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GEOTECHNICAL STUDIES FOR SINGAPORE MASS RAPID TRANSIT

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1. INTRODUCTION

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In December 1981 Dames & Moore were appointed geotechnical consult to the Provisional Mass Transit Authority to undertake the detailed geotechnical study for the Singapore MRT. The team comprised specialis engineers and geologists with advice relating to underground railway construction being provided both in-house and from Earth Sciences (Asia and Parsons Brinckerhoff International. Engineers from the Public Work Department, Singapore were seconded to the Project Team in line with th Singapore Government Policy on Technology Transfer during the course of project.

The work which commenced in February 1982 involved study of the MRn Basic System shown on Figure 1.

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The major tasks of the geotechnical study were: to review all existing geotechnical data along the MRT route alignm~ determine and establish a detailed programme for additional geotech~ investigation. to prepare contract documents and invite tenders from pre-qualified contractors to carry out all additional geotechnical investigations

3) to manage and supervise all site investigation and associated soil tests

4) to determine and evaluate all soil parameters, water table elevations and other relevant geotechnical factors required for the final detailed design of the MRT structures including temporary works.

5) to consider possible construction problems specific to the design of the Singapore MRT and the sub-surface conditions that prevail.

This paper summarises some of the findings of the study.

2. GEOLOGY

The geology of Singapore was the subject of a study by the Geological Unit of the Public Works Department in 1976. The map shown on Figure 2 and the major geological formations, described in

study.

Table I, are based on this

The geology of Singapore is structurally continuous with the Malaysian Peninsula. ~he oldest rocks are the sedimentary Sajahat and Gombak Norite formations and the Volcanics, all of Palaeozoic age. The Bukit Timah Granite was formed in early Mesozoic times. During the middle Mesozoic erz the Jurong formation was deposited in a sedimentary basin which was lifted and folded against the granite ~

The Old Alluvium is thought to represent a deltaic deposit which was laid down in a slowly subsiding basin during one of the Pleistocene

interglacial periods.

Fluctuations in sea level during glacial advance and retreat led to 1 erosion of deep valleys in all the earlier formations described above, an. subsequent sea level rises were accompanied by the filling of these valle with the Alluvial and Marine Members of the Kallang Formation.- Subsequen sea level fluctuations led to the exposure and erosion of these deposits further renewed deposition of the Alluvial and Marine Members.

More recent estuarine, beach, and littoral deposits of the Kallang Formation have been deposited since sea level has been established at, o

close to, its current level.

The geology of the MRT route may be considered in terms of t~ of materials - that which forms the shallow "basement", and that overlies the "basement".

Soil and Material Types 0, S1 to S4 and G1 to G4 constitute material which forms the "basement". They belong to geological f, of Pleistocene age and older. The material that overlies the teas' consists of the more recent deposits. This comprises Soil Types ' M, and Fill.

Varying types of older material are encountered along the ro **Granite is intersected on** the North-South line and the sediments Jurong Formation met on the West line. The Old Alluvium is encou the East line and Marina extension. It should, however, be noted Material Types S1 to S4 also occur widely on the North-South line very limited extent on the East and Marina lines.

Of the more recent sediments (Soil Types E, F, B, M and Fill

found on the North-South, East and Marina lines and all but Soil present on the West line, although the Marine Clay is of very lin there.

3. FIELD INVESTIGATION & TESTING

Fieldwork for the MRT study comprised a total of 310 boreho] CPT's, 20 continuous samples and 20 test pits.

The majority of boreholes were drilled by rotary wash borin~ using tractor mounted Gemco H7 rigs. However for more difficult either Boyles Bros BBS 17A skid mounted rotary rig or a Pilcon W percussion rig was used.

Soil samples were obtained using SPT, Denison and Dames and type samples. 'N' and 'H' size triple tube core barrels were us rock cores. In-situ testing in boreholes included SPT's, Vane T testing and Pressuremeter testing. Ground water levels were mon use of open tube Casagrande piezometers and PVC perforated stand

Dutch cone penetration tests were carried out from a purpose built ballast truck.

The results of the investigation were presented on borehole records giving details of soil profiles, sampling, classification and field test results.

4. PARAMETERS

One of the main purposes of the study was to obtain soil parameters t could be used in the design for the MRT structures and temporary works. Samples obtained from field investigations were delivered to laboratories a wide scope of tests carried out to determine the engineering properties the soil. The results were correlated and compared to those obtained from other studies in the area. In general a wide spread of the results was obtained due to several factors including: (a) Over simplification of classifi,cation system (b) Variability within soil - types (c) Partial saturation of soil (d) Depth mmbiguity

(e) Poor field and laboratory techniques

(f) Sample size and disturbance effects

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particularly E, F and S1 to S4 soil types (follows from a). resulting in ambiguous results from "undrained" tests. due to extensive cut and fill operations throughout Singapore, depth correlation cannot be expected. particularly with respect to some of the smaller studies for other developments not related to the MRT system. unavoidable in all soils and more signifi~ in some of the local soil types, particulc B, F1, M, S2-S4 and G2-G3.

All the results were presented in the "Interpretative Report" submitd to the Singapore Provisional MRT, in the form of tables and graphs. On t] basis of these plots "recommended design parameters" were selected and th, are summarized in Table II. In general the recommended design para~eters were based on the statistical mean of the data. However where the data sample was small, or where the spread of data might result in an unsafe

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design,~the design value selected erred on the safe side of th~ view of the large geographical spread of the MRT project it waE that, for each local unit of construction, specific data for th reviewed to assess whether the overall recommended parameter wa appropriate.

5. CONSTRUCTION CHARACTERISTICS

For the purpose of this paper consideration has been given relation between the soils encountered and possible constructio' The construction methods adopted for various sections of the sy~ shown on Figure 1. It was anticipated that the construction of cover stations and driving of long sections of bored tunnel wou] more significant problems. These are discussed below.

5.1 CUT-AND-COVER CONSTRUCTION

The construction of stations and cut-and-cover sections of require excavation to depths of up to 26 metres through most of encountered in the study. In order to construct these a number methods are available. Their suitability will depend on a numbe including:

(a) ground conditions

(b) allowable ground movements (in relation to adjacent roads a (c) permanent construction (top-down or bottom-up)

(d) cost effectiveness
(e) safety

A summary of the various systems together with the factors their use is given on Table III. It can be seen that, as would ~ the soft/loose alluvial deposits are the most difficult. The red cheaper traditional methods of deep construction such as sheet pi only be used in areas where larger ground movements can be accept for more sophisticated methods such as diaphragm walling **will rec** precautions in areas of the very soft ground if ground movements

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controlled within small limits.

For the sedimentary and granitic soils a wider variety of °E considered with much less risk of large ground movements. Howeve excavatiOns close to structures sensitive to the effects of settl

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care in both design and workmanship of the support system is still necessary.

5,2 TUNNELLING METHODS

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Tunnels will be required to be **driven through most of the soil** types encountered in the study. A summary of the types of tunnelling methods that could be used and their suitability for the conditions encountered is given on Table IV. Factors controlling the choice of method will include: (a) ground conditions (b) allowable ground movements (c) permanent construction (erection of tunnel lining) (d) cost effectiveness (e) safety

~ There are very few locations on the route where rock is of such **quality** and competence that excavation can be made without support. The Sl/G1 rocks usually degrade to G3-S3, depending on weathering, along any given **section** of tunnel drive where a minim~lm of in-situ bolting with gunite is required to provide temporary support.

The residual granitic and sedimentary soils are generally relatively stable and tunnelling should be possible through these soils without the absolute neccessity of the use of compressed air. However in areas where ground movements due to tunnelling are of concern the techniques adopted should be to minimize the movement at the tunnel face. This can be done by using a closed face shield or with attention to workmanship methods for open face shield techniques.

It will not be possible to tunnel through the soft alluvial and marine soils with an open face shield. Close face shields may provide a suitable method providing an appropriate technique can be found to deal with the particular soil type. Compressed air tunnelling is probably the most secure method to ensure that ground movements are minimized but in order to safeguard health it may place restrictive working hours on workers.

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TABLE I : DESCRIPTION OF SOIL AND ROCK TYPES

REFERENCE	SOIL & ROCK TYPE	GENERAL DESCRIPTION	GEOLOGICAL FORMATION
S4	SEDIMENTARIES (Continued)	Completely weathered rock or residual soil (Weathering Grades V & VI)	
S4a		Silty, sandy weak rock or partially indurated, very dense, predominantly granular soils.	
S4b		Fine grained weak rock or partially indurated, hard, cohesive soils.	
G	GRANITE (Rock & associated residual soils)		BUKIT TIMAH GRANITE
G1		Fresh to slightly weathered rock (Weathering Grades I & II).	
G2		Moderately to highly weathered rock (Weathering Grades III & IV).	
G3		Bouldery soil : Boulders of rock of variable weathering within completely weathered rock or residual soil.	
G4		Completely weathered rock or residual soil (Weathering Grades V & VI)	

TABLE II - PRINCIPAL SOIL PARAMETERS

Soil Type	Bulk Density Mg/m^3	Undrained Strength KN/m^2	Effective Cohesion KN/m^2	Effective Angle of Friction $\phi°$	Modulus Es:1/mv MN/m^2	Undrained Modulus Eu MN/m^2
B	1.7	-	0	30°	10	-
E	1.4	5 to 50	0	5°	-	400cu
F1	1.8	-	0	30°/34°	10 to 20	-
F2	1.9	20 to 50	0	22°	-	14.5
M	1.5	10 to 60	0	22°	-	200cu
O	2.0	45 to 150	0	35°	-	50 to 75
S1	2.4	-	-	-	-	-
S2	2,2	200	-	-	-	200
S3	2.2	100	10	28°	-	100
S4	2.0	45 to 150	0	30°	-	40 to 150
S4a/4B	2.2	150	0	30°	-	50

TABLE II - PRINCIPAL SOIL PARAMETERS

Soil Type	Ko Value	Permeability cm/sec	Compression Index Cc	Coefficient of Consolidation Cv m²/year	Pore Pressure Parameter 'A'
B	0.5	$5x10^{-5}/5x10^{-1}$	-	-	-
E	0.9 to 1.0	$8x10^{-9}/2x10^{-5}$	0.009(Wn-14)*	10	-
F1	0.4 to 0.7	$10^{-5}/10^{-2}$	-	-	-
F2	0.7 to 1.0	$4x10^{-3}/2x10^{-5}$	0.20	10	0.40
M	0.6 to 0.7	$4x10^{-9}/4x10^{-7}$	0.54(Eo-0.15)*	0.15	0.8 to 1.0
O	0.7 to 1.0	$1x10^{-8}/1x10^{-4}$	-	25	0.10
S1	-	-	-	-	-
S2	-	$1x10^{-8}/1x10^{-5}$	-	-	-
S3	0.7 to 1.0	$1x10^{-8}/1x10^{-3}$	0.03	30	0.10
S4	0.7 to 1.0	$5x10^{-6}/2x10^{-8}$	-	40	0.07
S4a/ 4b	0.7 to 1.0	$1x10^{-8}/1x10^{-5}$	-	20	0

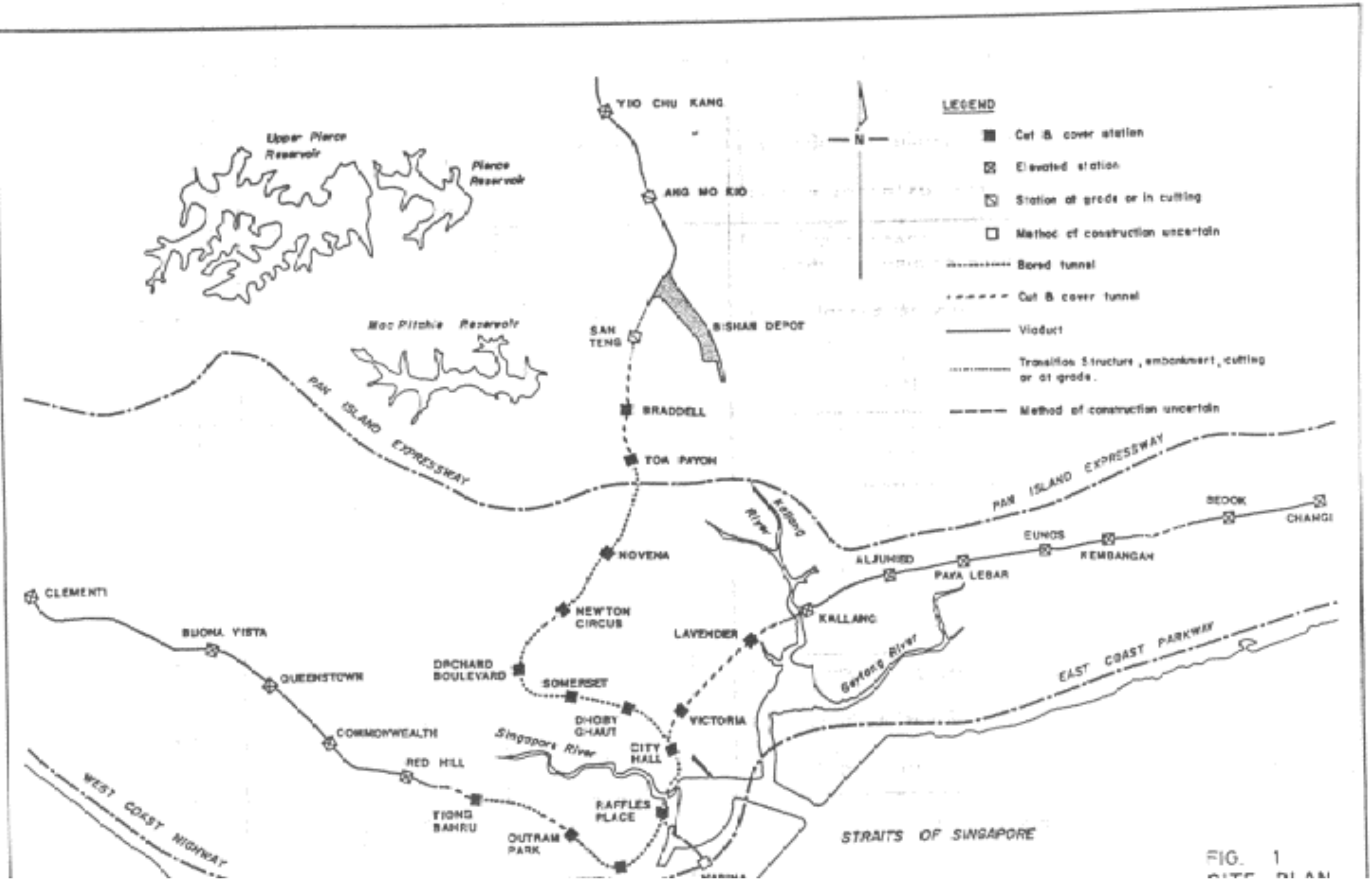
* Wn = Water Content   Eo = Void Ratio

TABLE III - CUT & COVER CONSTRUCTION METHODS

Type of Construction	Suitable Soil Types	Unsuitable Soil Types	Comments
Diaphragm Walls/ S.P.T.C. (Top-Down)	All including E, F & M	B & F1 - may have slurry 'loss'	1) Relatively expensive. 2) Good control of ground movement. 3) Require special slurry head for E & M soils.
Contiguous/ Secant Piles (Top-Down)	All including E, F & M	E, F & M may risk 'necking'	1) Relatively expensive. 2) Good control of ground movements. 3) Pile type may be varied for ground conditions.
Berlinoise Wall (H-Pile & Lagging) (Bottom-Up)	G4 & S4 pre-drill to toe in G2/S2	E, F, B & F1 risk ravelling	1) Relatively inexpensive and adaptable. 2) Medium ground movement control. 3) May induce drawdown of water table.
Sheet Pile Wall (Bottom-Up)	G4 & S4 (E, M & F risk large movements)	S3, G2, S2	1) Medium cost. 2) Can inhibit ground loss in granular soils. 3) Poor control of ground movement in soft soils.
Anchors/Bolts Gunite (Rock)	S1, S2	only suitable for soft rocks	1) Can be used where temporary wall stops on rock. 2) Has to be designed 'on exposure'.
Lateral Support	Struts	1) Conventional Method but still needs care in workmanship. 2) Pre-loading can reduce ground movements.	
	Ground Anchors	1) Allow greater working space. 2) Require wayleave of adjacent roads/structures.	

TABLE IV – TUNNELLING METHODS

Method	Suitable for Soil Types	Unsuitable for Soil Types	Comments
en Face Shield (No Air)	G & S soils	B, E, F & M	1) S2, S3 & G2 unsuitable for rotary excavator. 2) Granular seams may dictate breasting jack. 3) Recommended to erect lining within tail of shield.
ose Face Shields			
Slurry	B & F1	G, S, M & E	Difficult to remove clay fines from slurry.
Earth/Water Balance	B, E, F & M	G & S	Cannot turn shield in stiff/dense soils.
Partial Air	E, F2 & M	B & F1	May not restrict ground movement in soft soils sufficiently.
Compressed Air	E, F2 & M	B & F1	1) Best technical method to increase stability and reduce ground movement. 2) Requires safeguards for worker's health 3) High pressures limit working hours and become expensive.
N.A.T.M.	S2/S3, G2/G3 soft rocks	All soils	1) Adaptable to change on M.R.T. routes. 2) Requires in-situ bolt and gunite support. 3) Economic.


LEGEND
Cut & cover station
Elevated station
Station at grade or in cutting
Method of construction uncertain
Bored tunnel
Cut & cover tunnel
Viaduct
Transition Structure, embankment, cutting or at grade.
Method of construction uncertain
N
YIO CHU KANG
ANG MO KIO
BISHAN DEPOT
SAN TENG
BRADDELL
TOA PAYOH
NOVENA
NEWTON CIRCUS
ORCHARD BOULEVARD
SOMERSET
DHOBY GHAUT
CITY HALL
VICTORIA
LAVENDER
KALLANG
ALJUNIED
PAYA LEBAR
EUNOS
KEMBANGAN
BEDOK
CHANGI
RAFFLES PLACE
OUTRAM PARK
TIONG BAHRU
RED HILL
COMMONWEALTH
QUEENSTOWN
BUONA VISTA
CLEMENTI
Upper Pierce Reservoir
Pierce Reservoir
Mac Pitchie Reservoir
PAN ISLAND EXPRESSWAY
PAN ISLAND EXPRESSWAY
Kallang River
Geylang River
Singapore River
EAST COAST PARKWAY
WEST COAST HIGHWAY
STRAITS OF SINGAPORE
FIG. 1

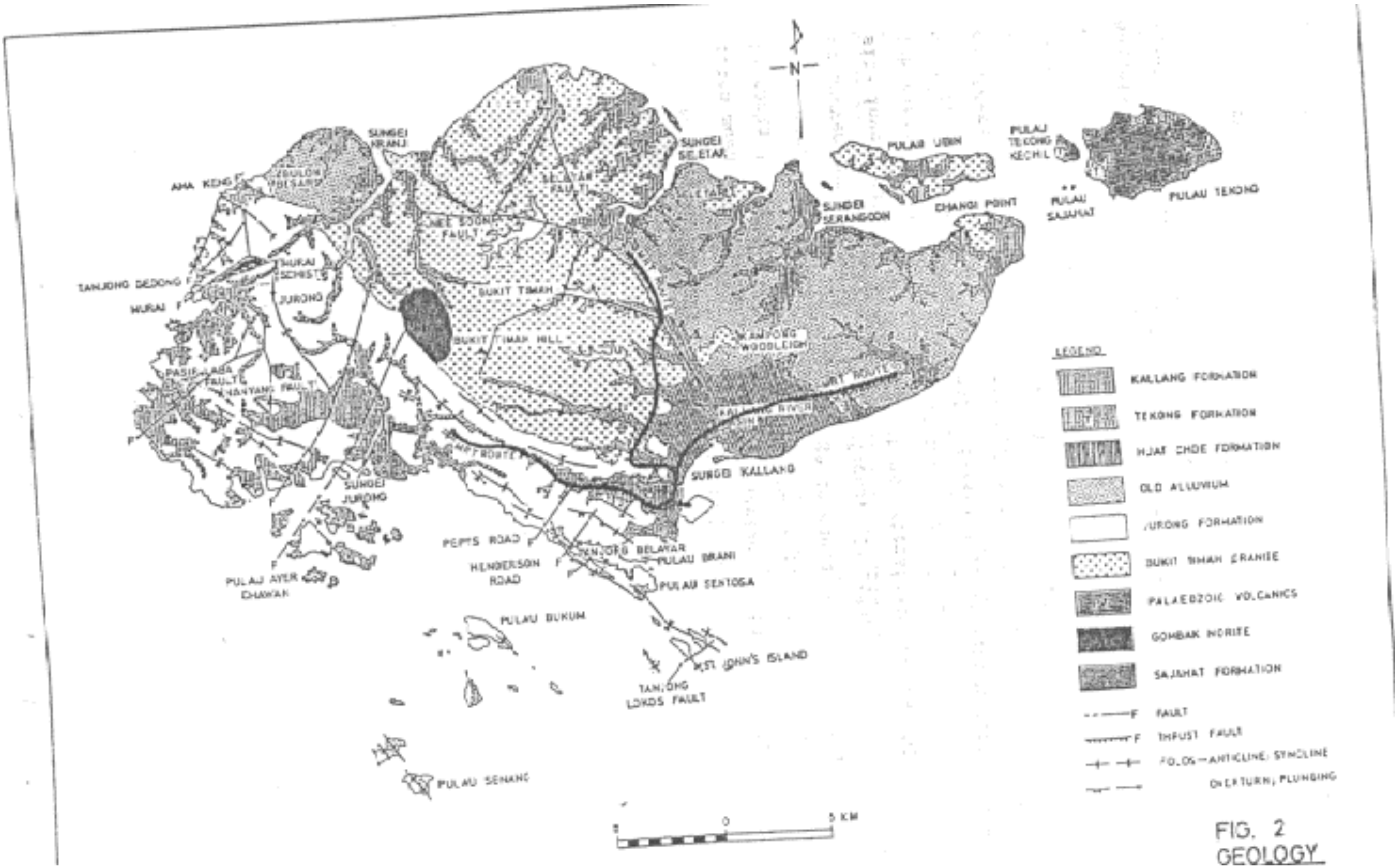


FIG. 2
GEOLOGY