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VII. PHYSICAL AND ENGINEERING PROPERTIES OF MANGANESE NODULES AND DEEP-SEA SEDIMENTS IN THE GH81-4 AREA

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This chapter describes the physical and engineering properties of manganese nodules and deep-sea sediments in the GH81-4 area. As well as in our previous works (TSURUSAKI and HIROTA, 1977; HANDA, 1979; HANDA and TSURUSAKI, 1981; TSURUSAKI and HANDA, 1981 a, b; SAITO and TSURUSAKI, 1981; TSURUSAKI, 1984), we conducted shipboard measurement of the dimension and weight of each manganese nodule sampled with freefall grabs and a double-spade box corer, water content and vane shear strength of deep sea sediments sampled with a piston corer and a double spade box corer, and adhesiveness between each manganese nodule and sediments in several box core samples. For a subsequent laboratory testing, a sub-core was taken from each box core.

These works were performed as a part of the special research program, *Mining Technology for Marine Mineral Resources*, by the National Research Institute for Pollution and Resources.

Dimension and weight of manganese nodule

The purposes of shipboard measurement of the dimension and weight of each nodule are to determine the quantitative relationship between nodule dimension and its weight, and to obtain basic data to estimate nodule abundance from deep-sea photographs.

The measured dimension of each nodule was its length of long and short axes and its thickness. They were measured by using a slide caliper. The weight of each nodule was measured by using the shipboard electrical balance which had been developed in order to avoid the influence of the ship's heaving and vibration (TSURUSAKI *et al.*, 1980).

Results and discussion of shipboard measurement

The measurement was carried out at 72 sampling stations, i.e. 6 box cores and 66 freefall grab samples.

Fig. VII-1 (A) and (B) show size and mass distribution of nodules with a smooth surface (s-type nodules) and with a rough surface (r-type nodules) respectively, which were sampled in the whole survey area. When the nodules were sized into the size fractions as shown in these figures, the maximum frequency or the mode of s-type nodules existed in the size fraction of 2-4 cm, whereas that of r-type nodules existed in the size of 1-2 cm. The average long axes of s-type and r-type nodules were 3.0 cm (standard deviation 1.2, total number of samples 1,258) and 2.1 cm (standard deviation 1.2, total number of samples 1,668) respectively. As for the cumulative mass, the size which in-

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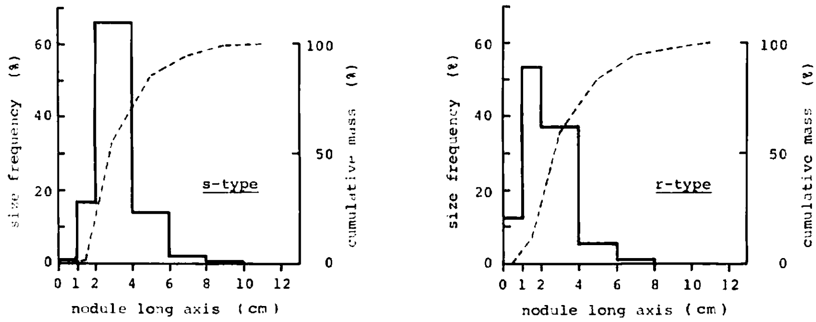


(A) (B)

Fig. VII-1 Size and mass distribution of nodules sampled in the whole survey area (A) s-type nodules, (B) r-type nodules.

dicated 50% of the whole mass or the median was approximately 3.0 cm in both type nodules.

The relationships between long axis and short axis, long axis and thickness, and long axis and weight of r-type nodules sampled in the whole survey area are shown in Fig. VII-2 (A), (B) and (C) respectively. In these figures, r-type nodules were divided into two groups based on their morphological types, such as Sr and others (e.g. SPr, Dr, DPr, SEr), and they were plotted by respective symbols. The regression lines for both groups were also drawn, which were obtained by the method of least squares using respective measured values. The equations for these lines are as follows:

for Sr type nodules (total number of samples 802)

$S=0.91L$ $(r=0.97)$

$T=0.87L$ $(r=0.96)$

$W=0.73L^{3.0}$ $(r=0.97)$

for other r-type nodules (total number of samples 412)

$S=0.77L$ $(r=0.92)$

$T=0.62L$ $(r=0.80)$

$W=0.44L^{3.0}$ $(r=0.94)$

where L: length of long axis of nodule (cm)
S: length of short axis of nodule (cm)
T: thickness of nodule (cm)
W: weight of nodule (g)
r: correlation coefficient

Geotechnical properties of deep-sea sediments

The purposes of shipboard measurement and subsequent laboratory testing are to determine geotechnical properties of deep sea sediments in the GH81-4 area and to obtain basic data for mining engineering of deep-sea manganese nodules. Geotechnical properties measured on board were water content and vane shear strength of deep-sea sediments, and adhesiveness between manganese nodule and sediments.

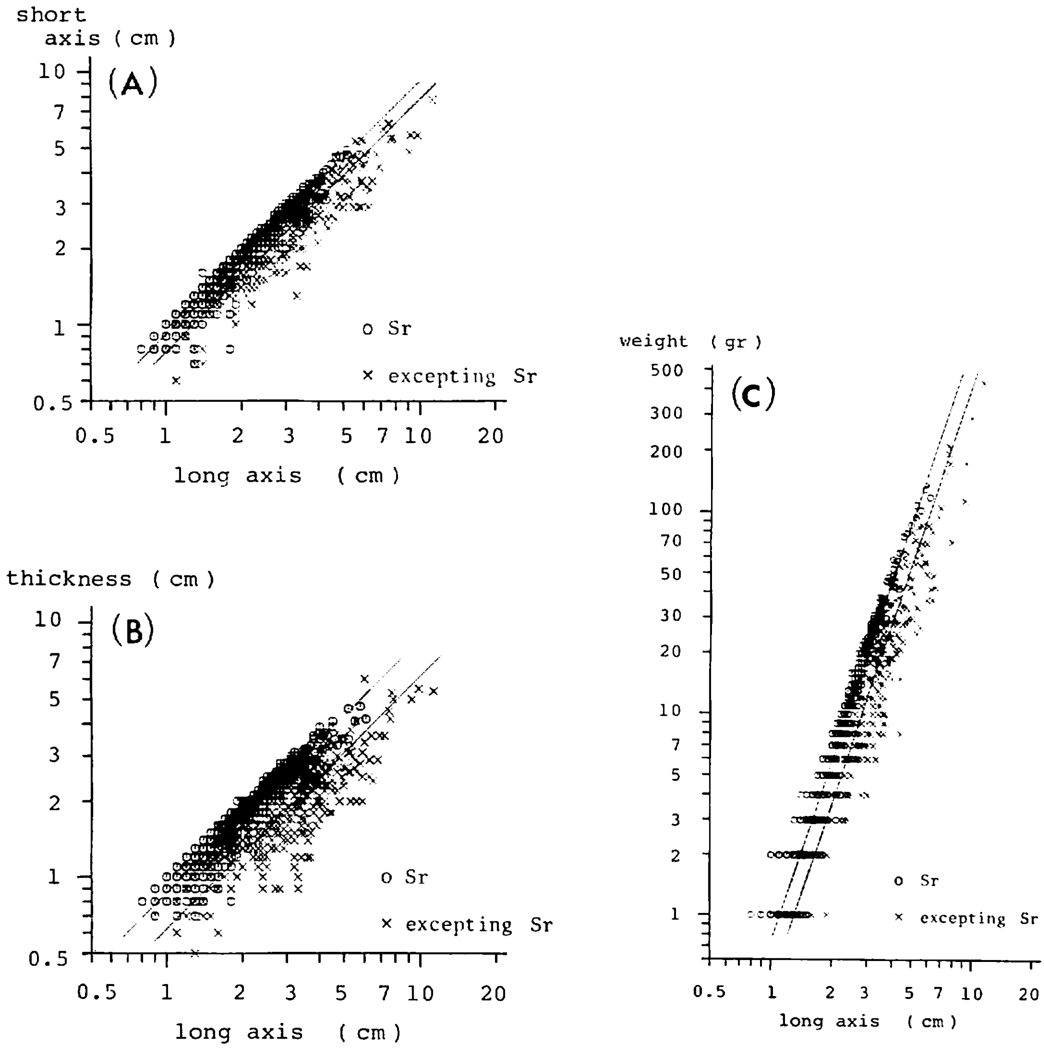


Fig. VII-2 (A) Relationship between long axis and short axis of r-type nodules sampled in the whole survey area, (B) Relationship between long axis and thickness of r-type nodules sampled in the whole survey area, (C) Relationship between long axis and weight of r-type nodules sampled in the whole survey area.

Procedure and equipment

Water content was determined from the weight of the sample before and after drying for 24 hrs. at 105° C, using the following formula:

$$\text{water content } (\%) = [(W_W - W_D)/W_D] \times 100$$

where W_W: wet weight (g)

W_D: dry weight (g)

A 5 cm I.D. PVC pipe was inserted into each box core and disc samples were cut out at 6 cm vertical intervals from the subcore. For piston core, one-fourth column

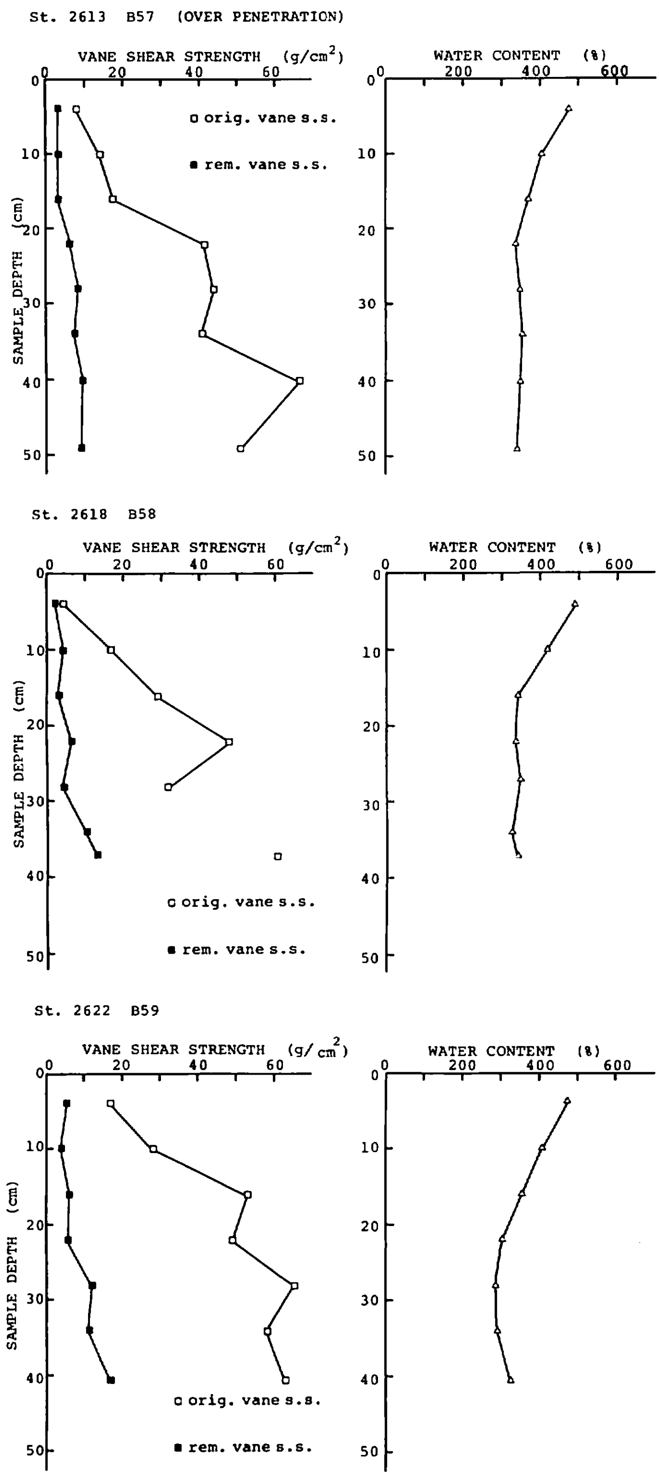


Fig. VII-3(1)

Fig. VII-3 Geotechnical profiles of box core samples in the whole survey area.

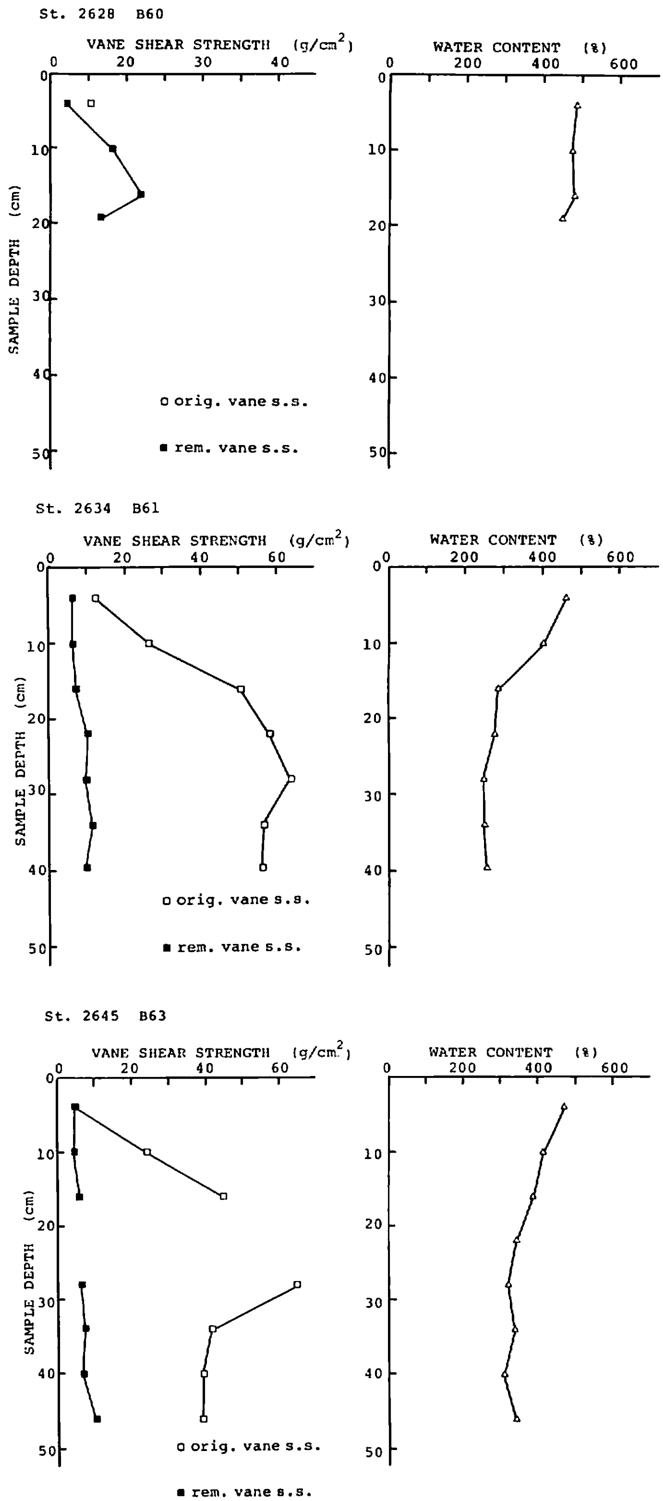

St. 2628 B60
VANE SHEAR STRENGTH (g/cm²)
WATER CONTENT (%)
SAMPLE DEPTH (cm)
o orig. vane s.s.
■ rem. vane s.s.
St. 2634 B61
VANE SHEAR STRENGTH (g/cm²)
WATER CONTENT (%)
SAMPLE DEPTH (cm)
o orig. vane s.s.
■ rem. vane s.s.
St. 2645 B63
VANE SHEAR STRENGTH (g/cm²)
WATER CONTENT (%)
SAMPLE DEPTH (cm)
o orig. vane s.s.
■ rem. vane s.s.

Fig. VII-3(2)

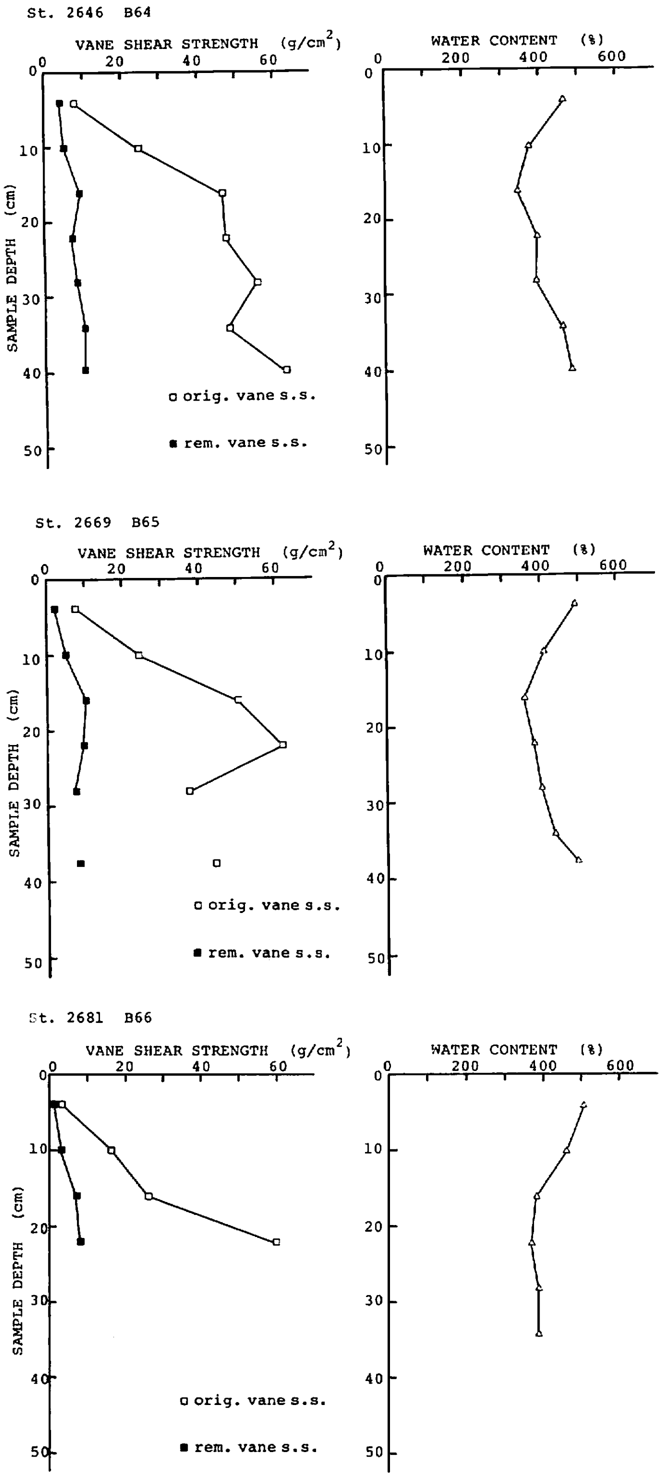

St. 2646 B64
VANE SHEAR STRENGTH (g/cm2)
WATER CONTENT (%)
SAMPLE DEPTH (cm)
0 20 40 60
0 200 400 600
0 10 20 30 40 50
o orig. vane s.s.
■ rem. vane s.s.
St. 2669 B65
VANE SHEAR STRENGTH (g/cm2)
WATER CONTENT (%)
SAMPLE DEPTH (cm)
0 20 40 60
0 200 400 600
0 10 20 30 40 50
o orig. vane s.s.
■ rem. vane s.s.
St. 2681 B66
VANE SHEAR STRENGTH (g/cm2)
WATER CONTENT (%)
SAMPLE DEPTH (cm)
0 20 40 60
0 200 400 600
0 10 20 30 40 50
o orig. vane s.s.
■ rem. vane s.s.

Fig. VII-3(3)

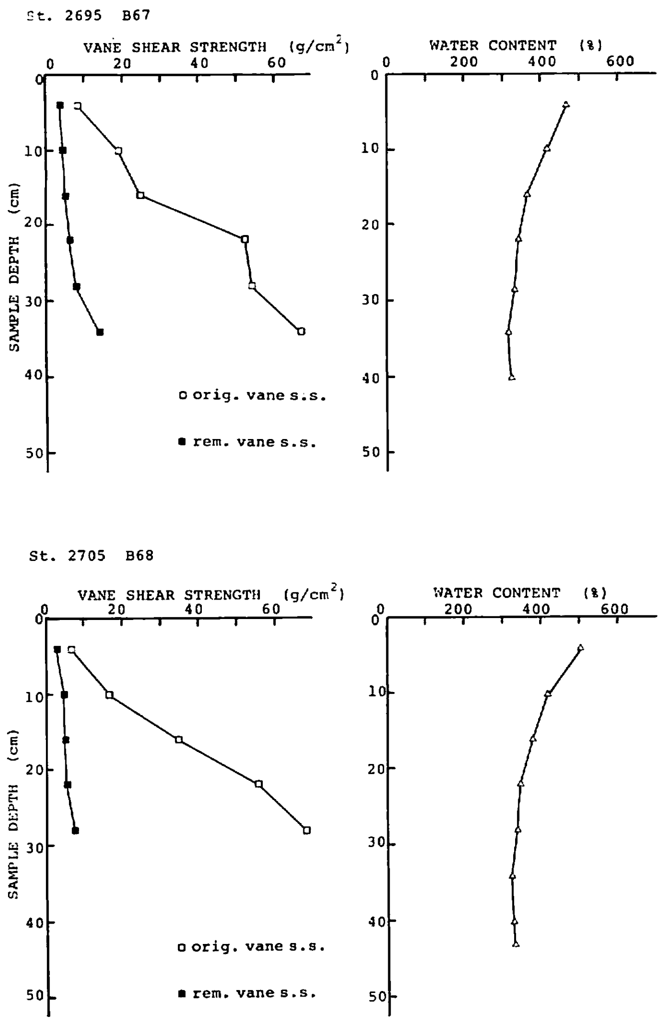
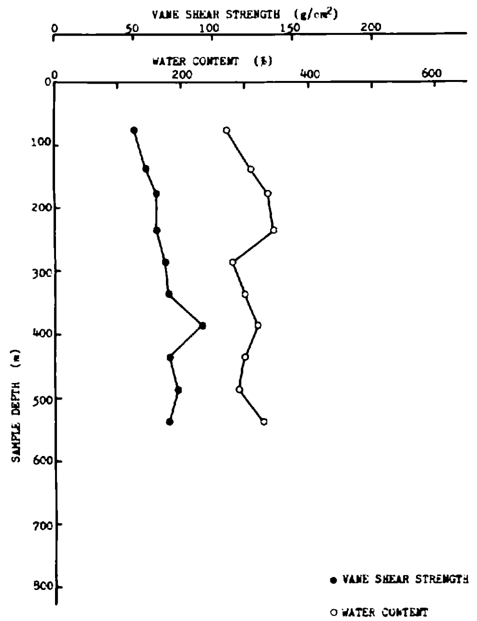


Fig. VII-3(4)

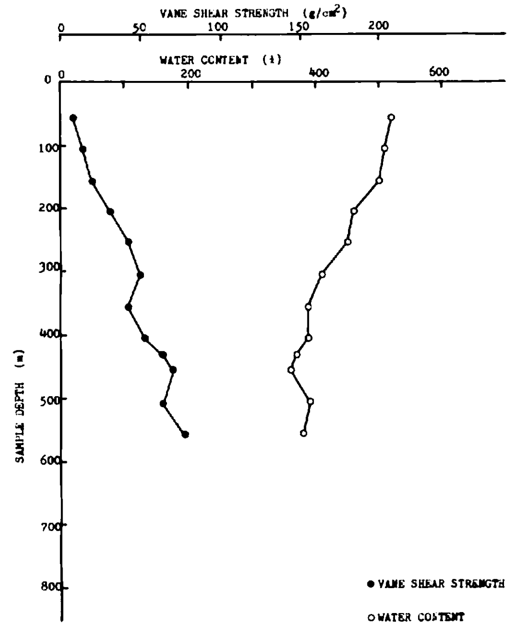
samples of 10 cm long were taken at 50 cm vertical intervals. The weight of the sample before and after drying was measured by using the shipboard electrical balance which was also used for measuring the weight of the nodules.

Vane shear strength was measured with a hand-operated vane shear tester. It consisted of calibrated torsional spring torque meter, whose capacity was 2 kg cm, attached to a 50 cm long stainless steel shaft and terminating with a 2 cm × 4 cm^H 90° vane. In the box core, strength measurement was made at 6 cm vertical intervals from the top. Each measurement consisted of original and remolded strength measurement. The original strength value reported was the maximum shearing resistance developed by the sediments when the vane was rotated at a constant increasing rate of torque, 0.1 kg cm/sec. The remolded strength was the resistance to shear the sediments shortly after the vane had been quickly rotated several times by hand. The torque was converted to shear strength (g/cm^2) by the following formula:

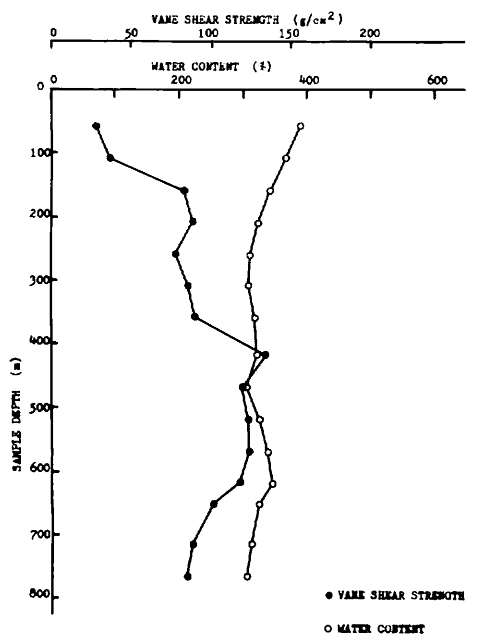
St. 2579 (P218)



St. 2586 (P219)



St. 2583 (P220)



St. 2591 (P221)

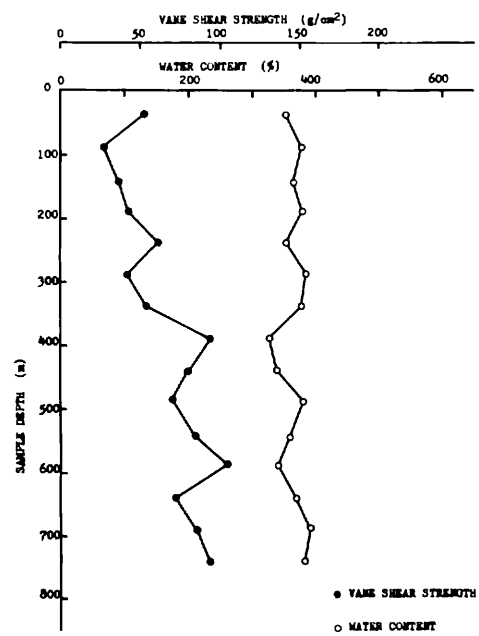
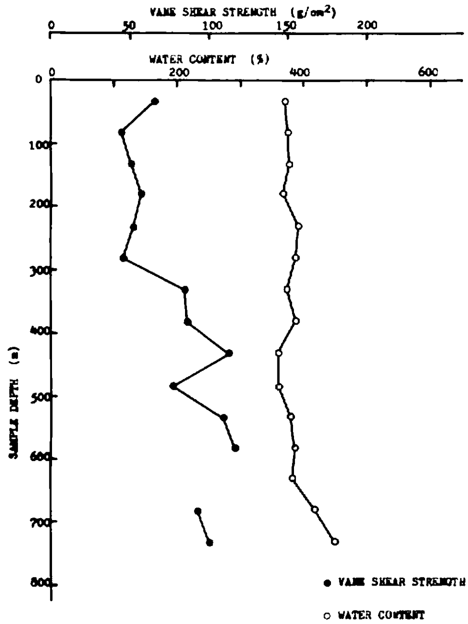


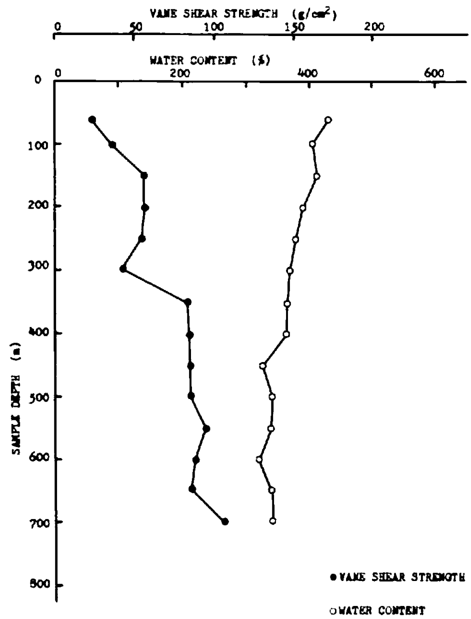
Fig. VII-4(1)

Fig. VII-4 Geotechnical profiles of piston core samples in the whole survey area.

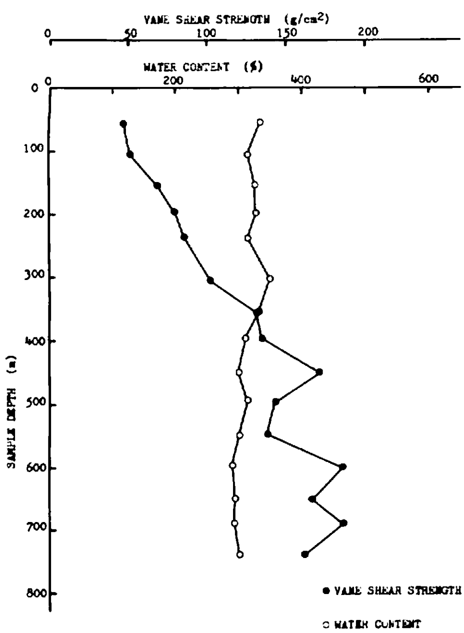
St. 2600 (P222)



St. 2596 (P223)



St. 2651 (P224)



St 2663 (P225)

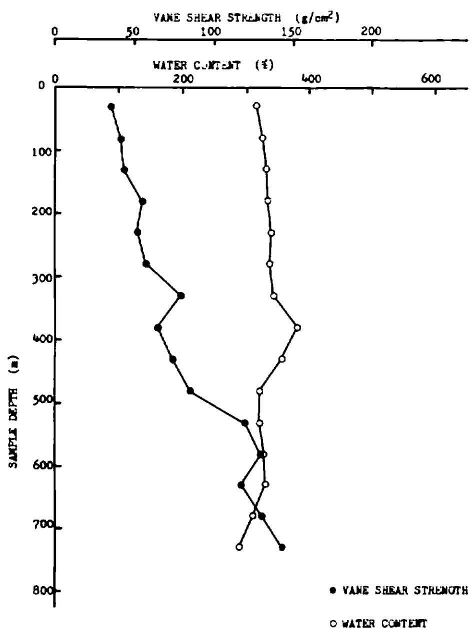
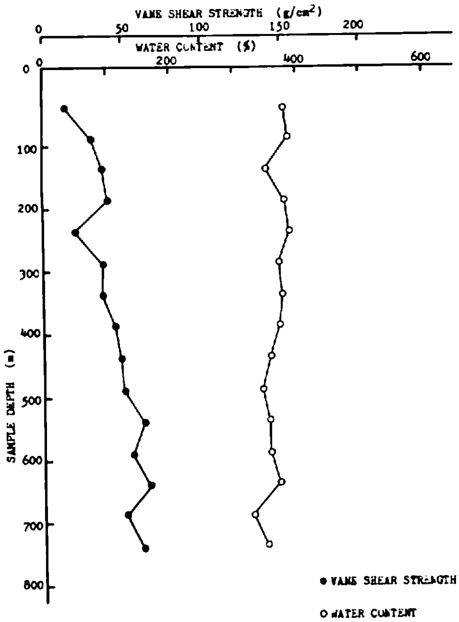
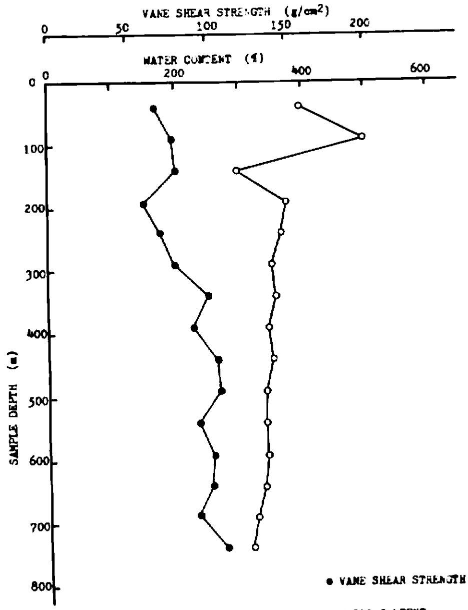


Fig. VII-4(2)

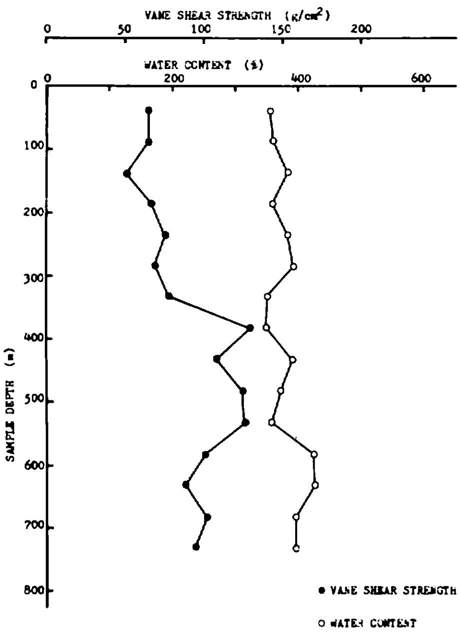
St. 2676 (P226)



St. 2688 (P227)



St. 2700 (P228)



St. 2712 (P229)

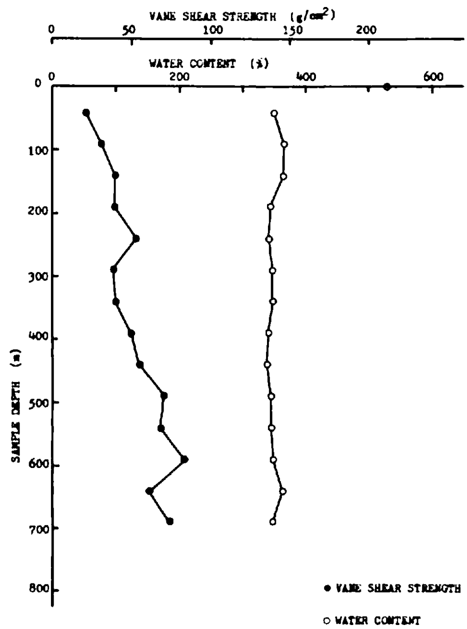


Fig. VII-4(3)

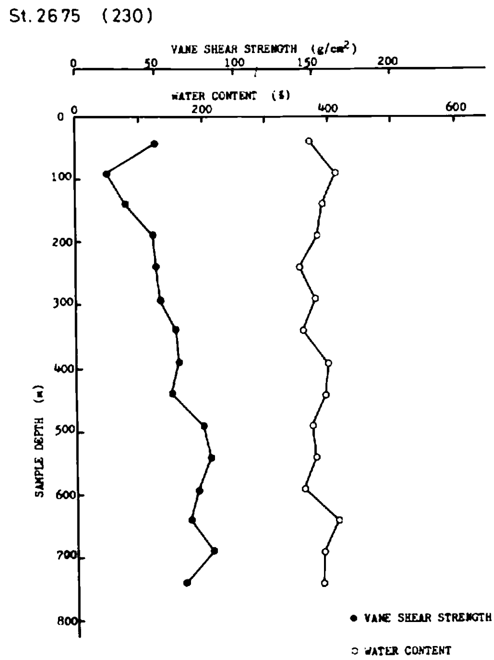


Fig. VII-4(4)

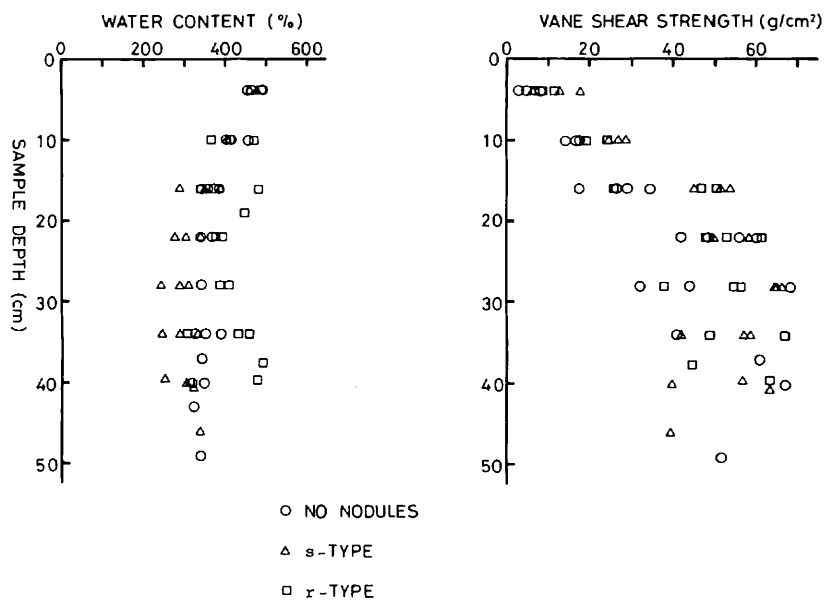


Fig. VII-5 Statistical geotechnical profiles of box core samples in the whole survey area.

vane shear strength (g/cm^2) $= 34.1 \times$ maximum torque (kg cm)

For the piston core, the vertical interval of vane measurement was 50 cm and the remolded strength was not measured. The vane was penetrated only one or two cm below the split surface of the piston core and was rotated vertically to the core axis. The formula to convert torque to shear strength for the piston core is:

vane shear strength (g/cm^2)

$= 119 \times$ maximum torque (kg cm) for 1 cm penetration

$= 68.2 \times$ maximum torque (kg cm) for 2 cm penetration

Adhesiveness between each manganese nodule and sediments was measured on several selected nodules in undisturbed box cores using tweezers and a strain gauge type load cell. Adhesiveness per unit area was determined from the picking-up force divided by the area where the manganese nodule had contacted the sediments. The area was measured by the projection figure which was taken by a camera.

Results and discussion of shipboard measurement

Water content and vane shear strength measurement was performed on 11 box cores and 13 piston cores. The profiles of water content and strength versus test depth for each core are shown in Figs. VII-3 and VII-4. The statistical results of them for all box cores are shown in Fig. VII-5.

The trend of water content versus test depth of the box cores shows that the largest decrease occurs in the upper 16 cm layer of the sediments, and below this layer the mean value decreases very slightly. The average water content is 479% at the depth of 4 cm; 368% at 16 cm; 341% at 28 cm; and 339% at 40 cm respectively.

The examination of vane shear strength versus test depth of the box cores shows that the largest increase occurs in the upper 22 cm layer, and below that layer the mean strength increases slightly but the amount of scatter becomes greater. The average strength is 8.5 g/cm^2 at the depth of 4 cm; 37.8 g/cm^2 at 16 cm; 52.7 g/cm^2 at 22 cm; 54.1 g/cm^2 at 28 cm; and 60.8 g/cm^2 at 40 cm respectively.

As for the piston cores, they had little change in their lithologic types throughout the whole depth, and showed siliceous clay and/or siliceous ooze. Therefore, the profiles of water content and vane shear strength versus test depth show a monotonous change throughout the whole depth.

The sediments of P 219 (st. 2586) had the highest values of water content and the lowest values of strength in the geotechnical profiles of the piston cores in this cruise, and it had also the lowest values in the heat flow measurement performed simultaneously with the piston coring.

Adhesiveness between each manganese nodule and sediments was measured on 18 nodules from 5 box cores, i.e. stations 2622 (B59), 2628 (B60), 2634 (B61), 2657 (B64) and 2695 (B67). The adhesiveness per unit area for all samples varies with great variation from 2.9 g/cm^2 to 14.7 g/cm^2. Its mean value is 7.7 g/cm^2 and the standard deviation is 3.1. It is necessary to continue obtaining data and to perform more considerations including the properties of sediment type in order to grasp the adhesive property between nodule and sediments for mining engineering.

Sub-sampling for subsequent laboratory testing was done for 11 box cores. A 10 cm I.D. and 50 cm long transparent acrylic acid resin tube was inserted into the box core using a vacuum pump. The sub-core was sealed with a plastic lid on the top of the sediments column and two rubber stoppers, one on the top and one on the bottom of the sediments column, and kept vertically in the refrigirator at about 4°C. Bulk samples were taken from 11 box cores after sub-coring and kept in large vinyl bags at room temperature.

Summaries and conclusions

1. Nodules with a rough surface (r-type nodules) are smaller than nodules with a smooth surface (s-type nodules). The former is concentrated in the size fraction of 1-2 cm with the average long axis of 2.1 cm, and the latter is in the size fraction of 2-4 cm with the average of 3.0 cm.

2. The relationship between long axis and short axis, long axis and thickness, and long axis and weight of r-type nodules can be linearized as linear equations (long axis vs. short axis and long axis vs. thickness) and a cubic equation (long axis vs. weight).

3. The average water content of the box cores in the whole survey area decreases from 479% at the surface to 368% at the 16 cm depth and decreases very slightly below the 16 cm depth.

4. The average vane shear strength increases from 8.5 g/cm^2 at the surface to 52.7 g/cm^2 at a 22 cm depth and increases slightly below this depth, but the amount of scatter becomes greater below the depth.

5. The geotechnical profiles of water content and the vane shear strength of piston cores in the whole survey area show monotonous change throughout the whole core depth because the piston cores have little change in their lithologic types throughout the cores.

6. The average of unit area adhesiveness between manganese nodule and sediments is 7.7 ± 3.1 g/cm^2. More considerations should be necessary for this study.

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