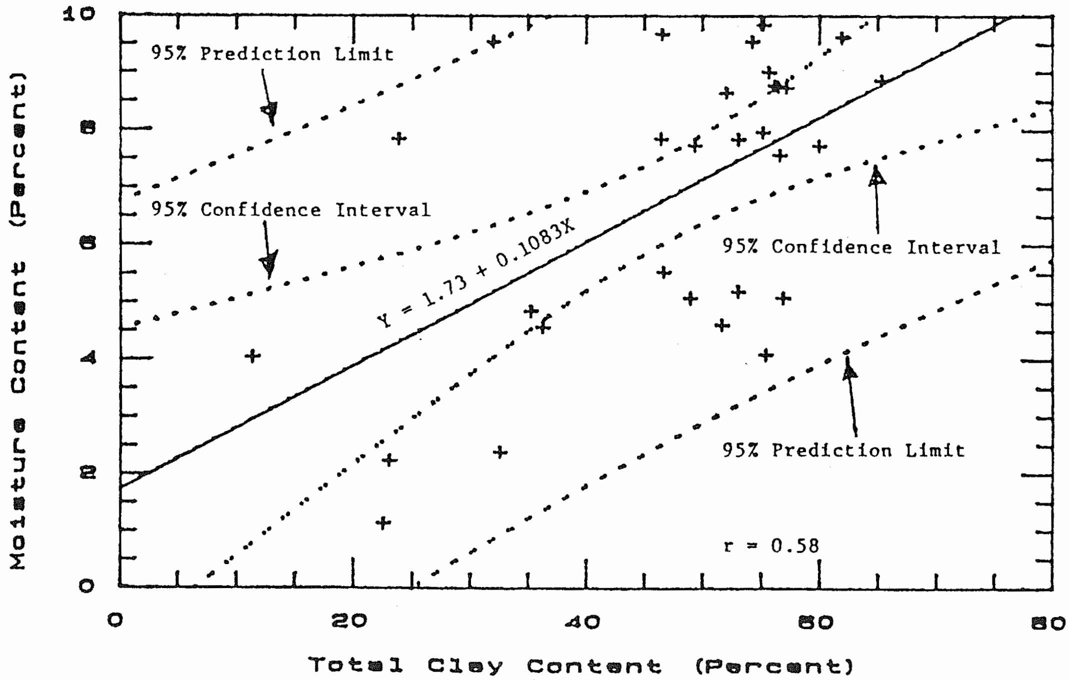



Figure C.33. Relationship between moisture content and total clay size content (mine 3).

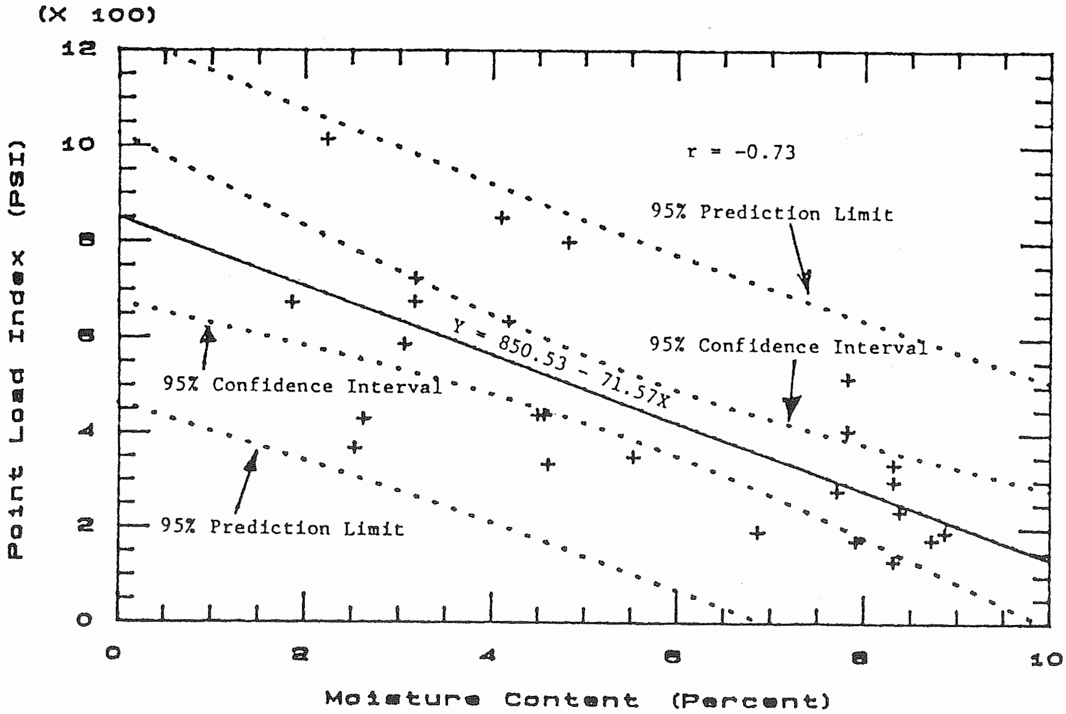



Figure C.34. Relationship between point load index and total clay content (mine 3).

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