

Research Report

UKTRP-83-2

MECHANICAL & ENGINEERING PROPERTIES
OF A CHERTY PALEOZOIC MATERIAL

A Supplemental Report
by

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INTRODUCTION

In September 1982, Research Report UKTRP-82-16 was issued to document the sampling of a cherty Paleozoic material from a test pit on Divide Cut Section 3A of the Tennessee-Tombigbee Waterway. Results of laboratory testing of the samples were also reported.

Subsequent to the issuance of Report UKTRP-82-16, additional testing and analyses have been completed. The purpose of this report is to document the results of those tests and analyses.

SAMPLE DESCRIPTIONS

As reported in the first report, four samples of the cherty material were obtained from the test pit (one sample at each of the following elevations: Sample 1 at 414.2 feet, Sample 2 at 412.6 feet, Sample 3 at 411.6 feet, and Sample 4 at 409.9 feet). Sample 1 was iron stained and appeared to have some infiltration of the alluvial overburden, including some organic matter. Because of this, the only test performed initially on that sample was to determine the natural water content.

The gradation for Sample 2 is shown in Figure 2 of the first report. This is the only sample on which a particle-size analysis was performed. Visually, the particle-size distribution of Sample 3 appeared to be much the same as Sample 2. Therefore, Samples 2 and 3 were combined to form one sample, and the tests reported in the first report were performed on the combined sample.

Sample 4 was collected near the bottom of the pit. There was considerable free water in the bottom and some of the sands from the alluvial overburden continued to fall to the bottom during the sampling operation. Consequently, there was some concern about the sample being contaminated. Therefore, only the natural moisture content was determined for this material. Although particle-size analysis was not performed on Sample 4, it appeared to be considerably more granular than the first three, having a top size of 3 to 3 1/2 inches.

After Sample 4 was collected, the pit was dug approximately three feet deeper for filming and photographic purposes.

TEST RESULTS/ANALYSES

A limited number of tests were performed to check the optimum moisture content, maximum dry density, and CBR values obtained previously from tests on the cherty paleozoic material and reported in the first report.

Sufficient quantity of unused cherty Paleozoic material from elevation 412.6 was not available for performing additional moisture-density tests. However, sufficient

material previously used was available. That material was processed and three additional moisture-density tests were performed according to ASTM D 698, Method C. Additionally, CBR tests (ASTM D 1893) were performed on the three moisture-density specimens. A summary of moisture-density and CBR results (specimen numbers 3, 4, and 6) as well as data (specimen numbers 1, 2, 5, and 7) previously reported in the first report is presented in Table 1. The moisture-density curve using the combined data is shown in Figure 1. The optimum moisture content and maximum dry density using the combined data (specimen numbers 1 through 7) were 19.6 percent and 103.0 pounds per cubic foot, respectively. Optimum moisture content and maximum dry density reported previously in the first report were 20.8 percent and 103.5 pounds per cubic foot, respectively. Hence, the optimum moisture content was only about 1 percent lower than the previously reported value of optimum moisture content and the maximum dry density was only 0.5 pound per cubic foot lower than the maximum dry density noted in the first report.

To determine if the optimum moisture content of 19.6 percent obtained for the cherty Paleozoic material was an atypical value, compaction data contained in a soils data bank (1) maintained by the Kentucky Transportation Research Program and a wet density-optimum moisture content curve given by Hilf (2, 3) were used. The soils data bank contains some 5,000 records of soils data. A request was made of the data bank to print-out optimum moisture contents of compaction tests that had a maximum dry density of 103 pounds per cubic foot. Some 172 optimum moisture contents representing the same number of compaction tests were listed by the soils data program. An analysis of those data gave an average or mean value of optimum moisture content of 19.3 percent (compared to 19.6 percent, Figure 1, obtained for the cherty Paleozoic material). The standard deviation of the data group was 17.6 to 20.9 percent. As another check, the curve in Figure 2 (2) was used. That curve represents some 1,300 samples analyzed by Hilf. Using the wet density (123.2 pounds per cubic foot) at the optimum moisture content of the cherty Paleozoic material, an optimum moisture content of about 19.3 percent was obtained from the curve (see dashed line in Figure 2). Hence, the optimum moisture content of 19.6 percent obtained for the cherty Paleozoic material (or the value of 20.8 percent reported originally) is typical. The cherty Paleozoic material, as tested, does not have unusual or abnormal values of optimum moisture content or maximum dry density.

CBR TESTS

CBR check data and CBR-values reported in the previous report are summarized in Tables 1 and 3, respectively. Additionally, the water contents of CBR-specimens before compaction, as compacted, after soaking, after the drying

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period, and after penetration are shown in Table 3. Swell deflection in the CBR test ranged from 0.0 to 0.022 inch for the five soaked samples. The cherty material exhibited almost no swelling characteristics. Values of CBR are also recorded on Figure 1 by their respective dry density-moisture content coordinate points. Those data show the CBR is very low when the moisture content of the CBR specimen is greater than optimum moisture content. When the moisture content is near or lower than optimum moisture content, the CBR value is very high. Specimens tested "wet of optimum moisture" had moisture contents of 21.0, 21.9, 21.7, and 22.3 percent; respective CBR values were 3.3, 2.7, 2.9, and 4.8. Specimens tested "dry of optimum moisture content" had moisture contents of 15.2, 17.4, 18.0, and 18.9 percent. The respective CBR's were 36.4, 16.3, 30.7, and 36.6. The two black square points in Figure 1 represent specimens that were compacted at moisture contents of 22.2 and 21.4 percent. Those samples were allowed to air-dry in CBR molds for 4 and 9 days, respectively. The CBR tests were performed after the drying period. The specimen having a moisture content of 22.2 percent (black box in Figure 1) dried to a moisture content of 17.4 percent (dashed box in Figure 1). The CBR of the specimen was 16.3. Similarly, the specimen that initially had a moisture content of 21.4 percent dried to a moisture content of 15.2 percent. The CBR of that dried specimen was 36.4. Therefore, it is obvious that a small decrease in moisture content below the soaked water content produces a dramatic increase in CBR value.

As shown in the lower portion of Table 1, two moisture-density tests were performed on specimens of the cherty Paleozoic material from elevation 414.2 feet. Additionally, a CBR test was performed on one specimen. Those data are shown in Figure 1. Sufficient material was not available to fully develop a moisture-density curve for the material from elevation 414.2 feet. A CBR test on that material performed at a moisture content of 20.8 percent yielded a value of 25.4. Based on the two moisture-density test specimens, the optimum moisture content of the material from elevation 414.2 appears to be higher than the optimum moisture content of the material from elevation 412.6. Additional testing would be required to confirm this observation.

An additional comment should be made concerning why the moisture content of the CBR specimens after soaking did not approximate the in situ water content. It should be noted that, for this to occur, the densities in situ and of the CBR specimens should be approximately equal. However, the in situ density of the cherty material was not determined. Although not known, it appears likely that the in situ density would be less than the density of the CBR specimens compacted using the standard compactive effort. This would mean, of course, a larger void ratio in situ and,

consequently, a higher moisture content.

ABSORPTION/DRYING CHARACTERISTICS

A series of tests to measure the "capacity" of the fine fraction (material passing the No.-200 sieve) of the cherty Paleozoic material to absorb moisture when placed in an atmosphere of high humidity was performed. For comparison, a sample of quartzite grains and a sample of pulverized bentonite pellets (all material passing the No.-200 sieve) were tested under the same conditions.

A summary of results obtained from a high humidity-absorption tests is shown in Table 2. Four specimens consisting of the minus 200-sieve fraction of the cherty Paleozoic material were prepared and placed in shallow, flat-bottom dishes 11 inches in diameter. The fine fraction of the cherty Paleozoic material was placed in each dish in such a manner that the surface area of each dish was covered. Initial air-dried cherty Paleozoic weights of the specimens ranged from 98.0 to 99.9 grams. To obtain an environment of high humidity, the compartment of a freeze-thaw machine was partially filled with water. Each sample was placed in the compartment on shelves located a few inches above the water surface. The temperature of the water was raised to 100 degrees Fahrenheit and maintained constant throughout the testing period. By maintaining a high water temperature, a high-humidity atmosphere was created in the compartment of the freeze-thaw machine. To determine if a high-humidity atmosphere was created and to provide a basis for relative comparison, pulverized bentonite pellets were obtained from the Slope Indicator Company of Seattle, Washington, and had an initial air-dried weight of 47.3 grams. The pellets are normally used to seal piezometers in borings because they absorb large quantities of water and swell.

Before the minus-200 cherty Paleozoic samples, bentonite samples, and quartzite grains were placed in the highly humid environment, initial hygroscopic water contents were obtained. As shown in Table 2, the initial water content of the minus-200 fraction of the cherty material ranged from 0.22 percent to 1.02 percent. The initial water content of the pulverized bentonite pellets was 8.13 percent, and the initial moisture content of the quartzite was 0.0 percent. The materials were air-dried in a laboratory environment. Specimen 1, Table 2, had an initial water content of 0.22 percent and was not placed in the humid environment. After one day, Specimen 2 was removed from the humid environment, weighed, and oven-dried to obtain a final water content. Similarly, after 2 and 3 days, respectively, Specimens 3 and 4 were removed, weighed, and oven-dried to determine final water contents, as shown in Table 2. The net increases in water content (final water content minus the initial hygroscopic water content) for Specimens 2, 3, and 4, were

2.5, 1.5, and 1.0 percent, respectively. The quartzite grains absorbed no moisture up to eleven days in the humidity box.

In the case of the pulverized bentonite, the initial water content of this material was obtained; the specimen was then placed in the humid compartment of the freeze-thaw machine. After about one day, the specimen was weighed and returned to the compartment. Total wet weights of the specimen were obtained after about (exact times are shown in Table 2) 2 and 3 days. After the third day, the specimen was removed and oven-dried to obtain the dry weight. The net increases in water content of the bentonite after each day in the humid atmosphere are shown in Table 2. After three days, the water content of pulverized bentonite increased from an initial water content of 8.1 percent to 18.9 percent, or a net increase of 10.8 percent. The bentonite pellets absorbed some 10 times more moisture than the minus-200 sieve fraction of the cherty Paleozoic material.

To examine the drying behavior of the cherty Paleozoic material, a loss of moisture versus time test was performed. ~~Material from elevation 414.2 feet was placed in a pan about 9 inches in width and 15 inches in length. The exposed surface area of the material was approximately one square foot. Depth of the material in the pan was about 1.5 inches. The material was air dried in a laboratory having a temperature of about 70 + 5 degrees Fahrenheit. Initial wet weight of the material was obtained immediately after placing the material in the pan. Several subsequent values of wet weights of the material were obtained. Weighing of the material (as a function of time) was continued until the wet weight of the material did not decrease with time; that is, the wet weight was constant. The material was then oven-dried to obtain the dry weight of the material. Hence, the moisture content of the material at any given time in the drying period could be calculated. The moisture content of the material as a function of time is shown in Figure 3. The initial moisture content of the specimen was 28.0 percent. Three additional (initial or in situ) moisture contents of the cherty Paleozoic material from elevation 414.2 feet were 26.4, 31.3, and 35.0 percent. The average value of the latter three values was 30.8 percent. Based on the curve in Figure 3, approximately 65 hours, or slightly less than three days, would be required for the cherty material to dry to a moisture content of about 20 percent. However, a thicker sample would probably require a longer drying period to reach optimum moisture content. The optimum moisture content of 19.6 percent shown in Figure 3 is for the material from elevation 412.6 feet and is shown in that figure only to obtain an indicated drying period. If the material was dried to a moisture content approaching or slightly lower than optimum moisture content, then high bearing strength could have been obtained, as shown by the~~

CBR data in Figure 1. Draining of the material in advance of excavation would have lowered the moisture content to some extent and aided in reducing the drying period. Additionally, some aeration of the material using such means as a moldboard pulled by a bulldozer could have been useful in reducing the drying time.

CLASSIFICATION

An additional analysis was performed related to the classification of the cherty Paleozoic material from elevation 412.6 feet. In the initial report, the cherty Paleozoic material from elevation 412.6 feet was classified as SC using the Unified Soil Classification System. The liquid and plastic limits of the material were 28.2 percent and 20.8 percent, respectively. Using the exact numbers from Table 2 of the first report, 72.3 percent of the material was retained on the No.-200 sieve. Hence, the cherty Paleozoic material is a coarse-grained soil. Some 34.2 percent of the material lies between the No.-4 sieve and No.-200 sieve (61.9 percent passing the No.-4 sieve less 27.7 percent passing the No.-200 sieve). Consequently, 47.3 percent of the coarse fraction lies between the No.-4 sieve and No.-200 or 52.7 percent of the coarse fraction is larger than the No.-4 sieve. Since the material contains an appreciable amount of fines (27.7 percent of the material is smaller than the No.-200 sieve), the material is a gravel with fines, and it is either a GM or GC soil. Since the Atterberg limits plot above the "A" line and the plasticity index (7.4 percent) is greater than 7, then the cherty Paleozoic material classifies as GC. However, considering the coarse fraction (greater than the No.-4 sieve) and the fraction between the No.-4 sieve and No.-200 sieves are nearly equal, then the cherty Paleozoic material is very close to a SC-classification. This illustrates the high variability of the material and helps to confirm data reported by the Corps in Appendix A to the specifications. That document reported 14 different Unified soils classifications for the cherty Paleozoic materials.

MINERALOGY

Attached at the end of this report is a detailed description of the method used by Dr. Richard Barnhisel of the University of Kentucky to determine the mineralogy of the cherty Paleozoic material. The process used requires that all material pass the ASTM No. 10 (<2.0 mm) sieve. For this reason, the fine matrix was considered to be all material smaller than 2.0 millimeters. The sample was divided into seven particle size fractions and an x-ray diffractogram was made of each fraction using a Phillips Electronics x-ray diffraction unit. Individual minerals were qualitatively identified on the basis of x-ray diffraction peak positions. Quantitative analysis for minerals was accomplished using peak height and particle size distribution data.

REFERENCES

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System, Kentucky Department of Transportation, Bureau of Highways, Division of Research, August, 1980.

2. Hilf, J. W.; A Rapid Method of Construction Control for Embankments of Cohesive Soils, Engineering Monograph No. 26, Bureau of Reclamation, 1959.
3. Winterkorn, H. F.; Fang, Hsai-Yang; Foundation Engineering Handbook, Van Nostrand Reinhold Company, New York, 1975 (Chapter by Hilf, J.W.).

Table 1. Summary of Moisture-Density Test Results and CDR-Values.

Moisture-Density Relation * ASTH D 598, Method C			Comments	CBR Test ASTH D 1883	Elevation in Test Pit (feet)
Test Number	Dry Density (pcf)	Water Content ** (percent)			
1 ‡	89.0	12.2	Fresh Material	-----	412.0
2 ‡	93.3	15.0	Fresh Material	-----	412.0
3	100.0	18.0	Re-Used Material	30.7	412.0
4	102.5	18.9	Re-Used Material	36.6	412.0
5 ‡	102.7	19.7	Fresh Material	-----	412.0
6	100.9	21.0	Re-Used Material	3.3	412.0
7 ‡	99.3	23.0	Fresh Material	-----	412.0

1	92.1	13.3	Fresh Material	-----	414.2
2	97.9	20.8	Fresh Material	25.4	414.2

* Optimum Water Content = 19.6 %
Maximum Dry Density = 103.0

** Total sample dried to obtain water content.

*** Sufficient material was not available to develop Moisture-Density Curve.

‡ These data were previously reported in the first report.

Table 2. Summary of Data Obtained from High Humidity Absorption Test.

Specimen Number	Test Period (days)	Initial Air Dry Weight (grams)	Final Weight after Test Period (grams)	Oven Dry Weight (grams)	Initial Hydrosopic Water Content (percent)	Final Water Content After Test Period (percent)	Percent Change of Water Content (percent)
1	0	99.74	-----	99.72	0.22	-----	-----
2	1	98.0	100.5	97.5	0.51	3.07	2.56
3	2	99.5	101.0	99.0	0.51	2.02	1.51
4	3	99.0	100.0	98.0	1.02	2.04	1.02
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Bentonite Pellets* (crushed)	0.92	47.3	49.98	43.82	8.13	14.39	6.26
	1.92	47.3	51.72	43.82	8.13	18.45	10.32
	2.92	47.3	51.90	43.82	8.13	18.87	10.74
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Quartzite	11	42.0	42.0	42.0	0.0	0.0	0.0

* Bentonite pellets were obtained from Slope Indicator Company, Seattle, Washington.

Table 3. CBR-Values of Soaked Samples

Test Number	Water Content Before Compaction (Percent)	Water Content as Compacted (Percent)	Water Content after Soaking (Percent)	Water Content after Drying (Percent)	Water * Content after Penetration (Percent)	Dry Density (pcf)	Soaking Period (days)	Drying Period (days)	Minimum CBR Value	Swell (inches)
1	21.4	22.3	22.58	-----	21.5	99.4	5		4.8	0.022
2	21.9	21.7	22.36	-----	21.42	99.5	9		2.9	0.004
3	22.6	21.9	22.98	-----	21.4	99.2	14		2.7	0.000
4	21.7	22.2	22.51	17.44	17.44	99.9	5	4	16.3	0.019
5	20.6	21.43	21.70	15.23	14.96	99.4	5	9	36.4	0.011

* Water content determined by drying and weighing entire specimen.

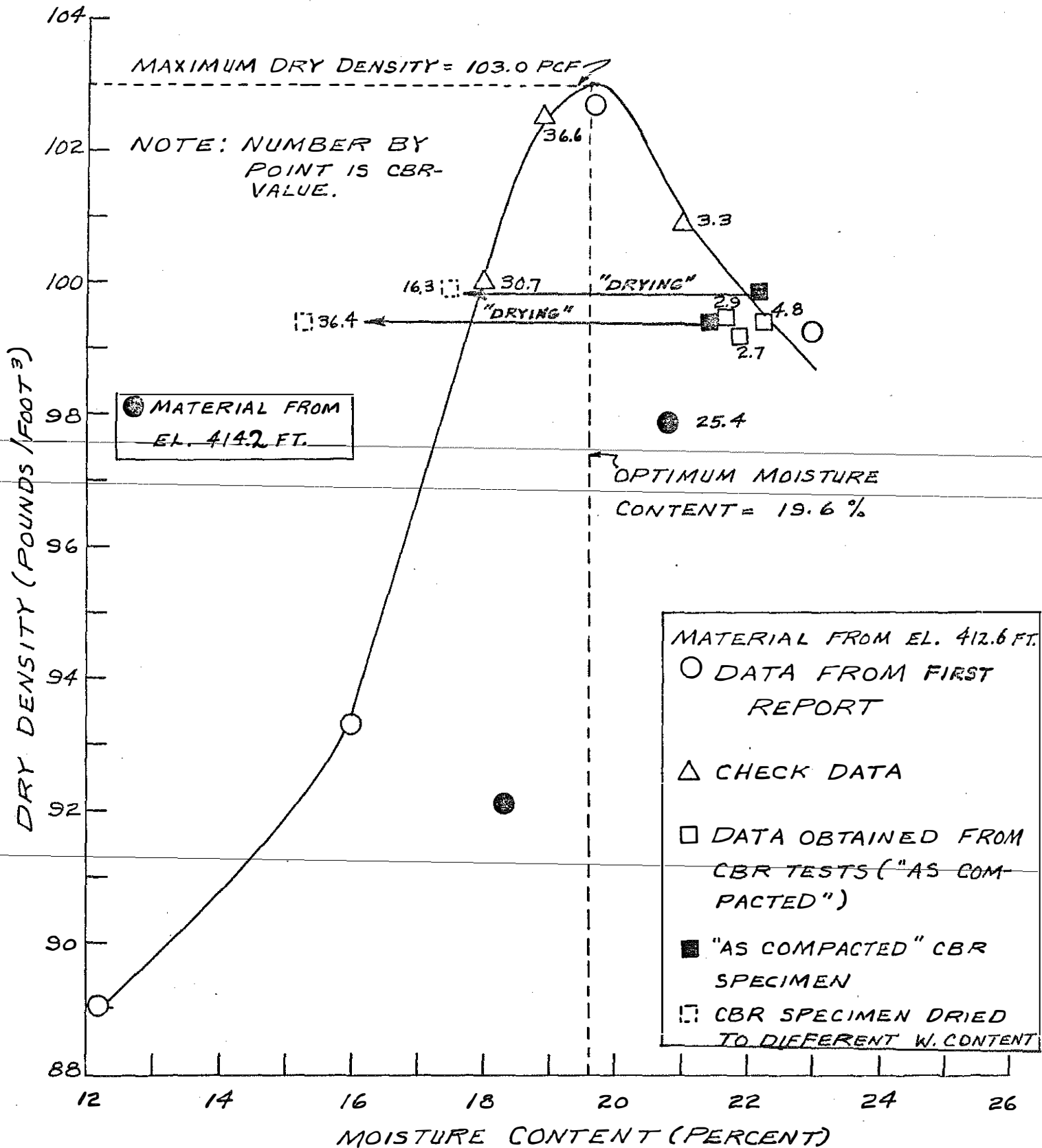


Figure 1. Moisture-Density Relation of Cherty Paleozoic Material.

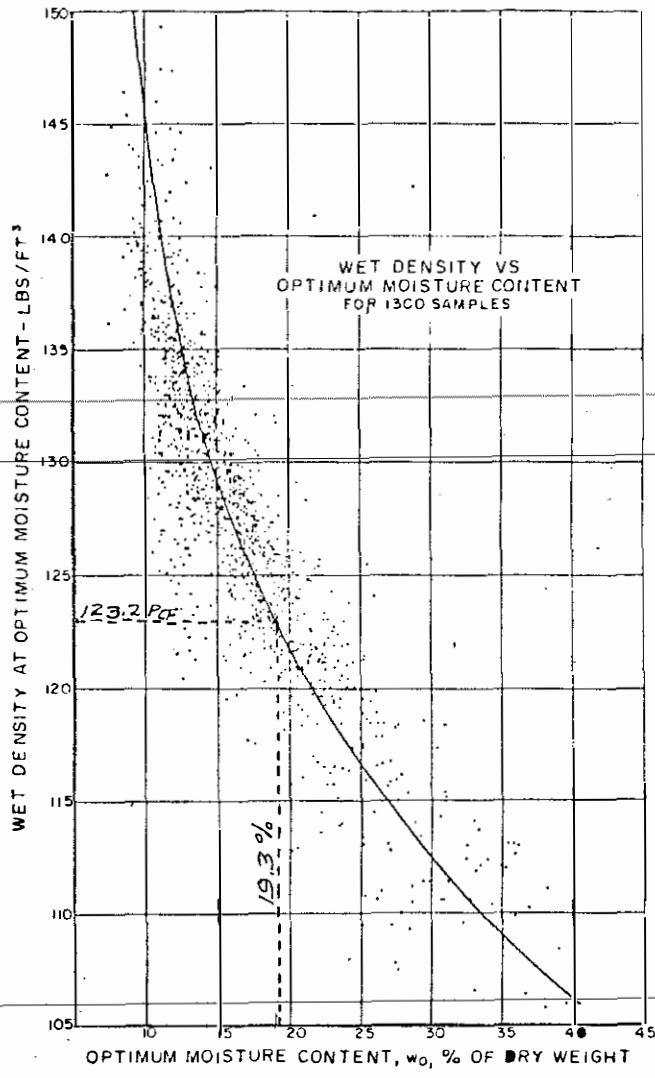


Figure 2. Wet Density-Optimum Moisture Content(after Hilf).

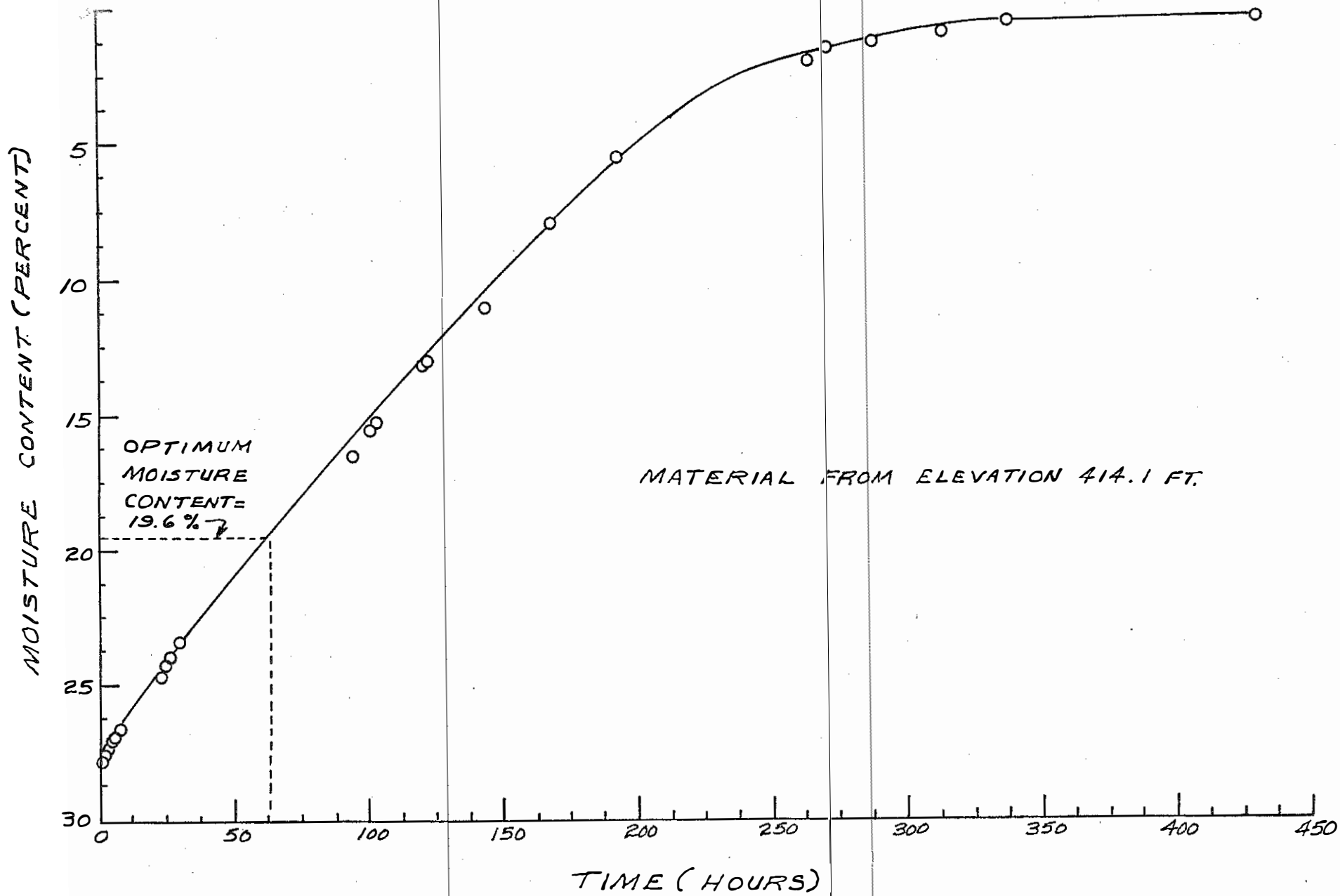


Figure 3. Moisture Content as a Function of Time.

METHODOLOGY FOR X-RAY MINERALOGY

Mineralogy

Mineralogical analyses were performed via x-ray powder diffraction. Individual soil and shale samples were disaggregated and separated into seven particle size fractions. Eight oriented clay films on unglazed ceramic tiles were prepared for each soil and shale sample. An x-ray diffractogram of each tile was obtained by using a Phillips Electronics x-ray diffraction unit. The unit employed Ni-filtered, Cu K α radiation generated with 35 kV and 15 ma. Silt tiles were scanned from 2 to 31° 2 θ at 25°C. Magnesium-saturated, glycerol-solvated clay tiles were scanned from 3 to 30° 2 θ at 25°C. At a subsequent heat treatment of 110°C, tiles were scanned from 3 to 15° 2 θ . Potassium-saturated tiles were scanned from 3 to 15° 2 θ at 25°C, 110°C, 300°C, and 550°C. All 2 θ angles of prominent peaks on the strip charts were measured, and respective spacings determined from Bragg's Law tables. Peak heights were measured from a base line which had been drawn to indicate the background radiation level.

Procedures for sample disaggregating and fractionation, ceramic tile preparation, and identification and interpretation of x-ray diffractograms are detailed below.

vermiculite present. Should the sample continue to exhibit a 14.7 Å spacing at higher temperatures, the presence of chlorite is confirmed. However, should the sample be altered via heat treatment to exhibit lattice spacing of 10.0 Å, the presence of vermiculite or smectite is indicated. When both vermiculite and chlorite were found to be present in the same sample, the height of the $6^\circ 2\theta$ peak of the potassium-saturated sample was subtracted from the peak height on the magnesium-saturated tile. The difference in peak intensities was attributed to the quantity of vermiculite present.

Montmorillonite. The quantity of montmorillonite present was calculated from a change in intensity of the $6^\circ 2\theta$ peak between 25°C and 110°C for the magnesium-saturated, glycerol-solvated tile. This quantity may represent free or mixed-layer montmorillonite.

Chemical Properties

Chemical properties measured during this study included water pH, SMP buffer pH, potential acidity, neutralization potential, acid/base titrations, extractable acidity, exchangeable acidity, organic matter content, cation exchange capacity, and phosphorus, potassium, and manganese concentrations.

pH

Water pH was determined on splits of each shale and soil sample using a pH glass electrode standard method (U. S. Department of Agriculture, Soil Conservation Service, 1972).

Sample Disaggregating and Fractionation

The procedure used to disaggregate and fractionate soil and shale samples is largely unpublished. Methods employed were developed and adapted by R. I. Barnhisel (personal communication, 1982), and are summarized below. Samples were disaggregated and fractionated into the following particle size ranges: sand ($>50 \mu\text{m}$), silts (20 to 50 μm ; 10 to 20 μm ; 5 to 10 μm ; and 2 to 5 μm), and clays (0.2 to 2 μm and $< 0.2 \mu\text{m}$).

Each soil and shale sample was dry-ground with an agate mortar and pestle to a -10 M (2.0 mm). Before separating the soil mineral matter into size fractions, organic matter and salts were removed. For this purpose, a 50 g sample of each soil (or shale) was placed in a 1000 ml tall form beaker and to this, 25 ml of water were added. The solution pH was adjusted to 3.5 using small additions of 1 N HCl and bromophenol blue indicator and a spot plate. To the acid solution, a 30 percent hydrogen peroxide solution (20 ml for topsoils, and 10 to 15 ml for subsoils and shales) was added, and allowed to stand overnight. After 10 to 15 hours, another 10 ml of hydrogen peroxide was added to each beaker. Samples were then gently heated on a hot plate for at least one hour. Once the suspension was somewhat cool, each beaker was filled with 500 ml of water, and salts were removed with a filter candle.

Next, each sample was adjusted to pH 10 using a 1 N Na_2CO_3 solution, in order to ensure particle dispersion. Each suspension was mixed using a "malt" mixer for 10 minutes, and then poured onto a 300 M ($< 50 \mu\text{m}$) sieve. The sand fraction retained on the sieve

was transferred to a preweighed beaker, and heated in an oven to 110°C until dry. The sand-filled beaker was then reweighed, and the sand fraction transferred to a glass vial and stored.

Separation of the four silt fractions and a collective clay fraction was performed using an elutriator with a large flask capable of removing the < 2 µm fraction. The -300 M material (silt and clay fraction) was transferred to a four-liter glass bottle, and stirred magnetically. The bottle containing the suspension was connected to an elutriation system similar to that described by Beavers and Jones (1966). Individual fractions were collected, oven-dried at 110°C, and retained for mineralogical analysis.

Finally, clay-size particles were separated into two size fractions (0.2 to 2 µm and < 0.2 µm) by means of a Sharples super centrifuge. The centrifuge was operated at a constant speed of 25,000 rpm, and the clay-size fraction passed through the system at a continuous flow rate of 380 ml per minute. Approximately four hours were required for complete separation of the sample. The < 0.2 µm fraction was collected in the effluent suspension, while the 0.2 to 2 µm fraction was retained in the centrifuge rotor cup.

Ceramic Tile Preparation

A simple suction apparatus was used to prepare clay mineral specimens for x-ray diffraction on unglazed ceramic tiles. The procedure used has been described by Rich (1969). For each soil and shale sample, eight tiles were prepared. Potassium-saturated tiles were prepared for the four silt fractions. Magnesium-saturated,

glycerol-solvated, and potassium-saturated tiles were prepared for the clay fractions.

The quantity of sample used to prepare each tile was determined using calculated values of Rich (1975). The quantities used were chosen in order to optimize x-ray diffraction patterns for clays by ensuring that specimens are infinitely thick with respect to the penetration of the x-ray source. Thus, diffraction peaks produced should be proportional to mineral concentrations over the entire scan.

Samples were saturated by passing chloride-salt solutions of potassium (1 N) or magnesium (1 N) through the films on the ceramic tiles. Following five 10-ml washes of either solution, excess salt was removed from the tile with two 10-ml washings with deionized, distilled water. A 10-ml wash with 20 percent aqueous solution of glycerol was used for glycerol solvation of the magnesium-saturated clay tiles. Tiles were air dried for at least 24 hours prior to x-raying.

Interpretation of X-ray Diffractograms

Mineral identification was accomplished largely on the basis of unpublished data, and through the use of interactive computer programs developed by R. I. Barnhisel (unpublished data). Individual minerals were qualitatively identified on the basis of x-ray diffraction peak positions. Quantitative analysis for minerals was accomplished using peak height and particle size distribution data. For each size fraction of a given sample, peak heights of each mineral were measured. These intensity measurements were summed, and each

individual mineral intensity divided by the total intensity, and then multiplied by 100. Thus, the mineralogy within a particular size fraction is expressed as a percent.

The total mineralogy of a given sample was determined by multiplying the percentage of a mineral present in an individual size fraction by the percentage which that size fraction represented of the total sample. The results for like minerals were summed across all seven size fractions, and divided by 100. Thus, total mineralogy for each sample was expressed in terms of percent. This method of quantitative mineralogical analysis is considered to be accurate within + five percent, based on chemical normative analyses performed on the quartz standard (R. I. Barnhisel, personal communication, 1982).

Minerals identified through the course of this investigation included: quartz, feldspar, kaolinite, mica, chlorite, vermiculite, and montmorillonite. Characteristic diagnostic features of each of these minerals are described briefly below.

Feldspar. Feldspars (e.g., plagioclase, potassium feldspar) can produce peaks, ranging in position from $33.85 \pm 0.10^\circ 2\theta$ to $23.0 \pm 1.0^\circ 2\theta$. Potassium feldspar and sodium feldspar were identified by peaks representing lattice spacings of 3.24 and 3.18 Å, respectively.

Quartz. For the purpose of this study a peak at the $20.8^\circ 2\theta$ position was interpreted to indicate the presence of quartz, and to represent a lattice spacing of 4.26 Å. (The $26.2^\circ 2\theta$ peak position,

although also characteristic of quartz, was not used, because the (003) reflection of mica appears nearly at this same position.)

Kaolinite. The presence of kaolinite was indicated by a peak at the $12.4^\circ 2\theta$ position, representing a lattice spacing of 7.15 Å as reflected from the (001) plane. Magnesium or potassium saturations do not affect this spacing. However, heating of the potassium-saturated tile to 550°C causes the $12.4^\circ 2\theta$ peak to disappear. (It should be noted that the second-order peak of chlorite shares nearly the same peak position of kaolinite. However, the intensity of the second-order peak, when chlorite is present, is generally very weak, and its contribution to peak height is small.)

Mica. Mica is characterized by a peak at the $8.8^\circ 2\theta$ position. This represents reflection from the (001) plane, and a lattice spacing of 10.0 Å. This peak is not affected by cation saturation at any heat treatment.

Chlorite. Under all heat conditions for both the potassium- and magnesium-saturated tiles, the presence of chlorite was indicated by the appearance of a peak at the $6^\circ 2\theta$ position. This peak represents a lattice spacing of 14.7 Å.

Vermiculite. Similarly, a diagnostic peak for vermiculite also occurs at the $6^\circ 2\theta$ position for magnesium-saturated, glycerol-solvated tiles. If little or no hydroxy interlayering is present, this peak would be altered to the $8.8^\circ 2\theta$ position upon potassium saturation at 25°C . The change in peak intensity at the $8.8^\circ 2\theta$ position was used as the basis for calculating the amount of