XI. GEOTECHNICAL PROPERTIES OF DEEP-SEA SEDIMENTS IN THE NORTHERN PART OF CENTRAL PACIFIC BASIN, WITH A TECHNICAL NOTE ON BOX CORE SAMPLING

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We describe and discuss the geotechnical properties of deep-sea sediments measured on board to obtain the basic data for mining engineering and geoscience of marine manganese nodule. As well as in our previous works (TSURUSAKI and HIROTA, 1977; HANDA, 1979; TSURUSAKI and HANDA, in preparation), geotechnical properties measured were vane shear strength and water content of deep-sea sediments and cohesiveness between manganese nodule and sediment. For a subsequent laboratory testing, a sub-core was taken from each box core and several sub-samples were taken from each piston core. The purposes of shipboard measurement and laboratory testing are to determine the geotechnical properties of deep-sea sediments in the Central Paicfic Basin which includes the area concentrated with manganese nodule, the trend of geotechnical disturbance caused by sampling, the relationship between geotechnical properties and sediment type, and the degradation of the sample due to sub-coring, handling, and storage. This work was performed as a part of a special research program *Mining Technology for Marine Mineral Resources* by National Research Institute for Pollution and Resources.

Procedure and equipments

Shipboard vane shear testing was done 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 × 4 cmH 90° vane. In the box corer, strength measurement was made at 6 cm vertical intervals from the top, making three profiles at distances 5, 10 and 20 cm from the sampler wall. 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 the vane has been rotated several times quickly by hand. The torque was converted to g/cm^2 shear strength unit by the following formula.

Vane shear strength (g/cm^2) = 34.1 × Maximum torque (cm·kg).

The vertical interval of vane measurement for piston core was 50 cm and the remolded strength was not measured. The vane was penetrated only 1 cm below 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:

Vane shear strength (g/cm^2) = 119.4 × Maximum torque (cm·kg).

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

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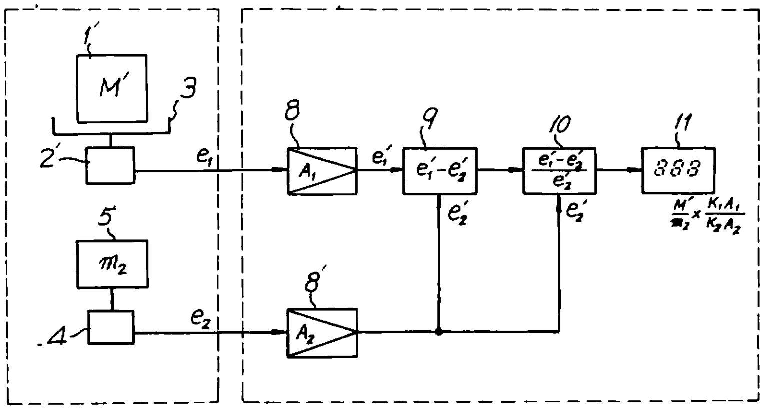

Fig. XI-1 Schematic chart of shipboard electrical balance 1': Sample, 2': Load cell, 3: Weighing plate, 4: Load cell, 5: Standard weight, 8: Amplifier, 8': Amplifier, 9: Calculator, 10: Calculator, 11: Indicator.

expressed as a percentage. 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 small sub-core. For piston core, one-fourth column samples 10 cm long were taken at 50 cm vertical intervals. The weight of wet and dry samples was measured by using newly developed shipboard electrical balance (shown in Fig. XI-1) in order to avoid the influence of ship's heaving and vibration. The shipboard balance consists mainly of one pair of load cells (2', 4), electric amplifiers (8, 8'), and calculators (9, 10) and digital indicator (11). One load cell is used for sample weight measuring and the other measures standard weight. Those two outputs are always changing according to ship's movement and then they are compared to each other at the calculators. The digital indicator shows the real sample weight instantly with the accuracy of 0.5%. The capacity of the balance is 200 g.

Cohesiveness between manganese nodule and sediment was measured on several selected nodules in undisturbed box cores using tweezers and spring balance. Cohesiveness 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 instant camera.

Sampling for laboratory geotechnical testing was done for box and piston cores. Thirty one sub-cores were taken from each box core. A 10 cm I.D. and 40 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 refrigirator (about 4°C). Bulk samples were taken from eleven box cores after subcoring and kept in large plastic bag at room temperature. One-fourth column sub-samples of 10 cm long were also taken from four piston cores at 50 cm vertical interval for laboratory testing and kept in plastic bag in refrigirator.

A freefall vane tester was newly developed for in-place vane shear strength measurement on the deep-sea floor (Fig. XI-2). It consisted of controller, recorder, electrical motors for penetrating and rotating vane, vane, sensors for torque and rotating angle, weight releaser, bottom switch, weight, and recovering buoys. Unfortunately the measurement was failed because of water leakage into the controller capsule.

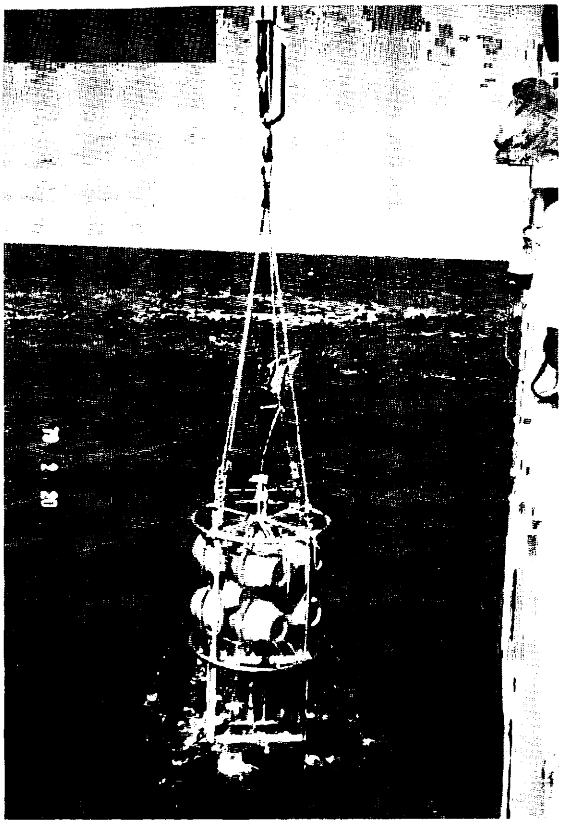

Fig. XI-2 A free fall vane tester.

Results of onboard measurements

Vane shear strength and water content measurement was performed on 33 box cores and four piston cores. The profiles of strength and water content versus test depth for each core are shown in Figs. XI-3, XI-4, and XI-5.

Cohesiveness between manganese nodule and sediment was measured on 49 nodules from 11 box cores (Sts. 1459, 1460, 1463, 1465, 1473, 1480, 1481, 1483, 1489, 1490, 1491). The result of measurement is shown in Fig. XI-6.

Discussion

Geotechnical properties in whole survey area

The statistical results of vane shear strength and water content versus test depth for all box core samples are shown in Fig. XI-7 and Table XI-1. The examination of the strength versus test depth shows that the largest increase in strength with depth occurs in the upper 16 cm layer of sediments; below this layer the mean strength increases very slightly or remains constant. The strength is 41.9 g/cm^2 in max., 7.2 g/cm^2 in min., and 14.8 g/cm^2 on the average at depth of 4 cm; 69.9 g/cm^2 in max., 20.1 g/cm^2 in min., and 44.5 g/cm^2 on the average at 16 cm; 69.6 g/cm^2 in max., 22.2 g/cm^2 in min., and 44.0 g/cm^2 on the average at 28 cm.

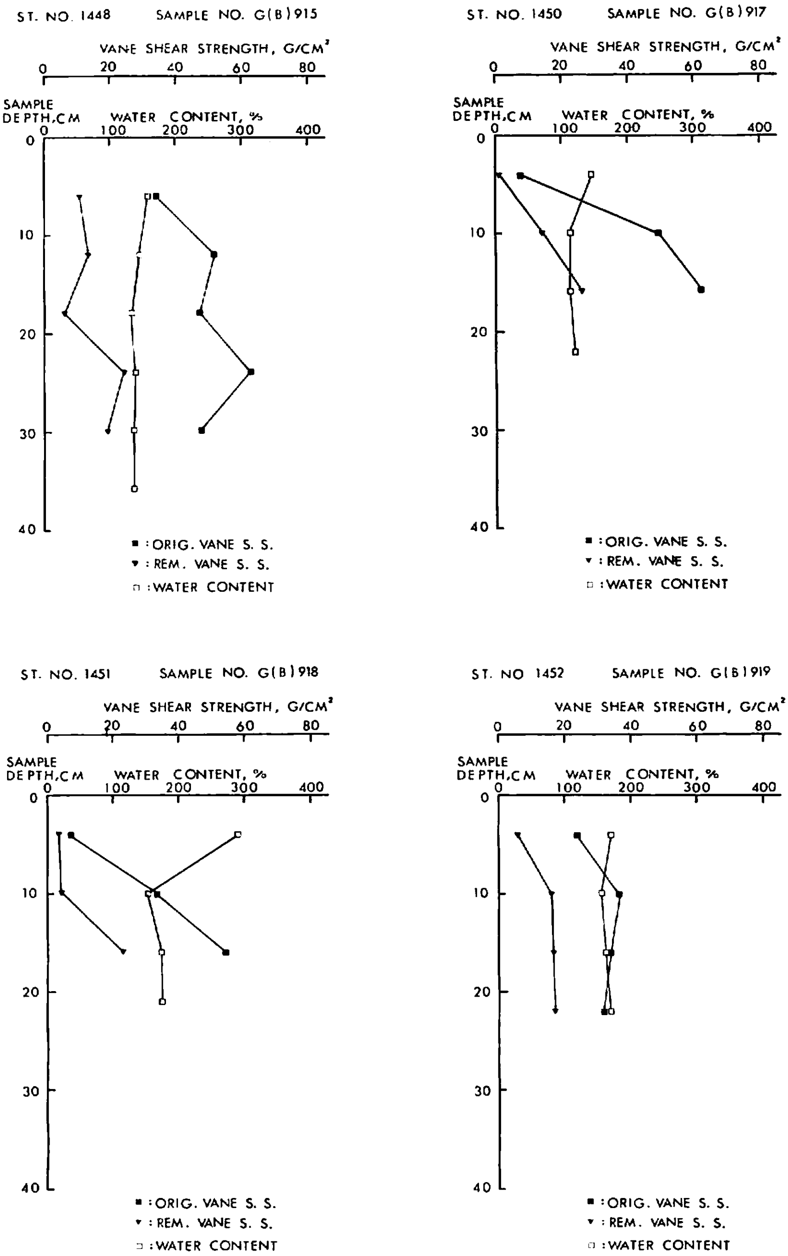

Fig. XI-3 Geotechnical profiles of box core samples in the main survey area.

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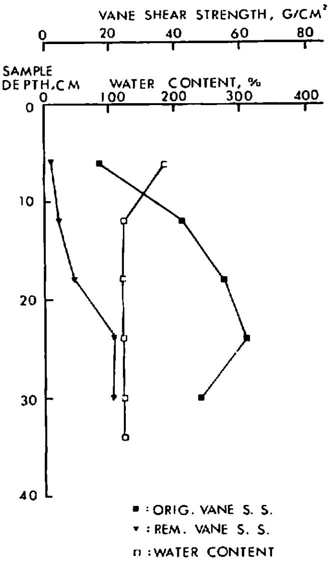

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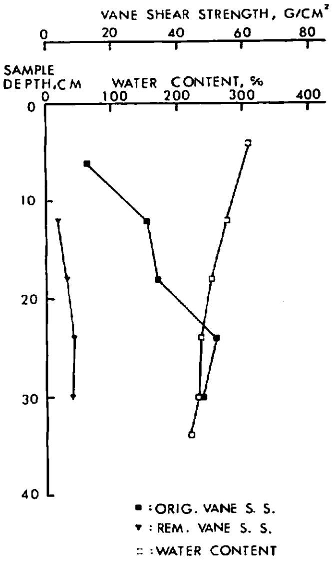

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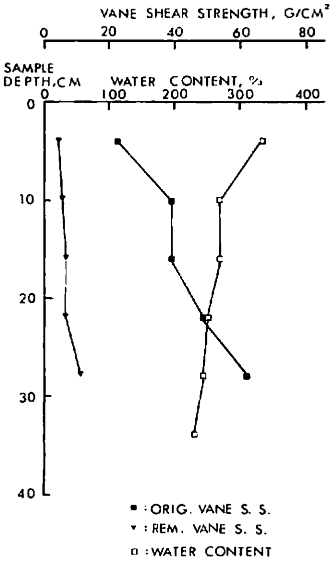

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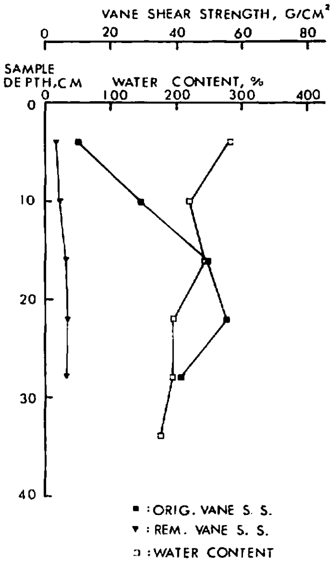

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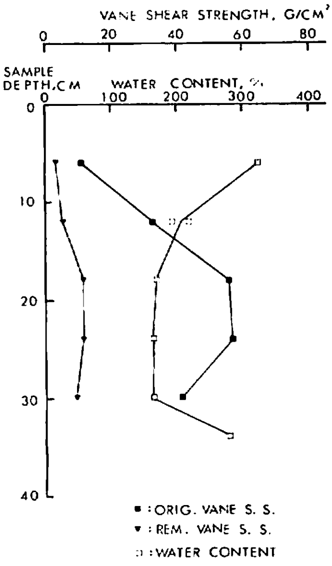

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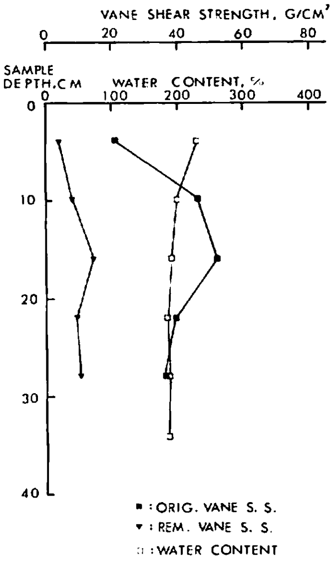

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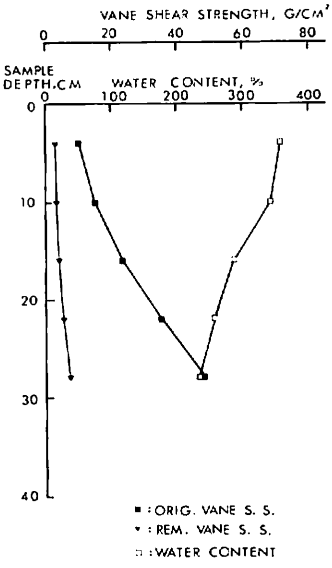

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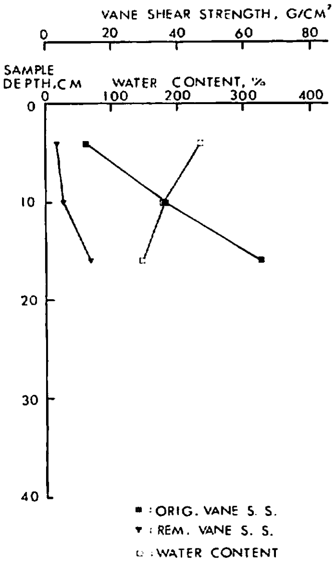

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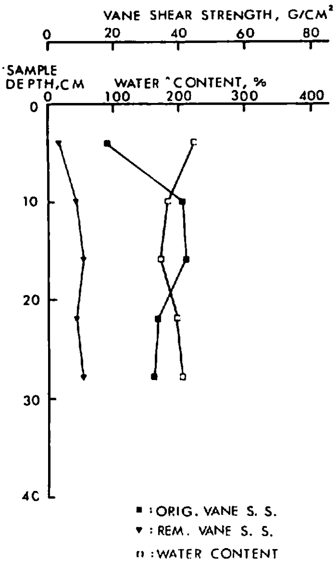

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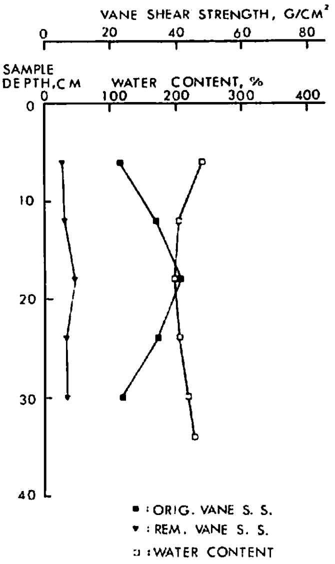

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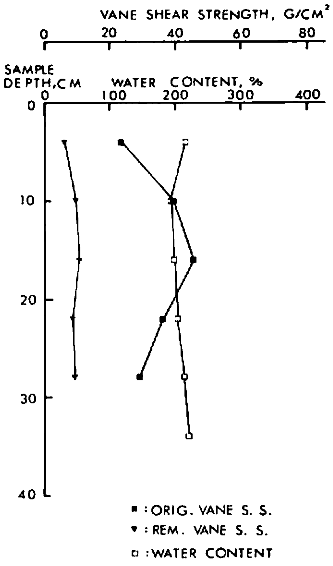

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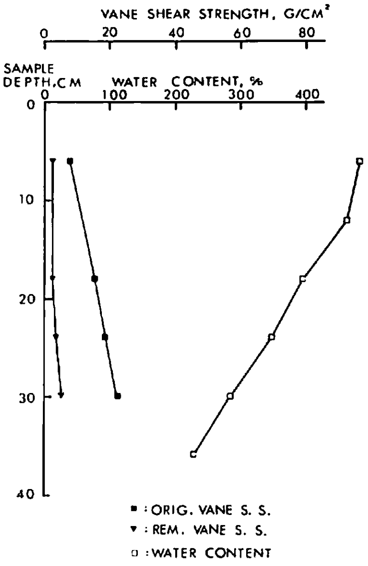

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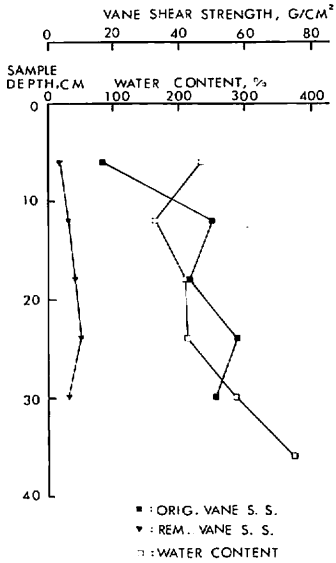

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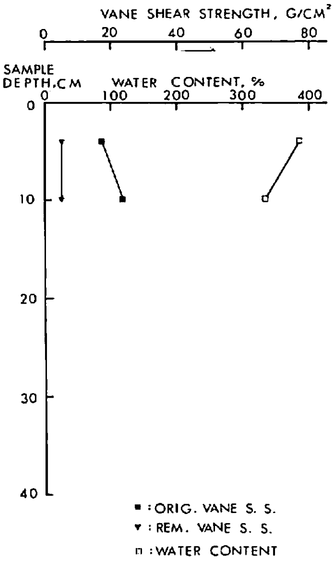

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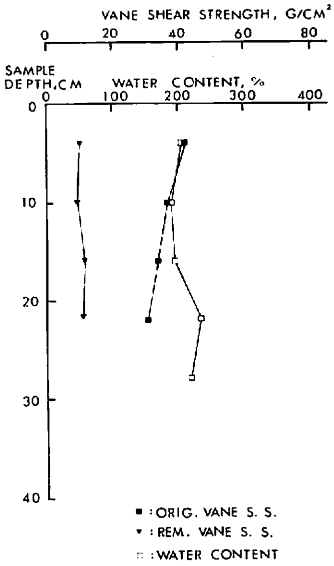

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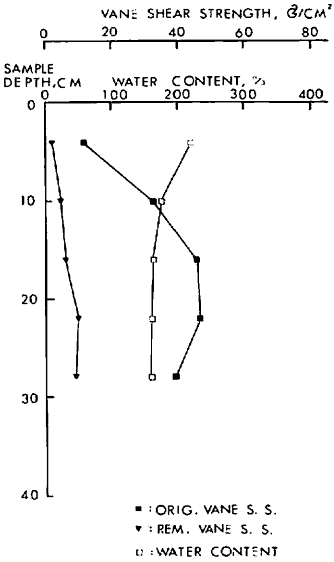

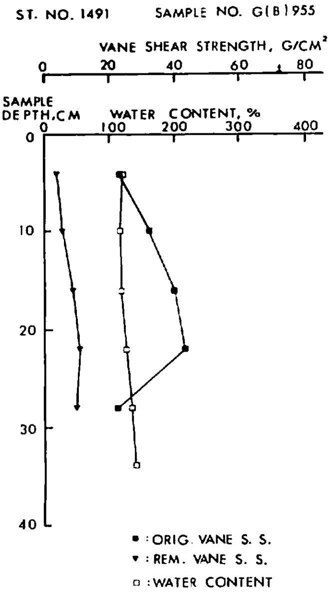

The trend of water content versus sample depth shows that the large decrease in water content with sample depth occurs also in the upper 16 cm layer; below this layer until 22 cm the mean value decreases moderately; below 22 cm it decreases very slightly or remains constant. The water content is 424% in max., 117% in min., and 301% on the average at 4 cm; 348% in max., 114% in min., and 219% on the average at 16 cm; 244% in max., 134% in min., and 210% on the average at 28 cm.

Geotechnical properties in manganese nodule rich area

Concerning to the manganese nodule mining, the examination of geotechnical properties for manganese nodule rich area is very significant. The stations where manganese nodule concentration is more than 10 kg/m² are Sts. 1449, 1454, 1455, 1459, 1460, 1461, 1463, 1464, 1465, 1481, 1487, 1488, 1489, 1490, and 1491. Among them at Sts. 1449 and 1461 very disturbed box core samples were taken and at Sts. 1487 and 1488 only piston core and freefall grab samples were taken. The statistical results of vane shear strength and water content versus test depth for nodule rich area except for St. 1449, 1461, 1487, and 1488 are shown in Fig. XI-8 and Table XI-2. The average of strength for nodule rich area varies from 20 g/cm² at the surface to 40 g/cm² below 16 cm sample depth. The strength at the surface for nodule rich area is higher than that for whole survey area. But below 10 cm those two values are very similar or the former is smaller than the latter. The rate of increase with sample depth is smaller than that for whole survey area.

The average of water content for nodule rich area varies from 250% at the surface to 200% below 16 cm sample depth. It is lower than that for whole survey area throughout the whole depth of sample and the rate of decrease with sample depth is very small.

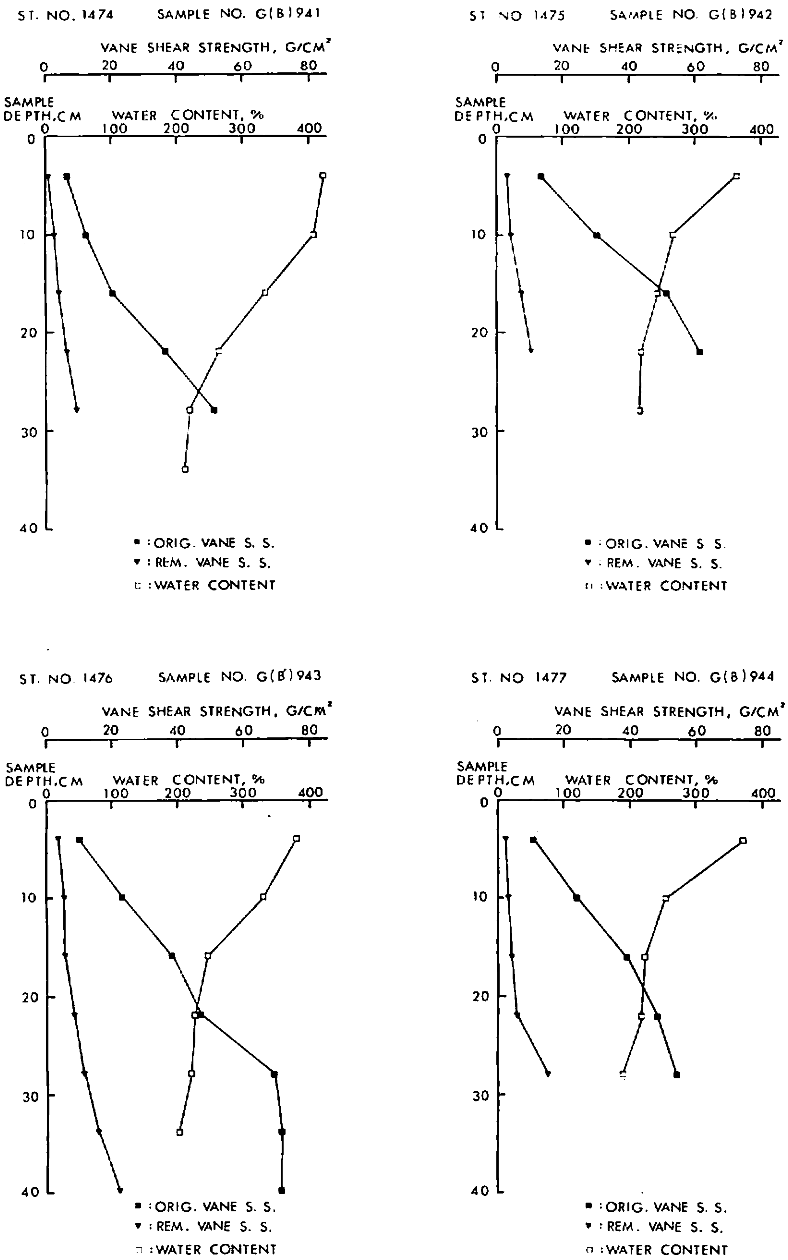

Fig. XI-4 Geotechnical profiles of box core samples in detailed survey area.

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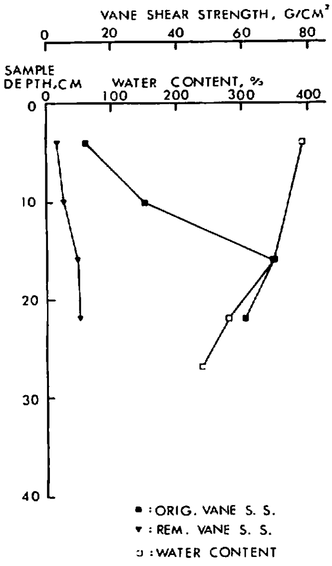

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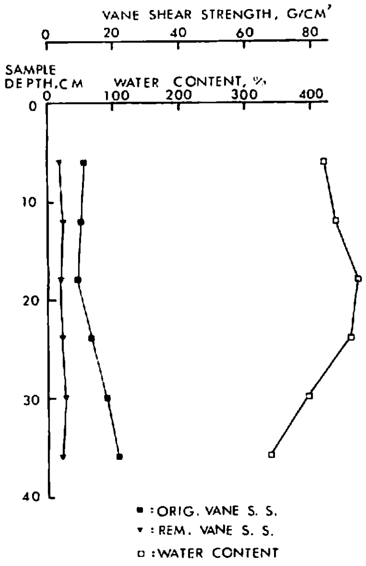

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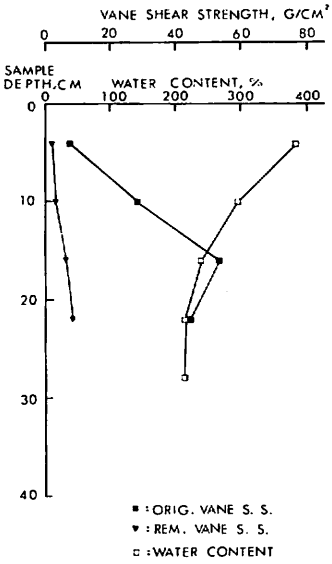

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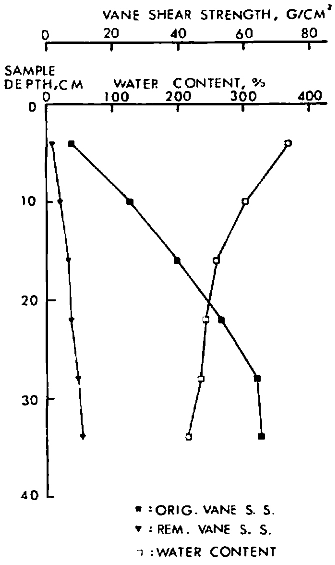

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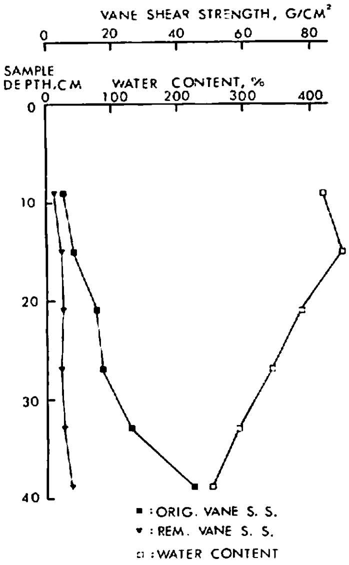

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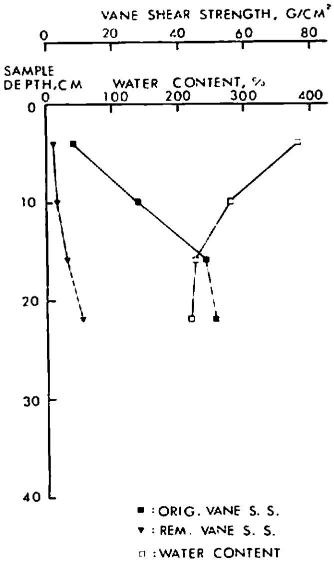

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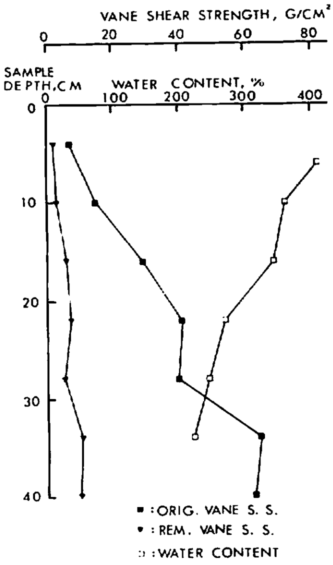

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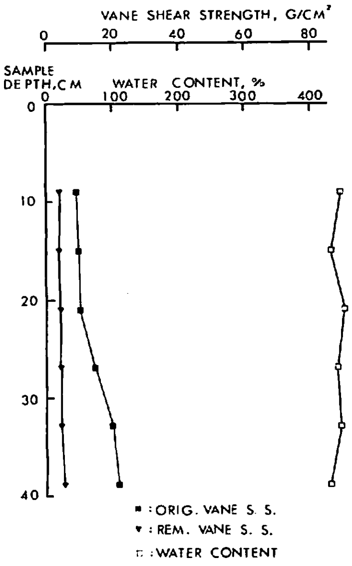

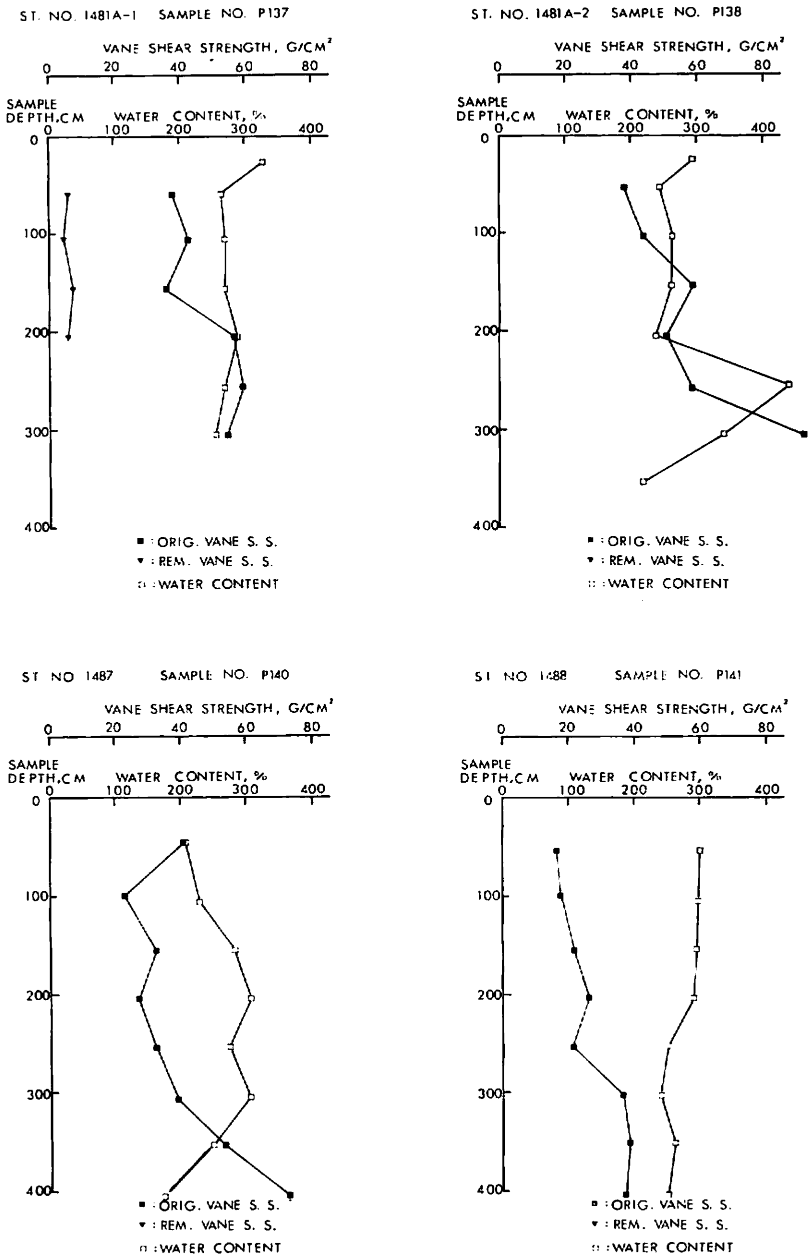

Fig. XI-5 Geotechnical profiles of piston cores.

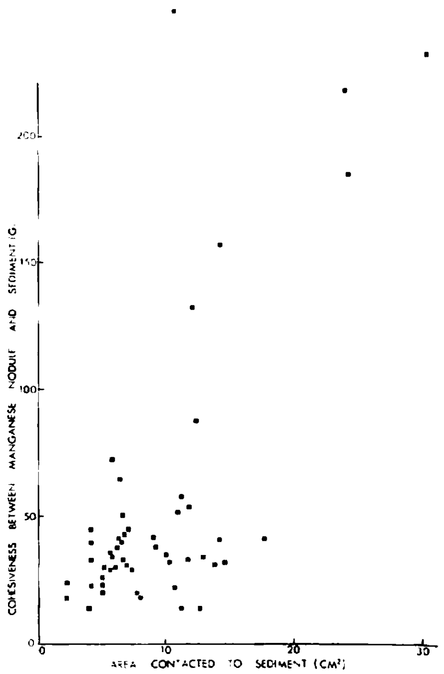

Fig. XI-6 Cohesiveness between manganese nodule and deep sea sediment.

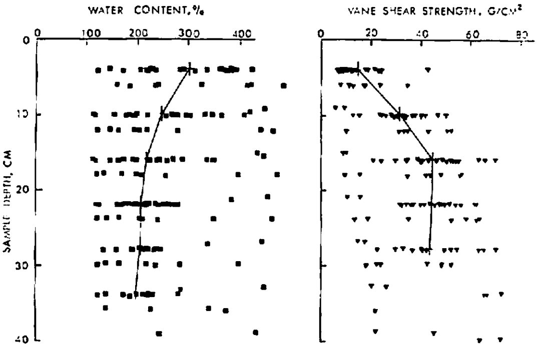

Fig. XI-7 Statistical geotechnical profiles of box core samples in the whole survey area.

Table XI-1 Vane shear strength and water content of box cores in the whole survey area.

Sample depth (cm)	Original vane shear strength (g/cm²) No. of sample	Max.	Min.	Mean	Standard deviation	Water content (% dry weight) No. of sample	Max.	Min.	Mean	Standard deviation
4	23	41.9	7.2	14.8	8.4	23	424	117	301	94.3
10	23	49.4	12.3	31.1	9.5	23	410	114	248	84.6
16	22	69.9	20.1	44.5	12.5	22	348	114	219	63.0
22	19	62.4	29.3	44.2	9.9	21	274	120	209	42.4
28	13	69.6	22.2	44.0	15.0	17	244	134	210	29.3
34						9	229	140	200	28.5

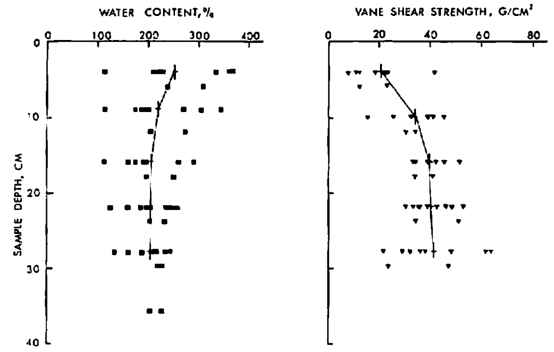

Fig. XI-8 Statistical geotechnical profiles of box core samples in manganese nodule rich area.

Table XI-2 Vane shear strength and water content of box cores in manganese nodule rich area.

Sample depth (cm)	Original vane shear strength (g/cm²)					Water content (% dry weight)				
	No. of sample	Max.	Min.	Mean	Standard deviation	No. of sample	Max.	Min.	Mean	Standard deviation
4	9	41.9	7.8	20.3	10.0	9	369	117	254	83.6
10	9	45.7	15.7	34.7	9.3	9	344	115	220	71.4
16	9	51.8	24.2	40.3	7.9	9	288	117	206	55.2
22	9	53.2	30.7	40.7	7.5	9	258	124	207	45.1
28	8	64.1	22.2	41.8	15.2	9	244	134	204	36.8

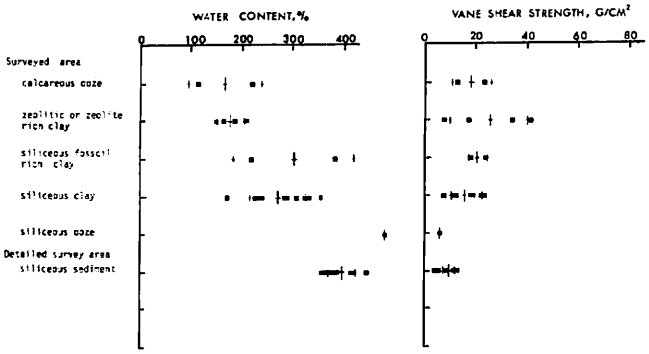

Fig. XI-9 Relation between geotechnical data and surficial sediment type.

Table XI-3 Geotechnical data and surficial sediment type.

Sediment type	Vane shear strength (g/cm²)	Water content (% dry weight)
Survey area		
Calcareous ooze	17.8± 7.7	168± 73
Zeolitic or zeolite rich clay	25.2±15.7	177± 27
Siliceous fossil rich clay	20.6± 4.1	303±120
Siliceous clay	16.4± 6.0	271± 56
Siliceous ooze	7.8	485
Detailed survey area		
Siliceous sediment	9.3± 2.4	399± 27

Geotechnical properties and sediment type

The surficial sediment lithology of the survey area is divided into calcareous ooze, zeolitic and zeolite rich clay, siliceous fossil rich clay, siliceous clay, and siliceous ooze (NISHIMURA, this cruise report). The relationship between lithologic type and geotechnical properties are shown in Fig. XI-9 and Table XI-3. The general trend of decreasing vane shear strength and increasing water content with increasing of siliceous component can be observed among the siliceous and clay component. Especially significant difference of water content between zeolitic clay sediment and siliceous sediment can be observed. It is noticeable that the water content of siliceous ooze is more than 400% dry weight. This siliceous ooze is considered as liquid nature of siliceous fossil suspension rather than solid nature.

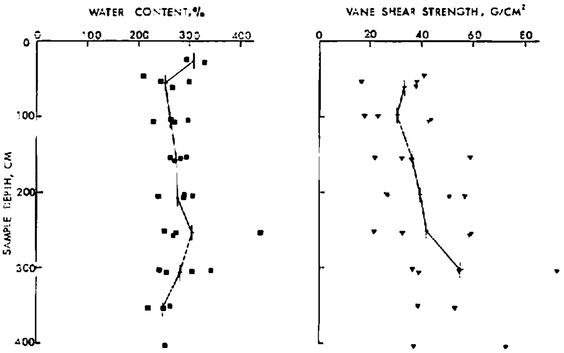

Fig. XI-10 Statistical geotechnical profiles of piston cores.

In the detailed survey area siliceous sediments (siliceous ooze, siliceous clay, and siliceous fossil rich clay) occur in the surface, underlain by clay sediments. The sudden change of the geotechnical data from about 400% to 300% in water content and from around 10 g/cm^2 to more than 20 g/cm^2 in vane shear strength can be observed in certain depth of each box core. These two geotechnical different layers are considered to correspond to siliceous sediment and clay sediment. According to Fig. XI-4 the siliceous sediment is thickest in the northern part in the detailed survey area because sudden change of geotechnical data does not appear in 40 cm depth of core. To the west and south the depth of the geotechnical change tends to be shallower. In the western part the change occurs in 20 cm from the surface and in southern part it occurs in 10 cm from the surface. These data show that the thickness of the siliceous sediments tends to become thinner from more than 40 cm in the northern part to 20 cm in the western part and less than 10 cm in the southeastern part.

Geotechnical properties of piston cores

The statistical profiles of water content and vane shear strength versus piston core depth are shown in Fig. XI-10. Piston cores P137 and P138 were collected from very near places in the western part of detailed survey area. Fig. XI-5 indicates that these two cores are very similar to each other geotechnically from the surface to 2 m depth. Water content for both cores is about 300% at 20 cm depth and remains at 250% below 20 cm to 2 m. Vane shear strength for both cores is around 50 g/cm^2 from 50 cm depth to 1.5–2 m. Below 2 m water content for P137 remains constant or decreases very slightly. Vane shear strength increases to about 60 g/cm^2 and remains constant. But for P138 water content becomes very large value of 450% at 2.5 m depth and decreases rapidly to 350% at 3 m and to 250% at 3.5 m. These are caused by dark reddish brown clay layer at 2.5 m and very pale brown nanno ooze layer at 3.4 m. Below 3.5 m core shows yellowish brown calcareous clay, which is very hard and crumbly. The layer from 2.5 m to 3.4 m should be paid attentions to its chemical properties because it is considered uncommon that both water content and strength are very high at the same time.

Lithology for P140 shows that it is entirely homogeneous clay throughout the whole depth. Usually water content of homogeneous clay decreases and strength increases with core depth. But according to the geotechnical profile for P140 the water content increases with core depth from 200% at the surface to 300% at 3 m depth and decreases to 200% at 4 m depth. Vane shear strength increases normally. The sediment of P141 is geotechnically homogeneous throughout the whole depth.

Cohesiveness between manganese nodule and sediment

The relationship between cohesiveness and contacting area is shown in Fig. XI-6. The cohesiveness tends to increase with contacting area but clear relationship can not be observed. The cohesiveness per unit area for all samples varies with great variation from 28.7 g/cm^2 to 1.1 g/cm^2. Its average value is 6.1 g/cm^2 and standard deviation is 4.4 g/cm^2. Some considerations including the properties of sediment type should be performed in order to grasp the cohesive property between manganese nodule and sediments for mining engineering.

Conclusions

1. The average vane shear strength of the sediments in the whole survey area increases from 15 g/cm^2 at the surface to 45 g/cm^2 at 16 cm depth of box core and remains at 45 g/cm^2 below 16 cm depth.
2. The average water content decreases from 300% at the surface to 200% at 16 cm depth and decreases very slightly below 16 cm depth for all box core samples.
3. The average vane shear strength of the sediments in the nodule rich area is greater than that for these in the whole survey areas by several g/cm^2 at the surface but below 10 cm depth the former is smaller than the latter.
4. The average water content of the sediments in the nodule rich area is smaller than that of those in the whole survey area by tens precent throughout the whole core depth.
5. Vane shear strength tends to decrease and water content tends to increase with the increase of siliceous component among the siliceous and clay sediments.
6. The geotechnical properties for Piston core P138 indicate the change of sediment type clearly with the core depth.
7. The average of unit area cohesiveness between manganese nodule and sediment is 6.1 ± 4.4 g/cm^2. More considerations should be necessary for this study.

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(in preparation).

APPENDIX Technical note on box core sampling

A double spade corer (Fig. XI-11) of which sampling area is 40 × 40 cm and 36 cm deep and a large spade box corer (Fig. XI-12) of which sampling area is 50 × 50 cm and 60 cm deep were used for taking bottom sample of manganese nodules and sediments.

Double spade box corer was used at 39 stations and succeeded in taking samples at 36 stations. At three stations the deployment were failed in taking samples caused by untripping, flapper unclosing, and wire rope caught between sample box and spade. At four stations of 36 none or very small amount of sediments was sampled but manganese crust and other carbonate materials. Rest of 32 samples were classified according to the grade of disturbance as followed.

Disturbance	No. of samples	Average of sample depth	
Intensive	12		27 cm
Moderate	12	31 cm	
Slight	7		
None	1		

Sample surfaces of six intensively disturbed cores and four moderately disturbed cores were cut out onboard entirely or slightly by the edge of corer main body when the inner box was pushed out from the main body because of over penetration of box corer into the sea floor.

Large spade box corer was deployed at four stations and one sample was disturbed intensively caused by flapper unclosing. At two stations it was deployed with one shot 16 mm camera and one picture of the sea floor just before sampling was taken at St. 1484.

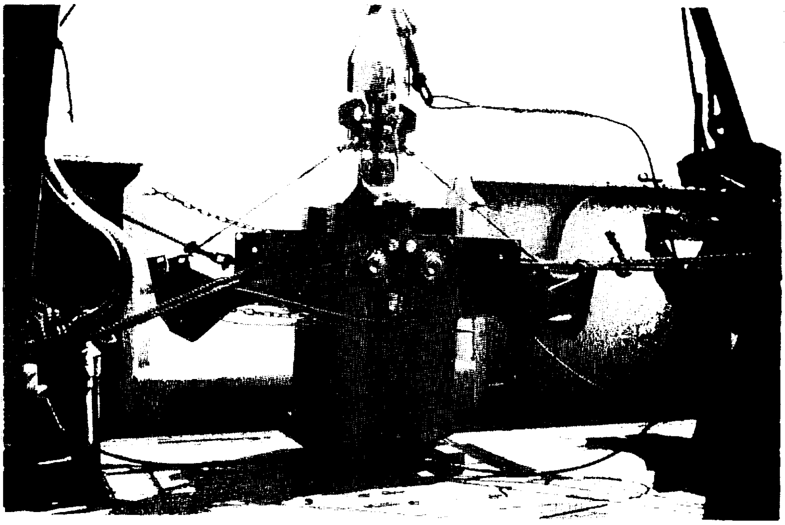

Fig. XI-11 A double spade box corer.

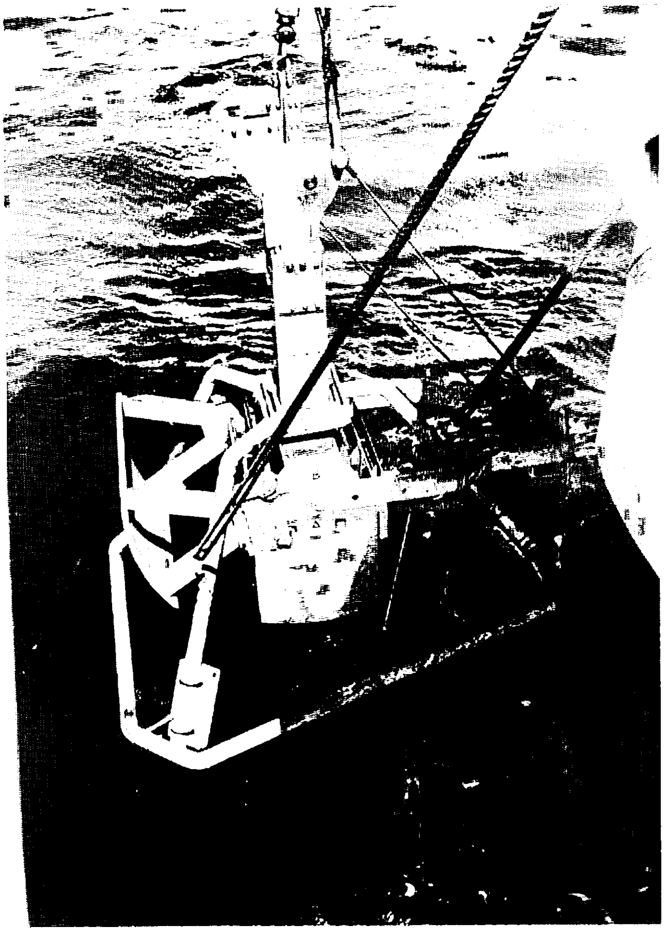

Fig. XI-12 A large spade box corer.