– Automatic Distance Meter :	Audister, type 9D010	1 set
– Echo Sounder :	Type SR-60	1 set

The survey was carried out in the following manner:–

A control station was set on a flat barge, and the probes fixed onto a frame were suspended in the sea water by a rope, which was controlled by a winch, confirming the water depth by an echo sounder, so that it may be kept all the time to be 1 m over the seabed. The flat barge was towed by a tugboat as shown in Fig. 2-3-1, of which position was measured by an automatic distance meter. Overall survey length counts 16.04 km along L-1, L-2 and L-3 in Outer Shoal, and 29.93 km along 16 lines in Offshore Changi, as shown in Fig. 2-1-1. For further details, see Appendix A.

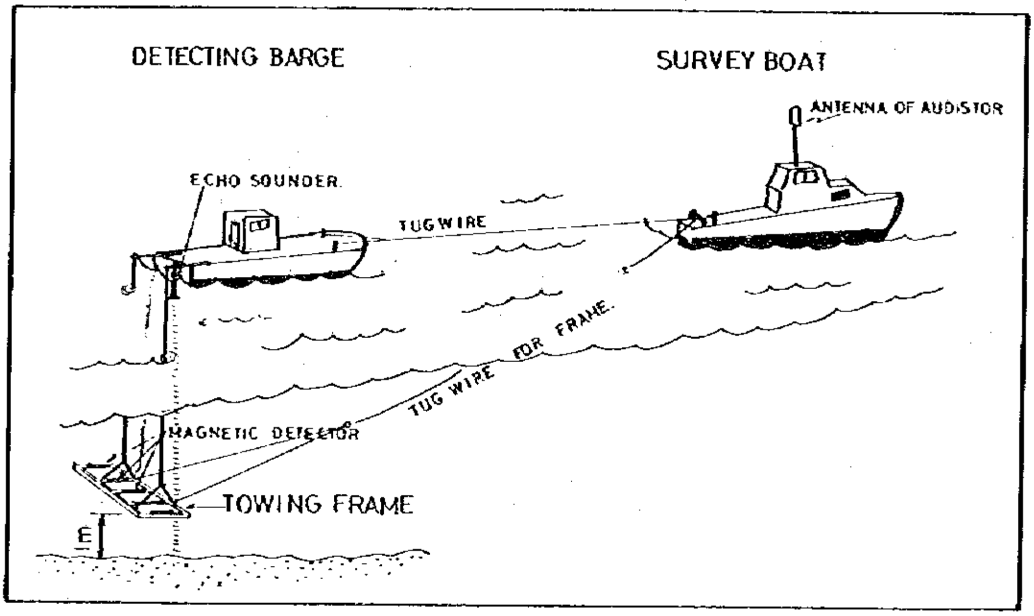


Fig. 2-3-1 The General Method of Magnetic Detection

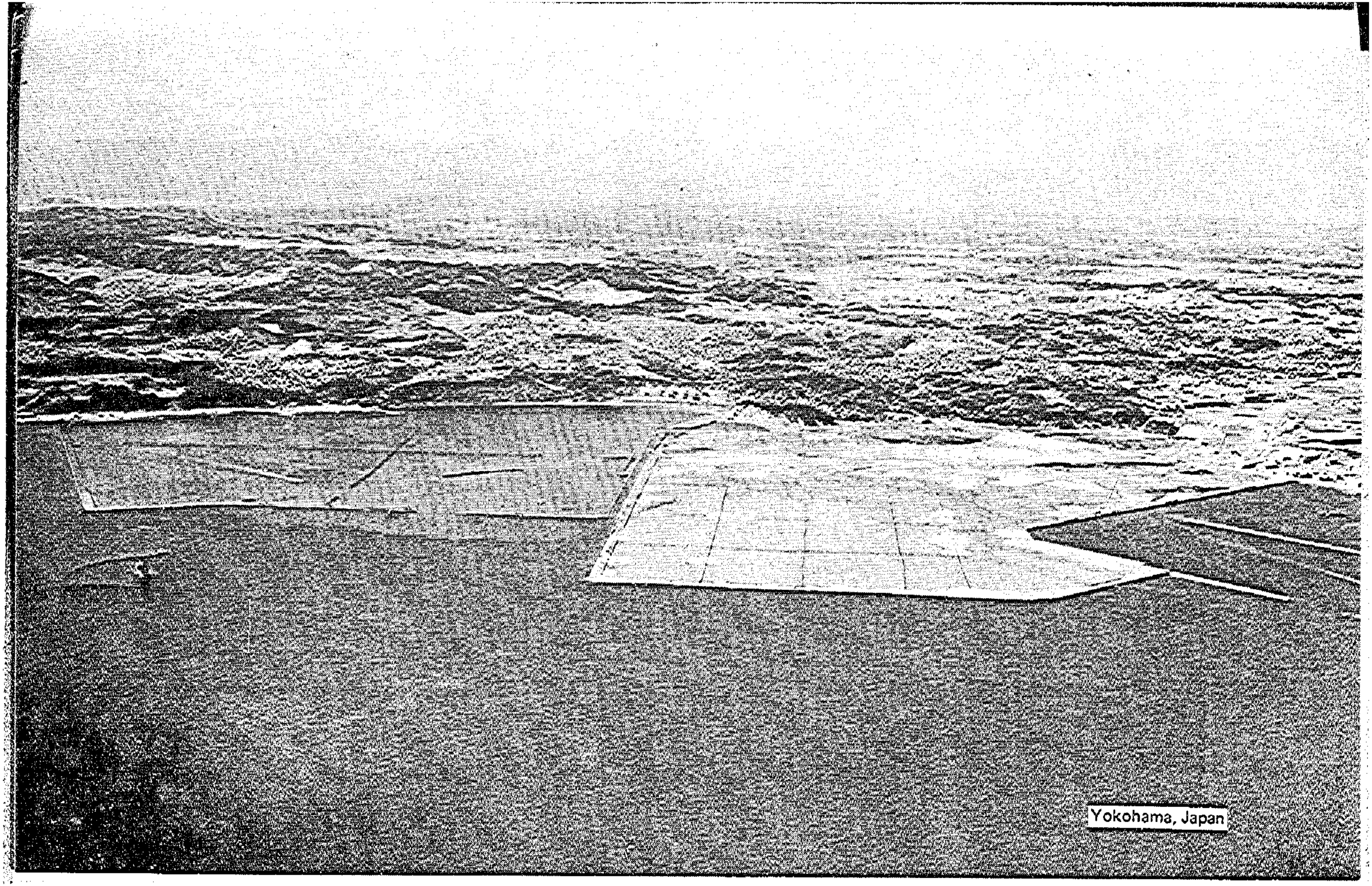
2-3-3 Boring

The borings were carried out in the following manner:–

First the steel scaffolding was placed by a floating crane at the proposed borehole location, which was lined by a set of automatic distance meter (Audister). Then pipe casing of which diameter was 97 mm, was lowered. Boring was carried out using a rotary boring machine to a level of –20 m to –37 m. Standard penetration tests were made at approximately every two meters. The soil samples obtained by the penetration tests were taken to a laboratory for the soil test and a series of physical soil tests were made.

The under-listed equipment was used for the boring:

– Steel Scaffolding :	15 m height	2 sets
– Rotary Boring Machine :	Model OZ-2L	2 sets
Maker :	Koken Boring Machine co., ltd.	
Drilling Depth :	200 m	
Spindle Rotation :	80-160-330-560 r.p.m.	
Torque :	50 kg.m	
Power Unit :	Yanmar engine, NS-110C	
– Boring Pump :	Model NG-5A	2 sets
Maker :	Koken Boring Machine co., ltd.	
Discharge Capacity :	25 ℓ/min, 35 ℓ/min, 65 ℓ/min.	
Working Pressure :	65 kg/cm^2, 40 kg/cm^2, 25 kg/cm^2	
Power Unit :	Yanmar engine, NS-65C	


Yokohama, Japan

(3) SEA BOTTOM SOIL IN SINGAPORE'S TERRITORIAL WATERS

The Public Works Department of Singapore conducted an extensive geological survey since 1972 and "Geology of the Republic of Singapore" was published by the Department in 1976 together with geological maps. It provides comprehensive geological information of the mainland of Singapore and her islands.

The geology of the sea bottom in the Singapore's territorial waters has not yet been put together systematically.

In this study, the Consultant has classified and discussed the borehole data of sea bottom in the Singapore's territorial waters provided by the Singapore government authorities together with the data obtained from the present survey.

3-1 Classification of and Discussion on Available Boring Data from the Authorities

In the past many borings have been carried out on the sea bottom in Singpore's territorial waters. Most of those borings have been conducted near shore-line, for they have been made mostly for structures or reclamation along the coast line.

There are not so many boring data that have been conducted to look for the fill materials for reclamation.

18 reports consisting of 205 boreholes altogether have been collected. They are listed in Table 3-1-1. The locations of the boreholes are shown in Fig. 3-1-1. As seen in Fig. 3-1-1, the locations of the boreholes are concentrated mainly in reclaimed lands already completed or under way and also around some islands and are not uniformly scattered over the whole territorial waters. Fig. 3-1-2a to Fig. 3-1-2f show the borehole logs for various areas. In Table 3-1-2 the depths of the boreholes can be seen. From the data collected considerable difference in soil conditions between various areas is recognized.

Table 3-1-1 Available Boring Data

No.	Report No.	Location	Year	No. of Boreholes	Authority Concerned	Legend	Remarks
1	PSA/SIU/P4/F1/73	Sembawang	1973	10	P.S.A	■	
2	ES/SI/P29/75	P. Seletar	1975	5	P.S.A	[symbol]	
3	PSA/SIU/P2/F1/72	Punggol, P. Seletar, Coney Isl.	1972	17	P.S.A	[symbol]	
4	ES/SI/P8/76	P. Ubin	1976	8	P.S.A	△	
5	ES/SI/P4/76	P. Ubin	1976	6	P.S.A	[symbol]	
6	ES/SI/P7/76	P. Tekong	1976	13	P.S.A	[symbol]	
7	————	P. Tekong	——	7	P.S.A	[symbol]	Soil Investigation
8	————	Johore Shoal	1973	8	H.D.B	[symbol]	
9	ES/SI/P30/75	Terumbu Retan Laut	1975	3	P.S.A	[symbol]	
10	ESD/SIU/P18/73	Sisters' Shoal	1973	4	P.S.A	+	
11	————	P. Pesek	1969	7	J.T.C	[symbol]	Coral Investigation
12	J312	P. Sakau, Sakra	1976	31	J.T.C	[symbol]	
13	J283	P. Busing	1975.11	19	J.T.C.	⊡	
14	SI/886/76	P. Semakau	1976	6	P.S.A	◎	Saeki Co., Ltd.
15	J249	P. Semakau Reef	1975. 8	31	J.T.C	∘	
16	————	P. Semakau	1976. 9	6	P.S.A	[symbol]	Kumagai-Gumi Co., Ltd.
17	ES/SI/P19/74	Straits of Singapore	1974	5	P.S.A	▼	
18	J116	Tuas Jurong Town West	1971. 4	19	J.T.C	•	

Table 3-1-2 Depth of Boreholes

Depth of Boreholes	Number of Boreholes
A.C.D. −10 m or less	20
−10 m∼−20 m	120
−20 m∼−30 m	60
−30 m or deeper	5
Total	205

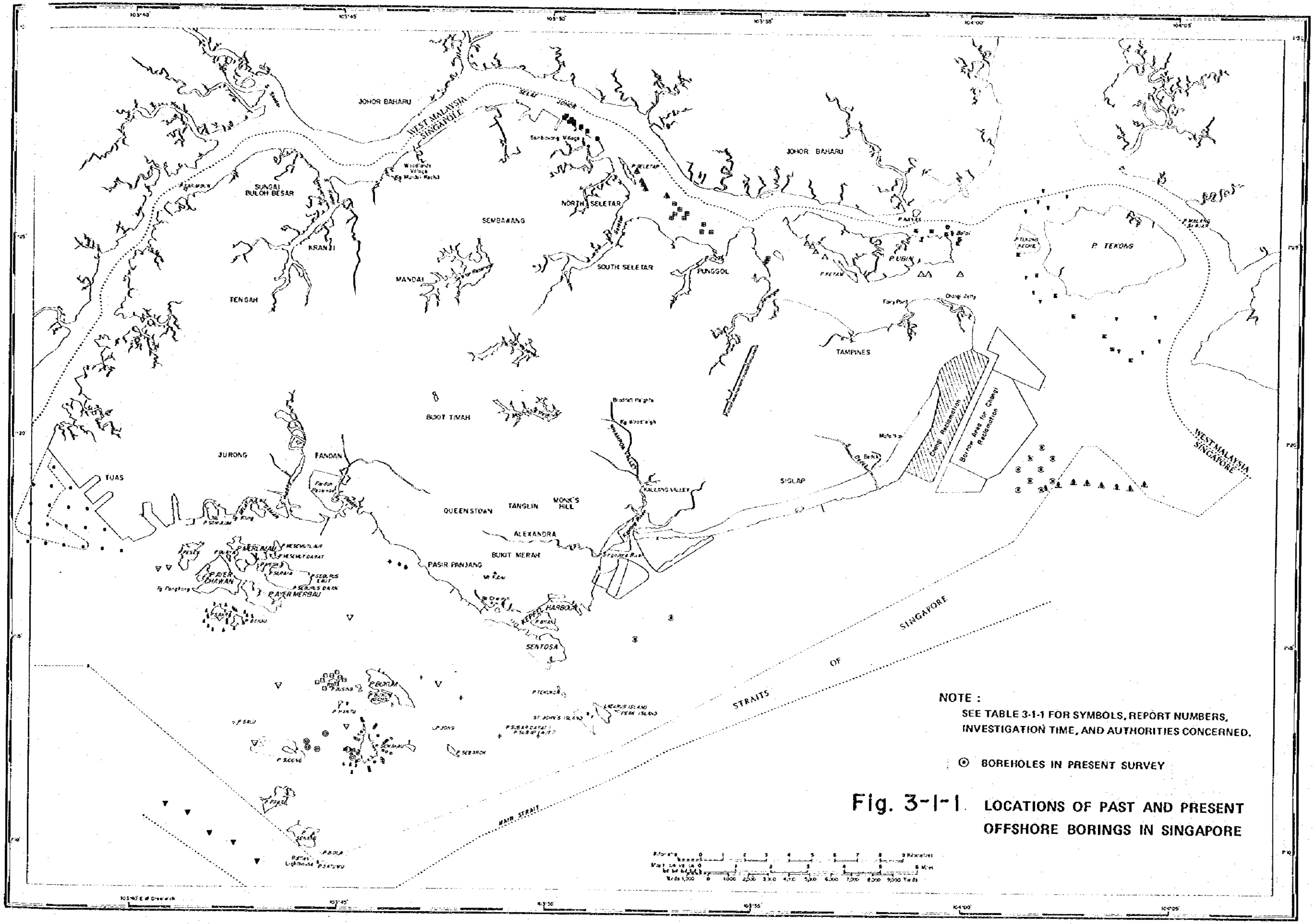
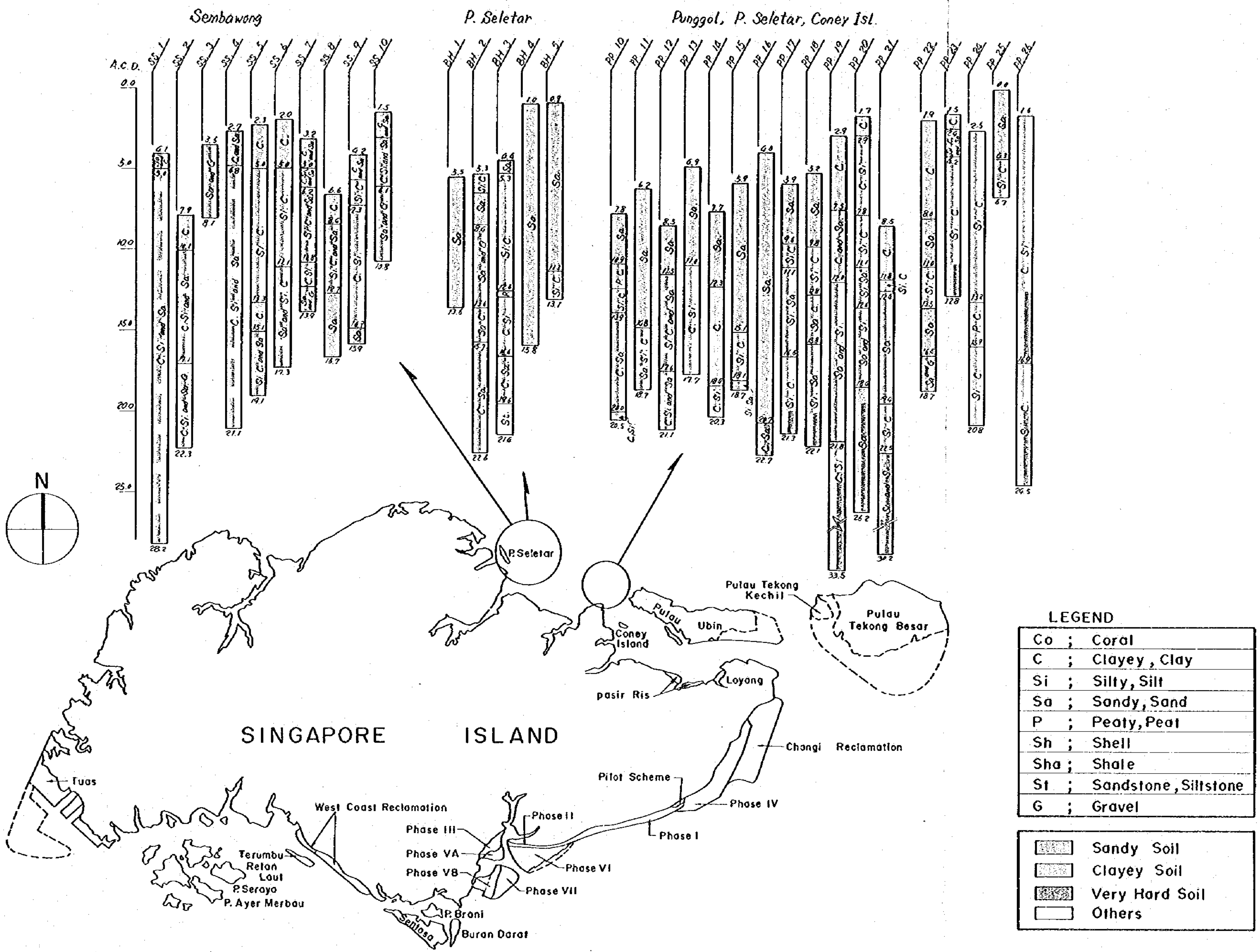
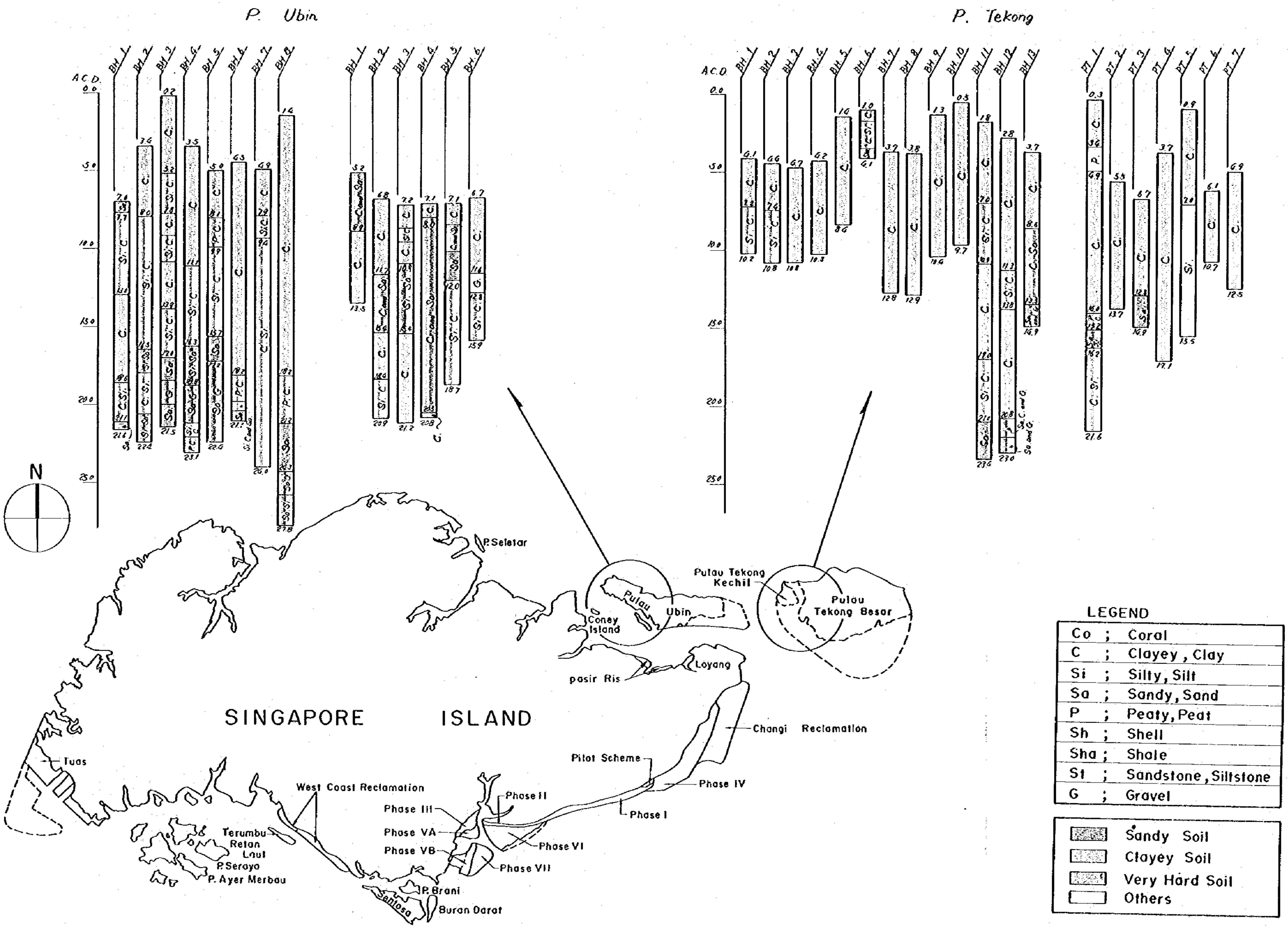


Fig. 3-1-1. LOCATIONS OF PAST AND PRESENT OFFSHORE BORINGS IN SINGAPORE



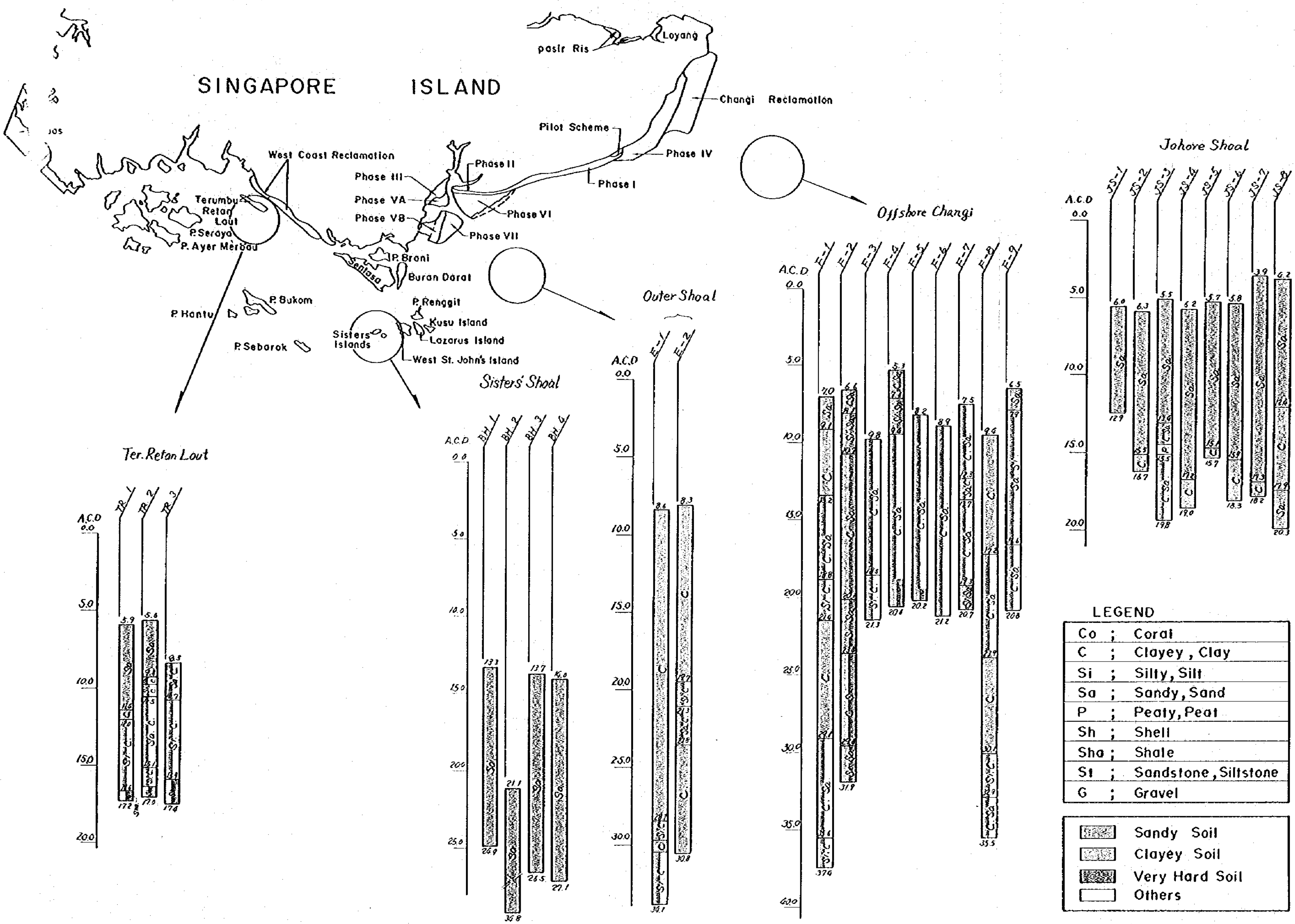
Sembawong
P. Seletar
Punggol, P. Seletar, Coney Isl.
A.C.D.
N
P. Seletar
Coney Island
Pulau Ubin
Pulau Tekong Kechil
Pulau Tekong Besar
Loyang
pasir Ris
SINGAPORE ISLAND
Changi Reclamation
Pilot Scheme
Phase IV
Phase I
Phase II
Phase III
Phase VA
Phase VB
Phase VI
Phase VII
West Coast Reclamation
Tuas
Terumbu Retan Laut
P. Serayo
P. Ayer Merbau
P. Brani
Sentosa
Buran Darat
LEGEND
Co ; Coral
C ; Clayey, Clay
Si ; Silty, Silt
Sa ; Sandy, Sand
P ; Peaty, Peat
Sh ; Shell
Sha ; Shale
St ; Sandstone, Siltstone
G ; Gravel
Sandy Soil
Clayey Soil
Very Hard Soil
Others

Fig. 3-1-2a



P. Ubin
P. Tekong
A.C.D.
N
P.Seletar
Pulau Tekong
Kechil
Pulau
Tekong Besar
Pulau
Ubin
Coney
Island
Loyang
pasir Ris
SINGAPORE ISLAND
Changi Reclamation
Pilot Scheme
Phase IV
Phase I
Phase II
Phase III
Phase VA
Phase VB
Phase VI
Phase VII
West Coast Reclamation
Tuas
Terumbu
Retan
Laut
P.Seraya
P.Ayer Merbau
P.Brani
Sentosa
Buran Darat
LEGEND
Co ; Coral
C ; Clayey, Clay
Si ; Silty, Silt
Sa ; Sandy, Sand
P ; Peaty, Peat
Sh ; Shell
Sha ; Shale
St ; Sandstone, Siltstone
G ; Gravel
Sandy Soil
Clayey Soil
Very Hard Soil
Others

Fig. 3-1-2b



SINGAPORE ISLAND
pasir Ris
Loyang
Changi Reclamation
Pilot Scheme
Phase IV
Phase I
Phase II
Phase III
Phase VA
Phase VB
Phase VI
Phase VII
West Coast Reclamation
Terumbu Retan Laut
P. Seraya
P. Ayer Merbau
P. Brani
Sentosa
Buran Darat
P. Bukom
P. Hantu
P. Sebarok
P. Renggit
Kusu Island
Sisters Islands
Lazarus Island
West St. John's Island
Ter. Retan Laut
Sisters' Shoal
Outer Shoal
Offshore Changi
Johore Shoal
A.C.D
TR 1
TR 2
TR 3
BH 1
BH 2
BH 3
BH 6
E-1
E-2
F-1
F-2
F-3
F-4
F-5
F-6
F-7
F-8
F-9
JS-1
JS-2
JS-3
JS-4
JS-5
JS-6
JS-7
JS-8
LEGEND
Co ; Coral
C ; Clayey, Clay
Si ; Silty, Silt
Sa ; Sandy, Sand
P ; Peaty, Peat
Sh ; Shell
Sha ; Shale
St ; Sandstone, Siltstone
G ; Gravel
Sandy Soil
Clayey Soil
Very Hard Soil
Others

Fig. 3-1-2c

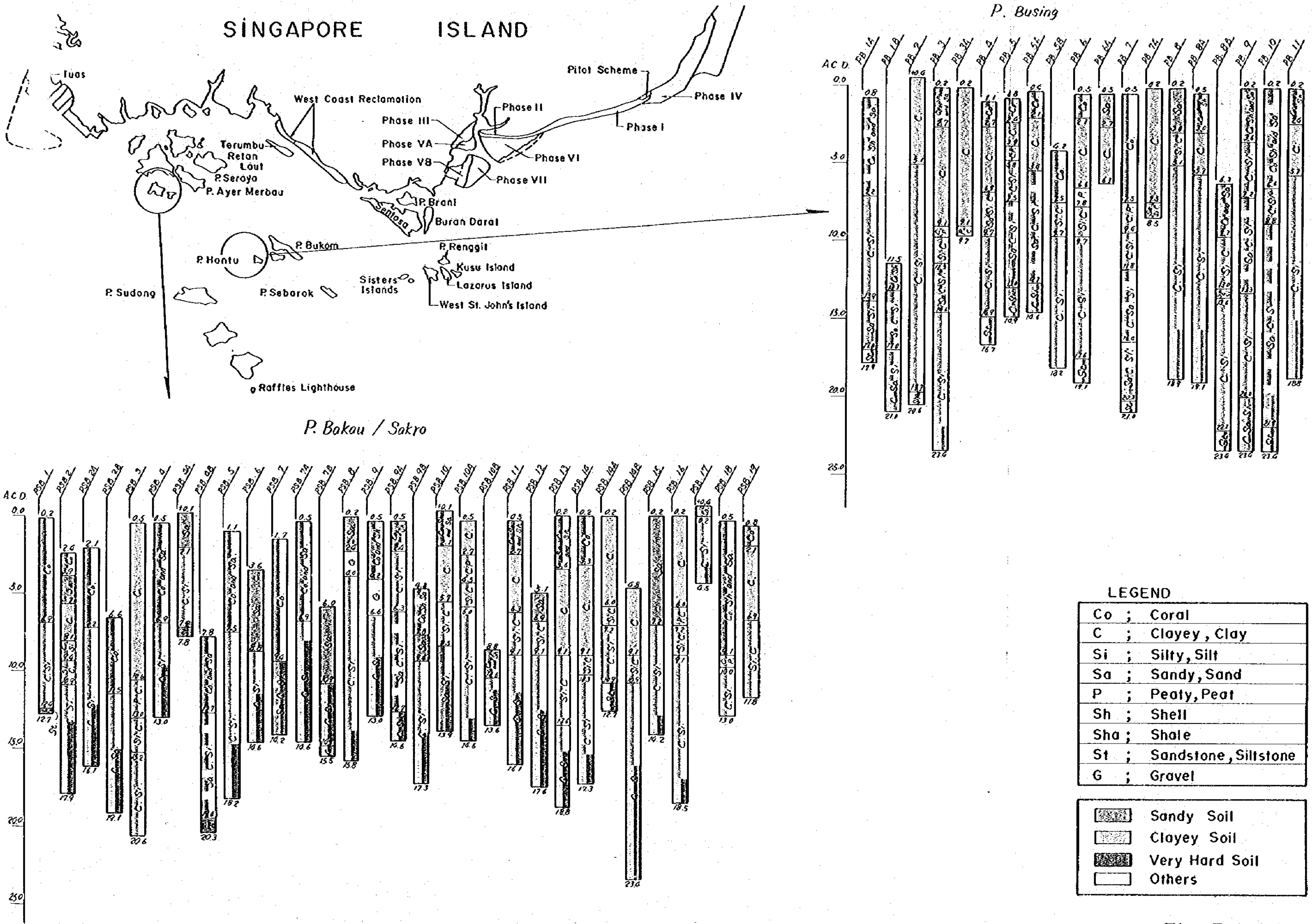

SINGAPORE ISLAND
Tuas
West Coast Reclamation
Pilot Scheme
Phase IV
Phase II
Phase III
Phase VA
Phase VB
Phase I
Phase VI
Phase VII
Terumbu Retan Laut
P. Seraya
P. Ayer Merbau
P. Brani
Sentosa
Buran Darat
P. Bukom
P. Hantu
P. Renggit
Kusu Island
Lazarus Island
Sisters Islands
West St. John's Island
P. Sudong
P. Sebarok
Raffles Lighthouse
P. Busing
P. Bakau / Sakro
A.C.D.
LEGEND
Co ; Coral
C ; Clayey, Clay
Si ; Silty, Silt
Sa ; Sandy, Sand
P ; Peaty, Peat
Sh ; Shell
Sha ; Shale
St ; Sandstone, Siltstone
G ; Gravel
Sandy Soil
Clayey Soil
Very Hard Soil
Others

Fig. 3-1-2d

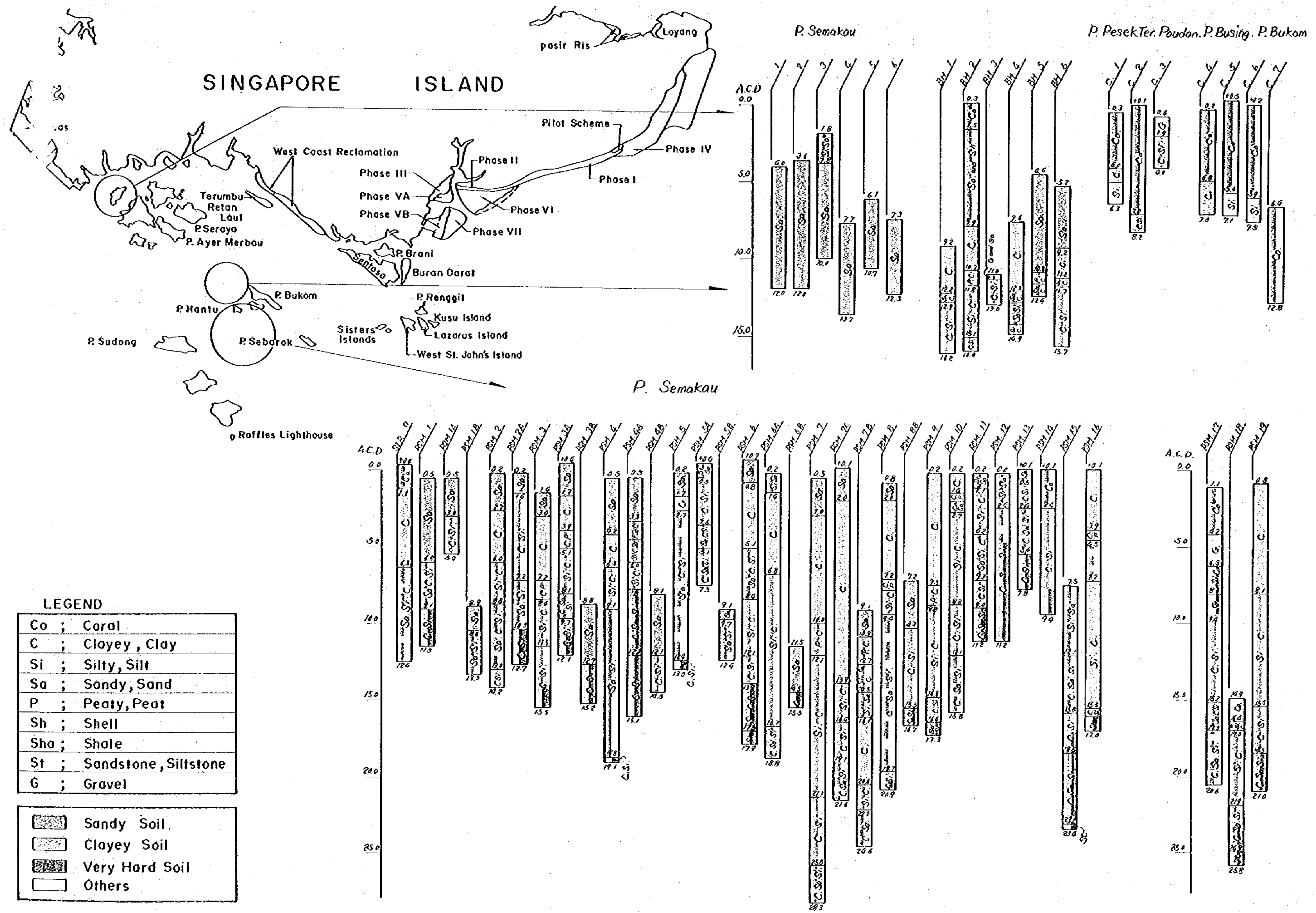

SINGAPORE ISLAND
pasir Ris
Loyang
Pilot Scheme
Phase IV
Phase I
Phase II
Phase III
Phase VA
Phase VB
Phase VI
Phase VII
West Coast Reclamation
Terumbu Retan Laut
P. Seraya
P. Ayer Merbau
P. Brani
Sentosa
Buran Darat
P. Bukom
P. Hantu
P. Renggil
Kusu Island
Lazarus Island
West St. John's Island
Sisters Islands
P. Sudong
P. Seborok
Raffles Lighthouse
P. Semakau
P. Pesek Ter. Poudon. P. Busing. P. Bukom
A.C.D.
LEGEND
Co ; Coral
C ; Clayey, Clay
Si ; Silty, Silt
Sa ; Sandy, Sand
P ; Peaty, Peat
Sh ; Shell
Sha ; Shale
St ; Sandstone, Siltstone
G ; Gravel
Sandy Soil
Clayey Soil
Very Hard Soil
Others

Fig. 3-1-2e

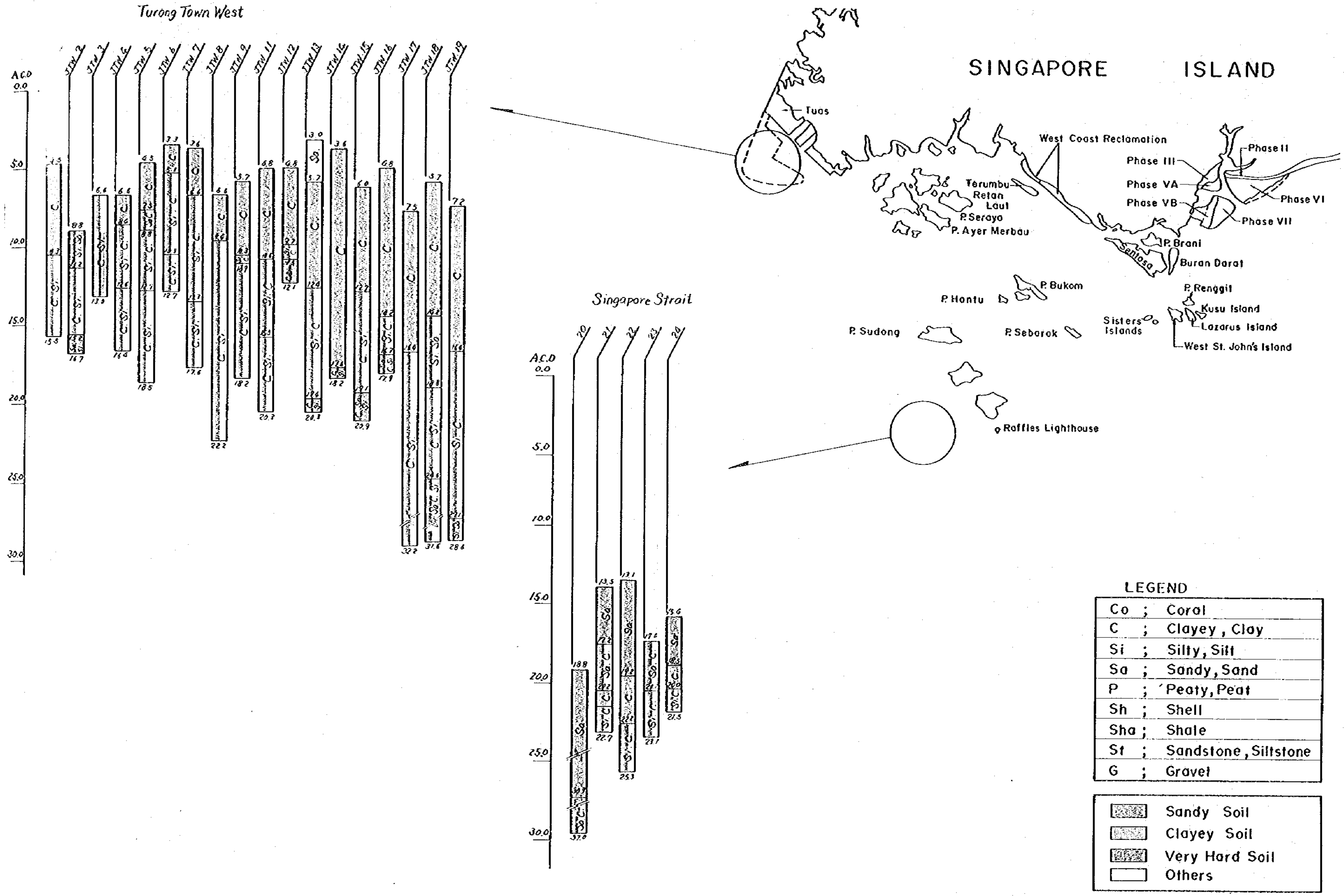

Turong Town West
A.C.D
0.0
5.0
10.0
15.0
20.0
25.0
30.0
JTW 2
JTW 3
JTW 4
JTW 5
JTW 6
JTW 7
JTW 8
JTW 9
JTW 11
JTW 12
JTW 13
JTW 14
JTW 15
JTW 16
JTW 17
JTW 18
JTW 19
Singapore Strait
20
21
22
23
24
SINGAPORE ISLAND
Tuas
West Coast Reclamation
Phase II
Phase III
Phase VA
Phase VB
Phase VI
Phase VII
Terumbu Retan Laut
P. Serayo
P. Ayer Merbau
P. Brani
Sentosa
Buran Darat
P. Bukom
P. Hantu
P. Renggit
Kusu Island
Lazarus Island
West St. John's Island
Sisters Islands
P. Sudong
P. Seborok
Raffles Lighthouse
LEGEND
Co ; Coral
C ; Clayey, Clay
Si ; Silty, Silt
Sa ; Sandy, Sand
P ; Peaty, Peat
Sh ; Shell
Sha ; Shale
St ; Sandstone, Siltstone
G ; Gravel
Sandy Soil
Clayey Soil
Very Hard Soil
Others

Fig. 3-1-2f

The following is the brief description for each area.

–Sembawang, Pulau Seletar, Punggol, Coney Island

In this area complicated stratification is seen and no typical profile can be grasped. In general, loose sand and dense sandy materials of considerable quantity can be seen at many boreholes.

– Pulau Ubin, Pulau Tekong

Under the sea bottom around Pulau Ubin is a marine clay layer 5 meters to 20 meters thick, under which silty clay or clayey silt is seen. Below the silty clay or clayey silt layer exisits a layer of loose sand with gravel in the south of Pulau Ubin.

On the marine clay or between marine clay layers, a layer of loose sand with a small amount of clay is seen in the north of Pulau Ubin.

Under the sea bottom around Pulau Tekong is generally thick marine clay, which seems to exist as deep as at least –20 m.

– Johore Shoal

Johore Shoal lies east of Offshore Changi where the present investigation was carried out. Previous boring data shows that there existed a thick loose sand layer from the seabed (about –5 m) to –17 m. It is considered that most of this loose sand has been won for past reclamation projects and there are not much sand left.

Below the loose sand is soft marine clay, underlain by dense sand or clayey sand layers which are considered to be the upper part of the Old Alluvium.

– Sisters' Shoal

A thick layer of loose sand more than 20 meters thick existed at the time of the boring in 1973.

Although the upper part of this sand has been exploited since then, a farely large amount of sand is still available. From the boring data, the depth of the sand layer is not known.

– Off-shore West Coast Reclamation (Terumbu Retan Laut)

A top layer of loose sand about 5 meters thick underlain by marine clay layers exists in

this area.
A hard stratum of shale is encountered at a depth of around −17 m.

– Pulau Bakau, Pulau Sakra, Pulau Pesek

Borings in these areas were mostly made on the coral around the islands. The thickness of the coral is 5 m to 7 m, and below the coral are the layers of marine clay, stiff to hard clay and finally at −15 m to −20 m very hard shaly structure (partly sand-stone) is encountered.

At Pulau Pesek only shallow borings have been made. But the state of the strata is considered to be similar to that of Pulau Sakra or Pulau Bakau.

– Pulau Semakau, Pulau Busing, Pulau Sudong, Pulau Bukum.

Borings around these islands have also been mostly concentrated on coral. The depths where shale is encountered are −15 m to −25 m. Seabed between these islands, outside of coral perimeters, consists mainly of marine clay partly overlain by loose sand.

– Singapore Strait (Raffles Shoal)

At the boring points in this area layers of loose sand varying in thickness from 5 m to 10 m and loose sand with clay (clay content 20 ~ 30%) are seen. The deepest borehole has gone as deep as −37 m but has not reached a hard stratum.

– Tuas

Many borings have been made in this area for a reclamation project.
This area is covered with marine clay varying in thickness from 2 meters to 10 meters, except the western part of the proposed reclamation area, where a layer, the maximum thickness of which is about 6 meters, of loose sand covers the marine clay.

Under the marine clay, there are stiff to very stiff clay and very dense clayey silt, which are considered to be weathered shale. The bed rock of this area is mainly shale, which is a part of Jurong Formation.

3-2 Classification of and Discussion on the Data Obtained from the Present Investigation

3-2-1 Scope of soil investigations and laboratory tests

The lengths of the surveying lines of sonic prospecting and the numbers of boreholes are shown in Table 3-2-1.

Table 3-2-2 shows the length of drilling and the numbers of soil laboratory tests.

Table 3-2-1 Sonic Prospecting & Magnetic Detecting Survey

	Area	Line No.	Length	Total Length
Sonic Prospecting Survey	Outer Shoal (E-Area)	L-1	5.5 km	
		L-2	5.7 km	
		L-3	5.9 km	
		L-4	2.2 km	
		L-5	1.4 km	
		L-6	1.4 km	
		L-7	1.4 km	
		L-8	1.4 km	
		L-9	1.3 km	26.2 km
	Off-Shore of Changi (F-Area)	L-1	7.4 km	
		L-2	4.7 km	
		L-3	3.8 km	
		L-4	3.3 km	
		L-5	3.2 km	
		L-6	3.7 km	
		L-7	3.6 km	
		L-8	3.4 km	
		L-9	3.5 km	
		L-10	3.5 km	
		L-11	3.5 km	43.6 km
	E-Area	L-2	20.05 km	20.05 km
Magnetic Detecting Survey	F-Area	L-6	7.2 km	
		L-7	6.8 km	
		L-8	6.8 km	
		L-9	8.8 km	29.6 km

Table 3-2-2 Boring & Soil Tests

Boring No.	Site Works			Laboratory Soil Tests				
	Drilling Length (m)	Depth (A·C·D m)	Standard Penetration Test	Wet Density	Natural Water Content	Specific Gravity	Grain Size Analysis	Liquid & Plastic Limits
E-1	25.45	34.05	13	13	5	5	5	5
E-2	22.45	30.75	11	11	5	5	5	5
F-1	30.35	37.35	15	15	15	15	15	9
F-2	25.27	31.87	13	13	13	13	13	3
F-3	11.45	21.25	6	6	6	6	6	2
F-4	15.25	20.55	9	9	9	9	9	0
F-5	12.00	20.20	7	7	7	7	7	0
F-6	12.34	21.24	6	6	6	6	6	0
F-7	13.24	20.74	7	7	7	7	7	0
F-8	2.612	35.52	8	8	8	8	8	3
F-9	14.27	20.77	7	7	7	7	7	4
Total	208.19	–	102	102	88	88	88	31

3-2-2 Results of sonic prospecting

3-2-2-1 Outer Shoal (E–area)

It has been found in the present soil investigation that the Outer Shoal area is covered witl a thick Upper Marine Member (so-called new marine clay) belonging to Kallang Formation Fig. 3-2-1 shows illustrative cross-section of this area. The bearing stratum is Old Alluvium of Pleistocene epoch, which underlies the Marine Member.

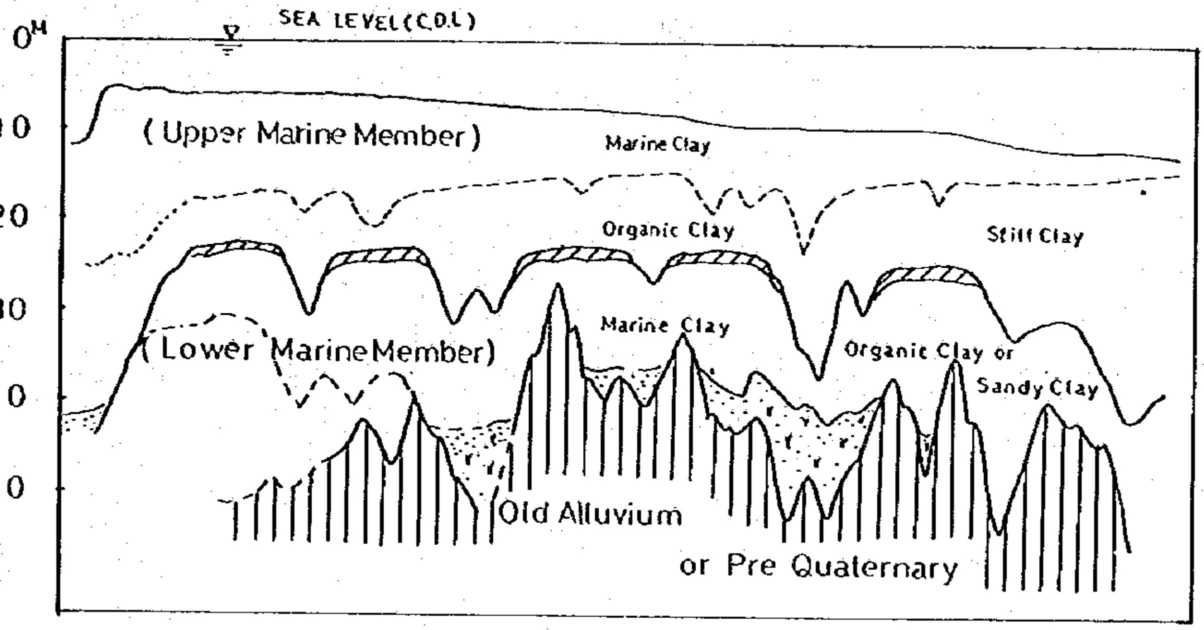


Fig. 3-2-1 Illustrative Cross-section of Outer Shoal

– Old Alluvium

As described in 3-4, this is a formation that is widely distributed in the eastern part of Singapore. It consists mainly of sand and gravel and clayey sand with gravel.
The upper part of the layer forms many valleys (waste-filled valleys), on which sandy soil (basal sand) and organic clay are deposited. The top level of the Old Alluvium is lower than A.C.D. –30 m. The distribution of this layer has been recognized but not confirmed by borings.

– Marine Member of Kalang Formation

This member is divided into two facies.
According to "Geology of the Republic of Singapore" they are Lower Marine Clay (so-called old marine clay) and Upper Marine Member (so-called new marine clay).

Lower marine clay consists of sand, sandy clay, organic clay, stiff clay, etc.
Boundary between lower and upper marine clay is generally formed by a stiff clay layer. In this area it lies at a level of A.C.D. –20 m ~ –25m. The layer has been recognized by the sonic prospecting and confirmed by the borings.

It is said that it usually lies at a level of A.C.D. –15 ~ –23 m near the shore line. This stiff clay layer, which is generally 2 ~ 6 m thick except at some places where there is none, is relatively well distributed.

Upper marine clay is very soft and relatively homogeneous. The distributed area of this layer and its depth are clearly recognized by sonic prospecting.

3-2-2-2 Offshore Changi (F-area)

The ground in this investigation area is composed of strata of sand, clayey sand with gravel corresponding to the old alluvium and the so called Marine Members corresponding to the alluvium. This difference is clearly seen in the records of sonic prospecting. However, where a thick newly deposited sand stratum forms the top layer, records of the underlying marine member becomes not clear. The geological cross section of this area is recorded as in the schematic illustration in Fig. 3-2-2.

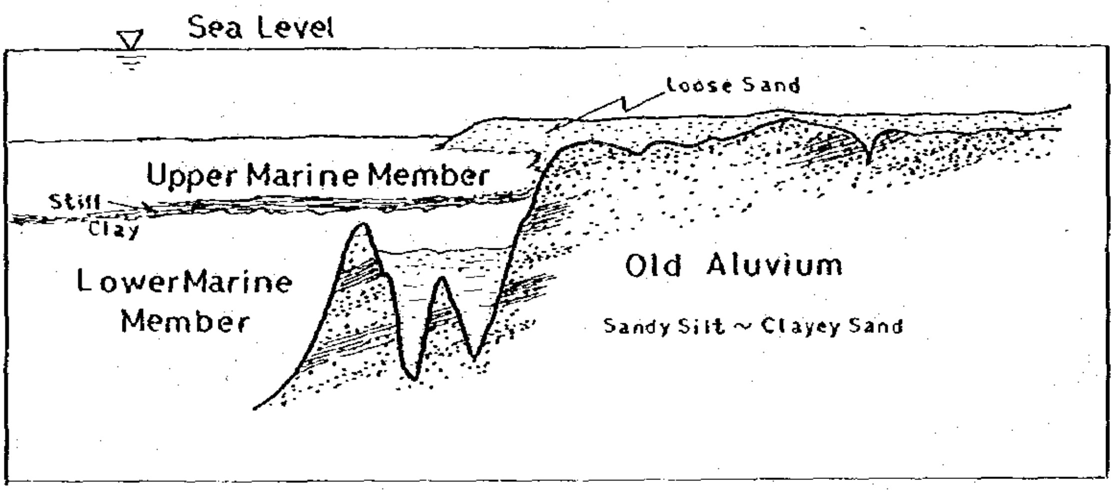


Fig. 3-2-2 Illustrative Cross-section of Offshore Changi

The geology of the investigation area is discussed below referring to the available data of previous investigations and the results of present boring tests.

- Old Alluvium

This soil stratum makes the hard bearing stratum of this area and is widely distributed throughout the whole area. As shown in Fig. 3-2-3, it is partially covered with marine clay in the north eastern – eastern areas. The main constituent of this stratum is clayey sand with gravel, while sandy clay and sandy silt are distributed in this stratum in a discontinuous manner. The sand is coarse with a grain size of 0.5 ~ 2 mm. The clay which fills the voids between the sand particles is a brownish clay with an extremely high cohesion. The gravel is mainly of quartz and angular in shape. In addition to this gravel of feldspar is also seen. Gravel with diameter as large as 2 cm also could be seen.

In the sonic prospecting, sonic waves have reflected at the upper surface of this stratum and the records are not clear for the underlying strata. In the zone of Marine Clay, irregularities on its surface are remarkable forming waste-filled valleys.

- Alluvium

The alluvium distributed in this area corresponds to the Marine Member in the Kallang Formation as classified in the "Geology of the Republic of Singapore" published by the P.W.D.

According to the results of sonic prospecting, a large number of valleys are formed in the old alluvium due to erosion and the alluvium has deposited filling these valleys. This soil stratum is discussed from the lowest layer upwards with the aid of the results of boring tests.

- Lower marine member (old marine clay)

  From the bottom of the waste-filled valleys, clayey sand, clay with organic matter, clay (marine clay), silty clay and clayey sand or stiff clay are deposited in that order. Out of these, stiff clay and clayey sand have responded with a relatively clear plane of reflection in the sonic prospecting.

  The stiff clay which makes the boundary with the alluvium is seen continuously at a depth of A.C.D. –15 to –25 m. Sandy clay which fills the waste-filled valleys below the stiff clay is distributed at depths below A.C.D. –18 m to –25 m. When the thickness of this layer becomes larger, records of underlying strata sometimes become not clear. Marine clay which is a Lower Marine Member, is very sticky and homogeneous and forms a typical soil stratum. In the sonic prospecting, this stratum responds in a blank condition. In addition to this, a brownish gray clay containing organic matter is distributed just above the basal sand formation and below the stiff clay or clayey sand.

- Upper marine member (new marine clay)

This is a layer of very soft clay and is deposited to a depth of about A.C.D. –15 m to –25 m from the sea bed. It is distributed in the entire area where Marine Members are distributed. This is a uniform clay grey to dark grey in colour. In sonic prospecting although it shows an almost blank record, but at some places depositional surfaces are recorded.

- Loose sand

This layer is a very new soil stratum distributed along Johore Shoal and where the soil changes from old alluvium hill to Marine Members. The thickness of this layer is about 2 m ~ 10 m. This loose sand is driven from the old alluvium and is composed of medium to coarse grained sand mixed with gravel. Where this layer is thickly deposited, the sonic waves in the sonic prospecting are reflected at this layer giving no clue to the underlying soil strata.

– Geological Structure

In this region, soil strata older than the old alluvium are not observed except for some outcrops of Bukit Timah Granite seen on land at a point 22 miles from Changi. According to the results of boring tests in other areas, the thickness of the old alluvium is recorded as 140 m. Although borings were made to a depth of A.C.D. –30 m in the present investigation, all of them have indicated the old alluvium.

In the past, a large number of eroded valleys were formed on this layer due to fluctuation of sea level. The waste-filled valleys existing above A.C.D. –45 m level are recorded in the present investigation (see results of sonic prospecting). All these valleys are filled with Marine Members of Kallang Formation.

The approximate area where the old alluvium is distributed at sea bed is as shown in Fig. 3-2-3. Marine clay is distributed from the northern part to the eastern part of the investigation area and widely distributed in the northeast direction (in the direction of Tekong Island).

Therefore, the area where sandy soil is distributed is on to the west of the above area. Further, according to the available data, waste-filled valleys which form a low lying area (an alluvial low lying area where a soft clay layer is thickly deposited) near Bedok New Town (Sungai Bedok) are distributed below the sea bed almost in the south direction. From the above discussions the area where sandy materials are distributed is estimated to be the area shown in Fig. 3-2-3.

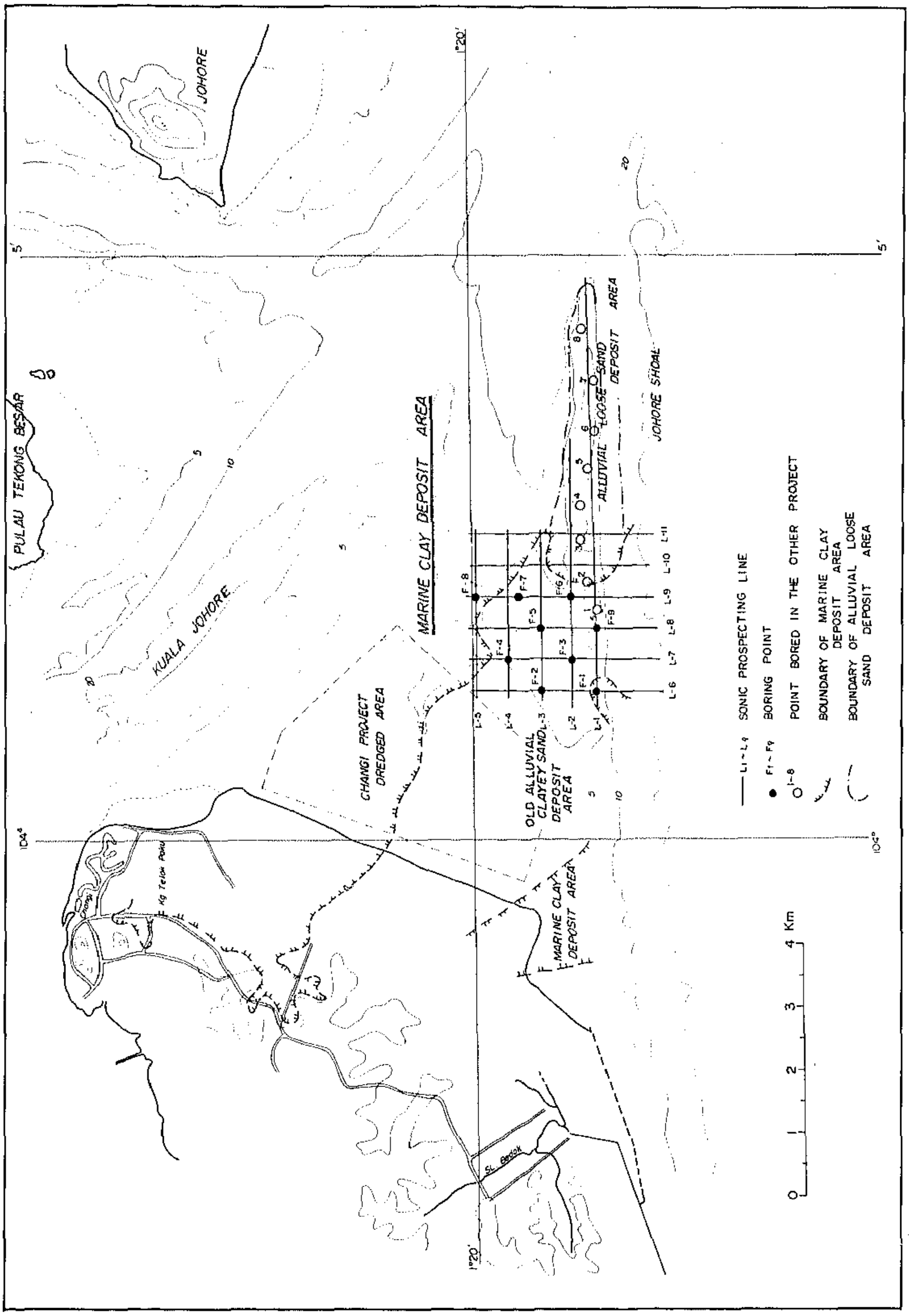


Fig. 3-2-3 Geological Schematic Map of Offshore Changi

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3-2-3 Results of borings

The results of 9 borings (7 borings in Outer Shoal and 2 in off-shore Changi) are described hereunder.

- Outer Shoal (E–area)

One of the two boring points made in this area has been selected at a point (E-2) where the record of the sonic prospecting was clear. The other has been selected at a point (E-1) where the record was not clear.

According to the results obtained, the top layer in this area is of very soft marine clay with N-values 0 to 1, of which thickness is 9 to 11 meters. In the lower part of the layer, organic clay is seen.
It is considered that this layer belongs to the Upper Marine Member. Below this, a clay layer (N = 3) and a sandy silt layer (N = 11 ~ 14) are seen. They are considered to belong to the Lower Marine Member.

Both at E-1 and E-2 any hard bearing stratum has not been encountered.

– Offshore Changi (F–area)

Nine borings have been carried out in this area. At all boring points but F-1 and F-8, the old alluvium was found from the sea bottom.

At F-1 and F-8, there is Marine Member which belongs to the Kallang Formation. On the Marine Member, a layer of loose sand is seen. The Marine Member is divided into Upper Marine Member and Lower Marine Member.
The Upper Marine Member in this area consists of a layer of soft marine clay to a level of –13 m to –17 m A.C.D. and a clayey sand layer which is very loose (N = 3 ~ 5) and 3 ~ 6 m thick.

The Lower Marine Member consists of a stiff clay layer (N = 18), marine clay (N = 3 ~ 4), clay with organic matters (N=6), and clayey sand (N=15~38) from the top layer downward.

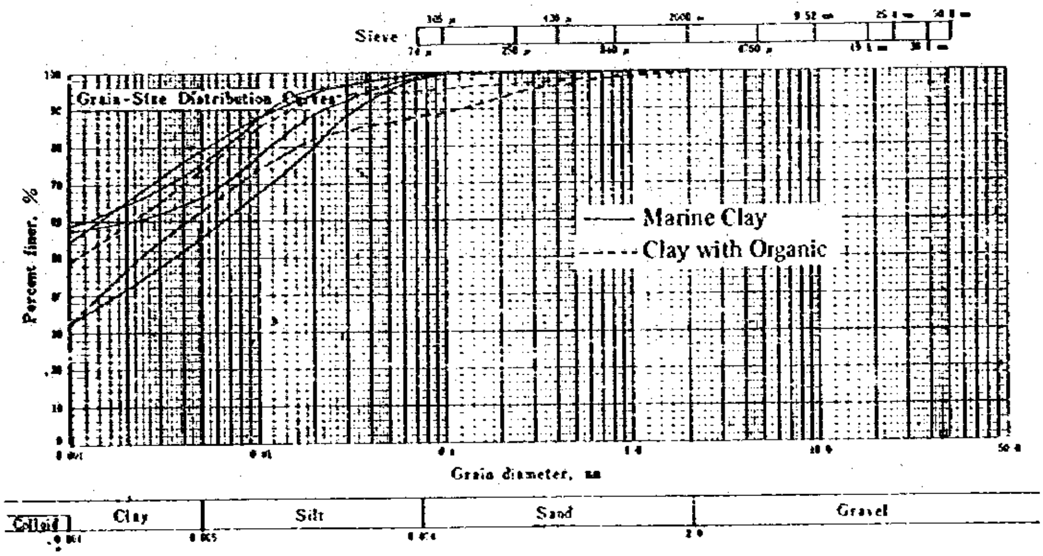
The Old Alluvium consists mainly of dense to very dense clayey sand, and locally with stiff clayey silt and silty clay. The N-values of the old alluvium are 15 ~ 50 for the weathered part and 100 ~ 150 for unweathered part.

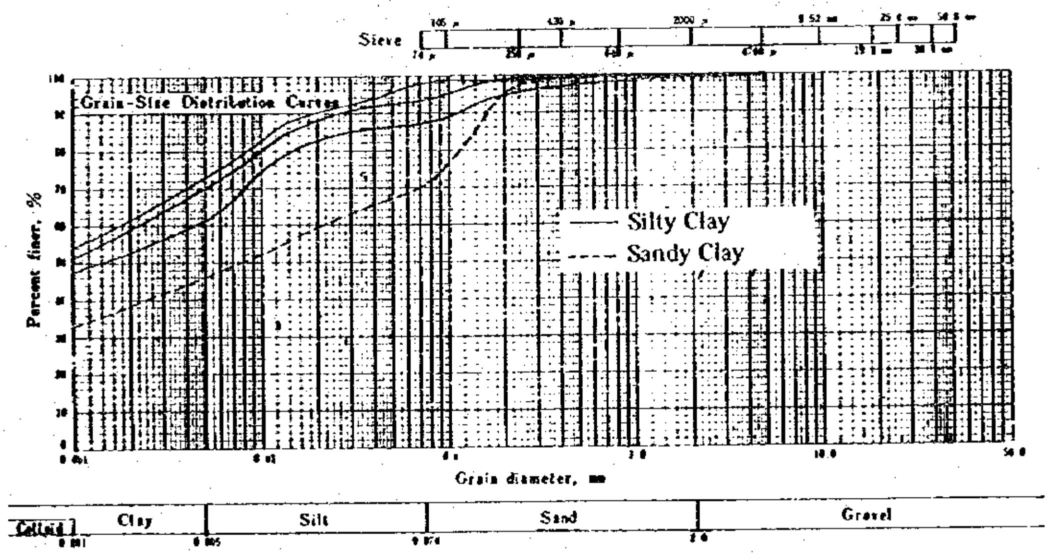
3-2-4 Results of laboratory tests

Data obtained from laboratory tests are summarized below. All data are collected in Appendix D.

- Results of Soil Tests for Outer Shoal (E–area)

The figure below shows the grain size distribution curves of the alluvial deposit (mainly marine clay) which is found from the sea bottom to A.C.D. –30 m.





The following are the physical properties of the marine clay at Outer Shoal.

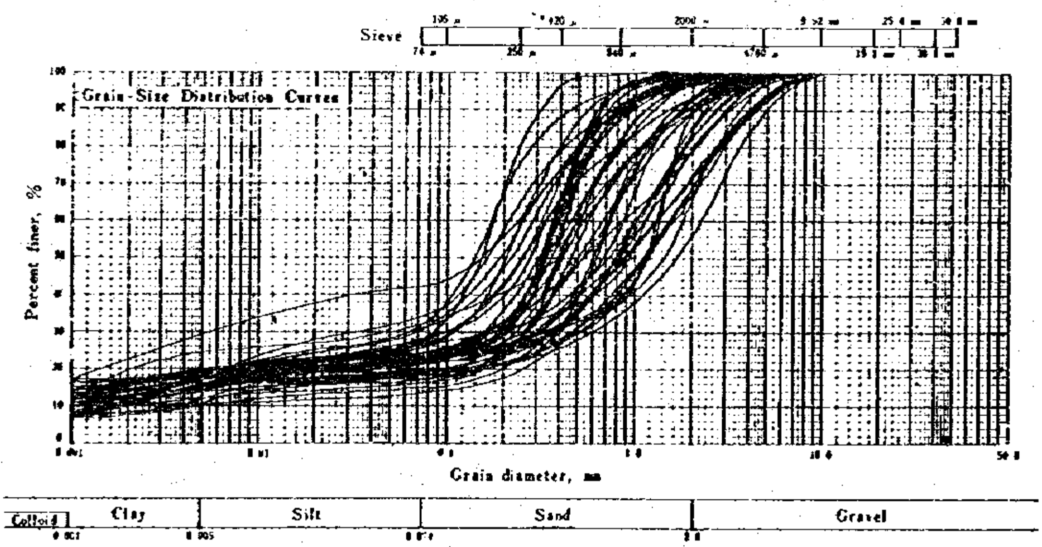
Natural water content		60 ~ 80%
Specific gravity of the soil particles		2.62 ~ 2.70
Bulk density		1.6 ~ 1.9 g/cu. cm
Grain size	Gravel	0 %
	Sand	1 ~ 10%
	Silt	20 ~ 30%
	Clay/Colloid	60 ~ 80%
Liquid Limit (L.L)		70 ~ 90%
Plastic Limit (P.L.)		20 ~ 30%
Plasticity Index (P.I.)		40 ~ 60%

– Results of Soil Tests for Off-shore Changi (F-Area)

Among the 9 boring points investigated in this area, only 2 points (F-1, F-8) show the existence of marine clay.
The other 7 borings were made on the old alluvial hill. Although N-values of the upper part of this old alluvium are less than 50, those of the main part of the old alluvium are above 50. The alluvium consists mainly of clayey sand and, in an irregular manner, alluvial clayey soil within the clayey sand.

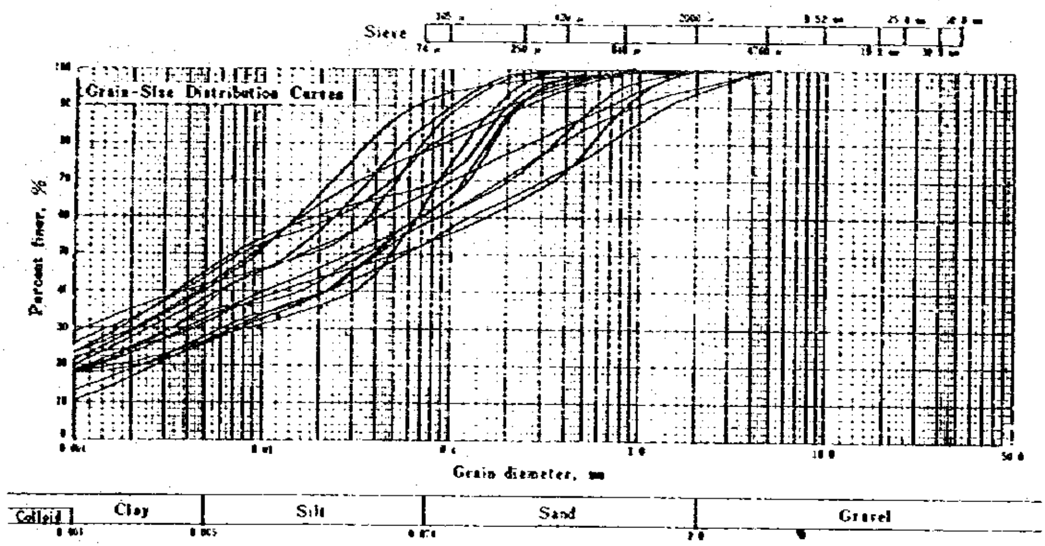
The following are the grain size distribution curves and physical properties of the typical sandy soil and clayey soil.

(a) Old alluvial sandy soil



Natural water content		11 ~ 20%
Specific gravity of soil particles		2.60 ~ 2.65
Bulk density		2.0 ~ 2.2 g/cu. cm.
Grain size	Gravel	0 ~ 30%
	Sand	50 ~ 80%
	Silt	1 ~ 15%
	Clay	10 ~ 20%

(b) Old alluvial clayey soil

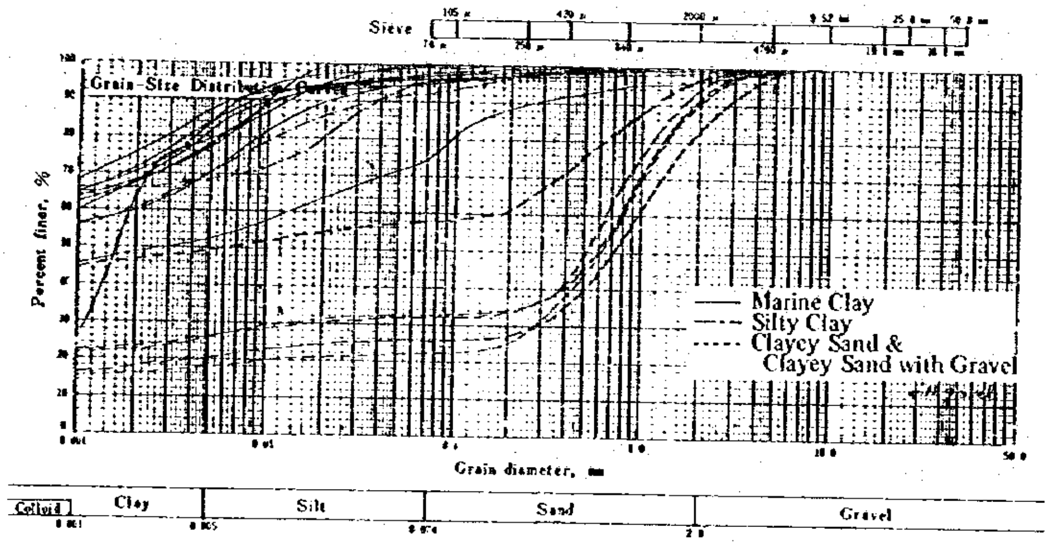


Natural water content		14 ~ 22%
Specific gravity of soil particles		2.60 ~ 2.70
Bulk density		1.9 ~ 2.1 g/cu. cm.
Grain size	Gravel	0 ~ 5%
	Sand	10 ~ 40%
	Silt	25 ~ 50%
	Clay	25 ~ 45%
Liquid limit (L.L.)		44 ~ 55%
Plastic limit (P.L.)		15 ~ 20%
Plasticity index (P.I.)		25 ~ 40%

(c) Alluvial soil

The alluvial deposit consists of two marine clay layers (upper and lower) and an intermediate layer sandwiched by them.

The grain size distribution curves of the alluvium are shown below.



The physical properties of the marine clay of this area are as follows:

Natural water content	60 ~ 80%
Specific gravity of soil particles	2.68 ~ 2.71
Bulk density	1.55 ~ 1.70 g/cm³
Liquid limit (L.L.)	70 ~ 90%
Plastic limit (P.L.)	20 ~ 30%
Plasticity index (P.I.)	50 ~ 60%

3-3 Result of Magnetic Detection

Magnetic detection survey was carried out on three lines at Outer Shoal area and on 1 . lines at the off-shore of Changi.

Total length of the lines was 45.97 km.

The results at Outer Shoal and at the off-shore of Changi are shown in Table 3-3-1 and Table 3-3-2 respectively.

Table 3-3-1 Number of Points of Magnetic Anomaly in Outer Shoal Area

Intensity of anomaly / Line	Gauss/cm²						Total Points	m²/ Anomaly
	0~4	5~20	21~50	51~100	101~200	Over 201		
L-1 (5,340 m)	0	3	10	8	17	16	54	989
L-2 (5,300 m)	1	2	12	11	3	11	40	1,325
L-3 (5,400 m)	1	6	9	6	14	25	61	885

In Outer Shoal 153 points of magnetic anomalies of more than 5 Gauss/sq.cm have been recorded. Total detected area was 160,400 m² since the width covered by one trip of the detector used here was 10 meters.

Therefore, in average one anomaly has been found per 1,048 square meters. The density of an anomaly of more than 21 Gauss/sq. cm is one point per 1,130 square meters.

Table 3-3-2 Number of Magnetic Anomaly Points (Off-shore Changi)

Intensity of anomaly / Line	Gauss/cm²						Total Points	m²/ Anomaly
	0~4	5~20	21~50	51~100	101~200	Over 201		
L-1 (2,270 m)	1	7	4	4	0	0	16	1,419
L-2 (2,220 m)	0	7	4	3	2	0	16	1,388
L-3 (2,190 m)	1	6	2	2	1	0	12	1,825
L-4 (2,370 m)	0	3	1	3	0	0	7	3,386
L-5 (1,700 m)	0	0	2	0	0	1	3	5,667
L-6 (1,740 m)	1	6	4	1	2	0	14	1,243
L-7 (1,720 m)	1	5	2	0	1	0	9	1,911
L-8 (1,780 m)	3	5	3	1	2	1	15	1,187
L-9 (1,700 m)	0	0	2	1	1	0	4	4,250
L-10 (1,690 m)	0	2	1	1	1	0	5	3,380
L-11 (1,710 m)	0	1	0	1	1	0	3	5,700
L-12 (1,680 m)	0	1	2	0	0	1	4	4,200
L-13 (1,720 m)	0	2	2	0	1	0	5	3,440
L-14 (1,820 m)	0	4	1	0	0	0	5	3,640
L-15 (1,790 m)	0	0	2	0	0	0	2	8,950
L-16 (1,830 m)	0	2	0	1	0	0	3	6,100

In offshore Changi the densities of anomalies more than 5 Gauss/sq. cm, and more than 21 Gauss/sq. cm, have been one point per 2,433 m² and one point per 4,605 m².

In general a large bomb lying on a sea bed gives a magnetic anomaly of more than 21 Gauss/sq. cm. If the bomb is buried in mud or sand, the intensity of the magnetic anomaly can be diminished to around 10 Gauss/sq. cm.

Therefore the intensity of the magnetic anomaly that requires detection by divers is generally considered as follows;

21 Gauss/sq. cm — when the seabed is hard
10 Gauss/sq. cm — when the seabed is soft

Since the above values, however, are dependent on the type of explosive object and the buried condition, they must be decided through a careful study prior to the dredging operation.

3-4 Study of the Data

3-4-1 General description of Singapore's geology

The three typical geologic formations in Singapore are granite (Bukitima Granite of early Mesozoic era), which is widely distributed in the middle part of Singapore, old sedimentary rock (Jurong Formation deposited in the middle to late Mesozoic era), which is seen in the western part, and old alluvium (sandy layer of granite origin deposited in early Quaternary period), which is distributed in the eastern part (see Fig. 3-4-1).

There is a small area where a palaeozoic rock is seen around Bukit Timah Hill.
In Jurong area, lowlands along Kallang River and coastal line, alluvial deposit is widely distributed.

Table 3-4-1 Quaternary Stratigraphy of Singapore

Age		Formation		Rock Facies (Content)	Remarks
Quaternary	Holocene	KALLANG FORMATION	Reef Member	coal, unconsolidated calcareous sand.	
			Transitional Member	unconsolidated esturaine mud, mudy sand or sand.	
			Littoral Member	well sorted unconsolidated esturaine mud, mudy sand or sand.	
			Alluvial Member	pebble bed, sand, mudy sand, clay to peat.	
			Marine Member	clayey mud, peatard sand.	site deposite
		TEKONG FORMATION		unconsolidated marine and littoral well sorted sand.	
		HUAT CHOE FORMATION		white kaolin clay and minor quartz gravel.	
	Pleis tocene	OLD ALLUVIUM		loose coase quartz stone/ conglomerate.	site deposite
Pre-Tertiary		Mesozoic & Paleozoic Sediments, BUKIT-TIMAH granit			

(Reference Data. P.W.D. 1976)

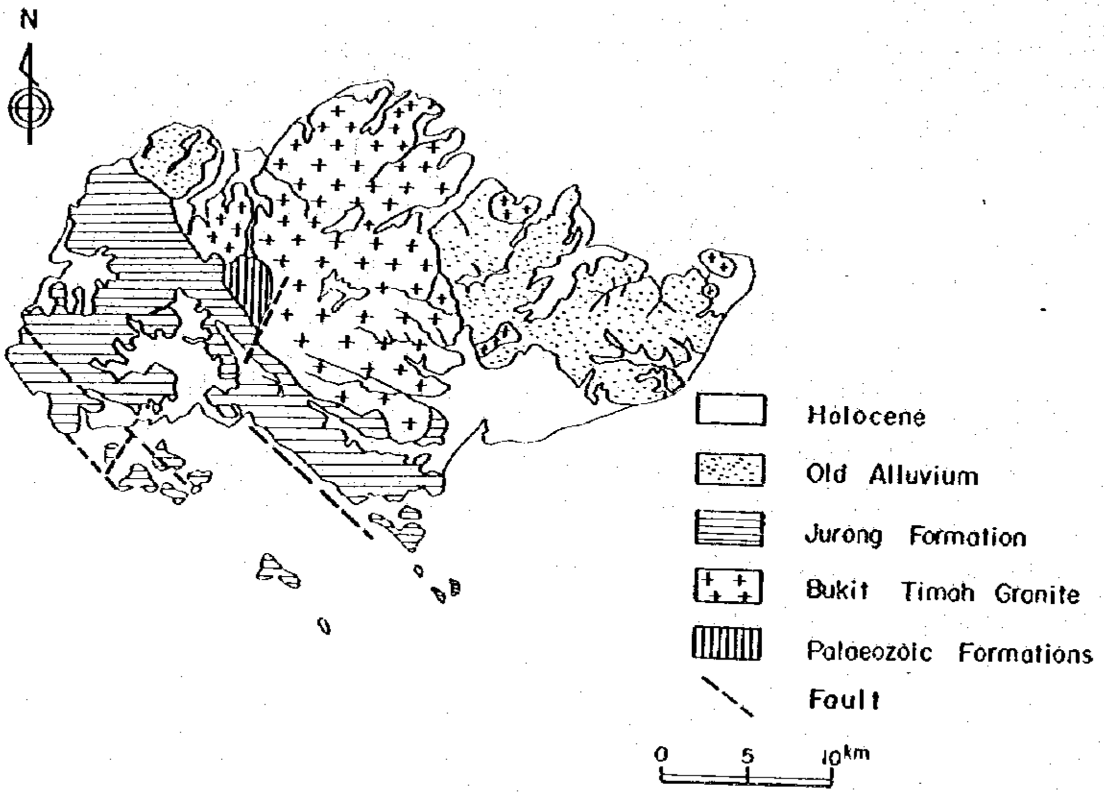


Fig. 3-4-1 Simplified Geological Map (after P.W.D., 1976)

The geologic formation of the two areas where the present survey has been conducted consists of old alluvium of pleistocene epoch overlain by the later deposits.

3-4-2 Sea bottom soil in Singapore's territorial waters

From the data collected from the governmental authorities and obtained from the present investigation, the sea bottom soil seen in the Singapore's territorial waters are mainly Jurong Formation, Old Alluvium, and Kallang Formation.

Jurong Formation is widely distributed in the western sea bottom. It consists of alterating layers of shale (mudstone), sand stone, and conglomerate. But upper part of it is mostly weathered and seen as stiff clay or hard clay. Hard rock is generally reached at –15 m to –30 m. Near shore line or below coral around the western islands the hard rock is reached at a rather shallow level. On the sea bottom between the islands the level becomes very deep. On Raffle's Shoal or Sisters' Shoal it has not been reached.

Old Alluvium is widely distributed in the eastern part of the territorial waters.
It is a deposit of land origin or a delta deposit. It consists of coarse quartz – feldspar sand, gravel and lightly cemented sandstone-conglomerate. Maximum size of the gravel is about 5 mm. As seen from the present soil investigation, the upper part of the Old

Alluvium has many valleys, which are filled with alluvial deposit. The borings made in off-shore Changi show that the upper part of the Old Alluvium consists mainly of clayey san with gravel, while sandy clay, sandy silt, and silty clay are distributed.

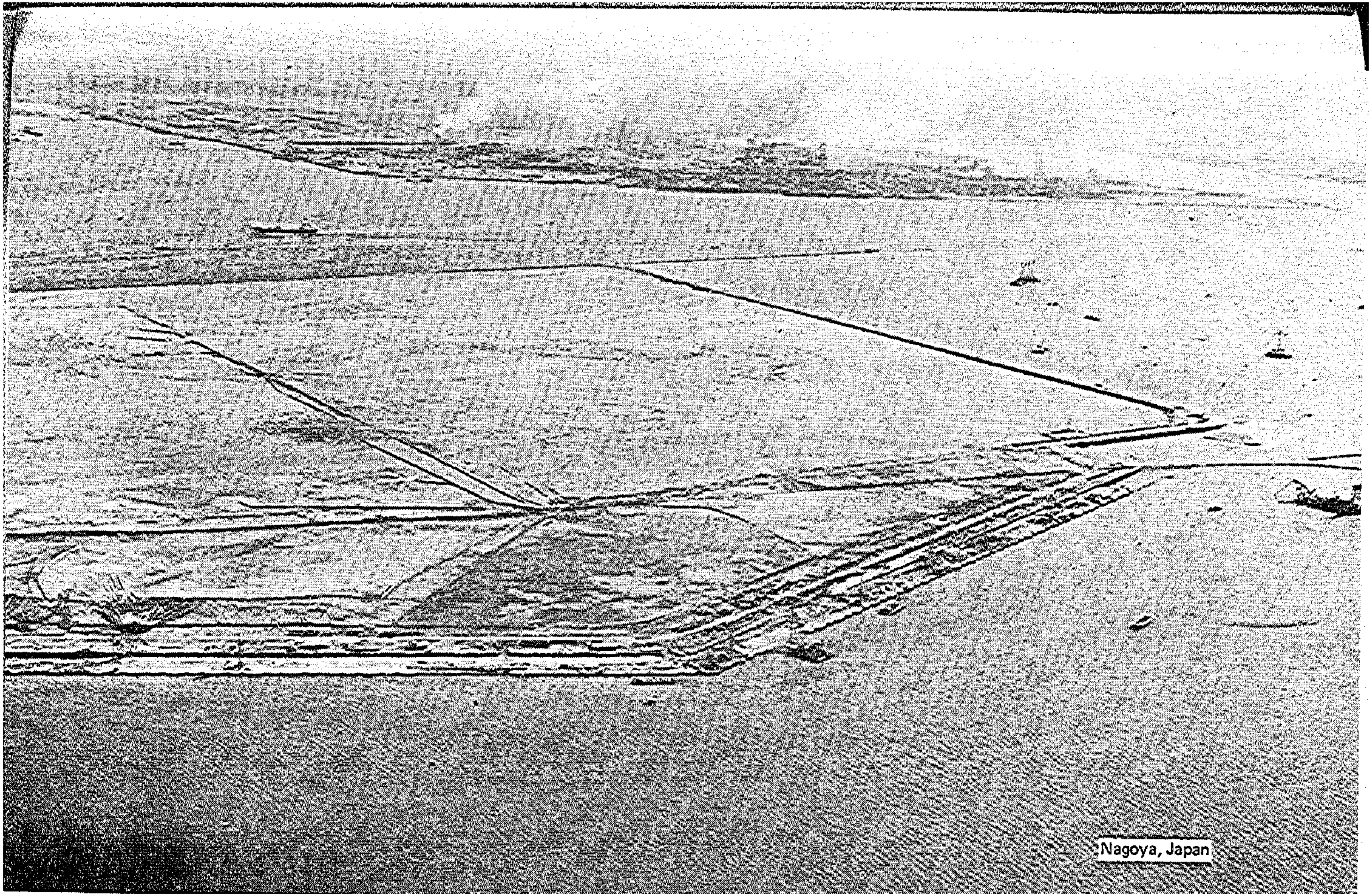
Kallang Formation is most widely seen over the sea bottom in the territorial waters amo g three Holocene formations seen in Singapore, while the other two formations, Teko i Formation and Huat Choe Formation, are seen in rather limited area. In Tekong Formation, Marine Member is the most commonly seen sea bottom deposit.
Marine Member which has been described in 3-2 is considered typical for all marine clay under the Singapore's sea bottom.

The result of soil tests indicate that marine clay has a very high colloid/clay content of 60 to 80 % and a high natural water content of 60 to 80 %, which is close to the liquid limit. The soil tests also show that no large differences in the soil characteristics between old marine clay and new marine clay are recognized except in N-values and natural water contents. The plastic limit of the both marine clays is about 27 % at the two areas.

The results of the particle size analyses of the clayey sand obtained at Offshore Changi indicate that it has commonly a very high sand content of 80 % and has a very low silt content. The clayey sand at the old alluvial hill at Offshore Changi is very dense with N-values more than 50, except for the upper part 5 meters or so in thickness, which has N-values less than 40. Clayey sand in other areas, where it is overlain with thick layers of marine member, would have the similar particle size distribution and density.

At some places at Offshore Changi, silty sand and sandy silt layers are seen. They are similar to the clayey sand in density but has higher silt content (30 to 40 %) and lower sand content (30 to 40 %). There are also seen stiff to hard layers of silty clay and clayey silt at some boreholes at Offshore Changi. The N-value of the layer is mostly over 50.

Loose sand which is seen on the marine clay can be found at various places. But it is believed that the sand which was found in the past borings has been mostly used for many projects.
A fairly large amount of sand may be available on Sisters' Shoal and Raffle's Shoal, but the amount is not known. Further investigation will be necessary in these areas.


Nagoya, Japan

(4) STUDY ON METHODS & COSTS OF DREDGING & RECLAMATION

It goes without saying that the hill-cut soil and the marine sand are the most suitable fill materials for reclamation, but it seems that securing such materials in large quantity is becoming more and more difficult in Singapore, or it will also be impracticable to procure them from any foreign sources for the reasons both of volume required and of cost incurred, which would result in quite expensive reclamation costs.

It is therefore important to look into the possibility of utilizing other materials that are obtainable from the sea bottom within Singapore's territorial waters.

Studies, together with cost estimation, are made below on the dredging and reclamation methods utilizing such fill materials in order to search for the most suitable way of reclamation in Singapore.

4-1 Study of Dredging Equipment

Among the various types of dredgers, listed below are main equipment commonly used in dredging:–

D-1 Cutter Suction (Pump) Dredger
D-2 Cutterless Suction (Pump) Dredger
D-3 Drag Suction Dredger (Trailing Hopper)
D-4 Deep Dredger (Suction)
D-5 Grab (Clamshell) Dredger
D-6 Dipper Dredger
D-7 Bucket Dredger
D-8 Back-hoe Dredger

The followings are the brief description of the dredgers.

A cutter suction dredger has been most commonly used, by which almost all of the dredged materials, widely ranging from hard one to soft one, can be utilized as the fill materials.

A cutterless suction dredger is suitable for dredging soft and loose materials, and is recently employed in order to remove polluted mud.

A drag suction dredger (or 'Trailing Hopper') is also suitable for dredging soft sea-bottom soil like mud or loose sand. Especially it is effective for the maintenance dredging of navigational channels.

A deep dredger, which is a variation of the cutterless suction dredger, is quite useful for winning sand lying at a stratum as deep as –80 m.

Grab-type dredgers are classified into several types by the shape of the grab, among which Clamshell grab is most widely used but is not suitable for dredging hard soils. Dipper and Backhoe dredgers are suitable for hard soils, while Bucket dredgers are commonly employed for dredging and winning gravel and sand.

Table 4-1-1 presents the equipment in comparison:–

Table 4-1-1 Comparison of Dredging Equipment

	Equipment	Merit	Demerit
D-1	Cutter Suction Dredger	1. Large capability of dredging available, except for hard soil. 2. Rock cutter type capable of dredging the hard soil. 3. Unit cost being usually cheaper than with other dredger. 4. Sea-bottom to be completed rather plain.	1. Unsuitable for rock and hard soil dredging. 2. Dredging of rock and hard soil incurs expensive cost.
D-2	Cutterless Suction Dredger	1. Suitable for soft soil dredging. 2. Effective against sea pollution with devices of mud intake.	1. Unsuitable for hard soil dredging. 2. Capability of dredging to be relatively small. 3. Costing expensive.
D-3	Drag Suction Dredger	1. Suitable for isolated dredging areas and navigational channel dredging. 2. Great capability available for muddy soil and loose sand. 3. High work efficiency expected because of self-propelling. 4. Capable of dredging in high mud content.	1. Continuous dredging operation incapable. 2. Unsuitable for hard soil. 3. Considerably specialized skill required for plain finishing due to linear movement.

	Equipment	Merit	Demerit
D-4	Deep Dredger	1. Useful for winning of sand lying very deep without removing overlying marine clay.	1. Unsuitable for hard soil. 2. Relatively expensive.
D-5	Grab Dredger	1. Suitable for dredging in narrow areas. 2. Suitable for small-scale dredging. 3. Relatively simple mechanism.	1. Small production due to intermittent operation. 2. Unsuitable for hard soil. 3. Hard to complete plain sea-bottom.
D-6	Dipper Dredger	1. High capability of excavation, and suitable for hard-pan. 2. Relatively less machine troubles.	1. Small production due to intermittent operation. 2. High skill required for operation.
D-7	Bucket Dredger	1. High capability of dredging various kinds of materials. 2. Capable of relatively plain-bottom completion. 3. Suitable for winning river gravel/sand.	1. Unsuitable for rock. 2. Occasional suspension of dredging operation during relocation of anchor.
D-8	Backhoe Dredger	1. Suitable for soft rock and hard soil.	1. Dredging depth limited. 2. Expensive.

4-2 Study of Reclamation Methods

The reclamation method means the method of transportation and filling of the materials dredged by dredgers described in the foregoing Section. This is also classified into several items, which consists of combination of both transportation method and filling method, because the reclamation is carried out through two processes, i.e. transportation and fill of the dredged materials.

Only typical ones will be briefed here :–

R-1 Direct Fill by Pump & Pipeline

R-2 Fill by Booster Pump

R-3 Transportation & Fill by Trailing Hopper

R-4 Direct Dumping by Barge

R-5 Fill by Unloader

Direct fill method is the method in which the dredged materials are pumped up by a cutter suction dredger directly into the reclamation area through a pipeline. By this method a large quantity of fill material can be transported economically because of its continuous operation.

Therefore this method is most commonly used. It should be noted, however, that reclamation cost will largely depend on such conditions as capabity of the pump delivering the materials, distance of transportation, and quality of the materials to be dredged. A booster pump is often used for rather long distance transportation to increase the delivering distance.

Trailing Hopper is useful for long distance transportation and used in combination with a suction dredger for filling.

There is another method of filling, where the dredged material is loaded onto a barge, is transported by a tugboat, or a pusher-boat, and is mechanically or hydraulically unloaded into the filling area. The material may be placed by direct dumping at economical cost where the water depth allows such operation of the barge and the boat. In general, the longer the transportation distance is, the more advantageous the barge method is.

Table 4-2-1 presents these methods in comparison:–

Table 4-2-1 Comparison of Reclamation Method

	Method	Merit	Demerit
R-1	Direct Fill by Pump & Pipeline	1. Capable of transporting a large amount of soil through a pipeline. 2. Economical because of continuous operation.	1. Operation unpracticable in rough sea conditions 2. Distance of delivery of the dredged materials to be limited.
R-2	Fill by Booster Pump	1. Possible to easily increase distance of delivery.	1. Rather expensive cost. 2. Simultaneous control with dredger required.

	Method	Merit	Demerit
R-3	Transportation & Fill by Trailing Hopper	1. Capable of long distance transportation. 2. Direct dumping and delivery possible.	1. Capacity of hydraulic delivery limited.
R-4	Direct Dumping by Barge	1. Capable of direct dumping in less wet condition. 2. Economical.	1. Water depth of operation limited.
R-5	Fill by Unloader	1. In mechanical unloading capable of unloading in less wet condition. 2. In hydraulic unloading capable of easy spreading.	1. Expensive costs incurred.

4-3 Recommendable Methods in Singapore

4-3-1 Sea bottom soil

The sea bottom soil in Singapore's territorial waters is more or less dependent on its lying area, but in general the surface layer of the sea bottom is of marine clay which is partially covered with loose sand, and thereunder exist clayey sand of the old alluvium (clayey sand, sandy clay, silty sand, etc. –hereinafter called as 'clayey sand'), and partly the old alluvium of stiff clay and hard clay.

As the present quantity of the loose sand is extremely limited, it is recommended that the remaining loose sand, one of the precious natural resources, sould be restrained in its utilization only for such purposes as revetment and artificial beach.

The under-listed soil other than the loose sand may be the potential fill materials according to the results of this investigation.–

1. Marine Clay
2. Clayey Sand (Old alluvium inclusive of sandy clay and silty sand with N-value less than 40.)
3. Stiff Clay (with N-value less than 40)
4. Hard Clay (with N-value more than 40)
5. Others

Among the above, the useful fill material will be limited to clayey sand and stiff clay with N-value less than 40, as well as to marine clay, in consideration of the economical dredging capability of the current equipment. Hard clay and other materials with N-value more than 40 will not be an economical material because its hardness results in rapid decrease of operational efficiency.

Judging from the results of the soil investigation described in Chapter 3, the clayey sand has high sandy content sutiable enough to be usefully filled as the material of good quality.

The stiff clay can also be used as the fill material, as it may be dredged and transported in lumps, though rather inferior in its characteristic to the clayey sand.

The marine clay exists in a large volume and has possibility of being utilized as the fill material despite of its unfavourable characteristic (A discussion will be made in detail in later chapters on the soft ground consisting of soft marine clay and its improvement).

It would be much desirable to dredge the clayey sand and the stiff clay alone for reclamation, however, they are covered with marine clay as already mentioned. Therefore, discussion is made hereinafter on the possibility of utilizing the marine clay for reclamation by collectively dredging it together with the clayey sand and the stiff clay.

In the meantime, these discussions will sufficiently cover the sea-bottom in the territorial waters other than the present investigation sites.

4-3-2 Recommendable method of dredging and reclamation in Singapore

In consideration of each method studied in Sections 4-1 and 4-2, and of the useful material described in the aforementioned section 4-3-1, the following combination and comparison of dredging, transportation and reclamation are given in Tables 4-3-1 and 4-3-2 and Fig. 4-3-1.

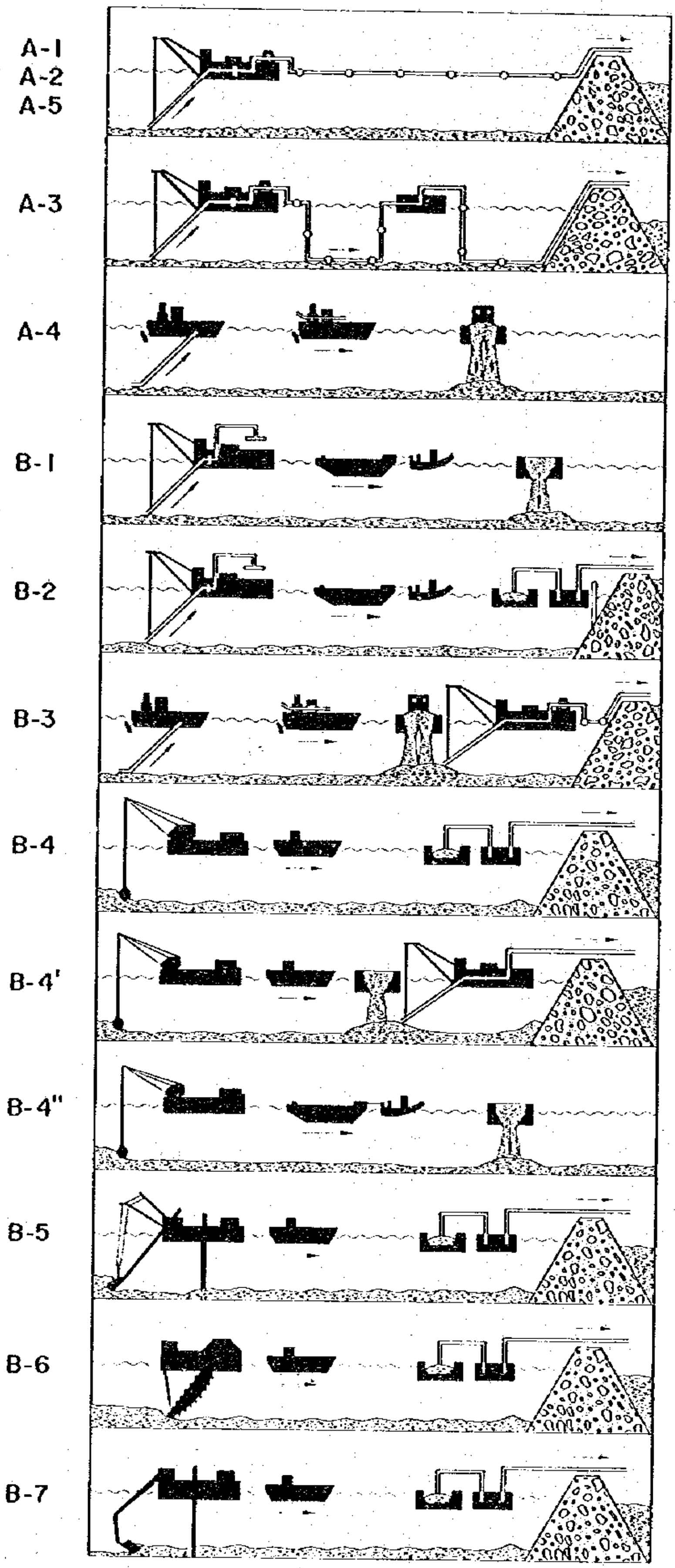
Table 4-3-1 Combination of Dredging, Transportation & Fill

Method No.	Dredging	Transportation	Fill
A-1	Cutter Suction dredger	→ direct fill →	Reclamation Area
A-2	Cutterless Suction dredger	→ direct fill →	Reclamation Area
A-3	Cutter Suction dredger	→ Booster →	Reclamation Area
A-4	Drag Suction dredger	→	Reclamation Area
A-5	Deep dredger	→	Reclamation Area
B-1	Cutter Suction dredger	→ Hopper barge →	Reclamation Area
B-2	Cutter Suction dredger	→ Hopper barge → Unloader →	Reclamation Area
B-3	Drag Suction dredger	→ Cutter Suction →	Reclamation Area (double pumping)
B-4	Grab dredger	→ Hopper barge → Unloader →	Reclamation Area
B-4'	Grab dredger	→ Hopper barge → Cutter Suction →	Reclamation Area
B-4''	Grab dredger	→ Hopper barge →	Reclamation Area
B-5	Dipper dredger	→ Hopper barge → Unloader →	Reclamation Area
B-6	Bucket dredger	→ Hopper barge → Unloader →	Reclamation Area
B-7	Back-hoe dredger	→ Hopper barge → Unloader →	Reclamation Area

Table 4-3-2 Comparison of Dredging, Transportation & Fill

Method No.	Adoptable Soil	Space Required	Merit	Grade of Economy
A-1	Mud, Clay, Sandy Soil	Large	Suitable for large-scale reclamation	A
A-2	Mud, Loose Sand	Medium	Small turbidity	E
A-3	Mud, Clay, Sandy Soil	Large	Suitable for large-scale reclamation	B
A-4	Mud, Loose Sand	Large	Suitable for channel dredging	A
A-5	Sand	Medium	Suitable for deep sand winning	C
B-1	Sandy Soil	Large	Long distance transportation	C
B-2	Sandy Soil	Large	"	D
B-3	Mud, Soft Clay, Loose Sand	Large	"	C
B-4	Mud, Clay, Sandy Soil	Medium	"	D
B-4'	Mud, Clay, Sandy Soil	Large	"	D
B-4"	Mud, Clay, Sandy Soil	Small	"	A
B-5	Stiff Soil	Medium	Long distance transportation & Stiff Soil dredging	D
B-6	Mud, Sand, Sandy Gravel	Large	Suitable for collection of sand and gravel	C
B-7	Soft Rock, Stiff Soil	Medium	Stiff Soil dredging	E

Fig. 4-3-1 Sketch of Equipments Chain



Based on these combination and comparison, most suitable method of dredging and reclamation in Singapore will be determined herebelow:

In general, the elemental factors for determination of the suitable methods will be such as volume of fill material, thickness both of the material to be dredged and of the fill, soil characteristics, distance of delivery, space for operation, capacity of dredgers, period of reclamation, and economy.

Properly speaking, the comparison of the suitable methods would be impracticable unless these factors were fixed to determine the proposed borrow area(s) and the proposed reclamation area, however, it is to be made herein based on such factors as are considered to be generally effective to dredging and reclamation in Singapore, where it must be noted that the suitable methods and the costs would be still affected by such factors.

At first, regarding Method-A group of Suction Dredgers, Cutterless Dredger (Method A-2) and Deep Dredger (A-5) will not be suitable because of their economical efficiency and adoptability to the soil. Booster method (A-3), where a booster is combined to a cutter suction dredger (A-1), is a variation of Method A-1 which will incur rather expensive cost, though the material can be transported a longer distance. Drag Suction (A-4) will not be adoptable for relatively stiff material with N-value about 40.

Thus, cutter suction (A-1) would be advantageous to a short distance transportation, or Method A-3 with a Booster jointed to Method A-1, to a long distance one, among the Method-A group.

As for Method-B group of Barge lines in the tables, Dipper (Method B-5), Bucket (B-6), and Back-hoe (B-7) will not be adoptable to the soil. From the economical point of view the following methods are all inferior to the Method B-4" (Barge Direct dumping), that is, Cutter Suction Dredger plus Hopper Barge (B-1); Method B-1 plus Unloader (B-2); Grab Dredger plus Hopper Barge plus Unloader (B–4); Grab Dredger plus Hopper Barge plus Suction Dredger (B-4'); and Drag Suction plus Cutter Suction (B-3). Method B–4 will receive the restriction of operational water depth depending on draft of the vessel.

Thus, Method B-4" (Grab Dredger plus Hopper Barge) would take advantage among the Method-B group.

–Tentative cost estimation

Tentative estimation of approximate costs is to be worked out herein regarding the recommendable Method A-1, A-3, and B-4", inclusive of the practicable Method B-4 above. It must be noted, however, that the costs so estimated will be fluctuated when some conditions such as the borrow area(s) and the reclamation area in Singapore, among others, are practically fixed, as described hereinbefore.

Now it is assumed that the materials to be dredged and filled is marine clay, stiff clay and clayey sand; that N-value of each material is about N = 2 on marine clay and N = 40 on stiff clay and clayey sand; and that unit cost of marine clay per cubic meter is one (1) unit as the standard for the cost estimation.

● Reclamation cost by cutter suction dredgers

At first, cost of reclamation by means of a cutter suction dredger (Methods A-1 and A-3) will be examined–

If the dredger is workable in full operation all the year round, the expenses of operation per month will be as shown in the following table:--

Pump Capacity	4,000PS.	6,000PS.	8,000PS.	with Booster
Expenses per month	$480 \times 10^3\alpha$	$705 \times 10^3\alpha$	$874 \times 10^3\alpha$	$1,225 \times 10^3\alpha$

Where, α (alpha) stands for a unit.

The following is the transporting capacity of pump dredgers for each material under the economical products.

Pump Capacity	4,000PS.	6,000PS.	8,000PS.	w/booster
Marine clay	3,000 m	4,000 m	6,000 m	9,000 m
Stiff clay	1,500 m	2,600 m	3,000 m	5,000 m
Clayey sand	2,500 m	3,500 m	4,000 m	6,000 m

The volume of each material per month to be dredged and transported within the above distance would be as shown in the following table:–

(Unit : cu.m.)

Pump Capacity	4,000PS.	6,000PS.	8,000PS.	w/Booster
Marine clay	480,000	600,000	680,000	680,000
Stiff clay	225,000	300,000	350,000	350,000
Clayey sand	290,000	350,000	400,000	400,000

From the values in the above tables, the unit cost of reclamation in each transportation distance, obtained from the following calculation, will be as shown in the table below:–

$$\text{Unit cost} = \frac{\text{Expenses per month}}{\text{Dredged volume per month}}$$

Marine Clay		Stiff Clay		Clayey Sand	
Distance	Unit cost	Distance	Unit cost	Distance	Unit cost
3,000 m	1.0α	1,500 m	2.2α	2,500 m	1.7α
4,000 m	1.2α	2,600 m	2.4α	3,500 m	2.0α
6,000 m	1.3α	3,000 m	2.5α	4,000 m	2.2α
9,000 m	1.8α	5,000 m	3.5α	6,000 m	3.0α

Judging from the above table, the dredging cost of clayey sand is about two times that of marine clay, and the cost of stiff clay about three times that of marine clay, when the fill material is hydraulically transported by a cutter suction dredger from a distance of 3,000 m to 5,000 m.

- Reclamation cost by grab dredger

The cost of reclamation by means of the Grab Dredger will be examined herebelow, where the dredged material is transported and is either directly dumped (Method B-4") or unloaded by the unloader (Method B-4), into the reclamation area–

The following table shows the costs in case the grab dredger with 13 cu.m. grab being used in line with barge/unloader:–

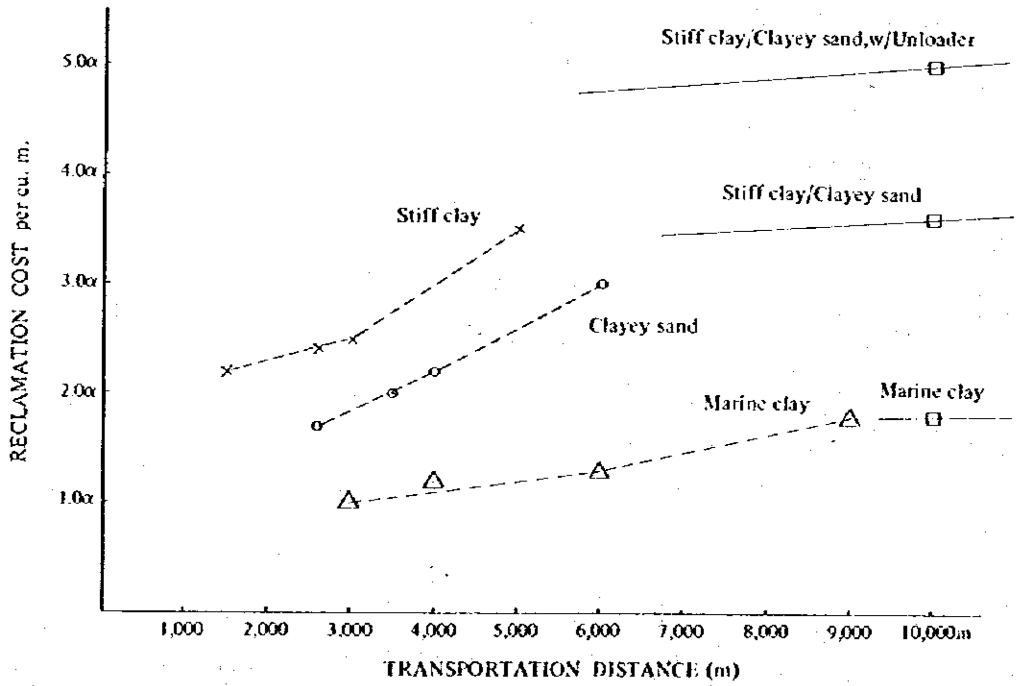
		Direct dumping	Unloading
Expenses per month		360 x $10^3\alpha$	500 x $10^3\alpha$
Product per month	Marine Clay	200,000 cu.m.	–
	Stiff Clay/ Clayey Sand	100,000 cu.m.	100,000 cu.m.
Cost	Marine Clay	1.8 α	–
	Stiff Clay/ Clayey Sand	3.6 α	5.0 α

Where, it is assumed that the transportation distance shall be about 12 ~ 13 km with minimum distance of 7 km to 8 km. The cost will be fluctuated by 10% for every 6 ~ 7 km. It will be unpracticable, however, to unload marine clay by means of unloader, and employment of the same will be useful only for calyey sand and stiff clay.

- Comparison of reclamation cost

The following shows the graphycal curves of the unit costs and distance both for the hydraulic fill and the barge line fill examined hereinbefore for each material.

RELATIONSHIP BETWEEN COST AND DISTANCE



NOTE: Doted line shows direct fill (pumping) by Pump Dredger.
Full line shows direct fill (dumping) by Grab Dredger.