Mineralogical, chemical, and physical properties of the regolith overlying crystalline rocks, Fairfax County, Virginia: A preliminary report

By

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This report is preliminary and has not been edited or reviewed for conformity with Geological Survey standards or nomenclature.

Abstract

Undisturbed cores of saprolite developed on crystalline rocks of the Piedmont Province in Fairfax County, Virginia have been obtained using a combination of Shelby tubes, Denison sampler, and modified diamond core-drilling. The principal purpose of the core study is to correlate variations in chemistry, mineralogy and texture with engineering properties throughout the weathering profile. Coring sites were chosen to obtain a maximum depth of weathering on diverse lithologies. The rocks investigated include pelitic schist, metagraywacke, granite, diabase and serpentinite. Four to twelve samples per core were selected, depending on thickness of 1) the weathering profile (from about 1 m in serpentinite to more than 30 m in pelitic schist) and on 2) megascopic changes in saprolite character for analysis of petrography, texture, clay-mineralogy and major element chemistry. Shear strength and compressibility were determined on corresponding segments of core. Standard penetration tests were performed adjacent to coring sites to evaluate engineering properties _in situ_.

Geochemical changes of saprolite developed from each rock type follow predictable trends from fresh rock to soil profile, with relative increases in Si, Ti, Al, Fe^{3+} and H_2O; variable K; and relative loss of Fe^{2+}, Mg, Ca, and Na. These variations are more pronounced in the weathering profiles over mafic and ultramafic rocks than metagraywacke. Clay minerals in granite, schist and metagraywacke saprolite are

kaolinite, dioctahedral vermiculite, interlayered mica-vermiculite, and minor illite. Gibbsite is locally developed in near-surface samples of schist.

Standard penetration test data for the upper 7 m of saprolite over schist and metagraywacke suggest alternations between stronger and weaker horizons than probably reflect variations in lithology including the presence of quartz lenses. Results for granite saprolite are most consistent but indicate lower strength. Shear strength increases fairly regularly downward in the weathering profile. The engineering behavior of diabase saprolite is controlled by a dense, plastic, near-surface clay layer (montmorillonite and kaolinite) overlying rock which is weathered to a granular state (grus), while engineering properties of serpentinite are determined by a very thin weathering profile.

Introduction

This is a preliminary report on the study in progress of upland regolith (e.g., the material between fresh bedrock and the geomorphic surface) of the Piedmont of Fairfax County; particularly of the saprolite which is the major component of that regolith. Saprolite is that part of the regolith which retains the structure of the parent rock. It was defined originally by Becker (1894) for the southern Appalachians as the:

"...thoroughly decomposed, earthy, but untransported rock." Some of the terms used in this report (e.g., unstructured residuum, weathered rock) are defined on figure 11.

Despite its ubiquitous occurrence over the Piedmont of the southeastern states, little is known about the basic textural, chemical, mineralogical and engineering properties of saprolite. Studies of the weathering processes which produce saprolite are numerous, and although several weathering studies have been made in the Maryland-Virginia Piedmont (Plaster and Sherwood, 1971; Cleaves, 1968, 1973; Cleaves and others, 1970, 1974) and experience with engineering properties of saprolite has been summarized by Sowers (1954,1963) and Deere and Patton (1971), no comprehensive attempt has been made, to our knowledge to study chemical, mineralogical and engineering properties.

This study is part of a broader program of investigation of environmental geology in Fairfax County that has been underway since about 1974. It is hoped that the information presented here, as well as information presented in reports such as Drake and Froelich (1977) should be useful in land use planning for construction, septic system design, landfill siting, etc.

Regional Geology

The geology of parts of Fairfax County has been described in several published reports (Johnson, 1962, 1964; Seiders and others, 1975), and has recently been revised by Drake and Froelich (1977). This map of Fairfax County which emphasizes rock types is shown in Fig. 1.

The major crystalline rock types of the Piedmont of Fairfax County are metasedimentary, with compositions varying between arenaceous and argillaceous, at metamorphic grades which range from chlorite phyllites, to sillimanite schists and migmatite. Next in abundance are granitic rocks, predominantly the foliated Occoquan Adamellite in the southern part of the County (Seiders and others, 1975). Several other granitic intrusives may or may not be related to the Occoquan batholith.

Rocks of mafic to ultramafic composition form a broad, generally northeast trending belt west and southwest of the city of Fairfax. Narrower, north trending, belts of serpentinite are common in the northcentral part of Fairfax County. Broad diabase bodies are intrusive into Triassic sandstone and siltstone in the Culpeper basin in the western part of the County. Unconsolidated sediments of the Coastal Plain province underlie the eastern third of the County and are not discussed here.

The crystalline rocks other than the diabase are structurally complex. During metamorphism they were subjected to isoclinal folding and refolding (Drake and Froelich, 1977). Steeply dipping multiple foliation and joint planes are the most characteristic structural features.

Rock types investigated.-- Rocks in which saprolite cores were obtained include pelitic schist (unit B on fig. 1) and metagraywacke (C) (western Wissahickon schist of Hopson, 1964); Occoquan Adamellite (F); serpentinite (H); and diabase (J).

General character of sampled units.-- The chief metasedimentary rocks in Fairfax County comprise two "end-member" rock types - metagraywacke and pelitic schist - with all degrees of compositional and textural variation between the two. At 1:24,000 scale these two types constitute mappable units, and even a third intermediate unit - metasemipelite (not shown on fig. 1) - has been locally distinguished.

Saprolite on metasedimentary rocks tends to be thick. The depth to fresh bedrock in the core holes varied between about 15 m (50 ft) and 34 m (111 ft). For mechanical reasons, several of the 6 boreholes were not continued to unweathered rock; hence, even deeper saprolite might have been encountered. In the cores recovered, the A and B soil horizons tended to be minimal, typically less than 60 cm (2 ft), which matches observations in roadcuts. Commonly, saprolite occurred within the first Shelby tube (2 ft. = 60 cm). Downward in the drill hole the hardness is variable but in general increasing until the typically abrupt transition to weathered rock is encountered. Two characteristic drill logs, for pelitic schist and metagraywacke, are summarized in figures 2 and 3 (columns entitled "Structure").

The Occoquan adamellite is white to light gray, medium-grained granitic rock with well-developed foliation and textures varying between hypidiomorphic and crystalloblastic. Depth of weathering in the granite is as much as 30 m (100 ft). In the longer of the two cores obtained, unstructured saprolite extends to 6 m (20 ft) below the surface, and the degree of weathering diminishes in a more progressive fashion than in the metasedimentary rocks (see figure 4).

A very thin weathering profile is developed on rocks of the mafic-ultramafic complex (see figure 5). Typically, the profile is less than 1 meter (3 ft) deep which is commonly removed by erosion. Saprolite <u>sensu stricto</u> is virtually lacking; instead dense soil is developed containing nearly fresh rock fragments that increase in abundance downwards. The transition to virtually fresh saprolite is rather abrupt. Where the underlying rock is mafic (i.e., gabbroic) instead of ultramafic, development of saprolite may be somewhat more complete, but because of the close association of mafic and ultramafic rocks in the complex, this variation was not confirmed in available cores.

Saprolite over diabase is commonly relatively thin (1-2 m, 3-6 ft), although locally it may be up to 10 m thick, and consists of granular pellets (grus) grading downwards into corestones of weathered diabase. In the core obtained, the grus is overlain by dense clayey soil several cm thick (see figure 6), but at many localities the dense clay exceeds 1 m in thickness.

Drill sites.-- Drill locations for representative rock types are shown on fig. 1 (cf figs. 2-6). An additional 6 cores from the same units were analyzed but locations and results are not included in this report. Sampling sites were chosen in order to obtain the thickest saprolite profile (e.g., those on the uplands) on well-defined rock types. At each site, a continuous core from the surface to unweathered bedrock was obtained, and a standard penetration test was performed in a closely adjacent hole to a depth of 6 m (20 ft).

Techniques and procedures of drilling and sampling.-- All sampling was done with a Mobile B-61 truck-mounted drill. Sampling was initiated from the surface to refusal depth by means of 61 cm (24-inch) Shelby tubes. Over metasedimentary rocks this depth ranged between 1.7 and 6 m (9 and 20 ft); over Occoquan Adamellite, 1-15 m (3 1/2-50 ft); over diabase, about 1 m (3 ft), and over serpentinite 45-60 cm (1.5-2 ft).

Several sampling methods were tried below the effective depth for the Shelby tube. The Denison sampler, because of its capacity for a high percentage of core recovery in unconsolidated material, was expected to constitute the primary sampling tool down to firm rock. In practice, however, the Denison proved excessively slow. Although yielding almost continuous cores, the Denison samples were too disturbed for engineering testing. An attempt was made to use normal core drilling with a No. 10 face discharge bit instead of the Denison, but problems were encountered including poor sample recovery due to the flushing action of cooling water. A variation of this method, using air instead of water for cooling, subsequently proved to be quite satisfactory, and all sampling after boring No. 4 was accomplished by a combination of Shelby tube and air-cooled diamond core drilling.

Cooling was effected by a portable air compressor of 160 CFM capacity. The air compressor was coupled to the water pump by means of an adapter. Drilling was begun at 50 psi and increased approximately 2 psi per 30 cm (1 foot) of depth to a maximum of about 120 psi. A sawtooth bit was used until penetration was less than about 1/2 in. per minute, after which a No. 10 diamond bit was substituted. This combination of drilling/sampling techniques was found satisfactory both in terms of efficiency and rate of core recovery.

Analytical procedures.-- Samples from each of the cores were split and processed according to the following flow chart:

SAMPLE

PETROGRAPHY	TEXTURE	CHEMICAL ANALYSES	ENGINEERING PROPERTIES
a. Impregnate samples	a. Disaggregate sample	a. Rapid rock analysis of major elements	Density
b. Prepare polished, uncovered thin sections	b. Hydrometer analysis for 63	b. Semi-quantitative spectrographic analysis for 60 elements	Uniaxial Shear
c. Petrographic study; X-ray analysis of unrecognized phases (plucked from section)	CLAY MINERALOGY	c. Determination of Mn by atomic-absorption spectroscopy	Triaxial Shear
	a. Pipette sample form 2 fraction		
	b. X-ray diffraction of untreated, glycolated and heated slides		

Analytical results.--Figures 2-6 summarize the analytical results from cores representative of the major crystalline rock types in Fairfax County.

Geochemical changes on each rock type follow predictable trends from fresh rock to soil profile, with relative increases in Si, Ti, Al, Fe^{3+}, and H_2O; variable K; and relative loss of Fe^{2+}, Mg, Ca, and Na. These variations are most pronounced in the weathering profiles over mafic and ultramafic rocks, least so over metagraywacke. Clay minerals in granite, schist and metagraywacke saprolite are kaolinite, dioctahedral vermiculite, interlayered mica-vermiculite, and minor illite. Gibbsite is locally developed in near-surface samples of schist.

The engineering tests are summarized in columns headed "Blow Counts", "Unified System Classification", and "Shear Strength". Figures 7-10 serve as explanatory keys for these mechanical tests. Figure 11 summarizes the criteria for distinguishing regolith zones illustrated on figs. 2-6, and also suggests tests for evaluation of engineering behavior.

Standard penetration test data listed in figures 2-6 under the heading "Blow Counts" for the upper 7 m of saprolite over schist and metagraywacke suggest alternations between stronger and weaker horizons that probably reflect variable lithology including quartz lenses. Results for granite saprolite are more consistent but indicate lower strength. Shear strength increases fairly regularly downward in the weathering profile. The engineering behavior of diabase saprolite is controlled by a dense, plastic, near-surface clay layer (montmorillonite and kaolinite) overlying grus-like weathered rock, while engineering properties of serpentinite are determined by a very thin weathering profile.

The following are general observations on the engineering properties of saprolite:

1. Not all of the engineering properties vary singly as a function of depth. In metasedimentary units, the heterogeneous composition of the parent rock (e. g., arenaceous to argillaceous) greatly influences the final weathered products. The mechanical properties of the weathered products, such as strength and compressibility are highly variable both vertically and laterally.

2. For a given blow count, the shear strength of the granite is greater than that of the more micaceous units (metapelite and metagraywacke).

3. Joints in the saprolite frequently control the laboratory measured (triaxial or uniaxial) shear strength of saprolite. Shear surfaces often developed in the joint fillings.

4. In granitic rocks, thin continuous clay-rich seams or residuum often traverse the saprolite samples. These seams are zones of weakness.

5. Saprolite of the highly micaceous rocks (metapelite) can have a very low density and high mica content. It has been suggested by other workers (Sowers, 1963, Deere and Patton, 1971) that saprolite of this nature may be susceptible to continuous, long-term deformation and settling.

6. The existence of highly micaceous or chloritic foliation shears may be of major importance to the local strength of saprolite or rock as a foundation material. Where present, these shear zones may be of much more significance to engineering behavior of the site than are the general regolith characteristics. Contacts between rock units of greatly different tecture (e.g., pelitic schist-metagraywacke contact) commonly exhibit shear zones; thick pelitic rocks also commonly exhibit shear zones.

Summary

This report represents an initial attempt to correlate mineralogical and chemical variations with engineering properties of the piedmont regolith along the weathering profile. Fig. 11 summarizes our observations in the context of a classification scheme for the regolith. The present report is preliminary and will be superseded by a fuller version containing more of our basic data. Meanwhile, the results reported here may provide some impetus for further research in different parts of the piedmont.

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Illustrations

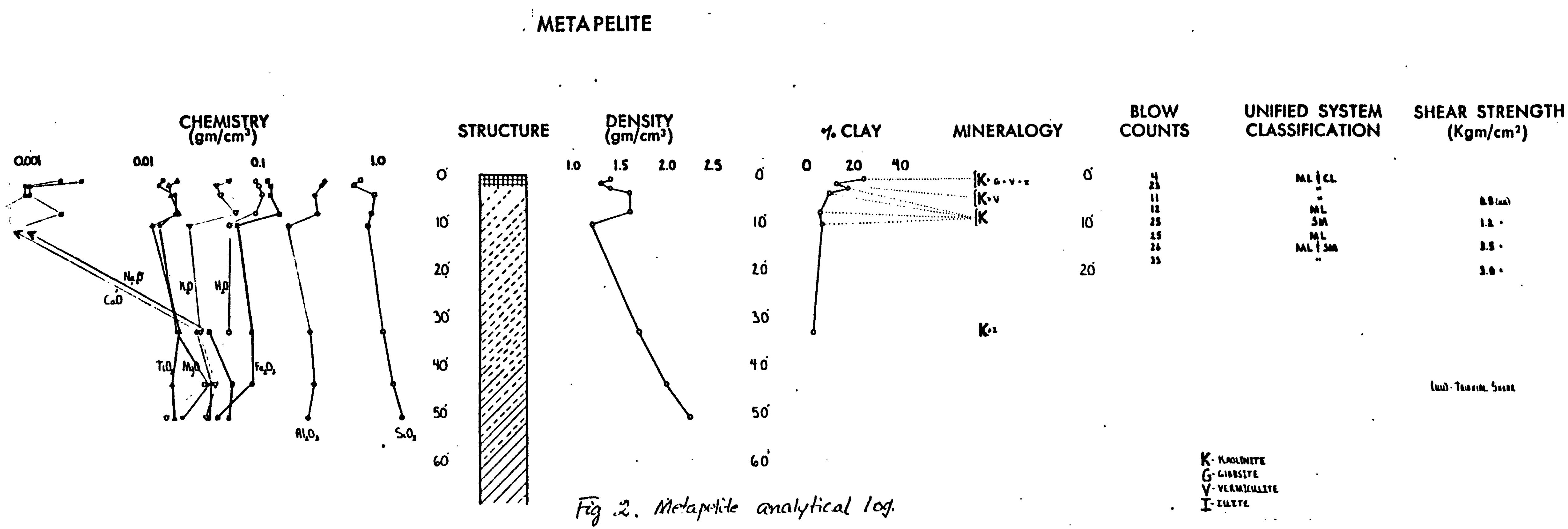

Fig .2. Metapelite analytical log.

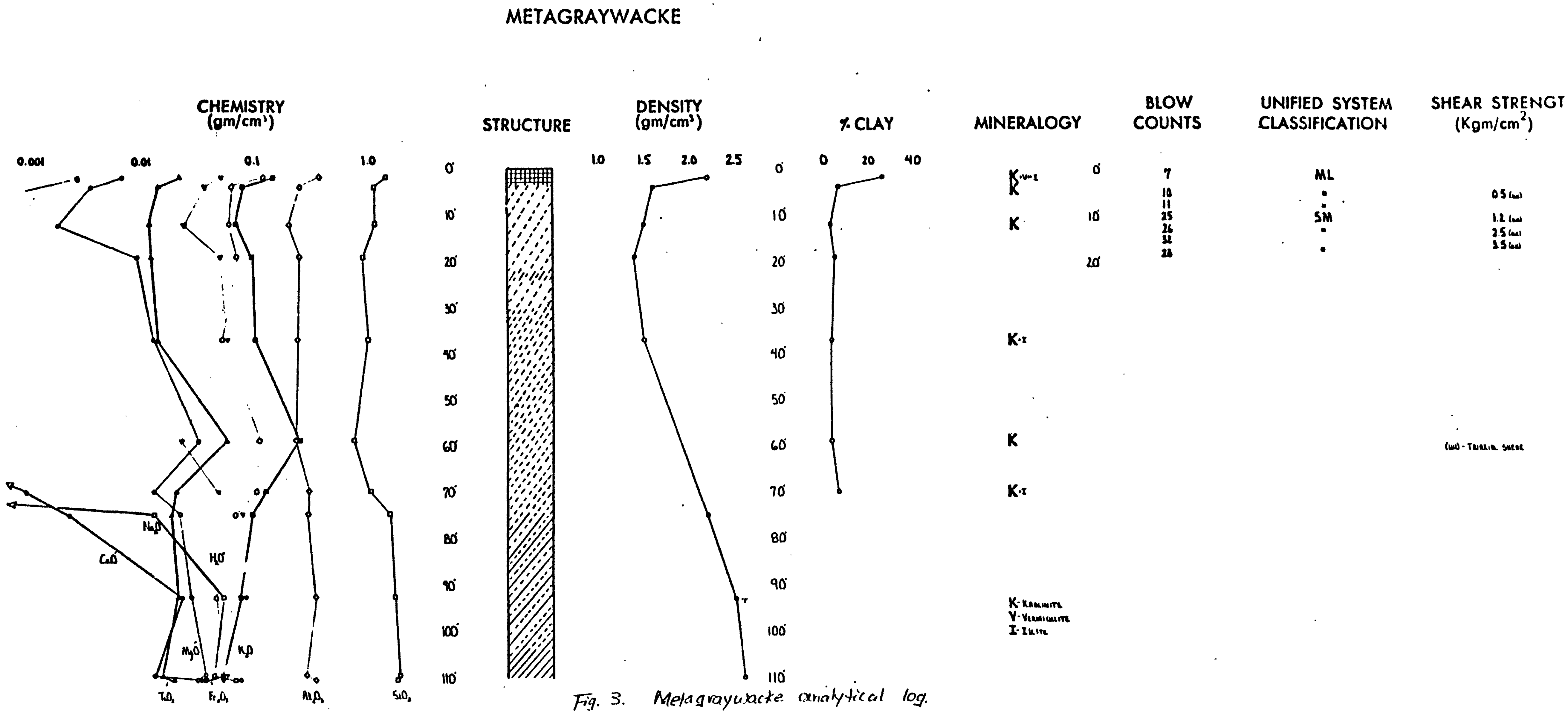

Fig. 3. Metagraywacke analytical log.

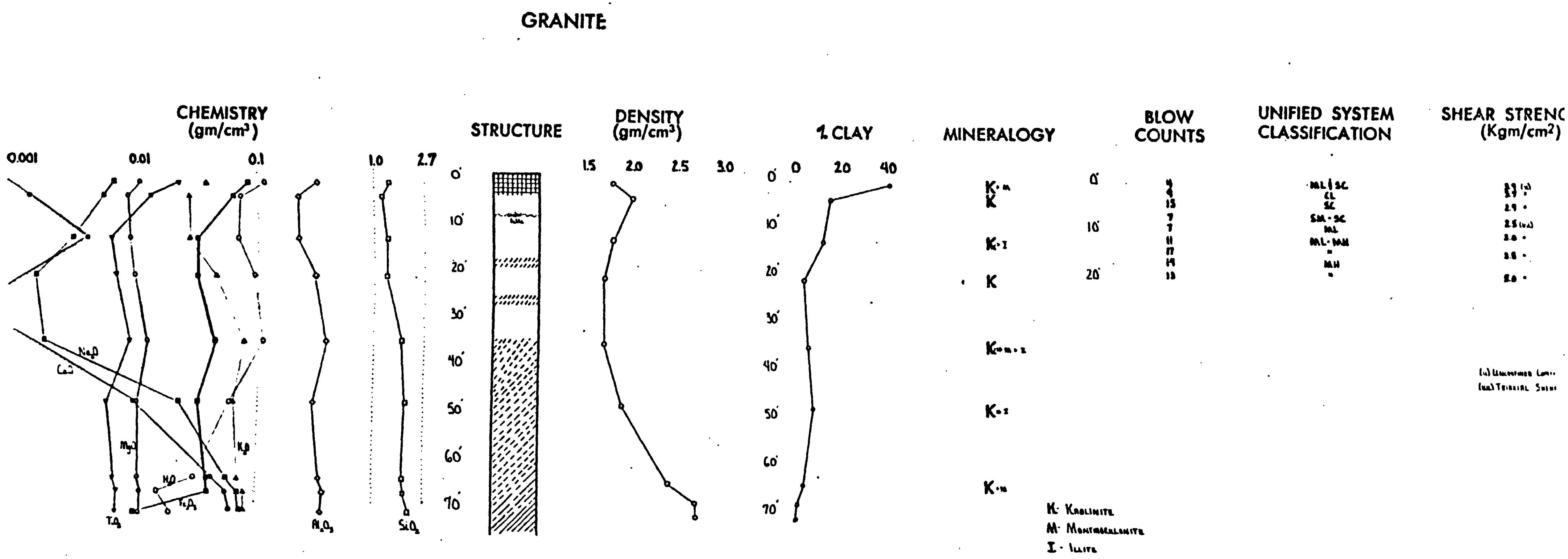

Fig. 4. Occoquan adamellite analytical log.

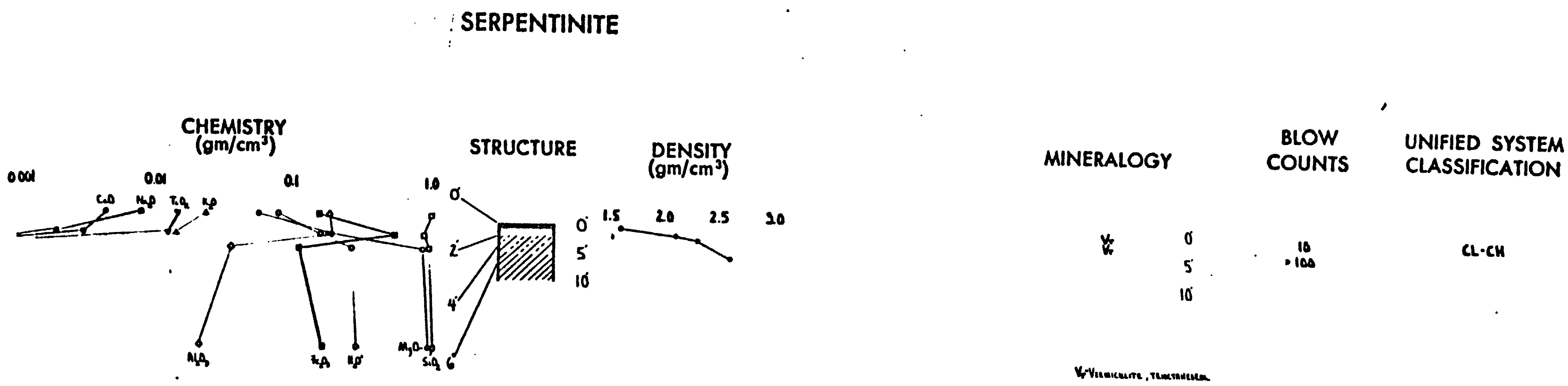

Fig. 5. Serpentinite analytical log.

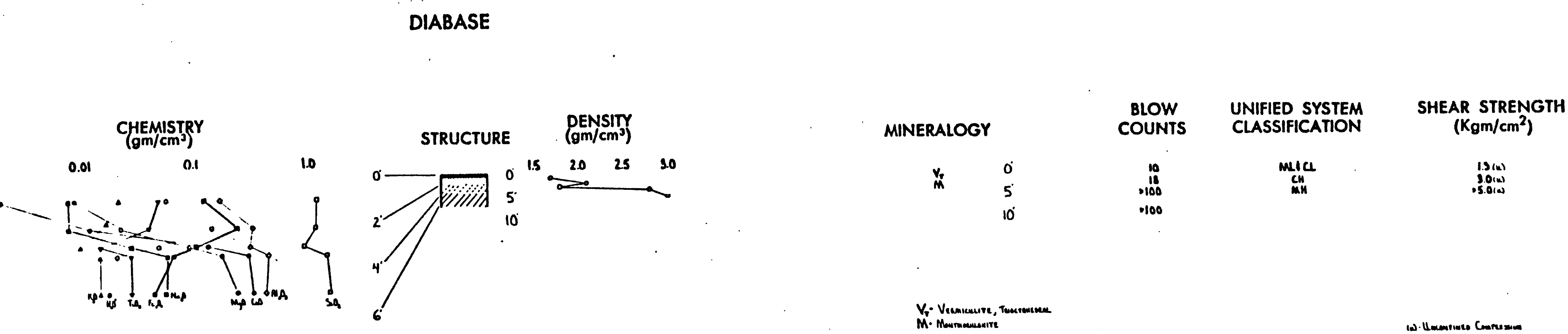

Fig. 6. Diabase analytical log.

Figure 7 USGS OPEN-FILE REPT. 77-644

UNIFIED CLASSIFICATION SYSTEM FOR SANDS AND FINE-GRAINED MATERIALS

Major Divisions			United Class. System	Typical Names	Field Identification Procedures		
Coarse-grained Soils More than half of material is larger than No. 200 sieve size.	Sands More than half of coarse fraction is smaller than No. 4 sieve size.	Clean Sands (Little or no fines)	SW	Well-graded sands, gravelly sands, little or no fines	Wide range in grain size and substantial amounts of all intermediate particle sizes		
			SP	Poorly graded sands or gravelly sand, little or no fines.	Predominantly one size or a range of sizes with some intermediate sizes missing		
		Sands with Fines (Appreciable amount of fines)	SM	Silty sands, sand-silt mixtures	Nonplastic fines or fines with low plasticity.		
			SC	Clayey sands, sand-clay mixtures	Plastic fines		
					Identification Procedures on Fraction Smaller than No. 40 Sieve Size		
					Dry Strength (Crushing characteristics)	Dilatancy (Reaction to shaking)	Toughness (Consistency near PL)
Fine-grained Soils More than half of material is smaller than No. 200 sieve size	Silts and Clays	Liquid limit is less than 50	ML	Inorganic silts and very fine sands silty or clayey fine sands or clayey silts with slight plasticity	None to slight	Quick to slow	None
			CL	Inorganic clays of low to medium plasticity gravelly clays sandy clays silty clays lean clays	Medium to high	None to very slow	Medium
	Silts and Clays	Liquid limit is greater than 50	MH	Inorganic silts micaceous fine sandy or silty soils elastic silts	Slight to medium	Slow to none	Slight to medium
			CH	Inorganic clays of high plasticity fat clays	high to very high	None	High

The No 200 sieve size is about the smallest particle visible to the naked eye.

Figure 8

Plasticity Chart for Laboratory Identification of Fine-Grained Soils

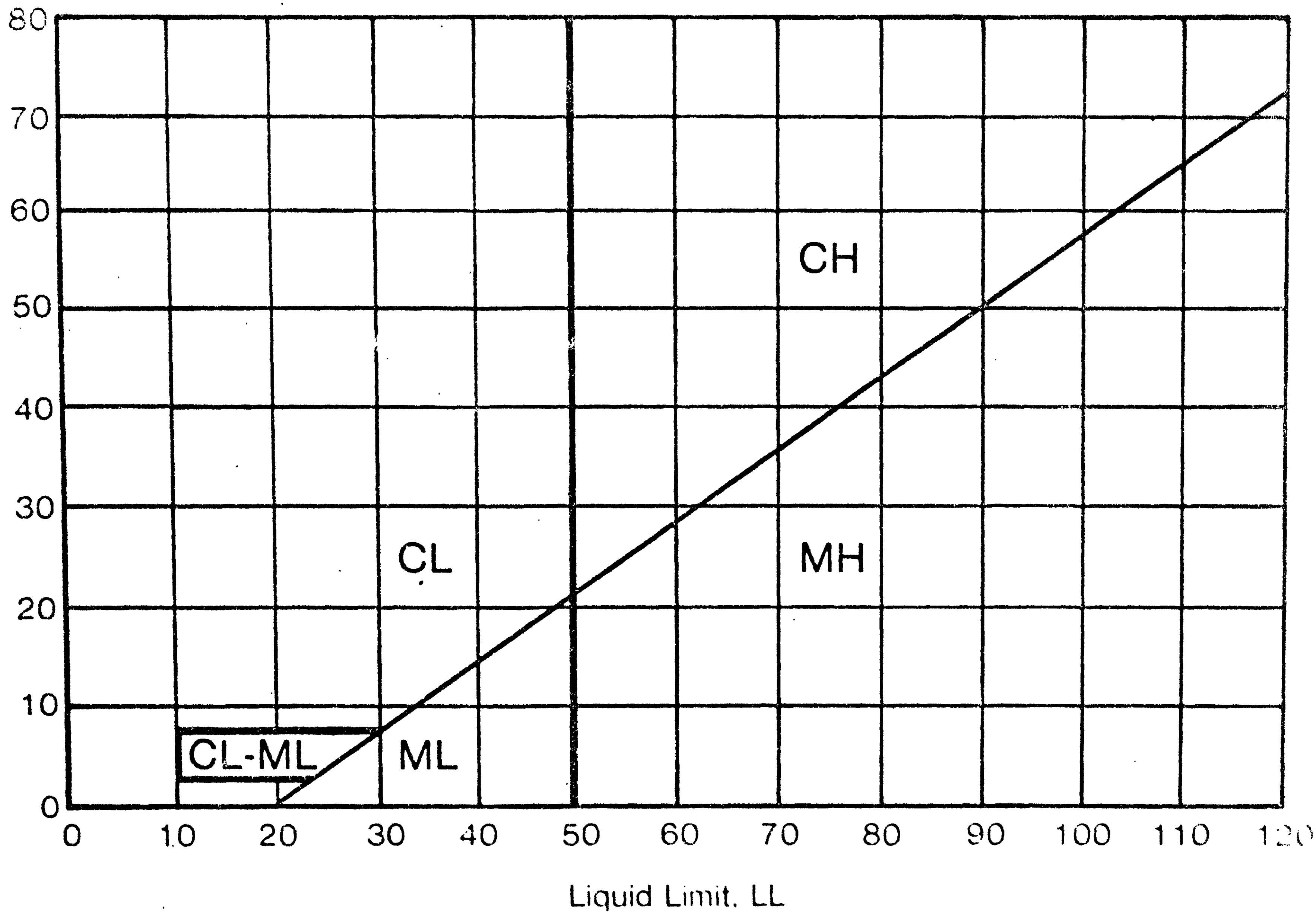

Figure 9

ENGINEERING BEHAVIOR OF COMPACTED MATERIALS, AS RELATED TO UNIFIED SYSTEM CLASSIFICATION

TYPICAL NAMES OF SOIL GROUPS	UNIFIED SYSTEM CLASS	IMPORTANT ENGINEERING PROPERTIES					
		PERMEABILITY WHEN COMPACTED	SHEAR STRENGTH WHEN COMPACTED AND SATURATED	COMPRESSIBILITY WHEN COMPACTED AND SATURATED	WORKABILITY AS A CONSTRUCTION MATERIAL	STRUCTURAL PERFORMANCE AS COMPACTED ROADWAY FILL FROST HEAVE POSSIBLE	OTHER IMPORTANT CHARACTERISTICS WHEN COMPACTED
WELL-GRADED SANDS, GRAVELLY SANDS, LITTLE OR NO FINES	SW	PERVIOUS	EXCELLENT	NEGLIGIBLE	EXCELLENT	EXCELLENT	
POORLY-GRADED SANDS, GRAVELLY SANDS, LITTLE OR NO FINES	SP	PERVIOUS	GOOD	VERY LOW	FAIR	GOOD	
SILTY SANDS, POORLY-GRADED SAND-SILT MIXTURES	SM	SEMIPERVIOUS TO IMPERVIOUS	GOOD	LOW	FAIR	FAIR	HIGHLY EROSIVE
CLAYEY SANDS, POORLY-GRADED SAND-CLAY MIXTURES	SC	IMPERVIOUS	GOOD TO FAIR	LOW	GOOD	FAIR TO GOOD	
INORGANIC SILTS AND VERY FINE SANDS, ROCK FLOUR, SILTY OR CLAYEY FINE SANDS WITH SLIGHT PLASTICITY	ML	SEMIPERVIOUS TO IMPERVIOUS	FAIR	MEDIUM	FAIR	POOR	HIGHLY EROSIVE
INORGANIC CLAYS OF LOW TO MEDIUM PLASTICITY, GRAVELLY CLAYS, SANDY CLAYS, SILTY CLAYS, LEAN CLAYS	CL	IMPERVIOUS	FAIR	MEDIUM	GOOD TO FAIR	FAIR	
INORGANIC SILTS, MICACEOUS FINE SANDY OR SILTY SOILS ELASTIC SILTS	MH	SEMIPERVIOUS TO IMPERVIOUS	FAIR TO POOR	HIGH	POOR	POOR	
INORGANIC CLAYS OF HIGH PLASTICITY FAT CLAYS	CH	IMPERVIOUS	POOR	HIGH	POOR	POOR	HIGH VOLUME CHANGE

Figure 10

Relation of allowable foundation pressure to standard penetration resistance blow count for residuum on Piedmont rocks, for column loads of 25,000 to 100,000 lbs. Band width represents range of allowable pressures used by different designers in Fairfax County area.