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Geotechnical Properties of Ash Deposits Near Hilo, Hawaii

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ABSTRACT

Two holes were hand augered and sampled in ash deposits near Hilo, Hawaii. Color, water content and sensitivity of the ash were measured in the field. The ash alternated between reddish brown and dark reddish brown in color and had water contents as high as 392%. A downhole vane shear device measured sensitivities as high as 6.9. A series of laboratory tests including grain size distribution, Atterberg limits, X-ray diffraction analysis, total carbon determination, vane shear, direct shear and triaxial tests were performed to determine the composition and geotechnical properties of the ash. The ash is very fine grained, highly plastic and composed mostly of gibbsite and amorphous material, presumably allophane. The ash has a high angle of internal friction ranging from 40-43° and is classified as medium to very sensitive.

A series of different ash layers was distinguished on the basis of plasticity and other geotechnical properties. Sensitivity may be due to a metastable fabric, cementation, leaching, high organic content, and thixotropy. The sensitivity of the volcanic ash deposits near Hilo is consistent with documented slope instability during earthquakes in Hawaii. The high angles of internal friction and cementation permit very steep slopes under static conditions. However, because of high sensitivity of the ash, these slopes are particularly susceptible to seismically-induced landsliding.

Introduction

Slope stability problems in volcanic ash deposits have occurred historically during earthquakes in Hawaii. To provide geotechnical data for a study concerned with seismic hazards of the Hilo area on the island of Hawaii (USGS Project 9550-02430-J. M. Buchanan Banks-Project Chief) we tested ash deposits near Hilo, Hawaii. Field and laboratory tests, including but not limited to water content, grain size analysis, Atterberg limits, X-ray diffraction analysis, vane shear, direct shear, and triaxial tests were used to determine the material properties and relate them to slope stability problems.

Geology

The distribution, thickness and characteristics of the volcanic ash on the island of Hawaii have been described by Wentworth (1938, p. 34-103) and Stearns and Macdonald (1946, p. 71-75, p. 157-159). The distribution of Quaternary ash (referred to as Pahala ash by Stearns and Macdonald) is shown in fig. 1. Because the ash was distributed by wind, the wind velocity and distance from the source affected the thickness, grain size, and other properties in any locality. Maximum thickness of the ash ranges from 16.8 m (55 ft) near Pahala to several beds totaling about 6.0 m (20 ft) interstratified with and overlaying lavas near Hilo. The ash consists of weathered, weakly cemented, very fine particles of volcanic glass. The ash ranges in color from light brown in semi-arid areas to brownish red in moist areas.

Slope Stability Problems

According to historic accounts, the April 2, 1868, Hawaii earthquake triggered a landslide of "loose red soil" above Wood Valley, Hawaii (fig. 1) that broke loose from "the side of the pali (cliff), burying in a minute thirty-one human beings, many hundred head of cattle, and entire flocks of goats, and ending four miles from its beginning ..." (this description of the Wood Valley landslide is from the letter of Rev. T. Coan which was reported by Brigham (1869)). The "loose red soil" refers presumably to the deeply weathered, thick Pahala ash mapped in this vicinity by Stearns and Macdonald (1946, p. 73). Brigham (1869) mentions that other landslides occurred in this earthquake near Wood Valley and along the Hamakua coast north of Hilo.

The 1973 Honomu, Hawaii earthquake (M_s 6.1) caused numerous soil falls and soil slumps north of Hilo along the Hamakua coast (Nielson and others, 1977). Most of these landslides, along with tension cracks and slumps of several inches in the shoulders of roadways, occurred in deposits of volcanic ash.

Problems have been encountered with volcanic ash during highway construction. Although cuts in ash as steep as 1/4 to 1 (76^o) are stable, the ash loses its strength when reworked for fill. During attempts to compact the ash for highway embankments, repeated passes of heavy equipment for spreading and compacting work the ash into a plastic state. Upon further working, the plastic state is changed to a semi-liquid state without the addition of moisture (Hirashima, 1948).

In order to develop a better understanding of the behavior of these volcanic ash deposits, samples of ash near Hilo were collected and tested in the laboratory to determine the material properties and the significant characteristics with respect to slope stability.

Field Sampling and Testing

Two holes were hand augered in ash deposits near Hilo, Hawaii (fig. 2), for sample collection and field tests. A hole at the Alenaio Canal was located in the top of the west embankment of a recent cut made during the construction of the Wailuku-Alenaio Drainage Diversion Canal that parallels Akolea Road. This first hole proceeded through several layers of interbedded ash before meeting refusal at a depth of 4.72 m (15.5 ft). The second hole at a spatter cone, Puu Hono in the Halai Hills, was advanced only 1.6 m (5.25 ft) before meeting refusal in a stiff volcanic spatter. Additional surface samples were collected for laboratory testing from several other localities shown in fig. 2.

Cylindrical tube samples, 5.1 cm (2.0 in) in diameter and 15.2 cm (6.0 in) in length, were taken every 46 cm (1.5 ft). The color of the bottom of the samples was identified using Munsell Soil Color Charts and then a small fraction of the sample was scraped into an aluminum can for a water content determination. Water content was measured as a fraction of the dry weight of the sample. The tube samples were immediately capped with plastic end caps, labeled and double bagged to prevent moisture loss during subsequent shipping and storage.

To provide a measure of undrained shear strength and sensitivity of the ash, vane shear tests were made in the hole every 46 cm (1.5 ft) using a Pilcon direct reading hand vane. The accuracy of this type of instrument is discussed by Serota and Jangle (1972). The vane was pushed into the soil to a depth about 6-8 cm (2.5-3 in) below the depth the hole had been advanced, and rotated at a constant rate of one revolution per minute. This rate was easily paced using the second hand of a watch. Two different size vanes were used, 1.9 cm (0.75 in) and 3.3 cm (1.3 in) depending on the strength of the ash. In addition to the vane shear tests in the augered holes near Hilo, several other vane shear tests were performed for comparison on surface outcrops near Hilo and in surface exposures of the Wood Valley landslide mentioned previously.

Laboratory Testing

A series of laboratory tests were used to determine the composition and strength characteristics of the ash. These tests included: grain size distribution, Atterberg limits, density, total carbon determination, X-ray diffraction analysis, vane shear, direct shear, and triaxial tests. Samples were transported by air freight in tightly sealed bags within cushioned boxes to prevent disturbance and stored in a humid room within the laboratory to prevent moisture loss until the samples were tested.

The grain size measurements were made using procedures prescribed in ASTM standard D 422-63 (ASTM, 1978, p. 71). Difficulty was encountered determining the clay size fraction of some samples because even after adding defloculating agents such as Calgon and sodium hexametaphosphate and centifuging several times the samples still did not defloculate. Problems in determining the particle size distribution of ash soils in Hawaii by standard mechanical methods has previously been experienced by other investigators (Hough and Byers, 1937; Hirashima, 1948). These investigators believed the high organic content of the soils to be responsible for the floculation problems. As will be discussed the samples we tested also had relatively high organic content. For samples where the separate clay and silt size fractions could not be determined, a total percentage for the combined clay and silt size fraction is reported.

Atterberg limits were determined using procedures in ASTM D 424-59 (ASTM, 1978, p. 86) and D423-66 (ASTM, 1978, p. 82). Special care was taken to insure the samples retained their natural moisture content, because previous investigators (Willis, 1946; Hirashima, 1948; and Terazghi, 1958) have pointed out the irreversible changes in grain size and plasticity that occur when ash soils dry out. Frauhauf (1946) pointed out that plasticity is affected by the irreversible change in the organic content of ash soils when they dry. Because organic material significantly affects soil properties, the amount of carbon was measured using techniques described by Kolpack and Bell (1968). To determine the mineralogy of the clay size fraction of the ash, an X-ray diffraction analysis was performed using a sample preparation and testing procedure outlined by Hein and others (1975).

In the laboratory an electrically driven vane shear device was used to measure undrained shear strength in the center of the cylindrical tube samples. A 1.2 cm (0.5 in) vane was rotated at a rate of 90^{o} per minute. After the peak was reached, the vane was turned two full revolutions by hand and then the test was resumed for several revolutions to assure a remolded reading. A stress transducer and chart recorder were connected to the vane shear device so that a continuous record of stress history from peak to remolded strength could be obtained.

A direct shear test was used to measure shear strength under drained conditions. Remolded material was consolidated into a shear box and sheared at a rate of $9.75x10^{-4}$ cm/min ($3.84x10^{-4}$ in/min), slow enough presumeably to permit sample drainage. Because of the limited amount of intact sample remaining after the previous test had been performed, only two triaxial tests could be performed to confirm the results of the direct shear tests. Isotropically consolidated undrained tests with pore pressure measurements were performed using a triaxial system similar to that used in the geotechnical laboratories at University of California, Berkeley (Chan and Duncan, 1966; Chan and Mulilis, 1976). Tests were performed on one undisturbed sample and one sample that had been remolded.

Results

Table 1 lists color, water content, moist density, in-situ vane shear strengths, and sensitivity of samples from Puu Hono and Alenaio test holes. Table 2 provides laboratory results of grain size analyses, Atterberg limits, specific gravity, laboratory vane shear tests, direct shear tests, sensitivity, friction angle, and total carbon determination.

The major and minor constituents of six ash samples as determined by X-ray diffraction analysis are listed in table 3. The relative proportions of the various minerals were estimated qualitatively. Despite the fine grained nature of the samples, no clay minerals were detected. The proportion of amorphous material in each sample was variable. Quartz was a common minor constituent. Gibbsite ($Al(OH)_3$) was the major constituent of all samples except for the sample from 4.57-4.72 m (15-15.5 ft) at the bottom of the hole at the Alenaio Canal. This sample is probably derived from a basaltic lava flow and therefore reflected a distinctly different mineralogy than the samples above it.

The amorphous fraction of the samples is presumeably allophane, a dominant constituent of young volcanic soils in the tropics and is commonly associated with halloysite, gibbsite and imogolite (Kitagawa and others, 1973; Gonzalez De Vallejo and others, 1981). Gibbsite and allophane have been identified in volcanic ash layers along the Hamakua coast of Hawaii (Bates, 1960). In general gibbsite has been recognized in Hawaii as a common end product where leaching is continuous and effective, and where time has been sufficient for weathering of the volcanic ash.

Total carbon contents of 0.7 to 5.6% by weight in the profile of the two holes listed in table 2 suggest that the ash soils of this part of Hawaii are high in organic matter. Ayres (1943) measured organic matter in surface samples from 7 to 27% by weight in humid subsoils of the Hilo and Hamakua coasts. The high carbon content through the profile is attributable to downward percolation and deposition of organics through the relatively loose, permeable ash structure as a result of the very high rainfall of this region.

Laboratory direct shear and triaxial tests on undisturbed and on remolded samples yielded friction angles from 40° to 43° listed in table 2. These friction angles appear unusually high for such fine-grained material, however such values are not unusually high for fine-grained granular particles lacking platy clay minerals. High angles of internal friction are also consistent with the steep slopes observed in ash deposits near Hilo. In a similar tropically weathered, tuffaceous soil containing material 40 to 50% by weight finer than 2 micron size, Terzaghi (1958) reported high angles of internal friction of 30° to 36°.

Sensitivity, S_t, defined as the ratio of the undisturbed to remolded strength (Mitchell, 1976) was calculated from the field and laboratory vane shear tests. Values of S_t, ranging from 1.6 to 6.9, are listed in tables 1 and 2. Degrees of sensitivity are shown below:

Classification of Sensitivity Values (after Rosenqvist, 1953)

Insensitive	1
Slightly sensitive	1-2
Medium sensitive	2-4
Very sensitive	4-8
Slightly quick clay	8-16

Field measurements of sensitivity were generally higher than laboratory measurements. A single cause for the difference in values could be not identified; several factors, however, including disturbance during sampling, effects of testing within the narrow tubes, different vane size and rate of shearing could be responsible for the discrepancy.

Alenaio Canal

On the basis of physical and index properties three separate ash layers (A,B,C) were identified in the geologic log of the hole at Alenaio Canal in fig. 3. The repetition of layers with similar physical properties suggests alternating periods of ash deposition and weathering.

As expected for air deposited ash the layers fine upward. The layers were divided into upper and lower parts (A_1, A_2, B_1, B_2, C_1) on the basis of differences in grain size, specific gravity carbon content, and plasticity. The upper part of the layers (A_1, B_1, and C_1,) have relatively fine textures. The lower parts of each layer (A_2 and B_2) have relatively coarse textures. In addition to being more fine grained, the upper part of each layer had lower specific gravity, higher total carbon content and higher plasticity than the lower parts of each layer. The difference in plasticity is evident on a plasticity chart, fig. 5, where data from both Alenaio and Puu Hono cluster into two different groups, distinguished by the part of the layer the sample came from. Other properties, such as color, shear strength, and sensitivity did not vary systematically between the upper and lower parts of each layer. The deepest sample at 4.57-4.72 m (15-15.5 ft) was distinguished from the ash by its distinctive dark brown color and coarse grain size distribution with a significant percentage of gravel-size particles. This sample represents either an old soil horizon or more likely the top of a saprolite (a severely weathered rubble layer atop the aa flow).

Ash stratigraphy similar to that described above of alternating sequences of very fine grained, highly plastic ash and more granular, less plastic ash was observed near Hilo by Wentworth (1938, p. 75-77). The conclusion here that these layers represent different episodes of air deposited ash is based only on interpretation of the physical properties. Further confirmation could be provided by chemical fingerprinting of each layer to determine if the different ash layers do represent separate episodes of deposition (H. McLean, pers. commun., 1981).

Puu Hono

The geologic log of the hole at Puu Hono shown in fig. 4 was prepared from field descriptions and laboratory tests. The volcanic ash at Puu Hono was found to be only about 1.5 m (5 ft) thick, beneath which very stiff basalt spatter was encountered. The dark reddish brown color (5YR 3/4) of the ash was similar to that of several of the layers at the Alenaio Canal. On the plasticity chart plot of fig. 5, the Puu Hono samples cluster with the low plasticity samples from Alenaio Canal. The ash at Puu Hono may be an eruptive deposit from a different volcano or may be more recent than ash at the Alenaio Canal (J.M. Buchanan-Banks, oral commun., 1980), and has undergone less weathering which could affect its plasticity. The other properties of ash at Puu Hono such as density, sensitivity, and shear strength are very similar to values from Aleneio Canal.

Surface samples

Surface samples collected from several localities near Hilo (fig. 2) have distinctly different grain size distributions (table 4) than do samples from the two holes. Surface samples were much coarser, probably because drying had irreversibly aggregated the very fine grained particles; also, downward infiltration of fine-grained particles may concentrate coarser particles at the surface. These samples also had very low plasticity as a result of drying. Surprisingly, the sensitivity of these samples was noteably high, possibly because partial drying caused them to behave in a more brittle manner than the material at natural water content sampled in the holes.

DISCUSSION

The geologic logs developed from field classifications and tests of samples show a stratigraphy of ash deposits similar to that observed by Wentworth (1938), although he identified several more layers, some of which were no more than 2.5 cm (1 in) thick. We did not identify such thin layers, probably because our sampling interval was too coarse. Continuous sampling as well as additional holes would have been necessary to provide a more complete picture of the ash stratigraphy.

According to Mitchell (1976) at least six factors contribute to sensitivity: 1) metastable fabric, 2) cementation, 3) leaching, 4) thixotropic hardening, 5) ion exchange and change in monovalent/divalent cation ratio during weathering, and 6) formation or addition of dispersing agents. From the lab and field evidence, the sensitivity of ash deposits in the Hilo area is due to at least several, if not all, of these factors.

Aeolian deposits, such as volcanic ash and loess, are characterized by a loose structure of grain to grain contacts which are subject to collapse when vibrated. During the 1978 Izu-Oshima-Kinkai, Japan earthquake, landsliding occurred along a thin layer of medium-very sensitive (S_t= 3.4-5.0) volcanic ash (Okusa and others, 1980). The 1920 earthquake in the Kansu Province of China caused the widespread landsliding of many loess slopes (Close and McCormick, 1922). Together with this evidence, the historic instability of ash deposits during earthquakes in Hawaii, particularly the Wood Valley landslide, suggests that collapse of a metastable fabric plays a significant part in contributing to the sensitivity of the aeolian Hawaiian ash.

Weak cementation by allophane, gibbsite or iron oxides could also contribute to the sensitivity of the Hawaiian ash. Wentworth (1938) suggested that some cementation of the ash is due to agglutination of the ash particles while still hot and plastic.

A tropical climate with rainfall exceeding 508 cm/year (200 in/year) and relatively constant high temperature along the Hamakua coast of Hawaii combined with good drainage provides ideal conditions for leaching. Leaching of the ash removes the bases and silica leaving the soil rich in alumina and iron (Hirashima, 1948; Dumbleton, 1967). Leaching changes the fundamental properties of materials, particularly the sensitivity, as has been well noted in clays (Bjerrum and Rosenqvist, 1956).

Experience with the ash as a highway fill has led Hirashima (1948) to suggest that the material behaves thixotropically. Thixotropy is an isothermal, reversible, time dependent process whereby a material stiffens while at rest and softens or liquefies upon remolding (Mitchell, 1976, p. 210). The behavior of the ash in embankment fills suggests that thixotropic hardening may account for part of the sensitivity of volcanic ash, as it does for quick clays (Skempton and Northey, 1952).

Weathering is tied closely to and cannot easily be separated from, cementation and leaching with regard to development of sensitivity. Soil sensitivity decreases after organic matter has been removed. Organic substances may act as dispersing agents and lead to increased double layer explusion aiding the development of sensitivity (Mitchell, 1976, p. 214). The relatively high total carbon contents of the Hilo ash deposits listed in table 2 indicate that dispersing agents may account for some of the sensitivity of the ash. It appears that a metastable fabric, cementation, leaching, thixotropy and formation or addition of dispersing agents all contribute to the development of moderate to high sensitivity of the ash.

CONCLUSIONS

1. The volcanic ash near Hilo is very fine grained, highly plastic, and composed mostly of gibbsite and amorphous material, presumably allophane. Air deposition of the ash results in a very loose structure which is responsible for very low dry density, high water content, and high sensitivity of the deposits.

2. A sequence of ash layers, substantiated by geotechnical properties including grain size distribution, plasticity, specific gravity, and total carbon content suggest a history of episodic deposition and weathering of ash.

3. The volcanic ash of the Hilo area , consisting of fine clay size particles, changes irreversibly upon drying to a friable, granular aggregation

of particles. Comparison of tests on surface samples and auger samples indicates that the physical properties of the ash, particularly grain size and plasticity, depend upon whether the tests are performed on samples which have remained at their natural water content or upon samples which have dried.

4. The thick ash deposits near Hilo are affected by weathering, leaching and cementation, and addition of organic matter. These factors combined with the loose aeolian fabric of the ash contribute to the sensitivity.

5. The sensitivities of volcanic ash deposits near Hilo are consistent with observed slope instability during earthquakes in Hawaii and other parts of the world. The high friction angle of the ash permits very steep slopes under static conditions, which because of high sensitivity, are particularly susceptible to seismically-induced landsliding.

REFERENCES

ASTM Standards, Part 19, 1978, Natural building stones; soil and rock, peats, mosses, and humus: American Society for Testing and Materials, Philadelphia, Pa.

Ayres, A. S., 1943, Soils of High-Rainfall Areas in the Hawaiian Islands, Hawaii Agricultural Experiment Station Technical Bulletin, n.1, 41p.

Bates, T. F., 1960, Rock weathering and clay formation in Hawaii, Bulletin, College of Mineral Resources, Pennsylvania State University, v. 29, n. 8, 4 p.

Bjerrum, L., and Rosenqvist, I. Th., 1956, Some Experiments with Artificially Sedimented Clays, Geotechnique, V. 6, p. 124-136.

Brigham, N. T., 1869, The eruption of the Hawaiian Volcanoes, 1868, Boston Journal of Natural History, v. 1, p. 564-587.

Chan, C. K., and Duncan, J. Md., 1966, A New Device for Measuring Volume Changes and Pressures in Triaxial Tests on Soils, Soil Mechanics and Bituminous Materials Research Laboratory Report, University of California, Berkeley, 5 p.

Chan, C. K., and Mulilis, J. P., 1976, Pneumataic Sinusoidal Loading System, Proc. ASCE Geotechnical Enmgineering Division, v. 102, n. GT3, p. 277 282.

Close, V., and McCormick, E., 1922, Where the mountains walked, The National Geographic Magazine, v. 41, n. 5, p. 445-464.

Dumbleton, M. J., 1967, Origin and minerology of African red clays and Keuper Marl, Q. Journal Engineering Geol., v. 1, p. 39-45.

Frauhauf, B., 1946, A Study of Lateritic Soils, Proceedings, Highway Research Board, v. 26, p. 579-593.

Gonzalez De Vallejo, L. I., Jimenez Salas, J. A., and Leguey Jimenez, S., 1981, Engineering Geology of the Tropical Volcanic Soils of La Laguna, Tenerife, Eng. Geol., 17, p. 1-17.

Hein, J. R., Scholl, D. W., and Gutmacher, C. E., 1975, Neogene Clay Minerals of the Far NW Pacific and Southern Bering Sea: Sedimentation and Diagenesis, Proc. of International Clay Conference, Mexico, p. 71-80.

Hirashima, K. B., 1948, Highway Experience with Thixotropic Volcanic Clay, Proc. Hwy. Res. Board, 28, p. 481-494.

Hough, G. J., and Byers, H. G., 1937, Chemical and Physical Studies of Certain Hawaiian Soil Profiles, U. S. Department of Agriculture Technical Bulletin n. 584, 26p.

Kitagawa, Y., Kyuma, K., and Kawaguchi, K., 1973, Clay mineral compositon of some volcanogeneous soils in Indonesia and the Philippines, Soil Sci. Plant Nutr., 19 (3), p. 147-159.

Kolpack, R. L., and Bell, S. A., 1968, Gasometric determination of carbon in sediments by hydroxide absorption, Journal of Sedimentary Petrology, v. 38, no. 2, p. 617-620.

Mitchell, J. K., 1976, Fundamentals of Soil Behavior, John Wiley & Sons, Inc., New York, 422 p.

Nielson, N. N., Furumoto, A. S., Lum, W., and Morrill, B. J., 1977, The Honomu, Hawaii, earthquake, report of inspection: Washington, D.C., National Academy of Science, 79 p.

Okusa, S., Tatsuoka, F., Taniguchi, E., and Ohkochi, Y., 1980, Natural slope failures during earthquakes: a case study, Proc. 7th World Conference on Earthquake Engineering, Istanbul, v. 3, Geotechnical aspects, p. 49-56.

Rosenqvist, I. T., 1953, Considerations on the Sensitivity of Norwegian Quick Clays, Geotechnique, v. III, no. 5, p. 195-200.

Serota, S., and Jangle, A., 1972, A direct-reading pocket shear vane, ASCE Civil Engineering January 1972, p. 73-74.

Stearns, H. T., and Macdonald, G. A., 1946, Geology and Ground-Water Resources of the Island of Hawaii, Bulletin 9, Hawaii Division of Hydrography, 363 p.

Skempton, A. W., and Northey, R. D., 1952, The sensitivity of clays, Geotechnique, v. 3, no. 1, p. 30-53.

Terzaghi, K., 1958, Design and performance of the Sasumua dam, Proc. Inst. Civil Engrs., London, 9, pp. 369-394.

Wentworth, C. K., 1938, Ash Formations of the Island Hawaii, Third Special Report of the Hawaiian Volcano Observatory, Hawaiian Volcano Research Association, Honolulu, Hawaii, 183 p.

Willis, E. A., 1946, Discussion: A study of lateritic soils, Proc. Hwy. Res. Board, 26, p. 589-591.

Table 1.--Field data from holes at Alenaio Canal and Puu Hono.

Sample #	Sample Depth m	Sample Depth ft	Color	Water Content (%)	Moist Density (lbs/ft^3)	Shear Strength (psi) Peak	Shear Strength (psi) Remolded	Sensitivity S_t
ALENAIO CANAL								
	0.08	0.25				4.20	1.30	3.3
1-1	0.15 0.30	0.5 1.0	5YR/6 yellowish red	333	72.2			
	0.38	1.25				4.06	1.16	3.5
1-2	0.46 0.61	1.5 2.0	2.5YR3/4 dark reddish brown	133	76.4			
	0.69	2.25				3.37	0.65	5.2
1-3	0.76 0.91	2.5 3.0	2.5YR3/4 dark reddish brown	208	76.0			
	1.07	3.5				3.33	0.80	4.2
1-4	1.22 1.37	4.0 4.5	5YR1/4 reddish brown	336	71.9			
	1.52	5.0				2.75	0.43	6.3
1-5	1.68 1.83	5.5 6.0	5YR3/4 dark reddish brown	392	74.2			
	1.98	6.5				4.50	0.72	6.9
1-6	2.13 2.29	7.0 7.5	5YR3/4 dark reddish brown	257	76.4			
	2.59	8.5				4.50	1.88	2.4
1-7	2.74 2.90	9.0 9.5	5YR4/4 reddish brown	97	82.6			
	3.05	10.0				4.57	1.45	3.2
1-8	3.20 3.35	10.5 11.0	5YR4/4 reddish brown 2.5YR3/4 dark reddish brown	131	88.6			
	3.51	11.5				5.65	2.03	2.8
1-9	3.66 3.81	12.0 12.5	5YR4/4 reddish brown	294	72.6			
	3.96	13.0				7.68	3.19	2.4
1-10	4.27 4.42	14.0 14.5	5YR4/4 reddish brown	207	75.0			
	4.50	14.75				15.22	2.32	6.6
1-11	4.57 4.72	15.0 15.5	7.5YR3/2 dark brown 10YR3/2 very dark grayish brown	203	89.9			

Table 1.--Field data from holes at Alenaio Canal and Puu Hono.--Continued.

Sample #	Sample Depth m	Sample Depth ft	Color	Water Content (%)	Moist Density (lbs/ft^3)	Shear Strength (psi) Peak	Shear Strength (psi) Remolded	Sensitivity S_t
PUU HONO								
	0.30	1.0	----------	----------	----------	8.26	2.17	3.8
2-1	0.46 0.61	1.5 2.0	5YR3/4 dark reddish brown	200	80.0	----------	----------	----------
	0.76	2.5	----------	----------	----------	6.96	2.17	3.2
2-2	0.91 1.07	3.0 3.5	5YR3/4 dark reddish brown	229	75.4	----------	----------	----------
	1.22	4.0	----------	----------	----------	7.18	2.03	3.5
2-3	1.37 1.52	4.5 5.0	7.5YR5/6 reddish brown	177	81.9	----------	----------	----------

Conversions: 1 ft = 0.305 m; 1 psi = 0.0703 kg/cm^2; 1 lb/ft^3 = 0.0161 gm/cm^3

Table 2.--Laboratory results from samples at Alenaio Canal and Puu Hono.

Sample #	Sample Depth		Grain Size (% finer)			Atterberg Limits		Specific Gravity	Shear Strength (psi)		Sensitivity	Friction Angle	Total Carbon
	m	ft	Sand	Silt	Clay	w_P	w_L	G_s	Peak	Remolded	S_t	(°)	(%)
Alenaio Canal													
1-1	0.15 0.30	0.5 1.0	9	-- 91* --		253	345	---	8.24	2.27	3.6	---	5.63
1-2	0.46 0.61	1.5 2.0	28	58	14	124	194	2.83	6.63	3.46	1.9	---	2.37
1-3	0.76 0.91	2.5 3.0	24	69	7	132	208	---	6.21	2.92	2.1	---	2.35
1-4	1.22 1.37	4.0 4.5	9	45	46	199	336	2.69	3.64	2.03	1.8	---	3.06
1-5	1.68 1.83	5.5 6.0	18	-- 82* --		244	362	---	7.64	4.18	1.8	41[2]	3.03
1-6	2.13 2.29	7.0 7.5	11	-- 89* --		229	344	---	9.55	2.98	3.2	40[2]	4.44
1-7	2.74 2.90	9.0 9.5	24	36	40	98	144	2.97	7.22	3.82	1.9	42[2]	1.80
1-8	3.20 3.35	10.5 11.0	40	-- 60* --		81	107	---	9.31	2.15	4.3	---	0.77
1-9	3.66 3.81	12.0 12.5	2	-- 98* --		240	319	2.76	9.85	5.37	1.8	---	4.00
1-10	4.27 4.42	14.0 14.5	8	-- 92* --		208	310	---	16.71	10.68	1.6	43[2]	3.60
1-11	4.57	15.0	21[1]	-- 79* --		134	178	---	17.91	7.88	2.3	---	2.76
Puu Hono													
2-1	0.46 0.61	1.5 2.0	9	-- 91* --		164	215	---	13.13	6.92	1.9	---	3.71
2-2	0.91 1.07	3.0 3.5	12	-- 88* --		153	210	2.82	14.92	8.24	1.8	---	2.24
2-3	1.37	4.5	--	--	--	138	171	---	19.70	7.88	2.5	---	1.55

* these percentages represent combined totals of silt and clay size fractions

1 this total includes 10% gravel

2 values of cohesion corresponding with these friction angles were negligible

Conversion: 1 psi = 0.0703 kg/cm^2

Table 3.--X-Ray diffraction analysis of ash deposits near Hilo, Hawaii.

Depth (ft)	Constituents Gibbsite	Magnetite/Hematite	Quartz	Amorphous
Alenaio Canal				
1.5-2.0	M	---	N	---
5.5-6.0	M	---	N	N
10.5-11.0	M	---	N	---
14.0-14.5	M	---	N	M
15.0-15.5	---	M	N	---
Puu Hono				
3.0-3.5	M	---	N	---

M - represents a major constituent and N represents a minor constituent based on a qualitative estimate of the relative size of peaks on the diffraction pattern

Table 4.--Laboratory tests on surface samples.

Sample #/Location	Grain Size (% finer) Gravel	Sand	Silt	Clay	Atterberg Limits w_L	w_P	Sensitivity S_t	Water Content (%)
HBA-80-1/Waipahoehoe Stream, south side ash	0.5	75	24.5	0	225	173	---	---
PBA-80-2/Alenaio Canal ash	1	38	35	26	NP	NP	---	---
PBS-80-3/Alenaio Canal saprolite	23	4	66	7	65	55	---	---
AFBA-80-4/Kaiwiki Rd. ash	0	54	39	7	NP	NP	---	---
AFBC-80-5/Kaiwiki Rd. clay bed	0	1	71	28	63	52	10-15.5	207
AFBS-80-6/Kaiwiki Rd. saprolite	0	9	74	17	45	36	6.4	78
Makakupu Gulch, Wood Valley landslide ash	--	--	--	--	--	--	10.7-11.7	84

NP - designates non-plastic soil.

Figure 1.--General location map of the island of Hawaii.

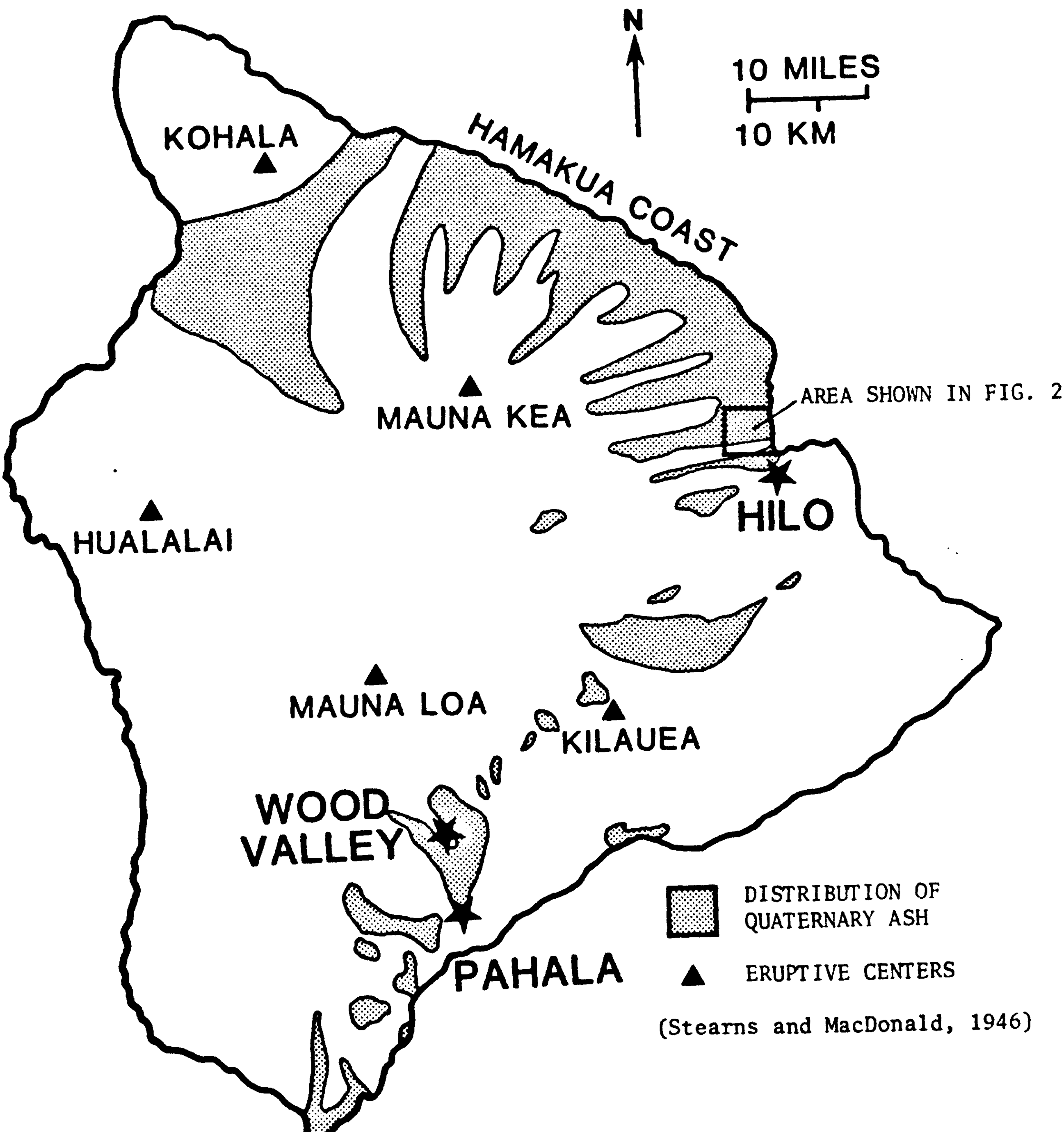

Figure 2.--Location of surface samples and holes for ash near Hilo, Hawaii.

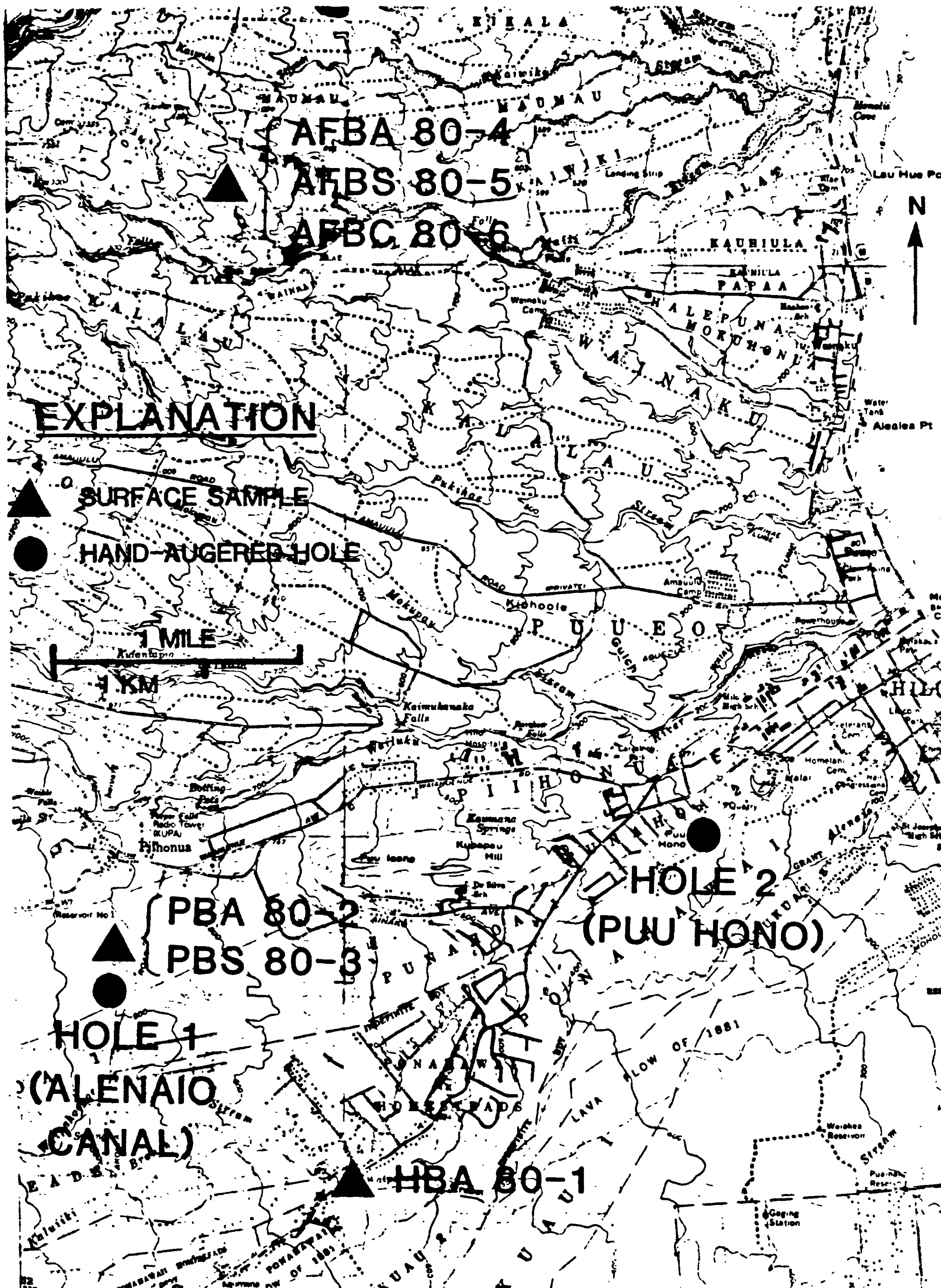

Figure 3.--Geologic log of hole at Alenaio Canal.

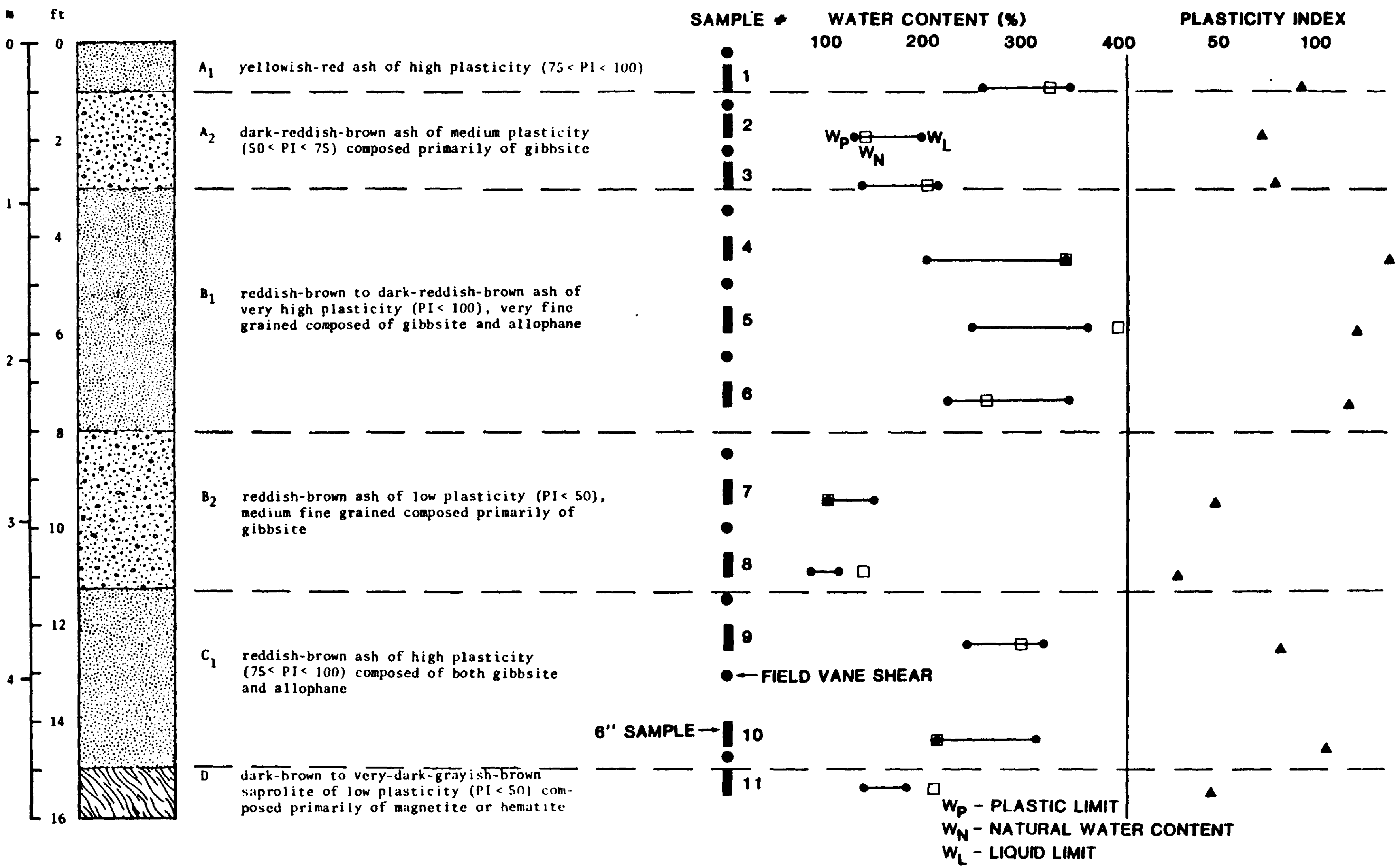

Figure 4.--Geologic log of hole at Puu Hono.

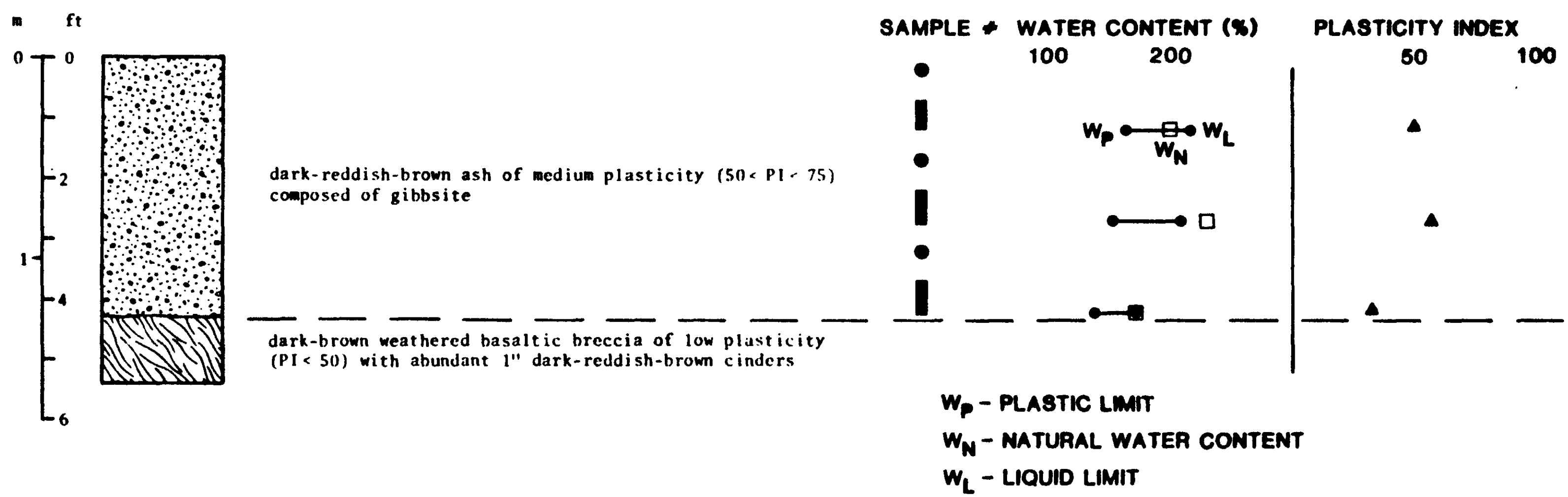

Figure 5.--Plasticity chart for samples from Alenaio Canal and Puu Hono.

● ALENAIO CANAL

◆ PUU HONO

SAMPLE	LAYER	SAMPLE	LAYER
1-1	A1	1-7	B2
1-2	A2	1-8	B2
1-3	A2	1-9	C1
1-4	B1	1-10	C1
1-5	B1	1-11	D
1-6	B1