UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

VANE SHEAR STRENGTHS AND INDEX PROPERTIES OF SEDIMENT OBTAINED FROM R/V KANA KEOKI; JANUARY, 1981: PRELIMINARY REPORT

BY

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This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature. Any use of trade names is for descriptive purposes only and does not imply endorsement by the USGS.

1. INTRODUCTION

Four sediment cores were obtained from the Research Vessel Kana Keoki in January 1981 in conjunction with the Oahu Ocean Thermal Energy Conversion (O'OTEC) project. The purpose of the present study is to determine general geotechnical characteristics of the seafloor sediment at selected core locations. This information may be required for development of OTEC facilities at the site.

The sediment, typically tan silty-clayey sand to tan sandy-clayey silt, was acquired from the southwest submarine slope of Oahu (Figure 1). Table 1 lists the lengths of recovered core sections; core recovery ranged from 175 cm to 550 cm. Vane shear strengths and engineering index properties of the sediment were determined at 33 locations within the cores. The measured properties consist of vane shear strength, water content, bulk density, grain density, Atterberg limits and grain size distribution. This suite of tests represents approximately 60% of the total index properties to be obtained on this sediment. Additional properties will be determined in conjunction with consolidation and triaxial tests to be performed at a later time.

2. SHEAR STRENGTH

Core sections were cut into 1.5 meter lengths, capped and taped aboard ship. The cores were vertically stored at a temperature of approximately 4°C aboard ship, during transit and prior to testing. Some sections dried out due to leakage of water around the bottom end caps and cracks, both horizontal and longitudinal, are present in some sections as evidenced by X-ray radiographs (Figure 2). Overall, the condition of the cores is believed to be satisfactory; the extent of dewatering, however, is not known in some sections.

The shear strengths listed in this report were determined by applying a torque to a four bladed vane that was inserted in the end of a core section. By measuring the peak resistance to rotation of the sediment and assuming a cylindrical failure surface, a vane shear strength was calculated. The determined vane shear strength (S_v) is often used interchangeably with in place undrained shear strength (S_u). However, many factors influence S_v: a large pebble may be present between the vane blades thereby increasing the measured sediment resistance; a large particle may be pushed in front of the vane during insertion thereby remolding the material and reducing S_v; or the failure surface may be larger than the cylindrical area bordering the outside edges of the blades thus increasing the vane shear strength. Drainage of pore water may occur during a test if the permeability of the sediment is sufficiently high. In this case S_u would not be accurately measured. The vane shear tests were performed on core sections in the laboratory; however, the stress histories of the lab samples were different from those of the in situ sediment. During sampling the sediment was disturbed, i.e., the geometric arrangement of the soil particles and the interparticle stresses between them were changed. The anisotropic stress state in the field was changed to an isotropic state, transportation induced some disturbance and dewatering occured during storage. The above factors influence how accurately the laboratory vane shear results agree with undrained in situ behavior. The laboratory vane shear test does not exactly duplicate seafloor conditions, but it does provide an indication of general shear strength values; laboratory strengths typically are less than in situ values due to disturbance.

Motorized vane shear tests were performed on the top of each section where possible. Due to disturbance, tests were not run on the top of each core. The vane is 1.27 cm in diameter and height. It was inserted until the bottom of the vane was approximately 2.54 cm below the sediment surface. The vane was rotated by a motorized torque sensor at a constant rate of 90° per minute. After a peak strength was recorded the sediment was remolded by rapidly rotating the vane one revolution. Immediately, a remolded shear strength was measured.

The sediment in core 1G is very soft (undrained shear strength S_u < 12.5 kPa) (Terzaghi and Peck, 1967, p. 30). In the other cores it is classified as soft (12.5 kPa < S_u < 25 kPa). The sediment in cores 6G and 8G is strongest with S_u values in the 15-17 kPa range. Sediment at depth may be stronger than the shallow material tested for this report.

The sensitivities (S_t) (shear strength of unremolded sediment/shear strength of remolded sediment) of cores 1G, 2G and 8G place the sediment in the medium sensitive (2 < S_t < 4) range. The material in core 6G is classified as sensitive (4 < S_t < 8). The sensitivity of most clays ranges between 2 and 4 (Terzaghi and Peck, 1967, p. 31). Shear strengths and index properties for the four cores are listed in Table 2 and are plotted versus subbottom depth in Figure 2.

3. WATER CONTENT, ATTERBERG LIMITS AND BULK DENSITY

The water content (w) ([weight of sea water assuming a salinity of 35 parts per thousand]/[weight of solid sediment particles]) of the sediment varies between 31 and 100 percent. A decrease in w with depth is typically noticed; however, a slight increase appears in core 2G. Water contents increase with depth in the lower sections of cores 6G and 8G.

By comparing the natural water content of a soil to a standard of engineering behavior, the soil's properties can be better anticipated. The relative position of w in relation to Atterberg limits indicates whether the remolded material behaves as a viscous fluid, a plastic solid or a solid. The performed Atterberg limits tests consisted of a liquid limit (LL) and plastic limit (PL) determination (Lambe, 1951, pp. 22-28). The difference between the liquid limit and the plastic limit is the plasticity index (PI). It expresses the range of water content over which the sediment behaves in a plastic manner. Plasticity indices tend to decrease with depth in cores 1G and 2G. In cores 6G and 8G the PI's are quite variable. In these two cores zones of non-plastic sediment are interspersed with zones of plastic material. The non-plastic sediment is almost exclusively a coarser grained material than the plastic sediment. Changes in the type and concentration of clay minerals and pore water ions of different strata will change engineering behavior also.

On a plot of liquid limit versus plasticity index (Figure 3), all of the points except one lie in the high compressibility (LL > 50) region. The sediment is classified as MH in the Unified Soil Classification System: inorganic silts, micaceous or diatomaceous fine sandy or silty soils (Peck et al., 1974, p. 28). Although the points are scattered, they roughly define a straight line that is parallel to the A line [PI = 0.73(LL-20)]. This trend is normal for different samples from soil of similar geologic origin.

The liquidity index (LI) is defined as (w - PL)/(LL - PL). When the index is a negative number, the remolded sediment will act as a solid; a LI between 0 and 1.0 indicates plastic behavior; and a liquidity index greater than 1.0 suggests that the sediment will behave as a viscous fluid upon remolding. The LI's range between 0.96 and 2.83 with almost all values between 1.0 and 2.0. Figure 2 illustrates the relationships between Atterberg limits and natural water contents. Grain size has a marked effect on the behavior of the sediment; fine grain sediment tends to be more plastic in behavior.

The bulk densities were determined by inserting a thin walled piston sampler, with an inside diameter of 2.46 cm, into the core and weighing the known volume of sediment extruded from the sampler. The measured bulk densities are in the low range between 1.54 and 1.73 g/cm^3. This is typical of marine sediment. Grain densities vary between 2.59 and 2.88 g/cm^3.

4. GRAIN SIZE DISTRIBUTION

Grain size distributions were determined from pipette analyses (Carver, 1971, pp. 79-88). Using a Wentworth size classification (Blatt et al., 1972, p. 46), almost all of the sediment is classified as a silty-clayey sand or a sandy-clayey silt (Gorsline, 1960, p. 113) (Figure 4). One sample in core 8G has some coarse (> 2 mm) material in it. The grain size distributions tend to be more variable with depth in cores 6G and 8G than in cores 1G and 2G (Figure 2).

5. X-RAY RADIOGRAPH LOGS

All core sections were x-rayed on continuous full scale (same size as the core section) film. The resulting radiographs show layers, cracks, clasts and voids that are present in the sediment. Interpretation of the logs reveal zones where laboratory test samples should be and should not be obtained. Gravity core x-ray radiograph logs are presented in Figure 2.

6. ACKNOWLEDGMENTS

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STATION	LATITUDE LONGITUDE	SECTION NUMBER	INTERVAL IN CORE (cm)
1G	21° 19.78'N 158° 10.20'W	II	0-55
		I	55-205
2G	21° 19.91'N 158° 11.61'W	II	0-25
		I	25-175
6G	21° 17.23'N 158° 11.96'W	IV	0-41
		III	41-191
		II	191-341
		I	341-491
8G	21° 16.44'N 158° 11.01'W	IV	0-100
		III	100-250
		II	250-400
		I	400-550

Table 1. Station locations and core section intervals.

STATION	DEPTH IN CORE(cm)	VANE SHEAR STRENGTH(kPa) UN-REMOLDED	REMOLDED	SENSITIVITY	WATER CONTENT(%)	ATTERBERG LIMITS (%) LIQUID LIMIT	PLASTIC LIMIT	PLASTICITY INDEX	LIQUIDITY INDEX	BULK DENSITY (gm/cm^3)	GRAIN DENSITY (gm/cm^3)	GRAIN SIZE (%) COARSE	SAND	SILT	CLAY
1G	4	*	*	*	101.8	74	41	33	1.84		2.63	0	49	33	18
	59	9.2	2.5	3.7	66.3/71.2	60	42	18	1.35/1.62	1.60		0	21	48	31
	85				76.7	61	34	27	1.58			0	34	35	31
	143				92.8	67	42	25	2.03			0	20	47	33
	172				71.6	49	41	8	2.83			0	39	37	24
2G	3	*	*	*	76.9	74	44	30	1.10		2.59	0	24	47	29
	28	13.0	3.3	3.9	64.6/63.1	64	44	20	1.03/0.96	1.60		0	24	48	28
	80				67.6	57	41	16	1.66		2.62	0	22	48	30
	108				83.1	74	47	27	1.34			0	40	34	26
	167				86.4	58	37	21	2.35			0	29	44	27
6G	3	*	*	*	, 84.9	72	48	24	1.54		2.64	0	25	59	16
	44	15.8	3.5	4.6	62.5/60.4	57	44	13	1.42/1.26	1.64		0	35	42	23
	86				62.8			NP				0	40	37	23
	140				61.6	55	38	17	1.39		2.88	0	16	53	31
	194	17.5	3.3	5.3	50.0/48.1			NP		1.73		0	54	27	19
	237				61.2			NP			2.82	0	46	31	23
	292				64.3			NP				0	78	11	11
	344	*	*	*	56.5/62.4			NP		1.64		0	60	26	14
	384				59.6			NP			2.64	0	46	34	20
	453				69.0	69	49	20	1.00			0	25	48	27
	485				77.3	77	40	37	1.01			0	24	41	35
8G	3	*	*	*	88.4	87	50	37	1.04		2.60	0	15	50	35
	39				81.4	70	45	25	1.46			0	13	54	33
	103	*	*	*	80.8			NP		1.54		0	67	24	9
	167				79.3	66	41	25	1.53			0	25	57	18
	213				66.2			NP			2.59	0	51	37	12
	253	14.8	3.9	3.7	61.6/65.5			NP		1.63		0	28	56	16
	300				71.0	64	40	24	1.29		2.77	0	11	32	57
	350				63.0	55	41	14	1.57			0	20	57	23
	403	16.3	4.2	3.9	46.9/30.6			NP		1.72		11	57	18	14
	450				53.9			NP			2.77	0	57	31	12
	491				73.4	67	37	30	1.21			0	13	51	36
	541				74.1	66	49	17	1.48			0	28	41	31

NP = Non-Plastic

* = Unable to perform vane shear test at this location due to disturbance at the top of the core or because the grain size distribution was too coarse.

Note: At some locations two water content samples were obtained.

Table 2. Vane shear strengths and index properties.

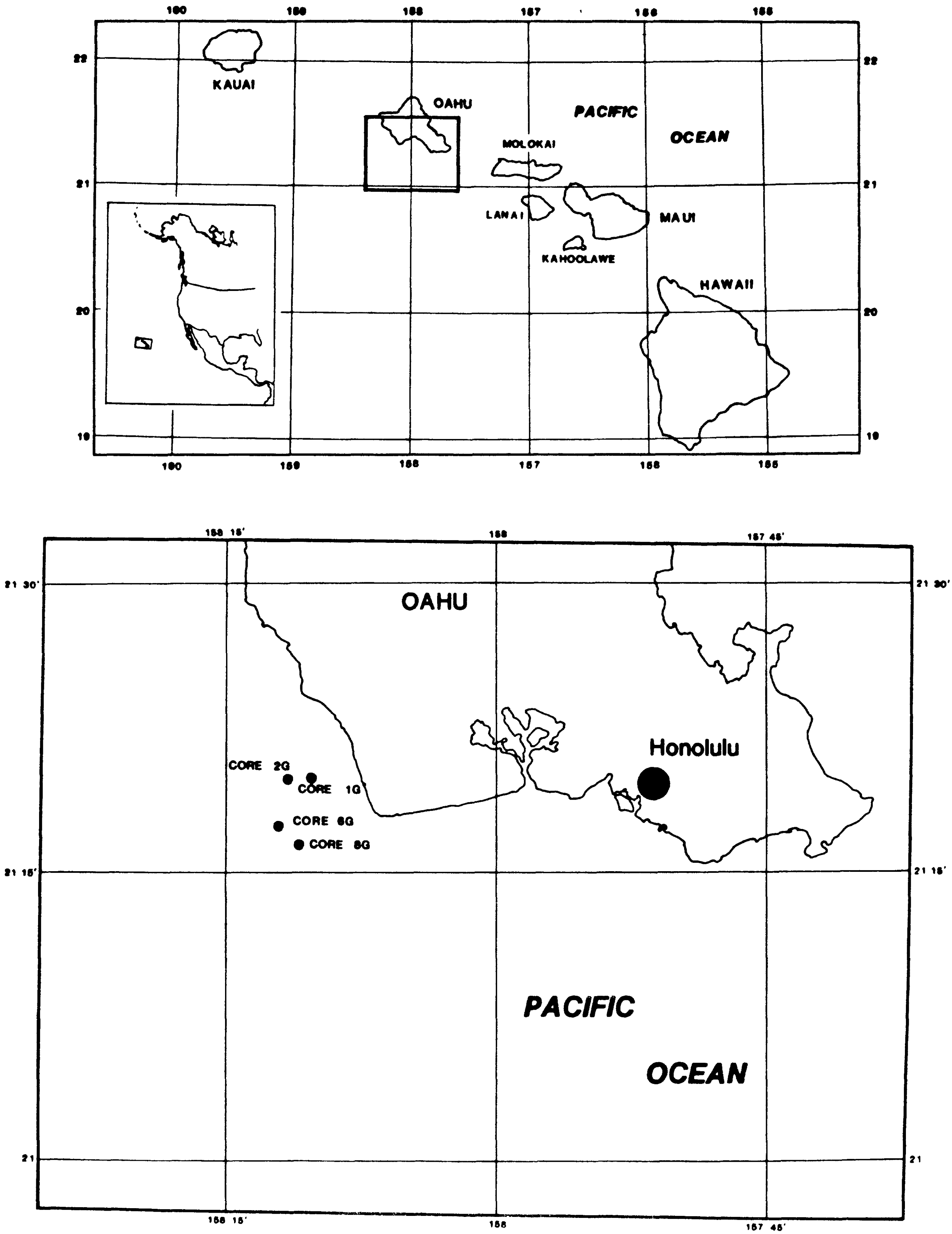


Figure 1. Station location map.

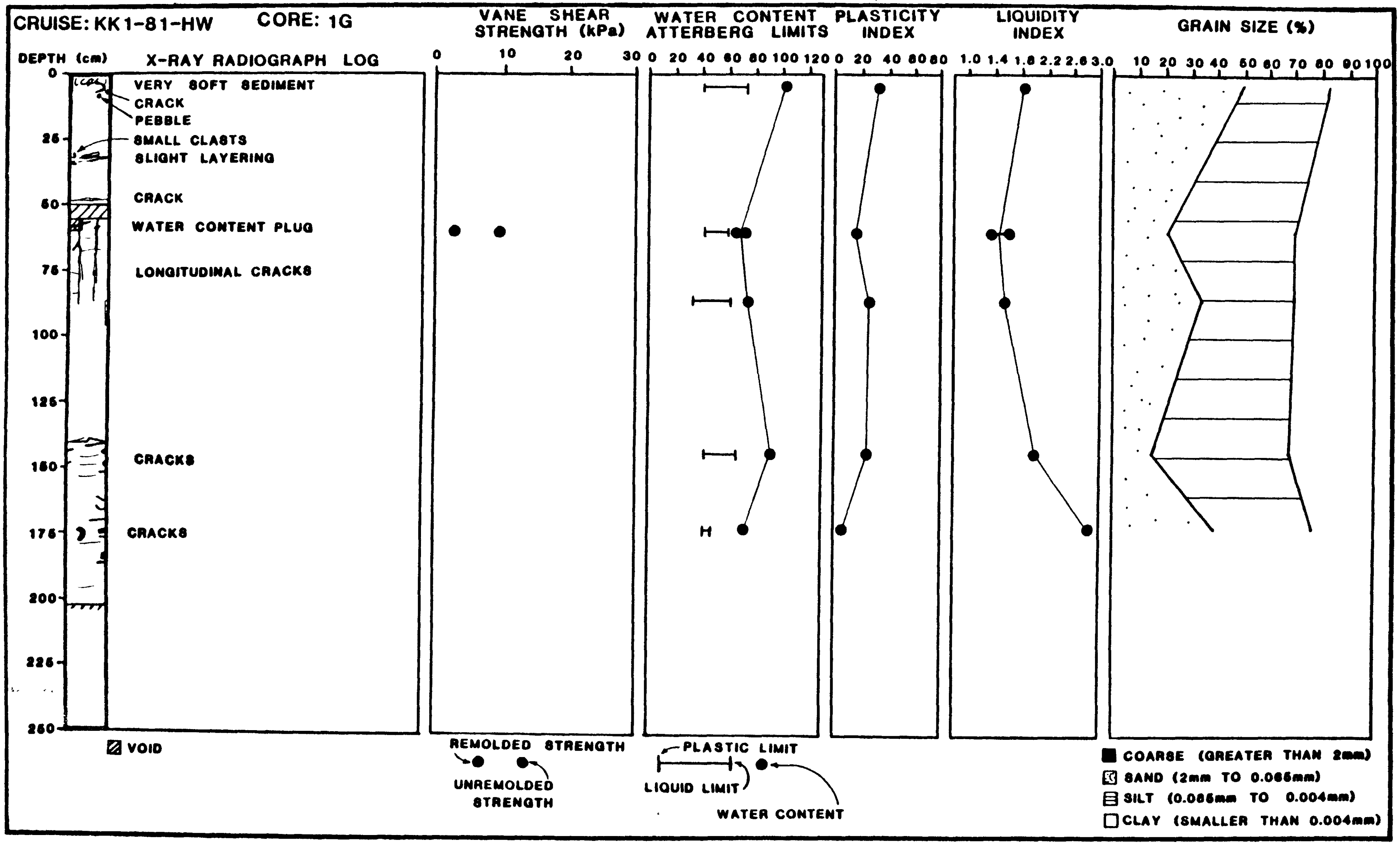


Figure 2. X-ray radiograph log, vane shear strengths and index properties.

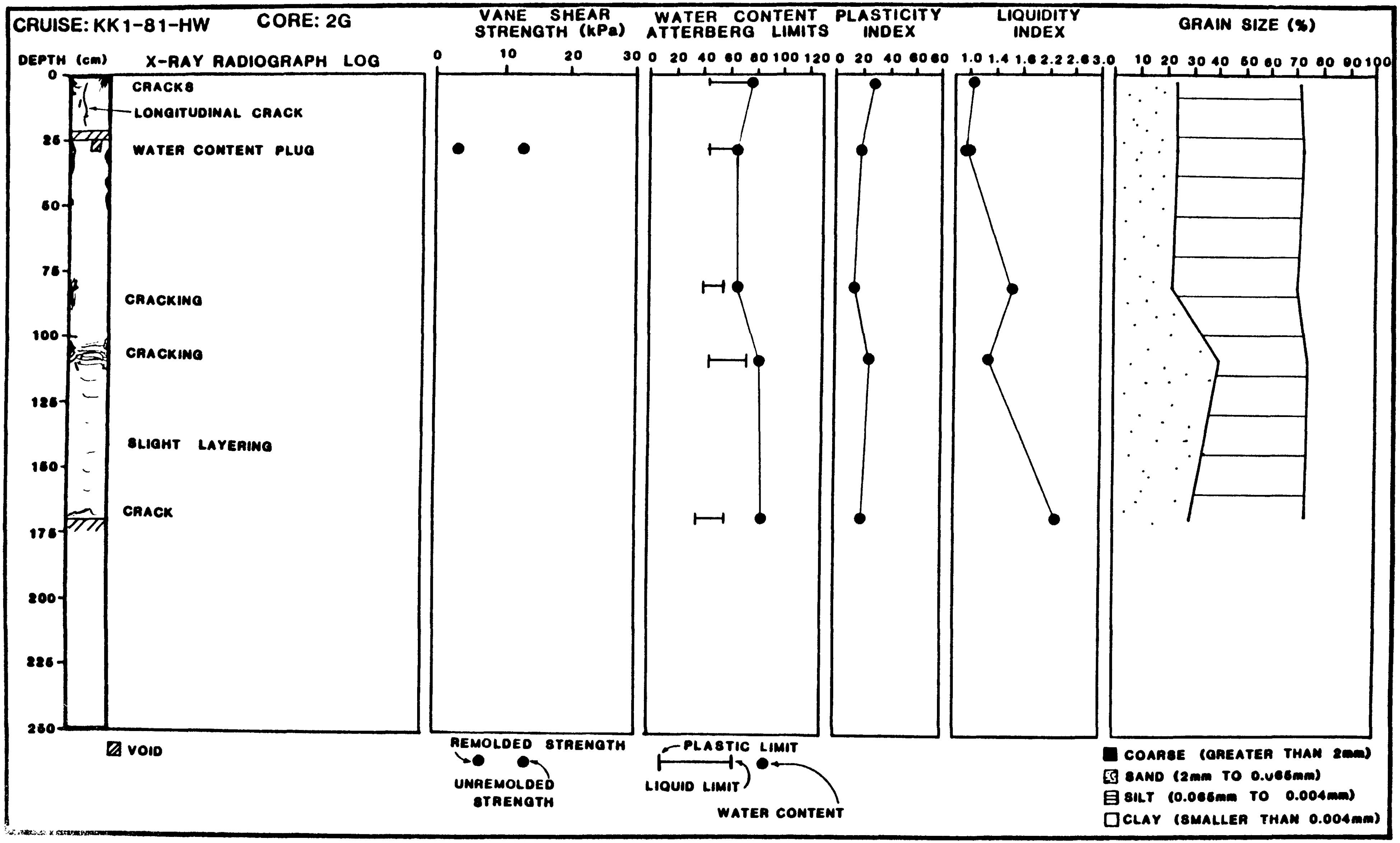


Figure 2 Continued. X-ray radiograph log, vane shear strengths and index properties.

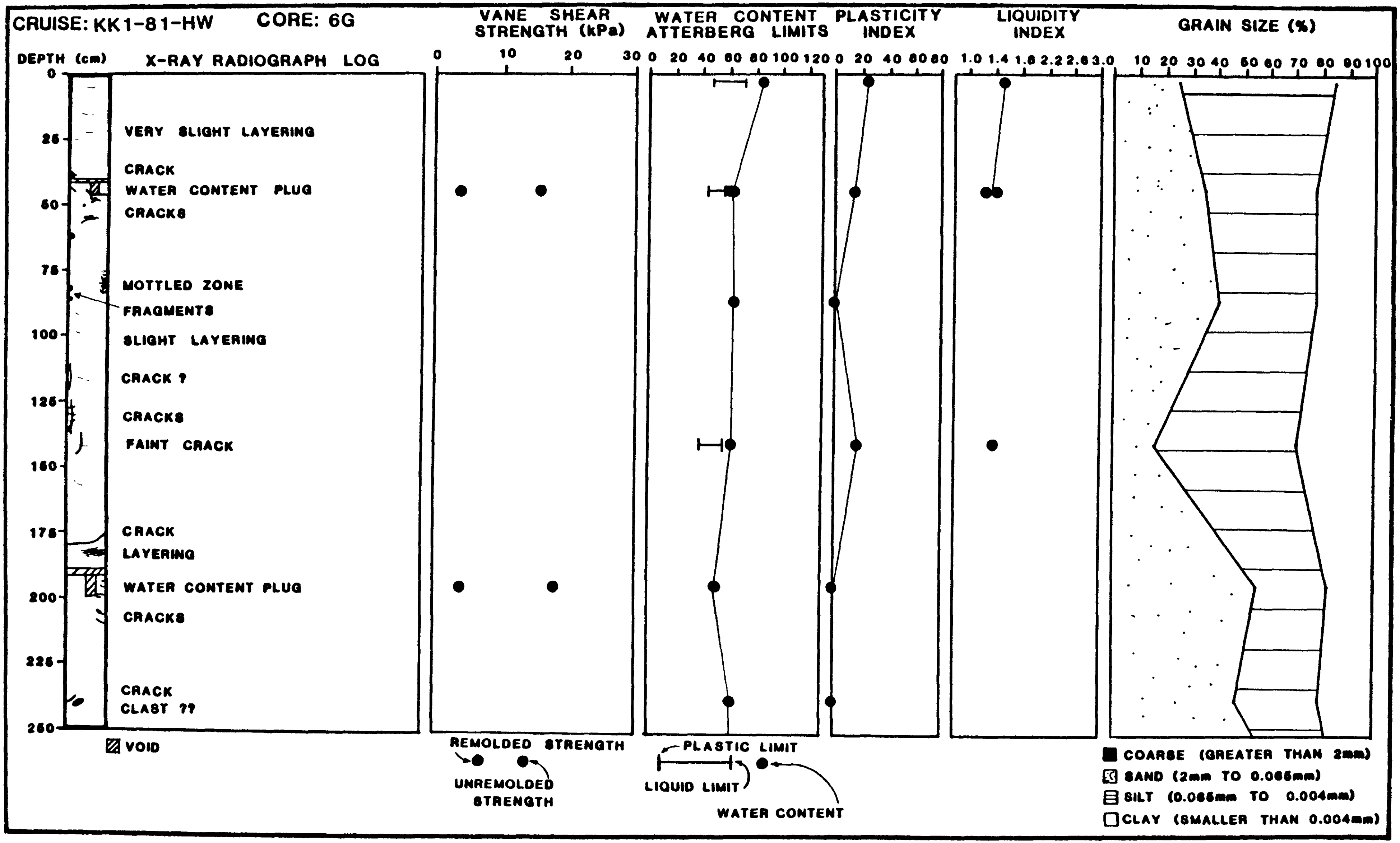


Figure 2 Continued. X-ray radiograph log, vane shear strengths and index properties.

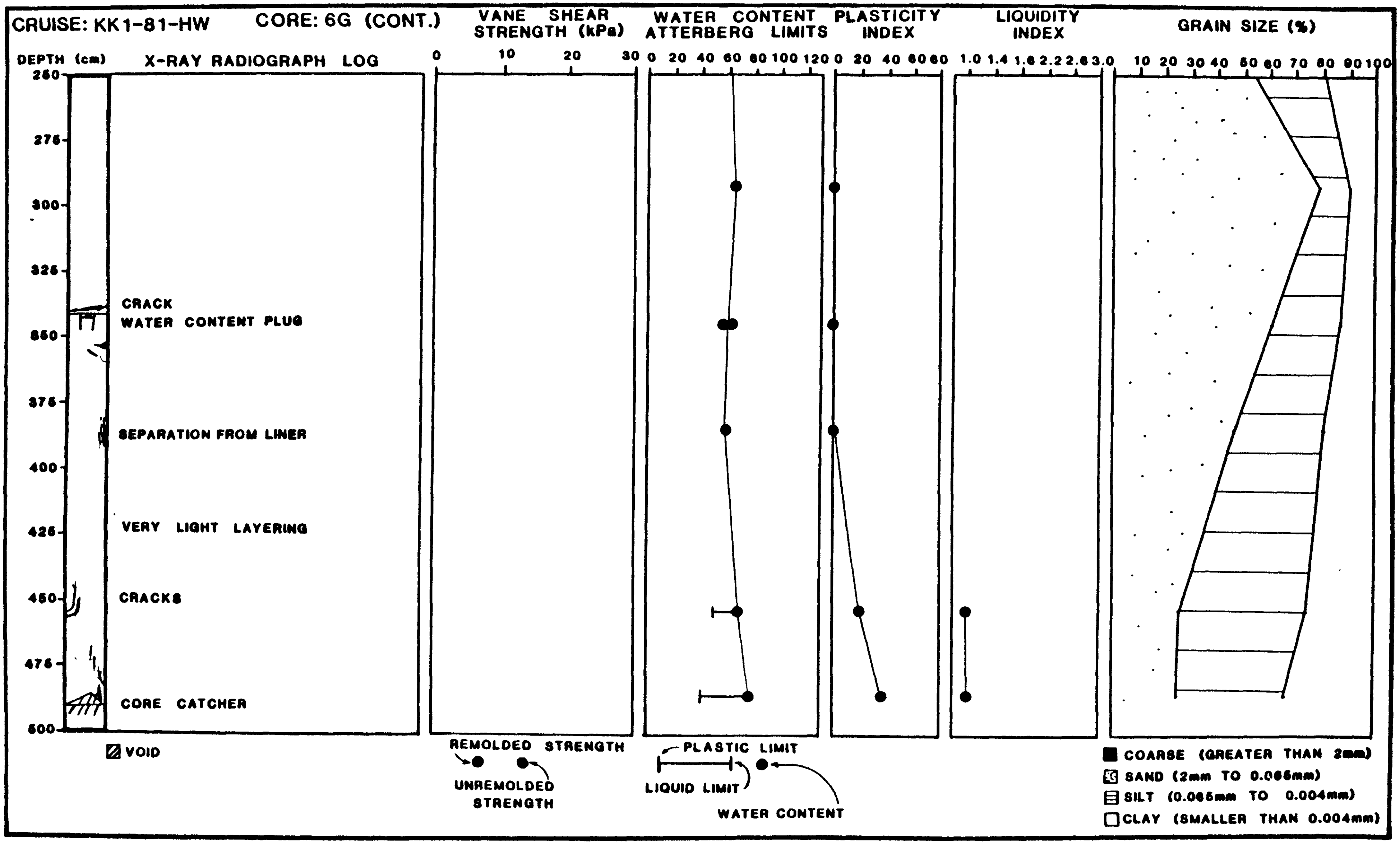


Figure 2 Continued. X-ray radiograph log, vane shear strengths and index properties.

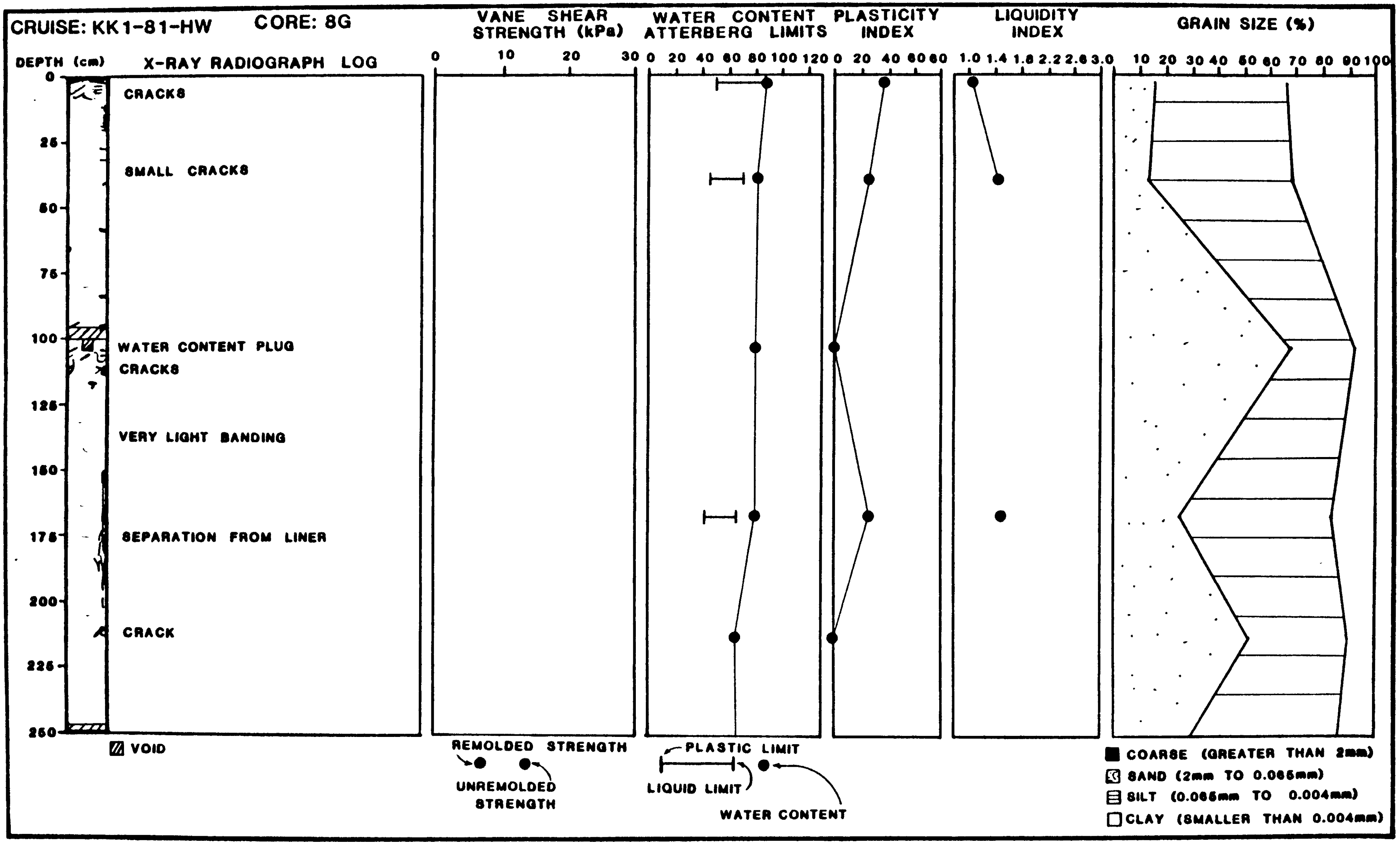
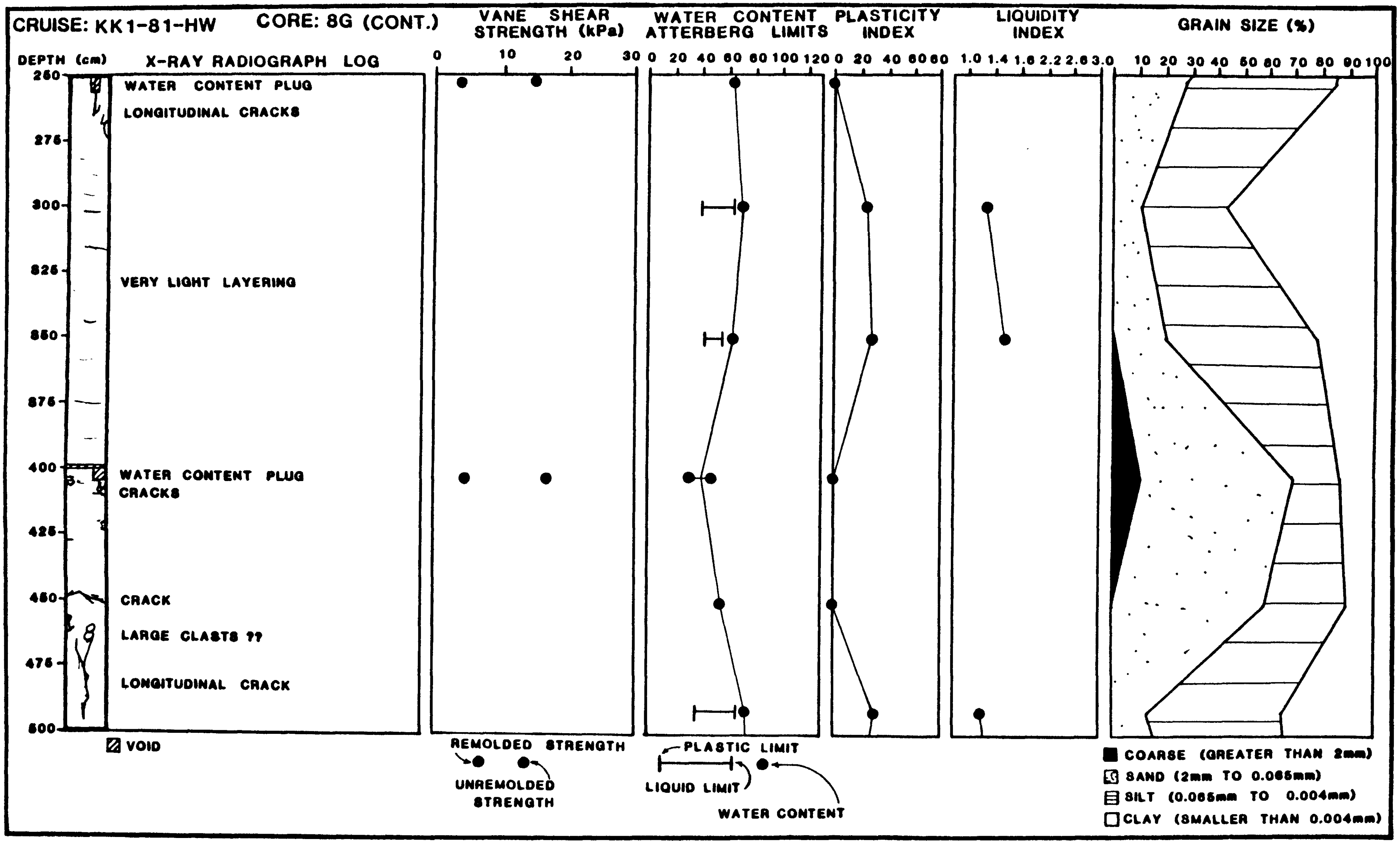


Figure 2 Continued. X-ray radiograph log, vane shear strengths and index properties.



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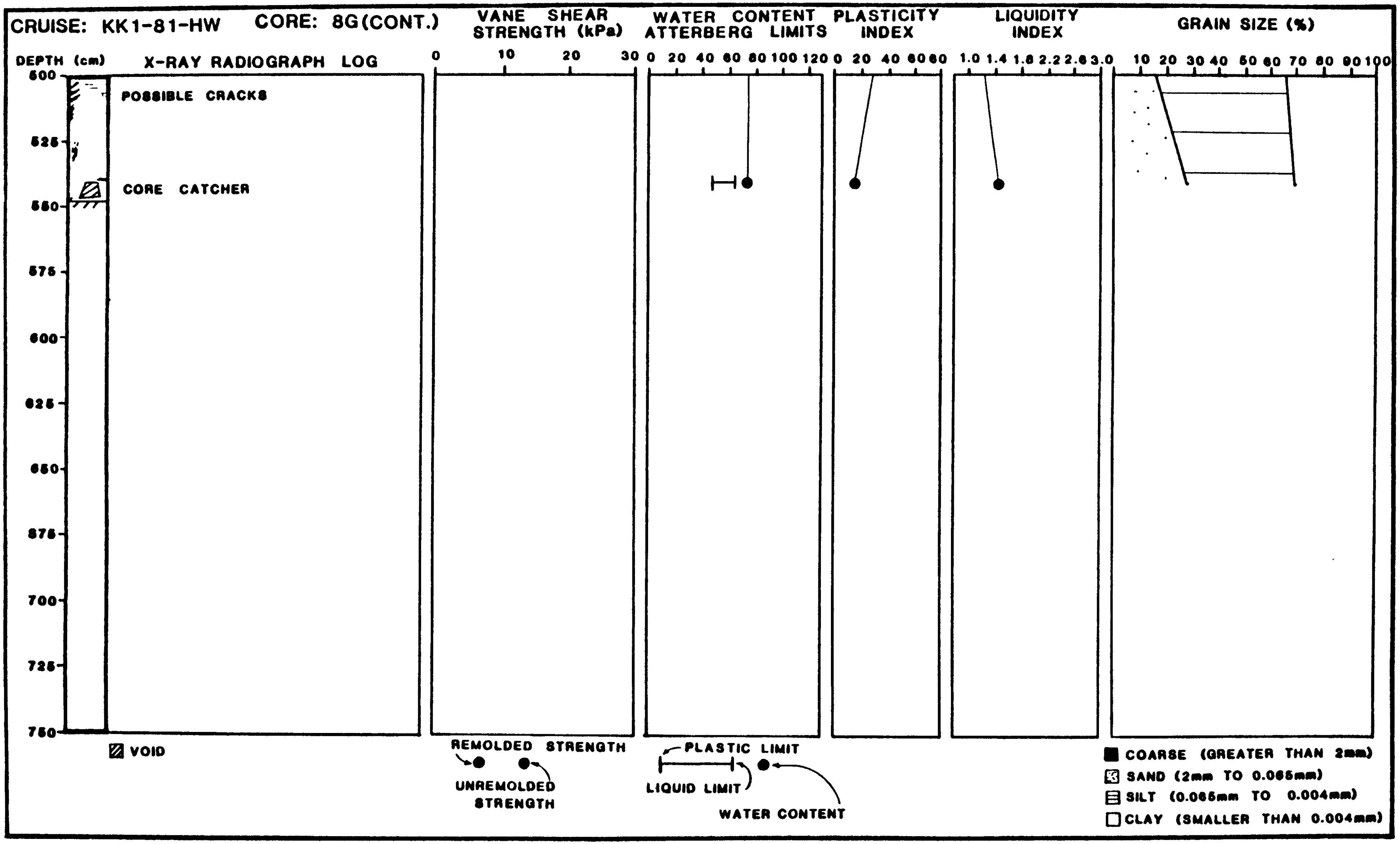


Figure 2 Continued. X-ray radiograph log, vane shear strengths and index properties.

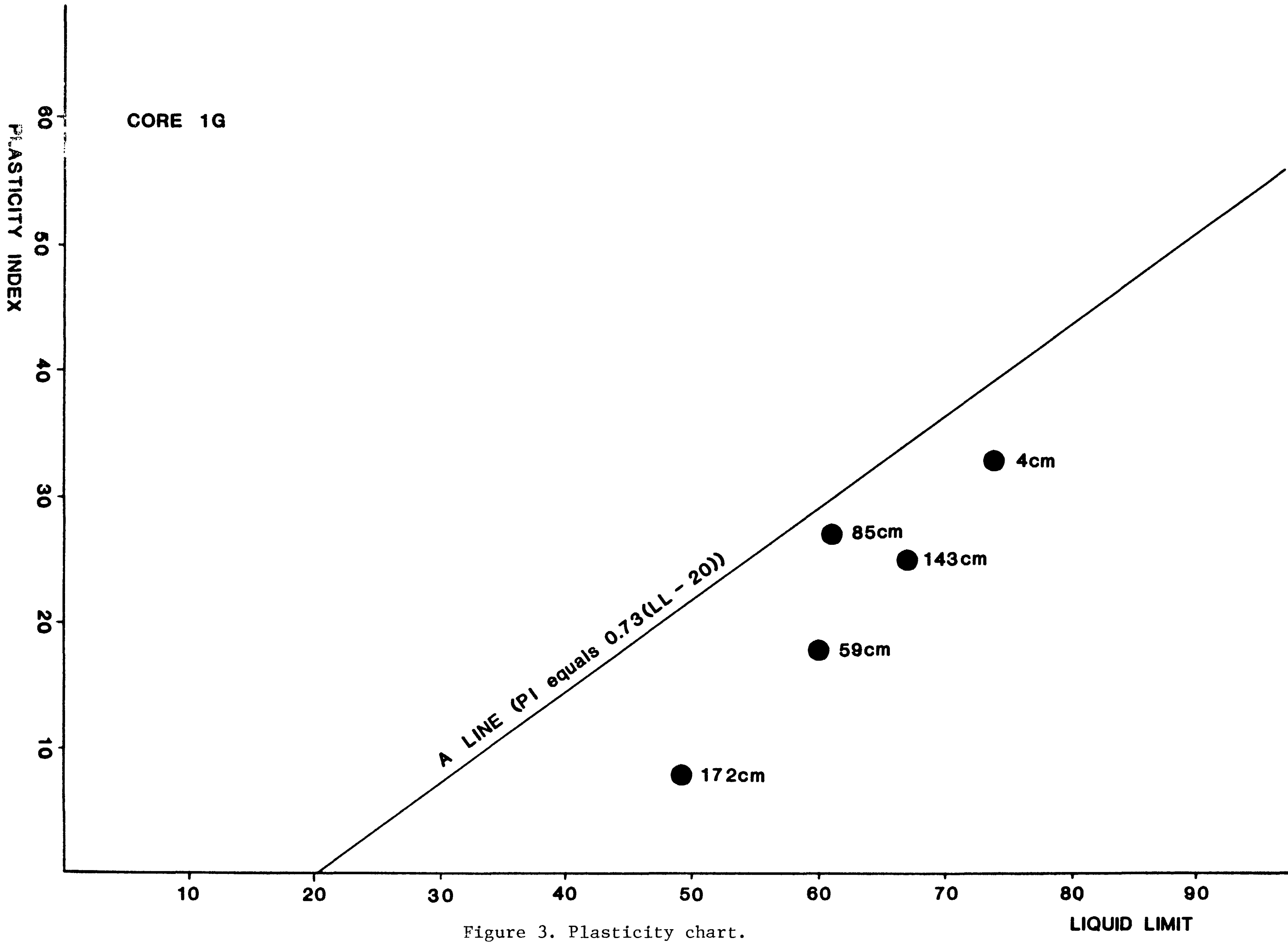
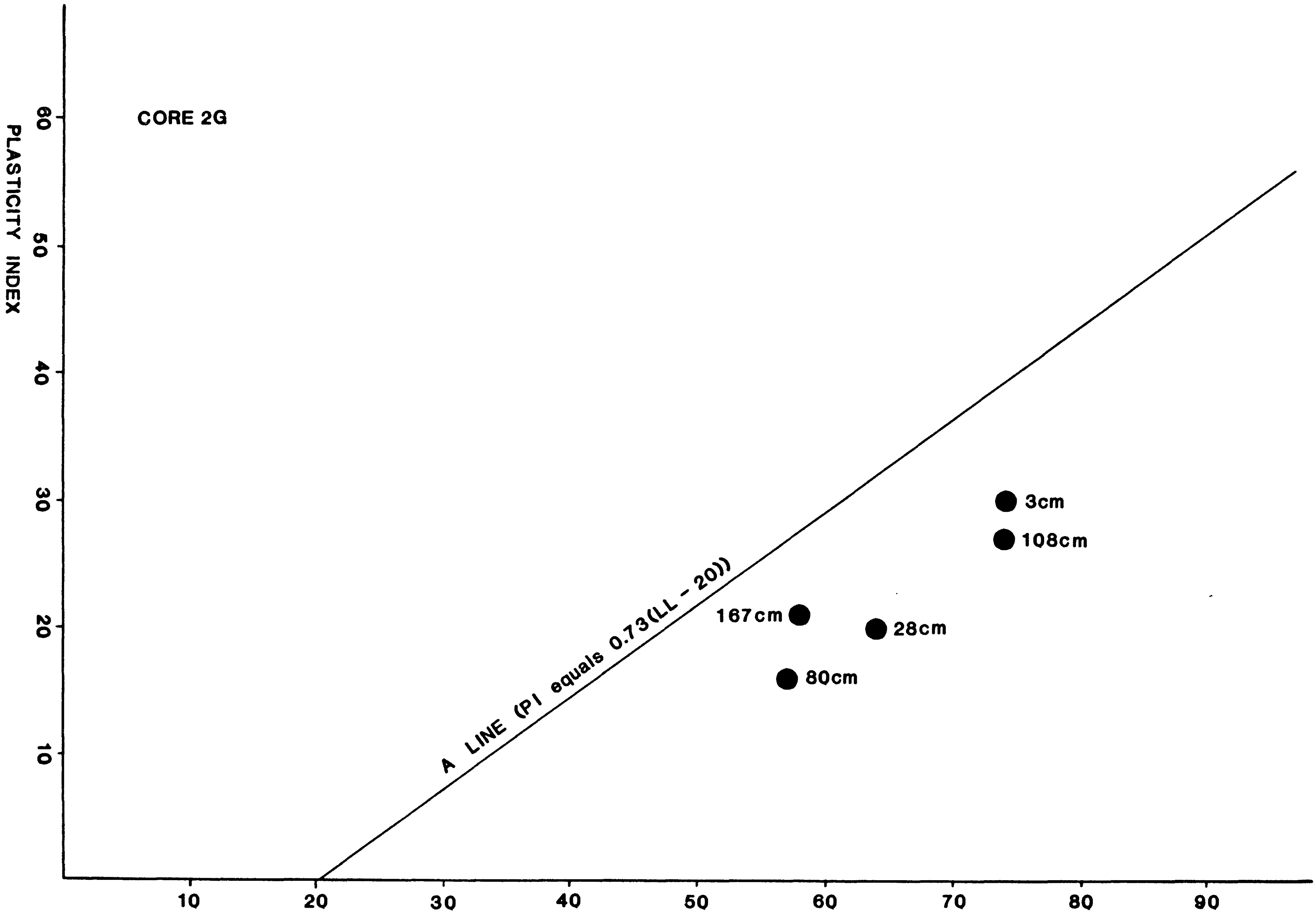


Figure 3. Plasticity chart.



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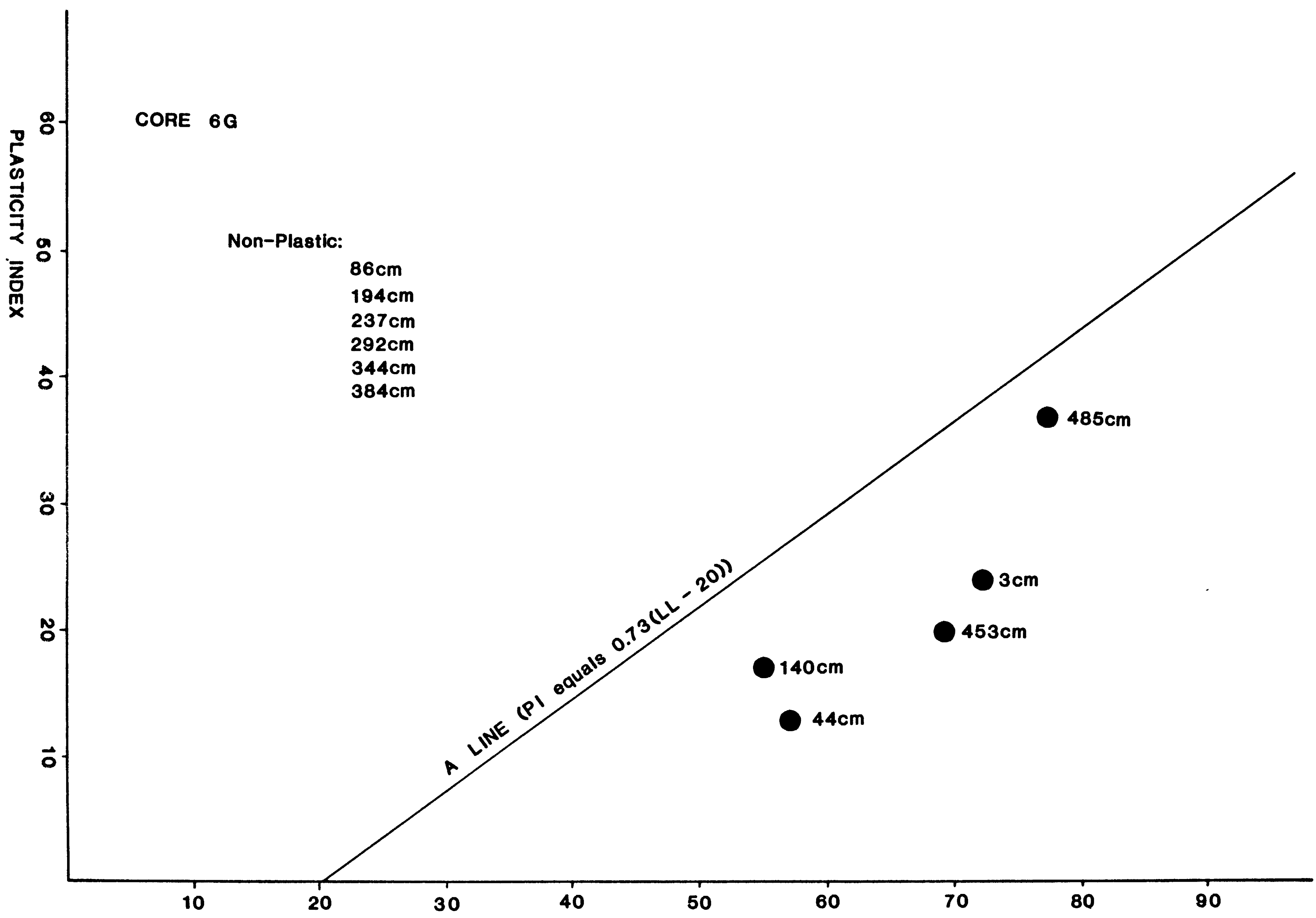

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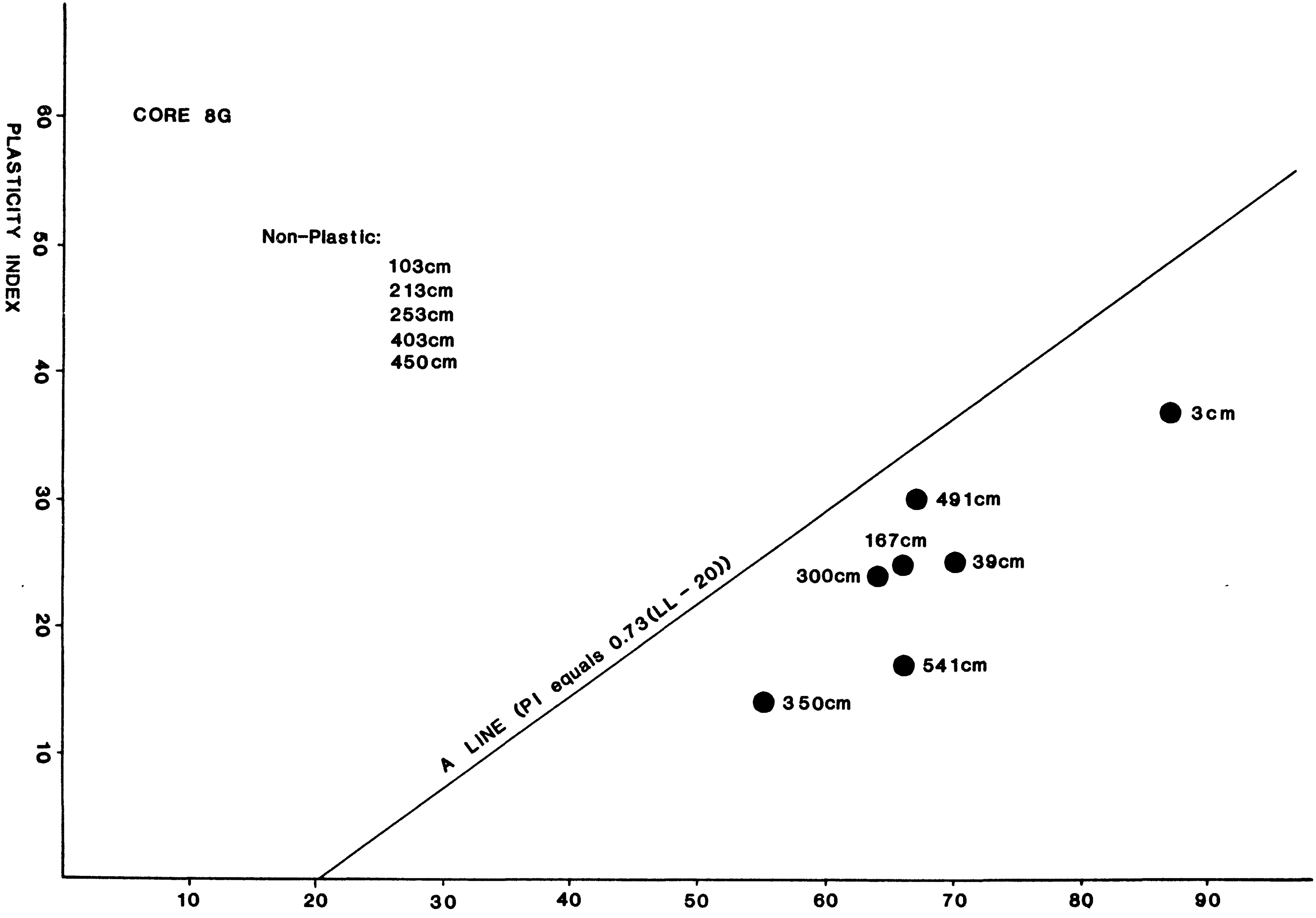

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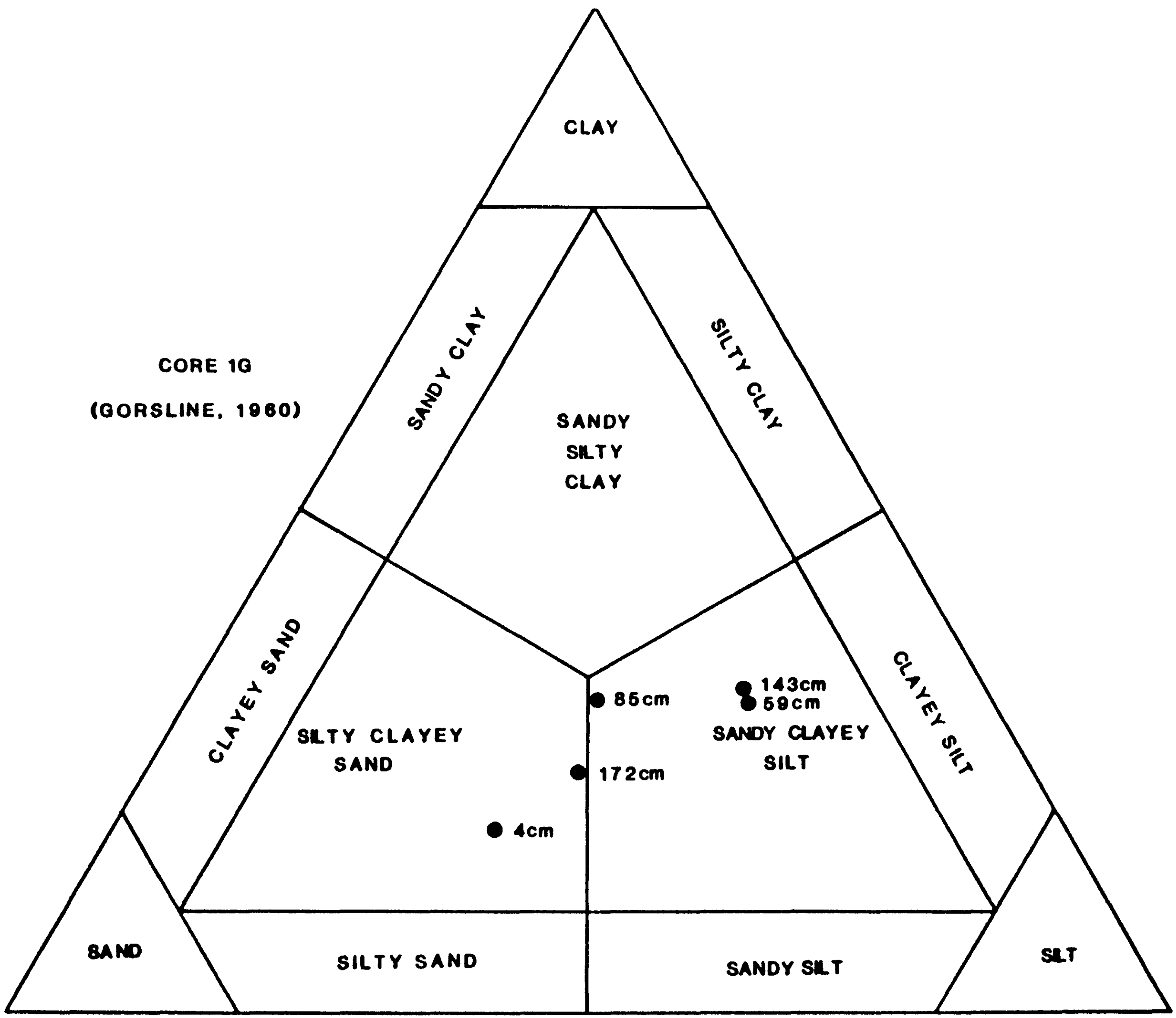
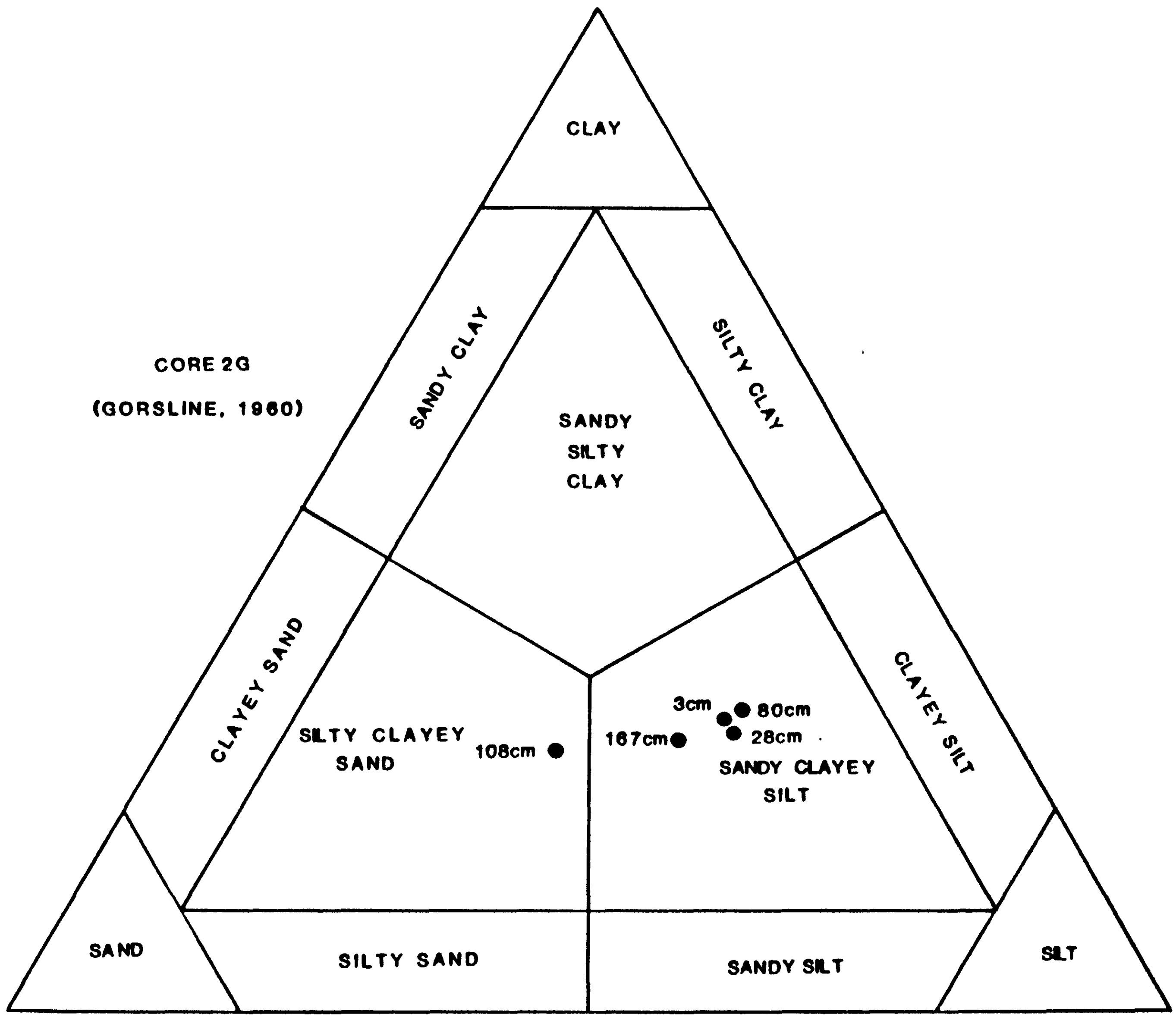


Figure 4. Grain size distribution.



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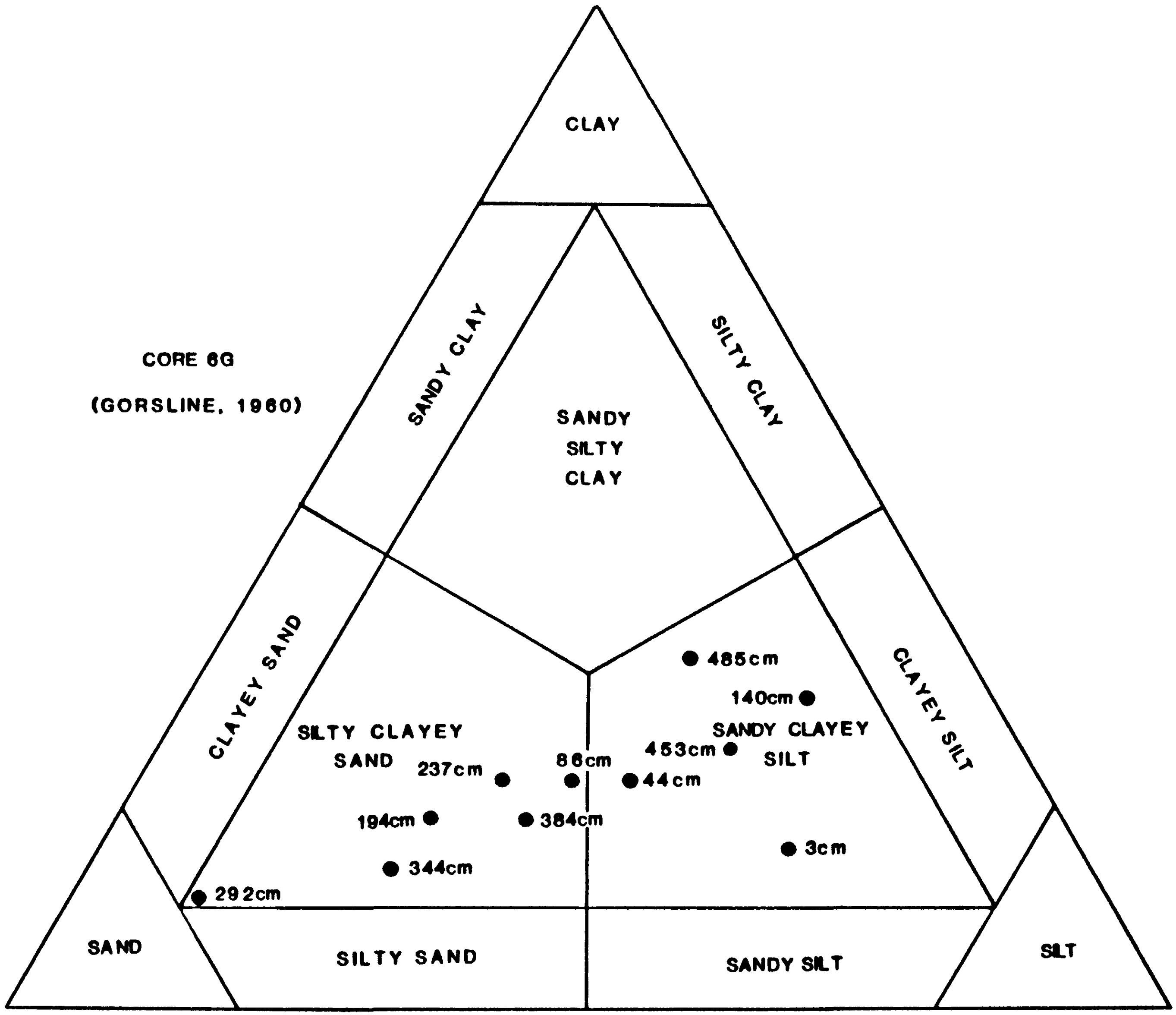

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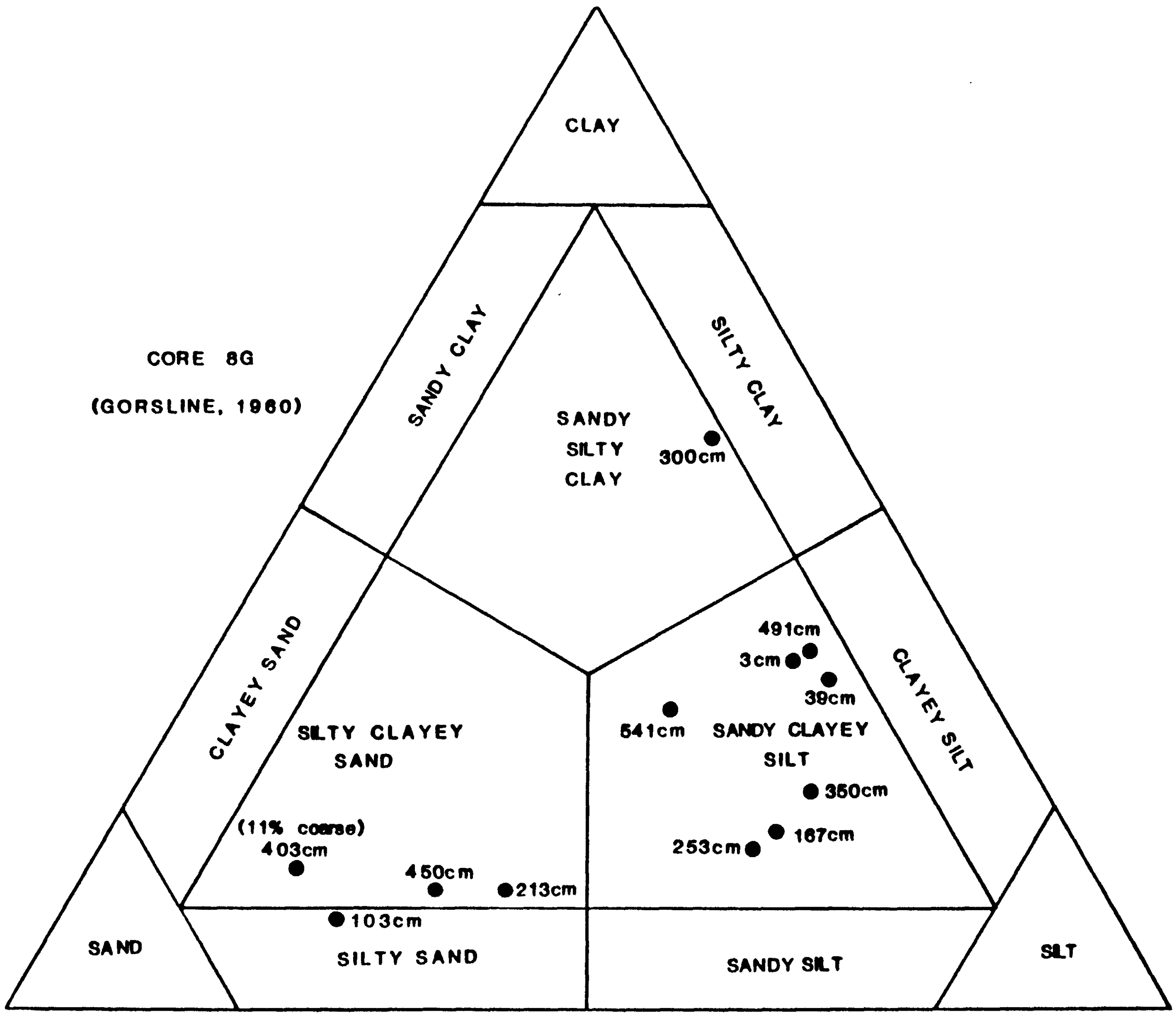

Figure 4 Continued. Grain size distribution.