Geological Survey of Japan Cruise Report No. 20, p. 90–105, 1984.

VIII. GEOTECHNICAL PROPERTIES OF DEEP-SEA SEDIMENTS IN THE NORTHERN PART OF CENTRAL PACIFIC BASIN (GH80–5 AREA)

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Some geotechnical properties of deep-sea sediments were measured on board to collect fundamental data for mining technology of deep-sea manganese nodule during GH80–5 research cruise. As well as previous works (TSURUSAKI and HIROTA, 1977; HANDA, 1979; TSURUSAKI and HANDA, 1981; TSURUSAKI and HANDA, 1981; TSURUSAKI and SAITOH, 1982), geotechnical properties measured on board were vane shear strength, cone penetrating resistance, and water content of deep-sea sediments and adhesiveness between manganese nodule and sediments. A sub-core was taken from each box core for a subsequent laboratory testing. The purposes of shipboard measurement and laboratory testing are to determine the geotechnical properties of deep-sea sediments in the Central Pacific Basin which includes the areas concentrated with manganese nodule, the relationship between geotechnical properties and sediment type, and the degradation of the sample due to sub-coring, handling, and storage. This was performed as a part of a special research program "Mining Technology for Marine Mineral Resources" of National Research Institute for Pollution and Resources.

Procedure and equipments

Shipboard vane shear testing was carried out by a hand-operated vane shear tester. It consisted of calibrated torsional spring torque meter (capacity: 2 cm·kg) attached to a 40 cm long stainless steel shaft and terminating with a 2 cm wide, 4 cm high, and 90 degree four bleades vane. Strength was measured at 6 cm vertical interval from the surface of box core. Each measurement consisted of original and remolded strength measurements. The original strength value reported is maximum shearing resistance developed by sediments when the vane was rotated at constant increasing rate of torque (0.12 cm·kg/sec.). The remolded strength is the resistance to shear the sediments shortly after vane has been rotated several times quickly by hand. The torque was converted to shear strength by following formula.

$$\text{Vane shear strength } (g/cm^2) = 34.1 \times \text{Maximum torque } (cm \cdot kg)$$

The vertical interval of vane measurement was 50 cm for homogeneous piston core and some more measurements were added optionally in the case of laminated core.

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The vane was penetrated only 1 or 2 cm into the split surface of piston core and was rotated vertically to the core axis. The formula to convert torque to shear strength for piston core is:

$$\text{Vane shear strength } (g/cm^2) = 119 \times \text{Maximum torque } (cm \cdot kg) \text{ for 1 cm penetration}$$

$$= 68.2 \times \text{Maximum torque } (cm \cdot kg) \text{ for 2 cm penetration}$$

Cone penetrating testing was carried out with a hand-operated electrical load cell type cone tester. It consists of 60 degree tip of cone with 3.5 cm in diameter, load cell, 60 cm long outer tube, amplifier, recorder, and depth marking unit. Penetrating resistance was measured at the center of box core with the penetrating rate of about 1 cm/sec. and penetrating resistance force was divided by the area of cone.

Water content was determined from the weight of sample before and after drying for 24 hrs. at 105°C. The weight lost during drying divided by the dry sample weight was expressed as a percentage. A 6 cm I.D. PVC pipe was inserted into each box core and disc samples were taken at 6 cm vertical intervals from the sub-core. For piston cores, one-fourth column samples of 10 cm long were taken at 50 cm vertical interval. The weight of wet and dry samples was measured by using shipboard electrical balance in order to avoid the influence of ship's heaving and vibration.

Adhesiveness between manganese nodule and sediment was measured on several selected nodules on undisturbed box core surface using tweezers and small electrical load cell. Adhesiveness per unit area was determined from the picking up force divided by the area where manganese nodule had contacted to the sediments. The area was measured by the projection figure which was taken by camera.

Sampling for laboratory geotechnical testing was done on each box core. A 10 cm I.D. and 50 cm long clear plastic tube was inserted into box core using vacuum pump. Sub-core was sealed with plastic lid and rubber stopper on the top and bottom of sediment column and kept vertically in refrigerator (about 4°C). Bulk samples were taken from box cores after subcoring and kept in large plastic bag for the material of laboratory model test.

Results of onboard measurements

Vane shear strength, cone penetrating resistance, and water content measurement were performed on 23 box cores and 17 piston cores. The profiles of strength and water content versus test depth for each core are shown in Figs. VIII–1 and VIII–2.

Adhesiveness between manganese nodule and sediment was measured on 88 nodules from 16 box cores (B36, 37, 38, 39, 40, 42, 45, 47, 48, 49, 50, 51, 52, 53, 55, 56).

Preliminary examination

Geotechnical properties of box core

The average value of vane shear strength, cone penetrating resistance, and water

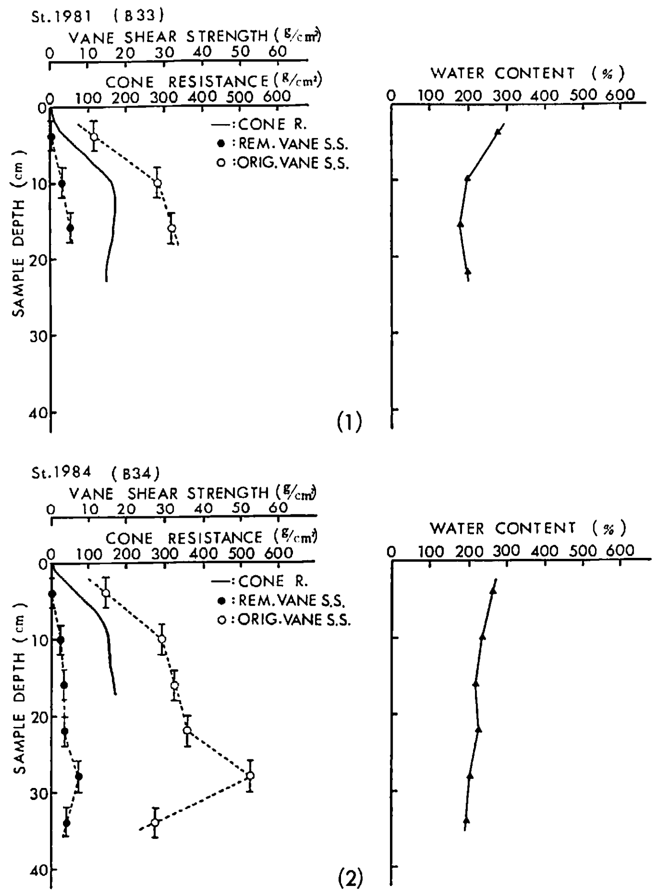


Fig. VIII-1 (1)

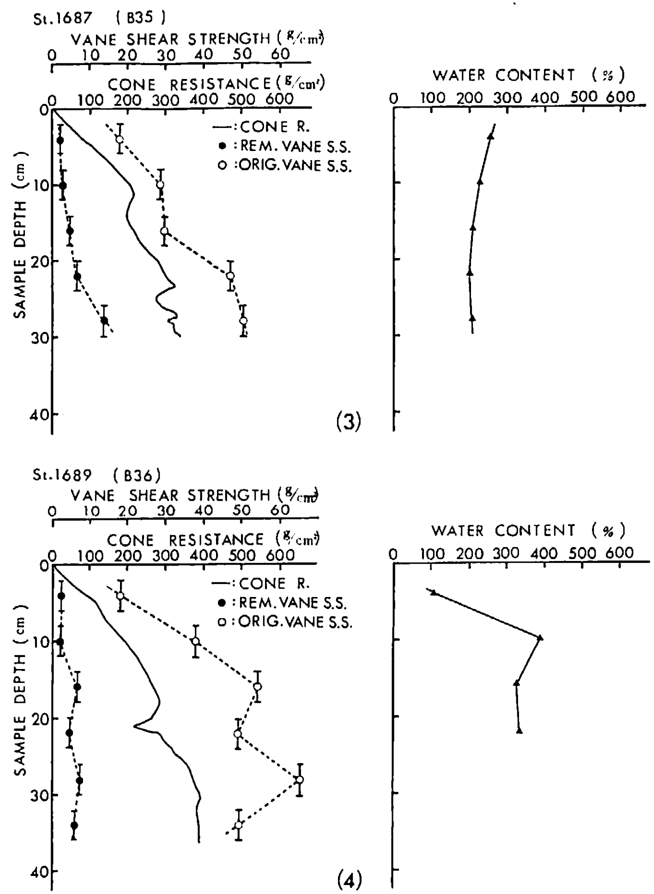


Fig. VIII-1 (2)

Fig. VIII-1 Geotechnical properties of box cores (B33–B56).

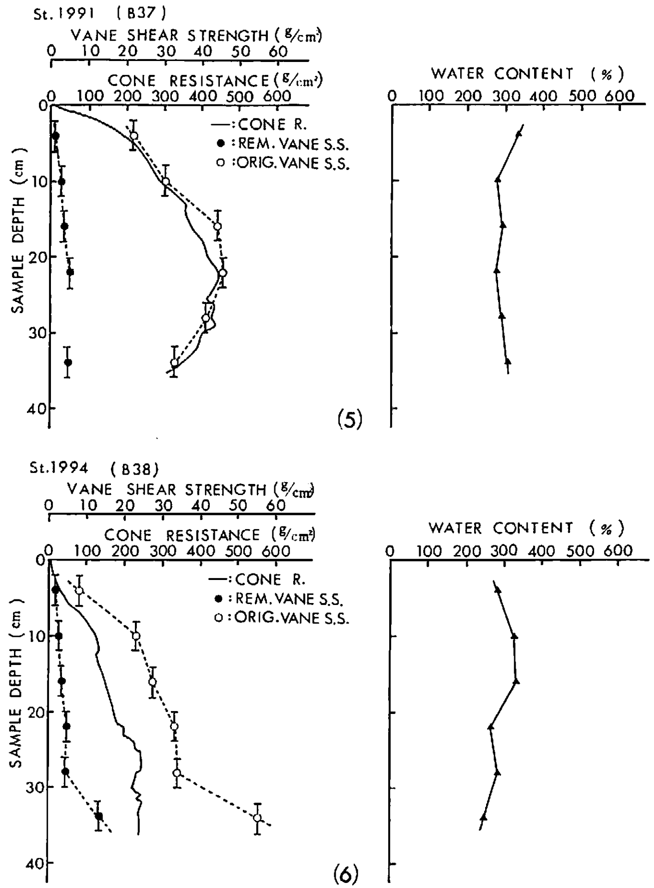


Fig. VIII-1 (3)

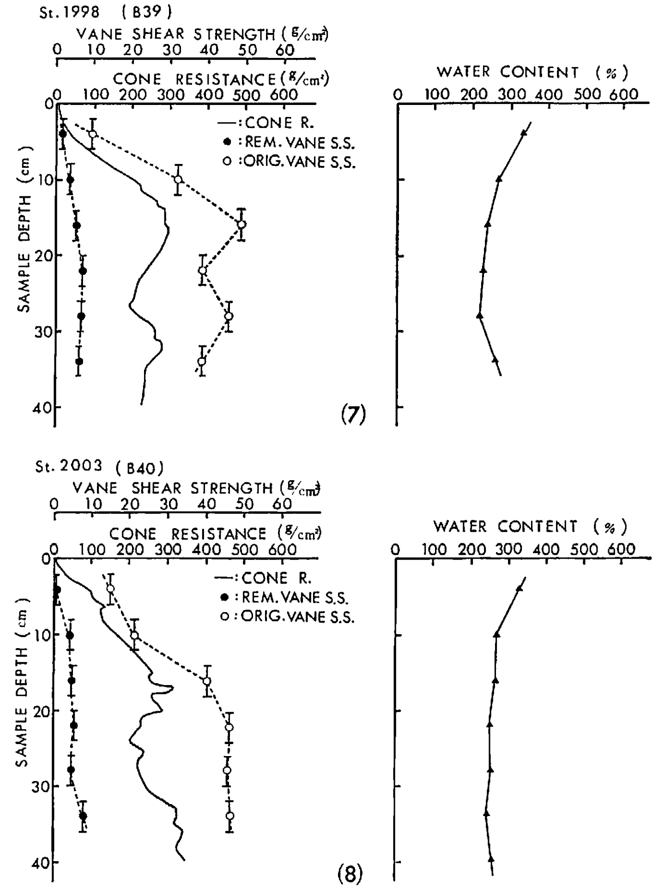


Fig. VIII-1 (4)

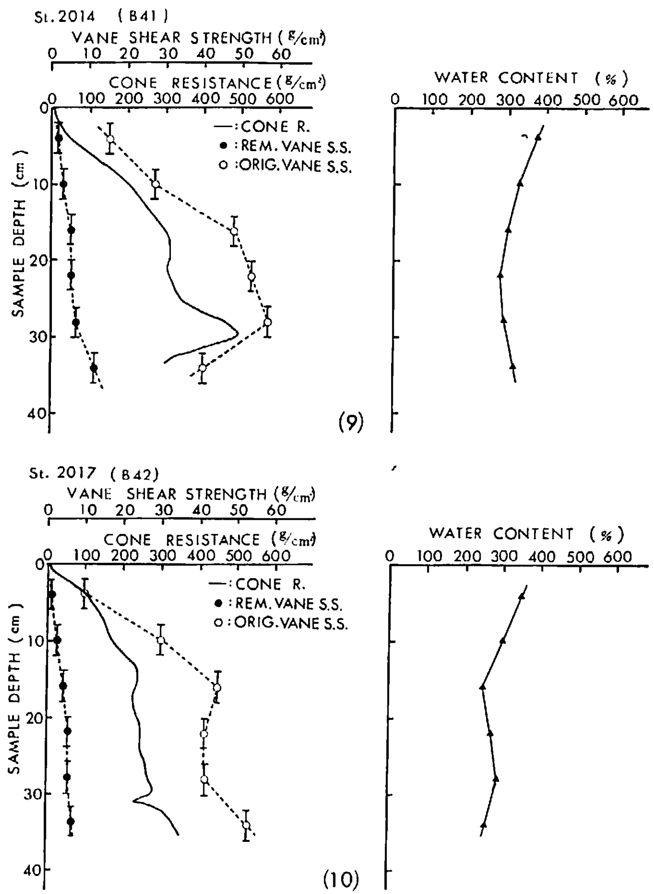


Fig. VIII-1 (5)

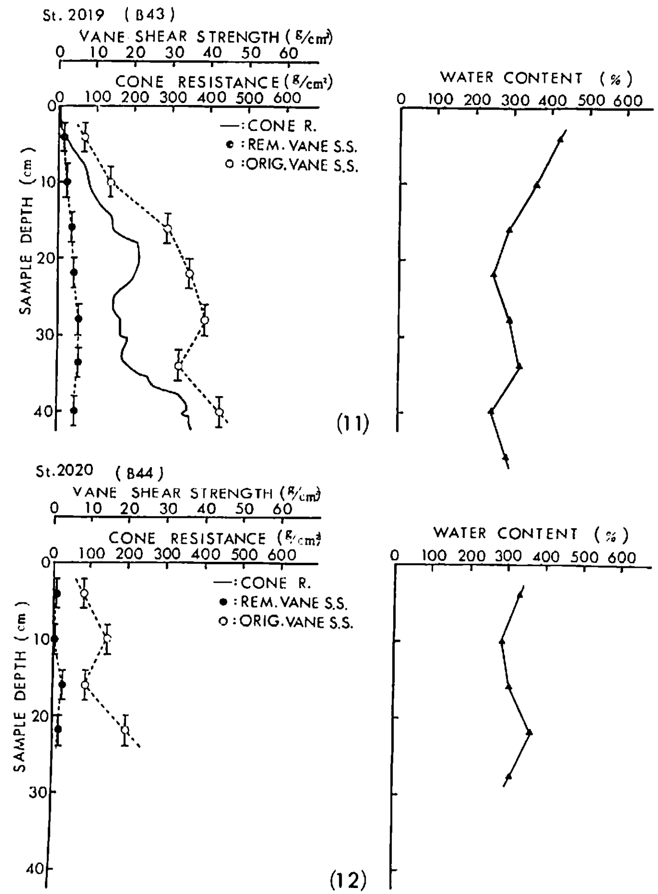
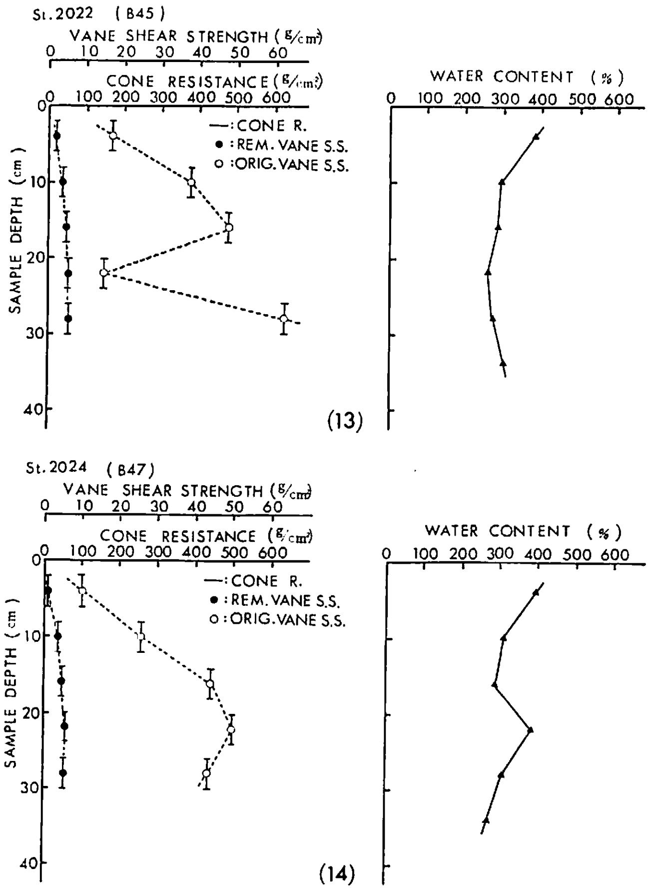


Fig. VIII-1 (6)



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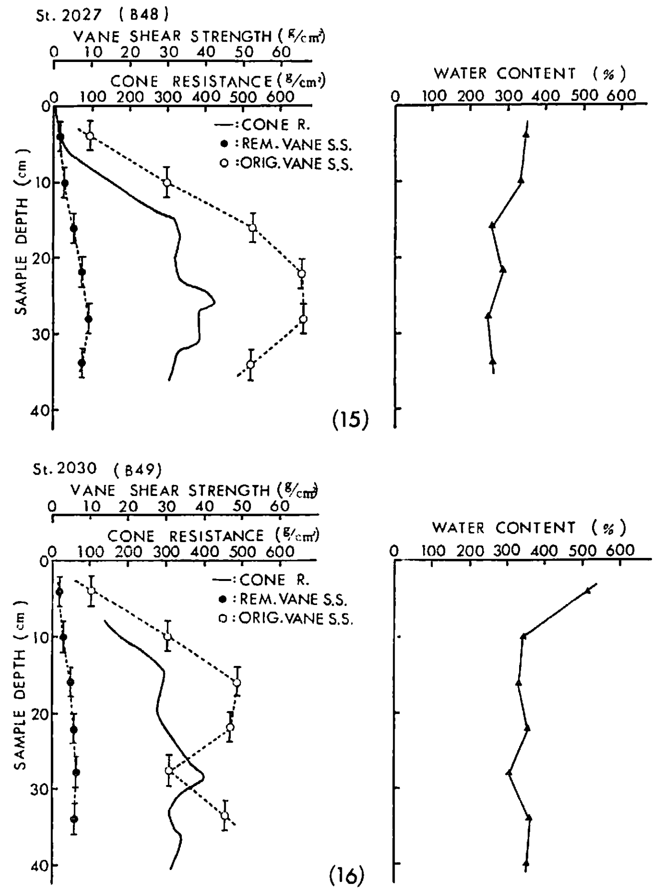


Fig. VIII-1 (8)

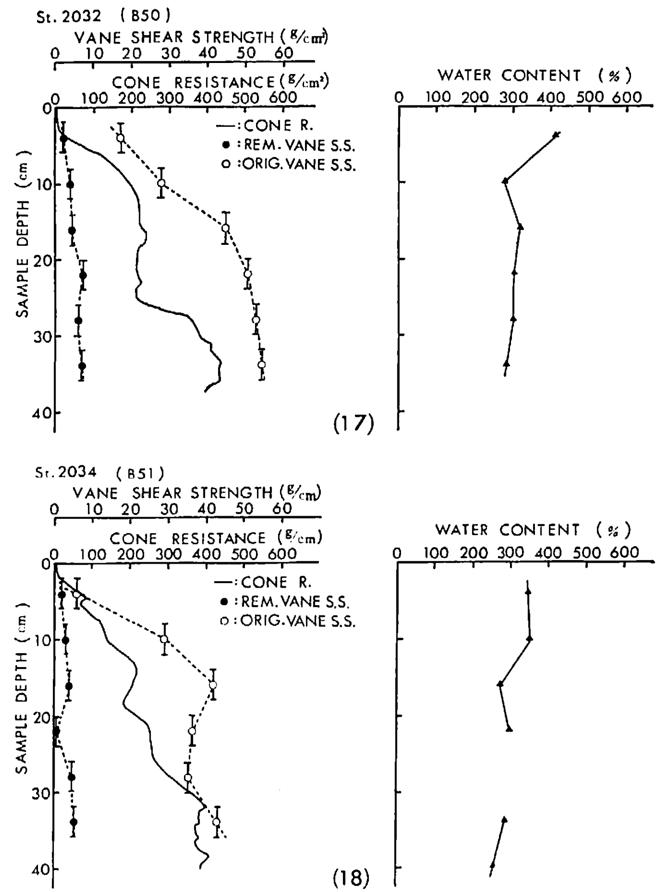
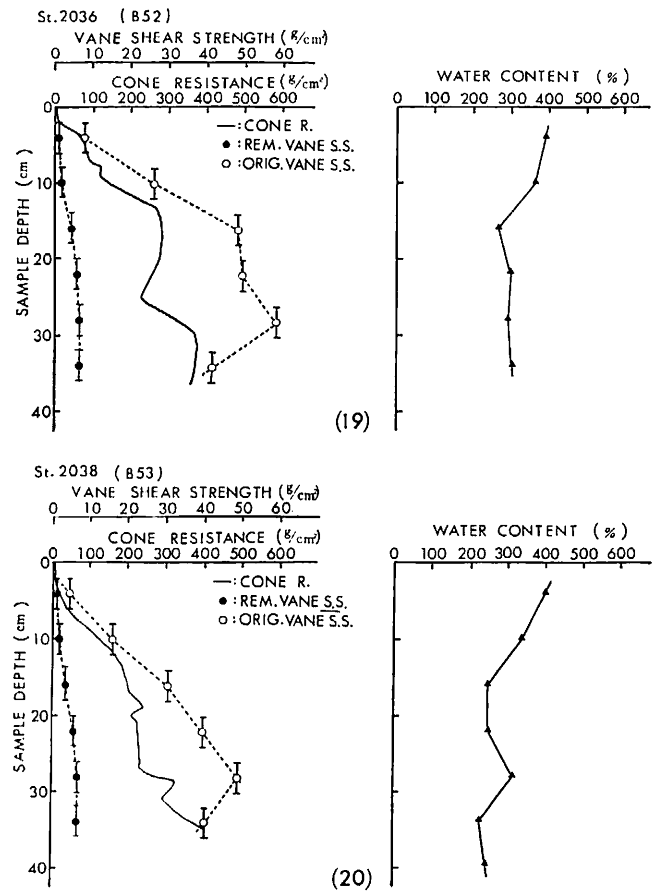


Fig. VIII-1 (9)



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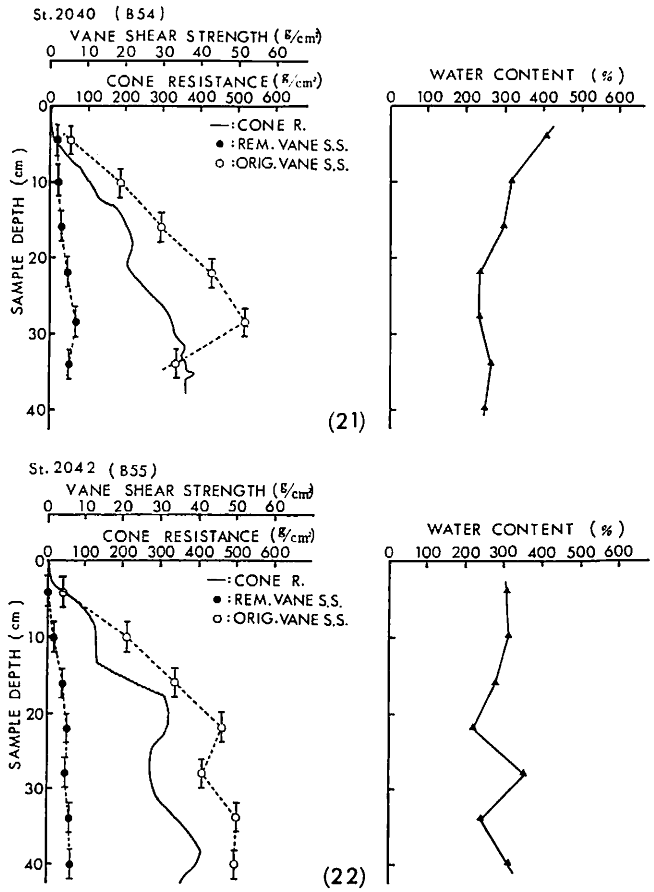

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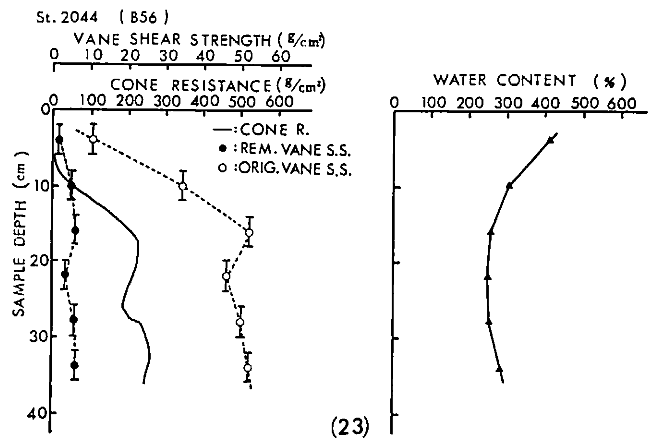

Fig. VIII-1 (12)

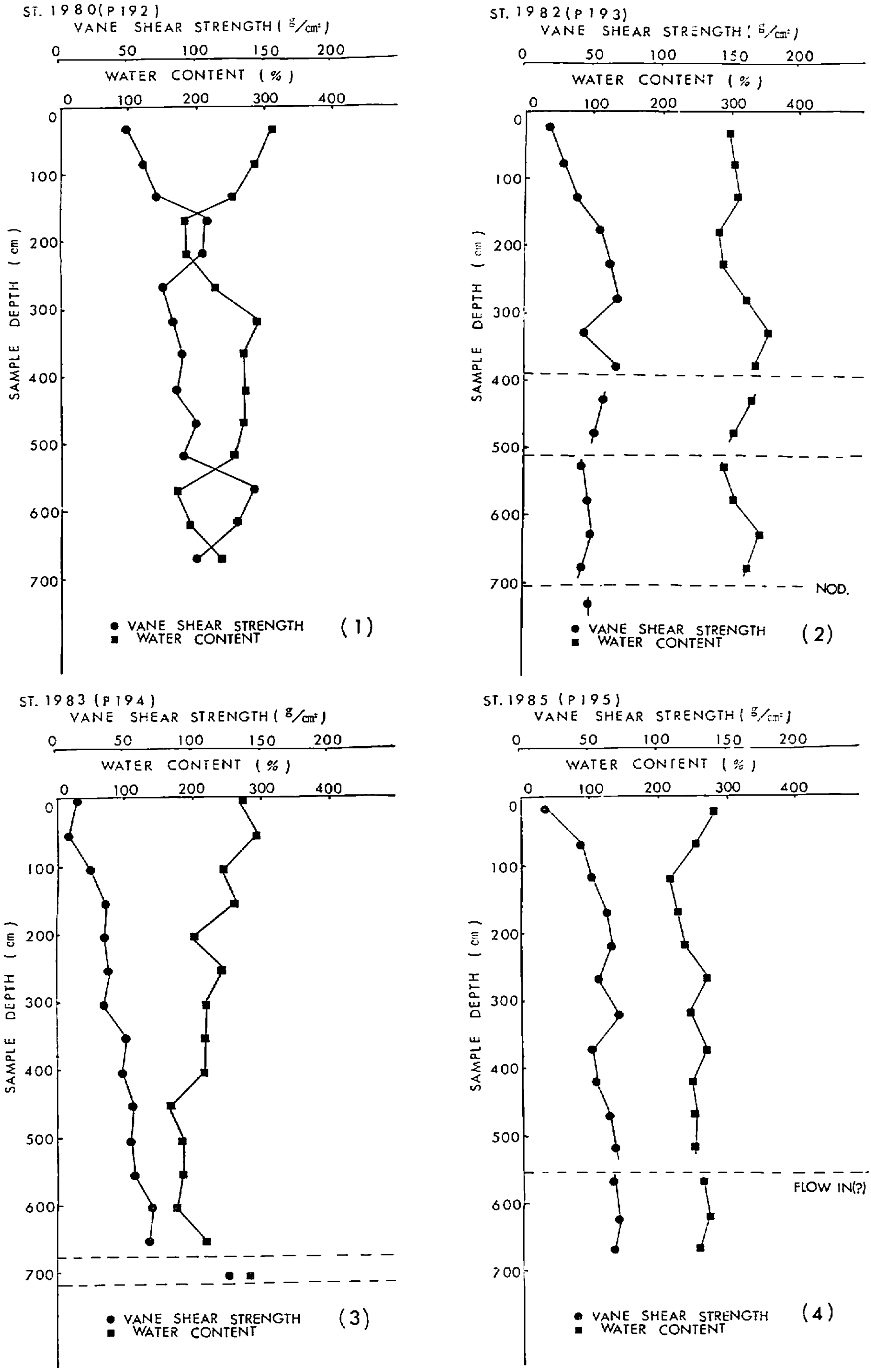

Fig. VIII-2 (1)

Fig. VIII-2 Geotechnical properties of piston cores, (P192–P208)

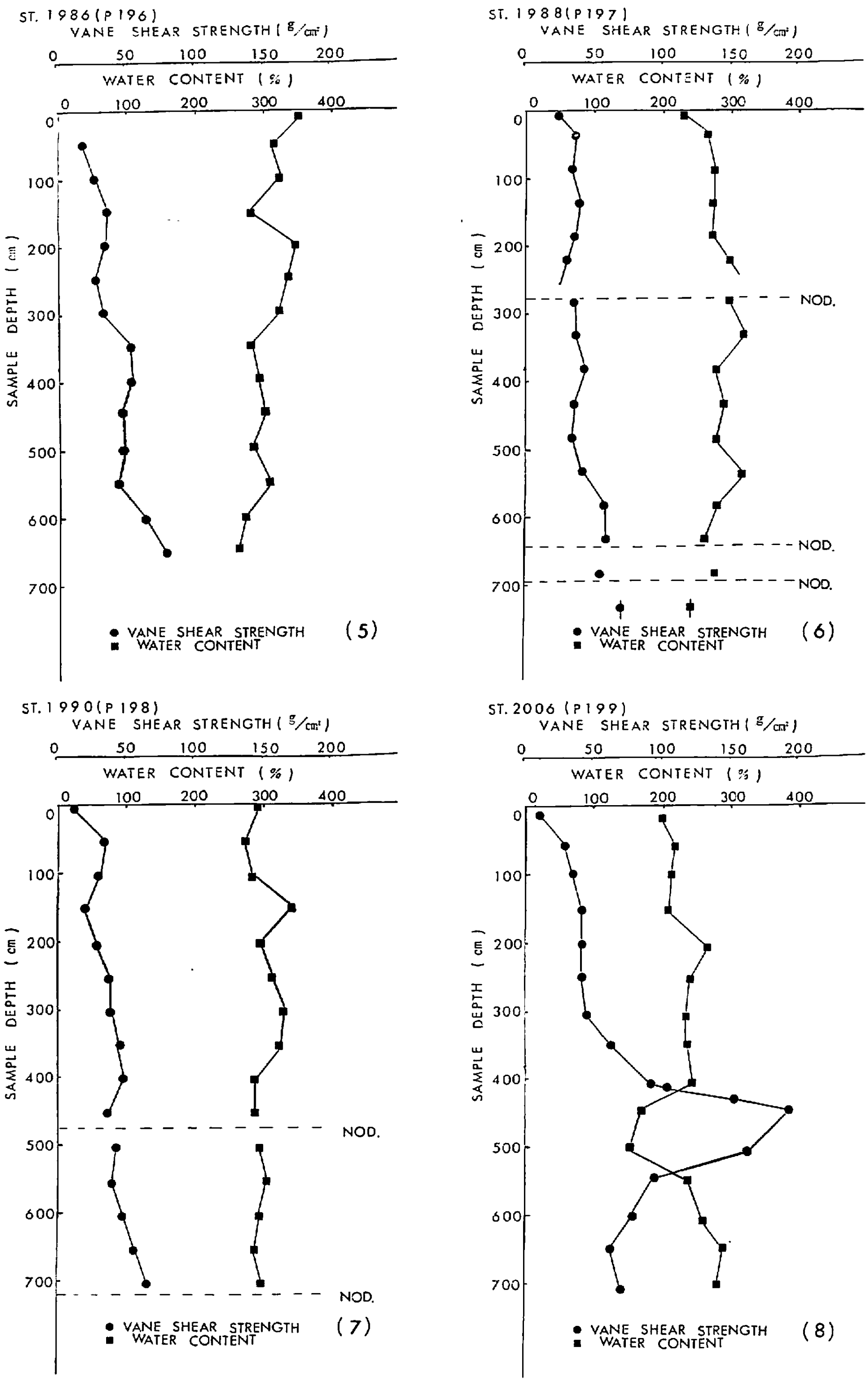
ST. 1986 (P 196)
VANE SHEAR STRENGTH (g/cm²)
0 50 100 150 200
WATER CONTENT (%)
0 100 200 300 400
SAMPLE DEPTH (cm)
0 100 200 300 400 500 600 700
● VANE SHEAR STRENGTH
■ WATER CONTENT
(5)
ST. 1988 (P 197)
VANE SHEAR STRENGTH (g/cm²)
0 50 100 150 200
WATER CONTENT (%)
0 100 200 300 400
SAMPLE DEPTH (cm)
0 100 200 300 400 500 600 700
NOD.
NOD.
NOD.
● VANE SHEAR STRENGTH
■ WATER CONTENT
(6)
ST. 1990 (P 198)
VANE SHEAR STRENGTH (g/cm²)
0 50 100 150 200
WATER CONTENT (%)
0 100 200 300 400
SAMPLE DEPTH (cm)
0 100 200 300 400 500 600 700
NOD.
NOD.
● VANE SHEAR STRENGTH
■ WATER CONTENT
(7)
ST. 2006 (P 199)
VANE SHEAR STRENGTH (g/cm²)
0 50 100 150 200
WATER CONTENT (%)
0 100 200 300 400
SAMPLE DEPTH (cm)
0 100 200 300 400 500 600 700
● VANE SHEAR STRENGTH
■ WATER CONTENT
(8)

Fig. VIII-2 (2)

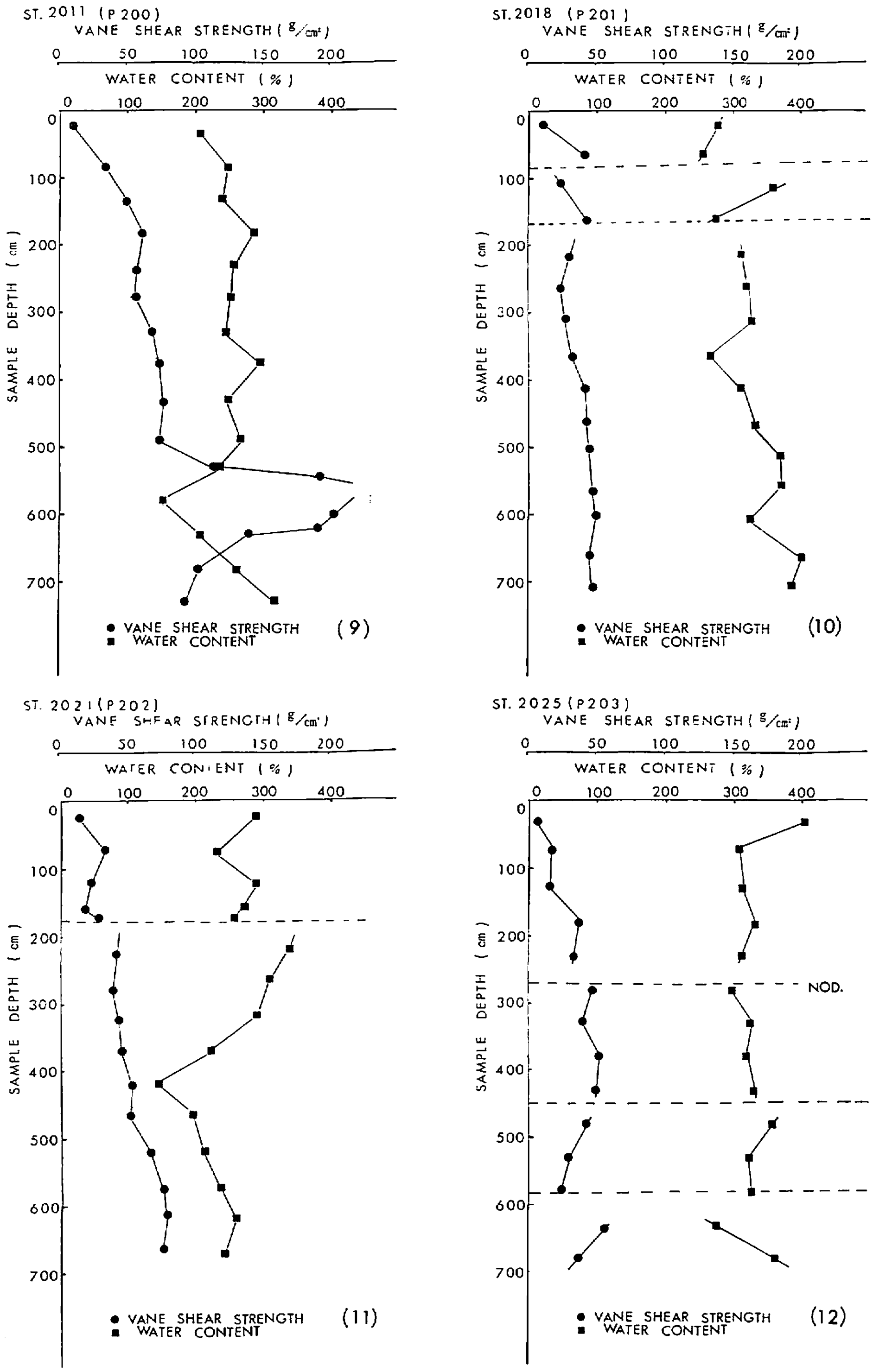
ST. 2011 (P 200)
VANE SHEAR STRENGTH (g/cm²)
0 50 100 150 200
WATER CONTENT (%)
0 100 200 300 400
SAMPLE DEPTH (cm)
0 100 200 300 400 500 600 700
● VANE SHEAR STRENGTH
■ WATER CONTENT
(9)
ST. 2018 (P 201)
VANE SHEAR STRENGTH (g/cm²)
0 50 100 150 200
WATER CONTENT (%)
0 100 200 300 400
SAMPLE DEPTH (cm)
0 100 200 300 400 500 600 700
● VANE SHEAR STRENGTH
■ WATER CONTENT
(10)
ST. 2021 (P 202)
VANE SHEAR STRENGTH (g/cm²)
0 50 100 150 200
WATER CONTENT (%)
0 100 200 300 400
SAMPLE DEPTH (cm)
0 100 200 300 400 500 600 700
● VANE SHEAR STRENGTH
■ WATER CONTENT
(11)
ST. 2025 (P 203)
VANE SHEAR STRENGTH (g/cm²)
0 50 100 150 200
WATER CONTENT (%)
0 100 200 300 400
SAMPLE DEPTH (cm)
0 100 200 300 400 500 600 700
NOD.
● VANE SHEAR STRENGTH
■ WATER CONTENT
(12)

Fig. VIII-2 (3)

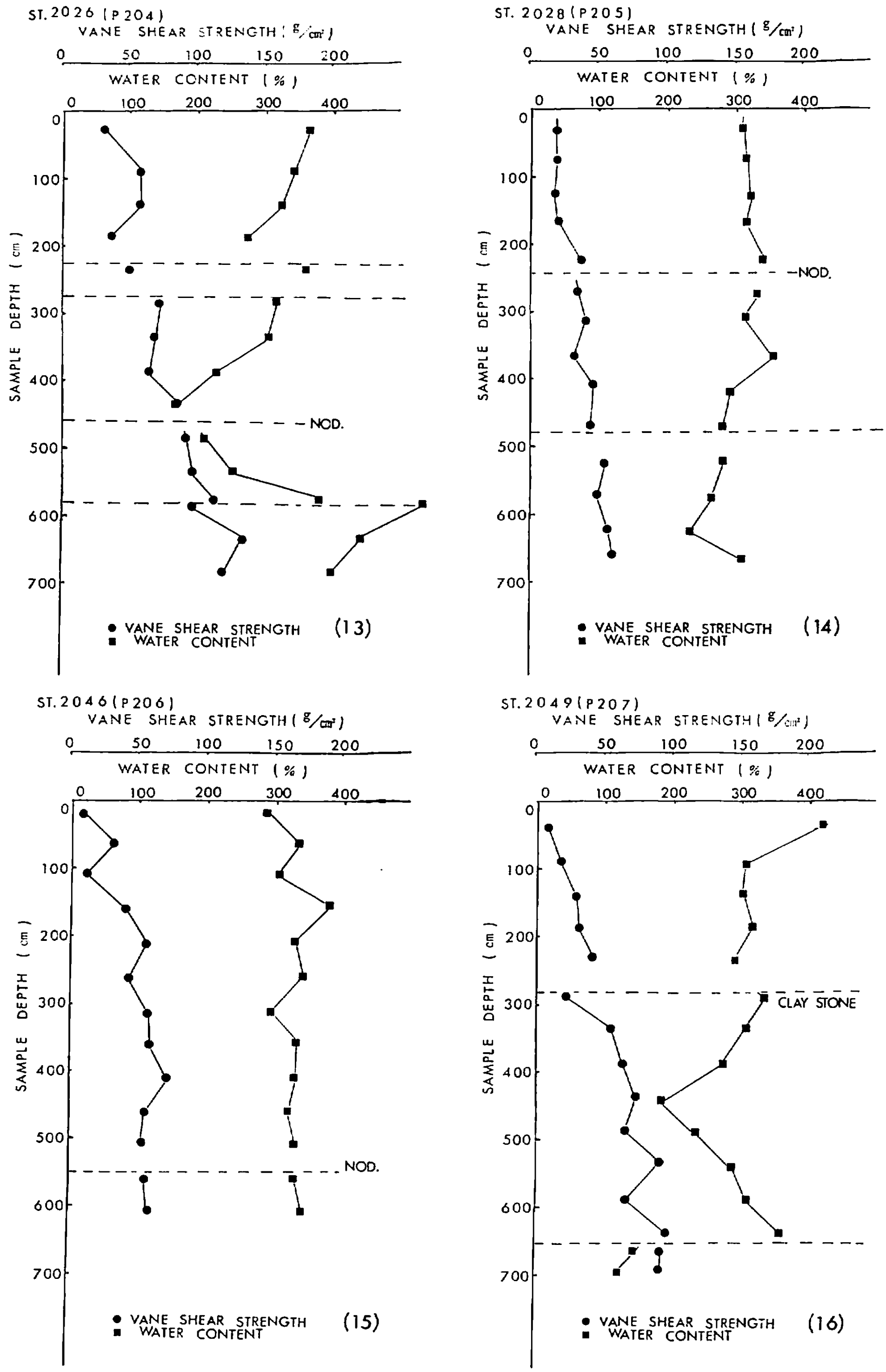
ST. 2026 (P 204)
VANE SHEAR STRENGTH (g/cm²)
0 50 100 150 200
WATER CONTENT (%)
0 100 200 300 400
SAMPLE DEPTH (cm)
0 100 200 300 400 500 600 700
NOD.
● VANE SHEAR STRENGTH
■ WATER CONTENT
(13)
ST. 2028 (P 205)
VANE SHEAR STRENGTH (g/cm²)
0 50 100 150 200
WATER CONTENT (%)
0 100 200 300 400
SAMPLE DEPTH (cm)
0 100 200 300 400 500 600 700
NOD.
● VANE SHEAR STRENGTH
■ WATER CONTENT
(14)
ST. 2046 (P 206)
VANE SHEAR STRENGTH (g/cm²)
0 50 100 150 200
WATER CONTENT (%)
0 100 200 300 400
SAMPLE DEPTH (cm)
0 100 200 300 400 500 600 700
NOD.
● VANE SHEAR STRENGTH
■ WATER CONTENT
(15)
ST. 2049 (P 207)
VANE SHEAR STRENGTH (g/cm²)
0 50 100 150 200
WATER CONTENT (%)
0 100 200 300 400
SAMPLE DEPTH (cm)
0 100 200 300 400 500 600 700
CLAY STONE
● VANE SHEAR STRENGTH
■ WATER CONTENT
(16)

Fig. VIII-2 (4)

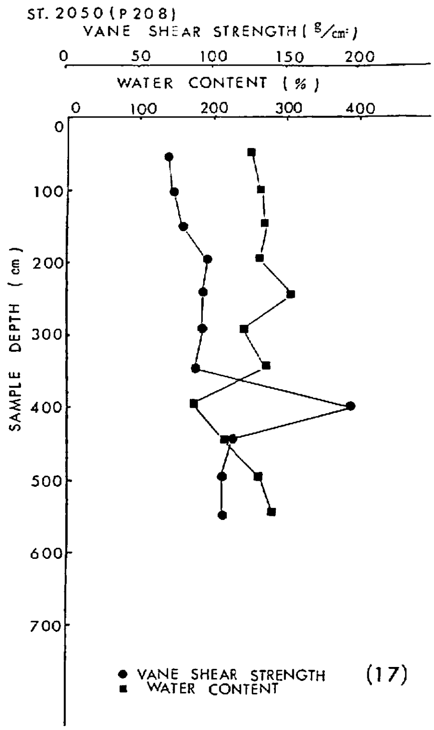

Fig. VIII-2 (5)

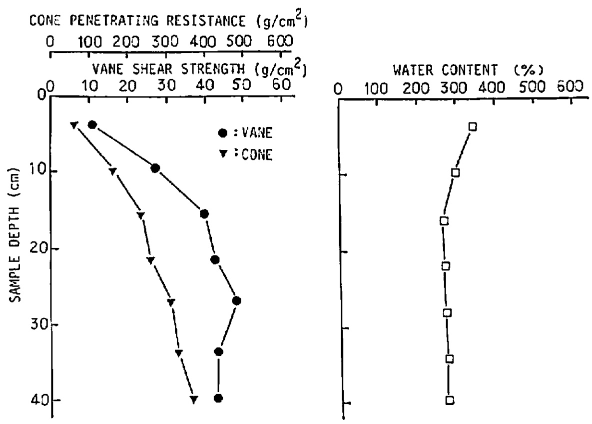

Fig. VIII–3 Profile of average values of geotechnical properties for all box cores.

content versus test depth for all twenty three box cores are shown in Fig. VIII–3. The figure shows that the water content is about 350% at the depth of 4 cm and decreases with depth to about 270% at 16 cm deep layer of sediments. Below this layer, it remains almost constant. Vane shear strength versus test depth shows the largest increase in strength with depth occurs in the upper 16 cm layer of sediments from 10 g/cm^2 at 4 cm to 40 g/cm^2 in the average value. Below this depth it increases very slightly to about 50 g/cm^2 until the depth reaches to 40 cm. Cone penetrating resistance increases also with depth from 60 g/cm^2 at 4 cm layer to 240 g/cm^2 at 16 cm and shows the tendency of slight increment to 310 g/cm^2 at 28 cm layer and 330 g/cm^2 at 34 cm. After putting together all the results of measurements of box cores the engineering properties of surficial part of deep-sea sediments shows that the contained water tends to decrease and the strength tends to increase with depth until about 20 cm deep and they change very little below that depth until about 40 cm deep layer. The water content shows the negative correlation to vane shear strength and cone penetrating resistance. Vane strength has the positive correlation to cone resistance at the upper most layer and the ratio of vane strength and cone resistance is about one sixth.

Table VIII–1 shows the statistical results of geotechnical properties of box cores classified by the contained manganese nodule type: i.e. rough type nodule area, smooth type nodule area, and barren area (less than 2 kg/m^2 of abundance). According to the table the water content of rough type area is small and barren area is large. But the difference between rough type area and smooth type area is very small and that of these two areas differs much from that of barren area. So, it can be

Table VIII–1 Geotechnical properties of box cores classified by contained manganese nodule type

SAMPLE DEPTH (cm)		ROUGH TYPE AREA			SMOOTH TYPE AREA			BARREN AREA		
		W. C. (%)	VANE (g/cm^2)	CONE (g/cm^2)	W. C. (%)	VANE (g/cm^2)	CONE (g/cm^2)	W. C. (%)	VANE (g/cm^2)	CONE (g/cm^2)
4	No. of data	10	10	8	9	9	6	4	4	4
	Ave.	335	11.1	60	347	13.3	91	378	6.1	23
	Stan. Dev.	55	4.5	14.7	108	4.7	60.7	54	1.5	9.0
10	No. of data	10	10	8	9	9	8	4	4	4
	Ave.	288	26.7	167	309	31.6	177	335	17.9	111
	Stan. Dev.	53	5.6	29.8	41	5.1	61.8	15	3.4	18.0
16	No. of data	10	10	8	9	9	8	4	4	4
	Ave.	262	36.4	227	277	48.4	281	290	29.3	176
	Stan. Dev.	44	11.3	44.9	35	4.5	52.7	31	1.2	28.4
22	No. of data	10	9	7	9	9	8	4	4	4
	Ave.	276	43.1	257	279	44.0	286	249	37.9	213
	Stan. Dev.	61	10.1	53.8	42	13.5	75.4	10	3.9	12.5
28	No. of data	8	8	6	8	9	8	4	4	4
	Ave.	269	49.0	339	266	50.0	318	305	43.7	259
	Stan. Dev.	71	7.9	57.3	29	12.4	84.9	52	7.3	63.2
34	No. of data	7	6	4	9	8	8			
	Ave.	272	42.7	384	292	46.3	317			
	Stan. Dev.	39	8.4	34.2	47	7.5	46.1			
40	No. of data	3	2	2	2					
	Ave.	299	44.2	392	303					
	Stan. Dev.	31	5.3	5.5	68					

clarified that the water content is lower and the strength is higher in the manganese nodule abundant area than in the barren area in spite of very small difference of lithology of the sediments. Although the water content is lower in the rough type area than in the smooth type area, the strength in the former area is lower than in the latter area without any lithological difference between these two areas. This may be effective reference in the discussion of the manganese nodule growth mechanism.

Geotechnical properties of piston cores

The relationship between water content and vane shear strength and sample depth on each piston core is profiled in Fig. VIII–2. The latteral dotted line on each profile means clearly visible lithological change and existence of solid material such as manganese nodule, clay stone, and chert in core sample.

In most cases of homogeneous sediment throughout a whole core column except very surficial part, water content decreases and vane shear strength increases monotonously with increment of sample depth. For example, P196 (Sta. 1986) sample consists of about 30 cm deep siliceous fossil rich clay on the top of core and about six meters deep homogeneous pelagic clay below the top. Water content decreases from 350% to 250% and vane shear strength increases from 20 g/cm^2 to 75 g/cm^2 monotonously with sample depth.

In some cases of homogeneous sediment like P199 (Sta. 2006) sample, however, great decrement of water content from 250% to 150% and increment of vane shear strength from 75 g/cm^2 to 180 g/cm^2 with one meter increment of depth are shown at a depth of 4.5 m in the homogeneous zeolitic clay layer. Similar tendency can be seen at a depth of 5.5 m in the P200 (Sta. 2011) sample. These two core samples were taken from very near location and these rapid change of geotechnical properties may be related to each other.

Many core samples include several lithological changes within the core column as shown in figures and those lithological changes have affected more or less on the geotechnical properties. P204 (Sta. 2026) sample consists of siliceous fossil rich clay at surficial 25 cm layer, pelagic clay layer down to 2.8 meter, zelolitic clay layer down to 5.8 m containing manganese nodule at 4.6 meter depth, and siliceous ooze layer below zeolitic clay layer. The geotechnical properties change very abruptly reflecting these lithological changes as shown in figure. Especially in the lowest layer of siliceous ooze water content is extremely high but vane shear strength is relatively high. At the middle layer of zeolitic clay water content decrease very much down to the manganese nodule existence portion and recovers very rapidly below the manganese nodule portion. But vane shear strength increases gradually with the increment of sample depth in the zeolitic layer without any influences of manganese nodule existence. These uncommon appearances of relationship between geotechnical properties are very interesting condition for study of the mechanism of sedimentation.

Statistically, water content of piston cores down to about seven meters depth ranges from 350% to 250% and vane shear strength ranges from 20 g/cm^2 to 80 g/cm^2.

Adhesiveness between nodule and sediments

Adhesiveness per unit area between manganese nodule and surficial sediments ranges very widely from 2 g/cm^2 to 18 g/cm^2. The average value for all 88 nodules is 5.3 g/cm^2 and standard deviation is 3.0 g/cm^2. The average value for rough type nodule is 4.5 g/cm^2±3.7 g/cm^2 and that for smooth type nodule is 5.6 g/cm^2± 2.6 g/cm^2. It is clarified that the adhesiveness between rough type nodule and surficial sediments is smaller and scattered much more than that of smooth type nodule. On the consideration of adhesive properties, it should be required to discuss with the strength property of sediments.

Summary

The geotechnical properties, measured on board, of deep-sea sediments in the northern part of Central Pacific Basin (GH80-5 area) were outlined.

The preliminary examined results are followed.

1. The average water content for box core samples decreases with the increment of sample depth from 350% at the surface to 270% at 16 cm depth and remains almost constant below 16 cm until 40 cm depth of sample.
2. The average vane shear strength for box core samples increases with the increment of sample depth from 10 g/cm^2 at the surface to 40 g/cm^2 at 16 cm depth and increases very slightly below 16 cm until 40 cm depth of sample.
3. The average cone penetrating resistance for box core samples increases abruptly from 60 g/cm^2 at the surface to 240 g/cm^2 at 16 cm depth and increases slightly from 310 g/cm^2 at 28 cm depth to 330 g/cm^2 at 34 cm depth of sample.
4. The geotechnical properties of piston cores were influenced much by the lithological changes of sediments.
5. The average water content of piston cores decreases from 350% at the top part to 250% at seven meters deep layer for homogeneous pleagic clay sediments.
6. The vane shear strength increases from 20 g/cm^2 at the top part to 80 g/cm^2 at seven meters deep layer for homogeneous pleagic clay sediments.
7. The average of adhesiveness per unit area between nodule and surficial sediments is 5.3 g/cm^2±3.0 g/cm^2. For further discussion the strength properties of sediments will be needed to consider.

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