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Record No. 1971/68

Rabaul Caldera: An Exercise in Structure Interpretation

by

M. G. Mancini

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CONTENTS

ABSTRACT

This exercise aims at elucidating the structure of the Rabaul Caldera by the interpretation of various published and unpublished seismic data.

Travel times and seismic velocities of shocks generated by a quarry blast and by the detonation of a war time bomb were computed. A profile across the Caldera was drafted showing the relationship between the geology and the computed seismic velocities. A velocity of 3.6 km/s was determined for the basalt and andesite lava flows on the northern and eastern sides of the caldera wall. A hypothetical limit for the 3.6 km/s refractor was computed inside the Rabaul Harbour.

INTRODUCTION

Volcanic activity (Vulcan 1937, Tavurvur 1937, 1942) near Rabaul's densely populated area, induced the T.P.N.G. Administration to support the establishment of a Volcanological Observatory which now possesses a telemetered Seismic Network which was completed in 1968. The location of RAB World Wide Standard System and Harbour Network stations is shown in Plate 1. Maximum network spread is about 6 km from the ideal centre, and the maximum distance between stations is 10.5 km (RAB - VUL).

The prime function of the network is volcanic surveillance, but it can also be used for the accurate hypocentre and mechanism determination of micro-tremors within the area covered by the network (e.g. magma movements, secondary magma chambers) and for the determination of local structural features from P-delays of small local tremors. Structural interpretation is complicated by the interlayering of many different lithologic types, lava, pyroclastics and sediments which have no predominant strata direction or gradation in density.

Successive geophysical surveys were carried out in the area between 1966 and 1969 by B.M.R. sponsorship in co-operation with the University of Queensland, the Australian National University and Hawaii Institute of Geophysics. The aim of these surveys was to provide basic data for the interpretation of volcanic and seismic local events.

This note is limited to the interpretation of a few events taken at random in the light of the 1966, 1967 and 1969 Seismic Surveys. A B.M.R. Record (Cifali et al.) covers the results of the 1966 preliminary Seismic Survey. Unpublished data from the 1966, 1967 and 1969 Surveys, computed independently by G.W.D'Addario and M.G. Mancini, were also used in this exercise and are shown in Plate 2.

GEOLOGY

No detailed geological description of the Rabaul Caldera has been published to date. R. Heming mapped the area in 1968-69. This study is now the subject of a Ph.D. thesis. Duplicate field notes left at the Observatory were used to compile both the Profile Section along the Caldera wall (Plate 3) and the following account of the geology. A general account of the geology is given by Fisher (1937).

The caldera is well preserved except on the south east side where it is breached to form the entrance to Rabaul Harbour. A number of minor volcanoes were developed on the flanks of the ancestral structure, namely Turanguna (South Daughter), Kombiu (The Mother) and Towanumbatir (North Daughter). Turanguna and Kombiu are composite basaltic cones while Towanumbatir is an andesitic composite volcano. Palangiagia straddles the caldera ring fault and developed after the formation of the caldera. Subsequently the southern walls of Palangiagia foundered and Rabalanakaia was constructed.

A number of small cones developed within the caldera. Tavurvur is a composite cone in the south east. Sulphur Creek is an elongated depression with two small explosion craters at its head. On the western side of the harbour is the ash cone of Vulcan, produced during the eruption of 1937, while to the north east lie the Beehives (Dawaipia Rocks) which are the remnants of an ash cone. Matupit Island also seems to be the eroded remnant of an ash cone.

A thick sequence of basalt is exposed in the eastern caldera wall between Turanguna and Palangiagia. Palangiagia consists of thin flows of an olivine rich basalt, while the nested cone of Rabalanakaia consists of partly glassy and aphyric andesites and partly of tuffs.

The northern sector of the caldera is composed of andesite flows, but to the west of the North Daughter beneath the Observatory, there is a considerable thickness of pyroclastics overlain locally by a thin lava flow.

Exposure in the western and southern walls is poor but the succession is apparently dominated by pyroclastics with only occasional glassy lavas.

Dacite pumice ash mantles the caldera wall everywhere except between Turanguna and Kombiu. The area of flat land on which the Rabaul township is built consists of out-wash materials derived from the caldera walls.

A well drilled by the Commonwealth Department of Works close to the waterfront, Park Street corner, encountered 60 metres of these fine pyroclastics.

METHODS AND EQUIPMENT

RAB World Wide Standard Seismograph and Harbour Network station characteristics are included in the APPENDIX.

New Britain Quarry shot

Plate 1 shows the location of the Quarry site and the recording stations. Table 1 shows distances, travel times, apparent velocities and standard curves between shot point and recording station.

Blasting in the quarry is carried out about twice a week but only on the 1st May, 1970 was an instrument available for the recording of an accurate origin time. For this exercise the WAN drum speed was increased to 120 mm/m and WAN and VUL were set at 11,400 relative magnification. The size of the charge was approximately 50 lb T.N.T.

A telemetry system, designed and built at the Rabaul Central Observatory (Myers 1969) was used to record the origin time of the blast. A seismometer was placed 100 metres from the shot point and the signal was telemetered into a high speed (180 mm/m) helicorder at the Observatory. Time mark was so obtained from the same clock for all records.

Simpson Harbour shot

On 28th May a Navy team exploded a war time bomb 100 metres west of the Beehives Islands. The explosive charge was about 1200 lb. Plate 4 shows the locations of the bomb and recording stations.

INTERPRETATION

New Britain Quarry shot

Readings were made to the nearest tenth of a second, although three records, RAB Eh, WAN and the quarry site were at high speed giving a higher reading accuracy. Primary time (W.W.S.S. clock) was used for all records.

Only first arrivals were used in the exercise.

All stations registered a strong compressional first motion. The quarry site seismometer however, showed a weak downward first motion. The polarity of this instrument was re-tested against the other network stations and was found correct. The seismometer was placed at a slightly lower level than the shot, upon incoherent material.

Simpson Harbour shot

Sharp first arrivals (compression) were read in all network stations to within one tenth of a second. No origin time was registered for this event, but shot 32 of 1969 Crustal Survey was found to have been fired 200 metres from the bomb. Shot 32's apparent velocity was computed to SUL, 3.0 km away, the nearest station. Assuming the same apparent velocity for both events, the travel time and origin time for the bomb blast were computed.

During the course of the exercise it was found advantageous to include in the computation data from shots 33, 34, 35 and 44 of the 1969 Crustal Survey. Thesedata are presented in Table II.

DISCUSSION

New Britain Quarry shot

Table 1 shows the apparent longitudinal wave velocities with estimated standard error for all recording stations. Except for RAB they were in close agreement.

WAN The data from WAN is the most representative of the exercise. The lava outcrop is practically continuous from the quarry to WAN, and both stations are sited on it. Rock density variation, if any, is so small that it should not affect the elastic wave velocity, hence the wave path is assumed to be straight. The underlying rocks certainly have similar or lower seismic velocities, hence it is assumed that the first arrival has not been refracted by an other strata in such short a distance. Thus the velocity of 3.6 km/s computed between WAN and quarry sites gives the actual seismic wave velocity of the Caldera wall lavas.

TAV TAV station results confirm this data for the eastern side of the Caldera wall. The small decrease in the apparent velocity could be due to local geological discontinuity, e.g. KOMBIU and/or PALANGIAGIA pyroclastics which have a lower seismic velocity.

RAL The RAL apparent velocity suggests a greater proportion of low velocity pyroclastics in the sequence.

SUL A considerably higher apparent velocity than anticipated was obtained for SUL. The high value computed suggests an extension of the 3.6 km/s lava refractor beneath the Caldera. That is, the Caldera wall is only the outermost of a series of downward stepping faults. This view is supported by the Harbour shot data.

RAB An unexpected low apparent velocity was computed for RAB. Beneath the Observatory lava flow there are about 70 metres of pumice tuffs, with a low velocity (1.5 - 2.8 km/s), but these are not extensive enough to account for a 3.6 km/s to 2.1 km/s drop in velocity.

Filtering and shadow effects could be responsible for this effect. In Fig. 1, Plate 3, both effects are shown. A wave train travelling east-west in the Caldera lava flow would be refracted by the pumiceous tuff with an angle close to 90°. The wave would arrive at the Observatory lava flow with an angle greater than the critical angle and most of the energy would be simply reflected. The caldera scarp would contribute to this in creating a topographic shadow corner. Similar delayed arrival has also been observed for near earthquakes located at the same azimuth from RAB.

The west-east and northwest-southeast profiles in Plate 3 show the relation of the geology and the seismic velocity between the shot point and the stations. SUL, RAL and WAN were projected onto the profile maintaining their proper altitudes.

Simpson Harbour shots

In computing the 1970 Harbour bomb explosion, it was found useful to expand the interpretation by using data from the 1969 Crustal Survey shots. The seismic velocity used in this exercise has already been mentioned in the B.M.R. Records No. 1969/125, Plate 2, although the authors did not introduce the 3.6 km/s velocity in the discussion. Because of the smaller scale this velocity is necessary in this exercise. A similar velocity range was determined by the writer and G.W. D'Addario from 1966 and 1967 Crustal Surveys' data. The work was limited to the Rabaul Harbour Network and preliminary results are shown in Plate 2. Seismic velocities and refractor depths for the different stations are shown together with the Crustal Model to be used for the area outside the Network for epicentre determinations.

A shot in the Caldera centre would propagate in a semispherical wave envelope. In the present interpretation the wave path between shot point and every point along the Caldera wall is supposed to be similar. The Caldera itself would present roughly a radial symmetry from the centre to the periphery. Plate 4 illustrates two different models of wave propagation from a shot in the centre of the Simpson Harbour. A top layer with 1.5 km/s velocity includes water and unconsolidated sediments. It overlies a higher velocity layer (2.4, 2.8 or 3.6 km/s) with stepwise ring faults. The Caldera wall, where the stations are located, represents the most elevated and external one. The intermediate faults have not relevant influence in the present interpretation. The last and more internal one should drop sharply under the central part of Simpson Harbour. It is the limit case referred as Case I in Plate 4. In this case the seismic path passes laterally from the low velocity to the higher velocity refractor. The refraction angles are negligeable and the path length is equal to its horizontal projection. In Case II (Plate 4) the second layer is steadily dipping toward the shot point and none of the ring faults has enough displacement to divert the travel path. A two-layer model has to be assumed for the computation and incidence and refraction angles also must be taken into account. The depth to the refraction point "h", is negligeable in Case I, but it increases and becomes noticeable passing from case I to case II.

The formula used were

(1) $$tt = \frac{\Delta x}{V_1} + \frac{\Delta y}{V_2}$$

(2) $$\Delta_1 + \Delta_2 = \Delta$$

$$\Delta_2 \cong \Delta_y$$

(3) $$\Delta_1 = \Delta_x \sin(i_1 + \delta)$$

$$h = \Delta_x \cos(i_1 + \delta)$$

$$i_1 = \sin^{-1} \frac{V_1}{V_2}$$

with:

tt - travel time shot-station

Δ - distance shot station

V_1 - upper layer velocity

V_2 - second layer velocity

Δ_x - path length in the upper layer

Δ_y - path length in the lower layer

Δ_1 - horizontal projection of Δ_x; it is assumed equal in the first approximation to Δ_x for case I only

Δ_2 - horizontal projection of Δ_y; it is assumed equal in the first approximation to Δ_y

i_1 - upper layer incidence angle

δ - lower layer dip angle (a dip of 10% is assumed comprehensive of depth compactization in the upper layer sediments)

h - refraction point depth

Case I is solved by the system of equations (1) and (2).

(4) $$\Delta_1 = \frac{V_1 (ttV_2 - \Delta)}{V_2 - V_1}$$

Case II is solved by the same system and the additional equation (3).

$$(5) \quad \Delta_1 = \frac{V_1\ (ttV_2 - \Delta)}{V_2 - V_1 \sin\ (i_1 + \delta)} \sin\ (i_1 + \delta)$$

Equations (4) and (5) were solved for V_2 equal to both 3.6 or 2.8 km/s. However the 2.8 km/s value was too little because it gave Δ_1 distances either negative or smaller than the sea depth itself (Table II). Therefore 2.4 km/s as well as 2.8 km/s velocities were excluded from the discussion. The 3.6 km/s refractor is present in wide areas of the Caldera (see DISCUSSION WAN) and it was already assumed underlying the Caldera floor (see DISCUSSION SUL) thus the 3.6 km/s velocity is chosen as V_2 and Δ_2 indicates the extension of this refractor beneath the Caldera. Data and results are tabulated in Table II. Refraction points for case I and case II are represented in Plates 5 and 6 respectively. Refraction points for case I fall on a line while in case II points are scattered. In case II the assumption $\Delta_2 = \Delta y$ is not contained in the limit of approximation and it introduces a 10% error in the Δ_2 values.

In Plate 5 a line joins the refraction points for each event. This line shows the theoretical intersection of the 1.5 km/s seismic wave with the 3.6 km/s refractor. No line was drawn for VUL due to the excessive scattering of the points. However, the close fit between VUL intersections and the bathymetric contour suggests that case I applies on that side of the harbour.

The presence of higher velocity bodies ($V > 3.6$ km/s) between shot and station causes the bays shaded in Plate 5 line.

In Plate 6 a shadowed area replaces the line because Δ_1 changes with the increasing dipping angle of the lower layer.

CONCLUSION

(a) The telemetry system's performance was highly satisfactory and extremely useful as the interpretation Paragraph, New Britain Quarry, emphasizes. After this exercise the telemetry has been successfully applied in several volcanic surveillance exercises.

(b) A seismic velocity of 3.6 km/s which is higher than expected, was determined for the lava outcrop extending from WAN to the New Britain Quarry. The continuous distribution of this velocity was demonstrated on the northern and eastern sides of the Caldera and is attributed to the basalt-andesite lava which is predominant there.

(c) An attempt was made to explain the late arrival at RAB station of the quarry blast and near surface earthquake approaching RAB from the eastern direction.

(d) A wide distribution of the 3.6 km/s refractor was found under the alluvium on the Caldera floor.

(e) A similar exercise could be implemented with any other shot fired inside the Harbour in the future if exact origin time and location are obtainable.

REFERENCES

CIFALI, C., D'ADDARIO, G.W., POLAK, E.J., and WIEBENGA, W.A., 1969 - Rabaul Preliminary Crustal Seismic Test, New Britain 1966. Bur. Min. Resour. Aust. Rec. 1969/125 (unpubl.).

CIFALI, G., MILSON, J.S., and POLAK, E.J., 1968 - Warangoi Dam site geological survey, New Britain, TPNG 1966. Bur. Min. Resour. Aust. Rec. 1968/96 (unpubl.).

FISHER, N.H., 1939 - Geology and vulcanology of Blanche Bay and the surrounding area, New Britain. Terr. of New Guinea Geol. Bull. 1.

MYERS, N.O., - A Telemetry System for Transmission of Short Period Seismic Data, TPNG, Geol. and Volcan. Branch Note on Inv. 69/501 (unpubl.).

APPENDIX 1

SEISMOGRAM STATIONS

Station	Code	South Latitude	East Longitude	Elev. (m)	Foundation
Rabual	RAB	04°11'28.6"	152°10'11.4"	183.5	Basalt Flow
Wanliss Street	WAN	04°11'39.6"	152°10'32.5"	25.0	Basalt Flow
Sulphur Creek	SUL	04°13'09.8"	152°12'33.3"	8.5	Unconsol. Ash
Rabalanakaia	RAL	04°13'13.0"	152°12'01.0"	91.0	Unconsol. Ash
Tavurvur	TAV	04°13'52.2"	152°13'13.0"	30.0	Andesite Flow
Taviliu	VUL	04°16'58.2"	152°08'44.6"	332.2	Unconsol. Ash

STATION INSTRUMENTATION

Station & Instrumentation	Comp.	To.	Tg.	Trace Speed mm/min.	Approx. Relative Mag. at To=1.0s	Approx. Damping
RAB World Wide Standard System	Z	1.0	0.74	60	12,500	Critical
	N.E.	1.0	0.74	60	6,250	"
	Z/N/E/	15.0	100.0	15	750	"
Benioff VR 14.7Kg.	Eh	1.0	0.02	180	4,000	"
WAN) Benioff VR 14.7Kg.	Z	1.0	0.02	60*	5,700°	"
SUL)	Z	1.0	0.02	60	1,425°	"
RAL)	Z	1.0	0.02	60	11,400	"
TAV)						
VUL)	Z	1.0	0.02	60	5,700°	"
[illegible])	Z	1.0	0.02	60	11,400	"

* Velocity of WAN drum was increased at 120 mm/m for the New Britain quarry blast.

o Relative magnification at WAN, SUL and VUL was doubled for the New Britain quarry blast.

PRESENTATION OF DATA

All times are reduced to Greenwich Mean Time (GMT) which is 10 hours behind Eastern standard time.

Primary time is provided by W.W.S.S. equipment. The time signal is marked every minute on each seismogram record.

TABLE I

NEW BRITAIN QUARRY DATA

	NEW BRITAIN QUARRY			
	Distance in Km	travel time in sec	seismic velocity Km/sec	standard error Km/sec
RAB	2.5	1.2	2.1	± 0.1
WAN	1.8	0.5	3.6	± 0.2
SUL	2.7	0.8	3.4	± 0.2
RAL	3.1	1.0	3.1	± 0.1
TAV	5.2	1.5	3.4	± 0.1
VUL	11.0	-	-	

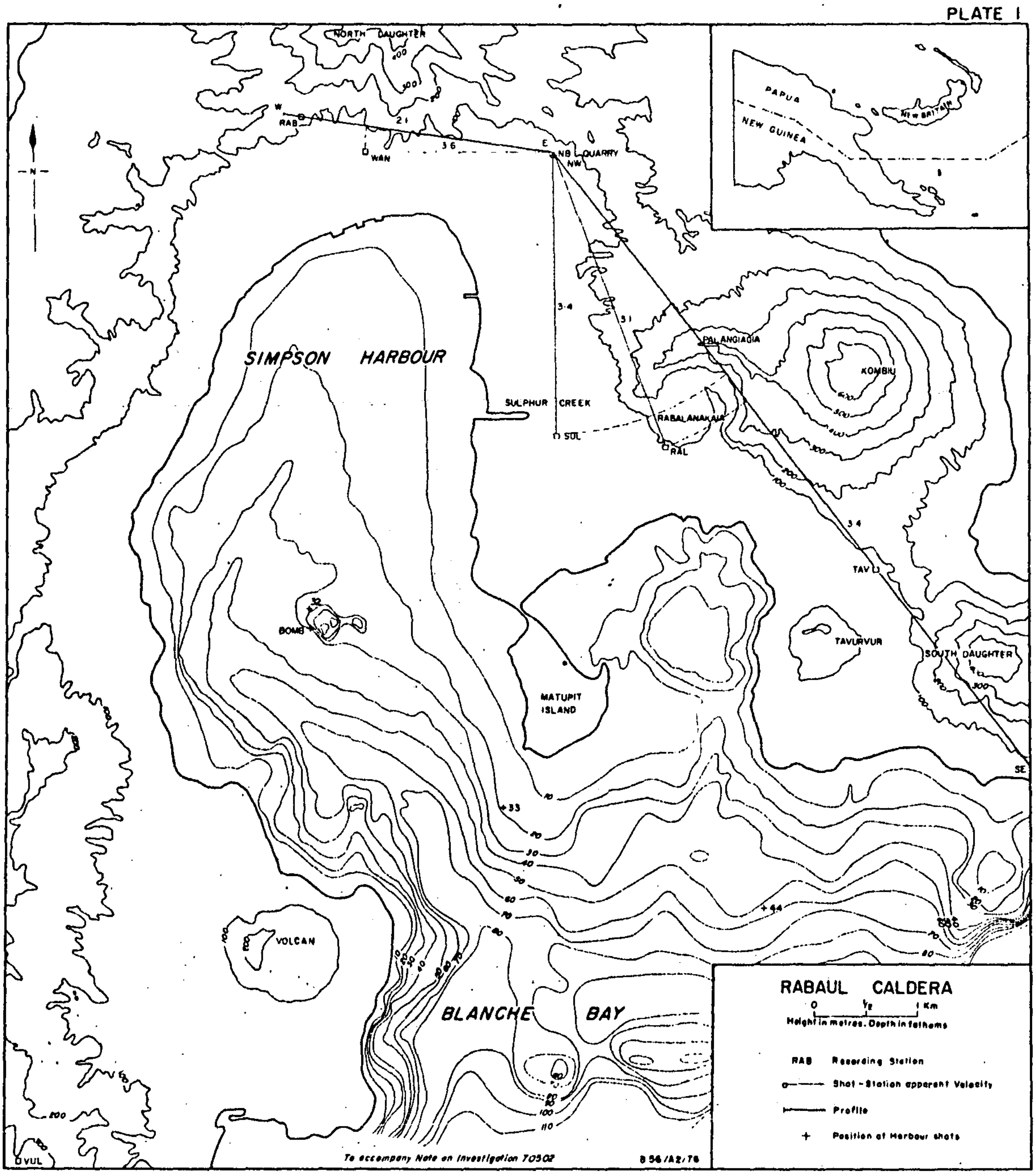
TABLE II

SIMPSON HARBOUR SHOT DATA																					
SHOT			RAB	WAN	SUL	RAL	TAV	VUL		V_2 = 3.6						V_2 = 2.8					
										RAB	WAN	SUL	RAL	TAV	VUL	RAB	WAN	SUL	RAL	TAV	VUL
BOMB		Δ	4.9	4.7	3.1	3.9	5.5	5.9	Δ_1 (case I)	2.2	1.8	1.9	2.1	1.5	1.4	1.4	1.0	1.7	1.7	0.4	0.3
									Δ_1 (caseII)	1.2	1.0	1.1	1.2	0.8	0.8						
		tt	2.2	2.0	1.6	1.9	2.1	2.2	Δ_2 (case I)	2.7	2.9	1.2	1.8	4.0	4.5	3.5	3.7	1.5	2.2	5.1	5.6
									Δ_2 (caseII)	3.7	3.7	2.0	2.7	4.7	5.1						
FROM 1969 CRUSTAL STUDY	32	Δ	4.8	4.5	3.0	3.8	5.5	6.0	Δ_1 (I)	1.5	0.9	1.7	1.7	1.5	1.1	0.4	0.0	1.4	1.1	0.4	-0.1
									Δ_1 (II)	0.8	0.5	1.0	1.0	0.8	0.6						
		tt	1.9	1.6	1.5	1.7	2.1	2.1	Δ_2 (I)	3.3	3.6	1.3	2.1	4.0	4.9	4.4	4.5	1.6	2.7	5.1	6.1
									Δ_2 (II)	4.0	4.0	2.0	2.8	4.7	5.4						
	33	Δ	7.1	6.6	3.7	3.9	4.3	5.7	Δ_1 (I)	1.2	0.5	2.2	2.0	2.1	1.3	-0.4	-1.1	1.5	1.5	1.5	0.1
									Δ_1 (II)	0.7	0.3	1.2	1.1	1.2	0.7						
		tt	2.4	2.0	1.9	1.9	2.0	2.1	Δ_2 (I)	5.9	6.1	1.5	1.9	2.2	4.4	7.5	7.7	1.9	2.4	2.8	5.6
									Δ_2 (II)	6.4	6.3	2.5	2.8	3.1	5.0						
	34	Δ	10.0	9.9	6.8	6.7	6.1	5.7	Δ_1 (I)												
									Δ_1 (II)												
		tt	2.5	2.8	2.6	1.5	1.5	1.3	Δ_2 (I)												
									Δ_2 (II)												
	35	Δ	12.0	11.3	8.0	7.6	6.2	8.2	Δ_1 (I)	-1.0	0.3	1.2	0.8	0.9	1.1						
									Δ_1 (II)	-0.6	0.2	0.7	0.4	0.5	0.6						
		tt	2.8	3.2	2.7	2.4	2.1	2.7	Δ_2 (I)	13.0	11.0	6.8	6.8	5.3	7.1						
									Δ_2 (II)	12.6	11.1	7.3	7.2	5.7	7.6						
	44	Δ	8.9	8.3	5.0	4.6	3.4	7.7	Δ_1 (I)	1.1	1.0	2.1	1.5	1.7	1.8	-1.0	-0.9	1.3	0.7	1.3	0.2
									Δ_1 (II)	0.6	0.6	1.2	0.8	1.0	1.0						
		tt	2.9	2.7	2.2	1.9	1.6	2.8	Δ_2 (I)	7.8	7.3	2.9	3.1	1.7	5.9	9.9	9.2	3.7	3.9	2.1	7.5
									Δ_2 (II)	8.3	7.7	3.8	3.8	2.4	6.7						

Δ - distance shot-station
tt - travel time shot-station

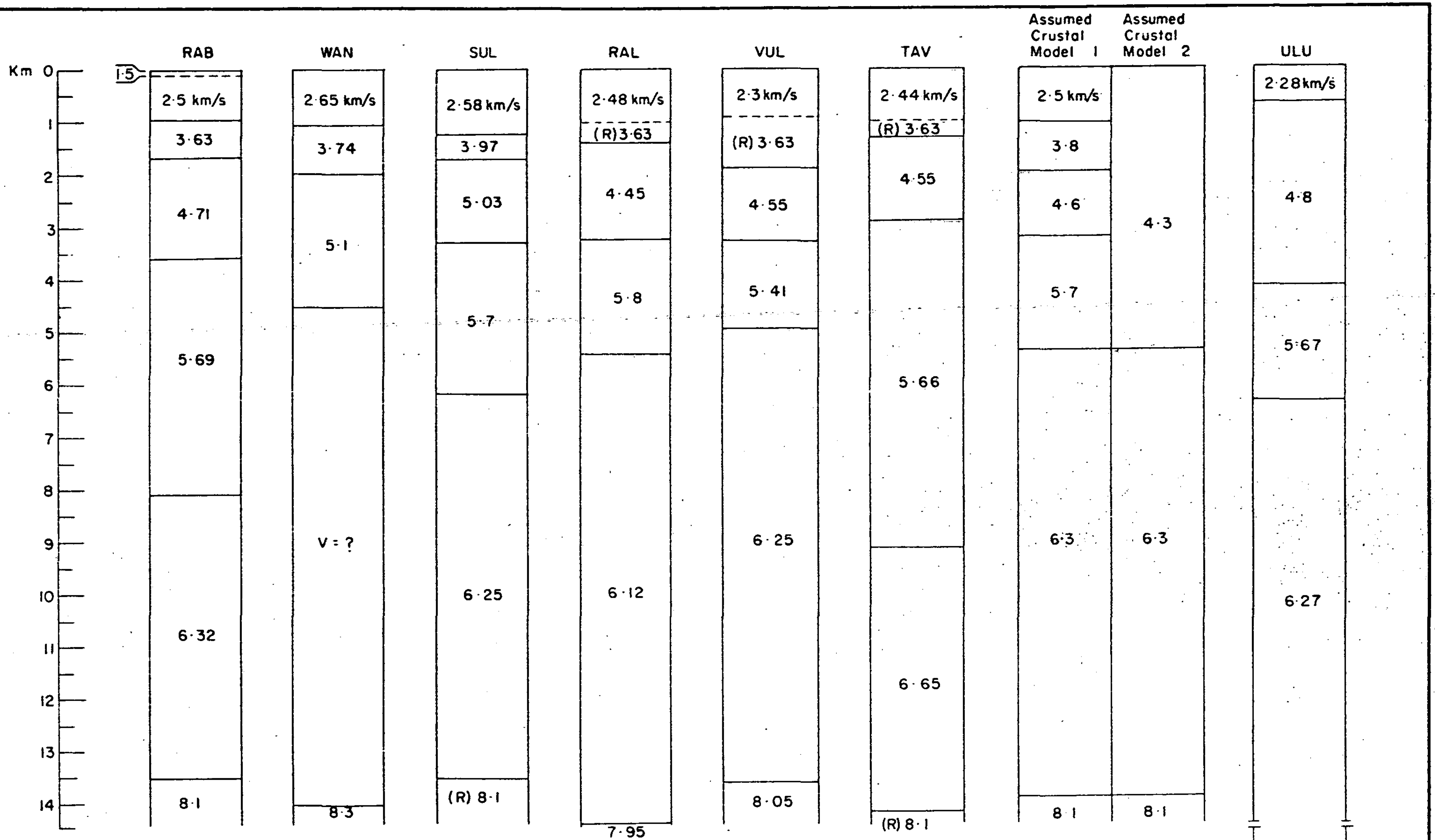
Δ_1 - horizontal projection of path length in top strata(V_1=1.5Km/s)
Δ_2 - horizontal projection of path length in lower strata(V_2=3.6or 2.8 Km/s)

PLATE 1



NORTH DAUGHTER
RAB
WAN
NB
QUARRY
SIMPSON HARBOUR
SULPHUR CREEK
SUL
PALANGIAGIA
KOMBIU
RABALANAKAIA
RAL
TAV
TAVURVUR
SOUTH DAUGHTER
MATUPIT ISLAND
BOMB
VOLCAN
BLANCHE BAY
VUL
PAPUA
NEW GUINEA
NEW BRITAIN
RABAUL CALDERA
Height in metres. Depth in fathoms
RAB Recording Station
Shot - Station apparent Velocity
Profile
Position of Harbour shots
To accompany Note on Investigation 70502
B 56/A2/76

PLATE 2



Model 1 : to be used within Harbour Network < 14 Km from centre of network.
Model 2 : to be used outside Harbour Network > 14 Km from centre of network.

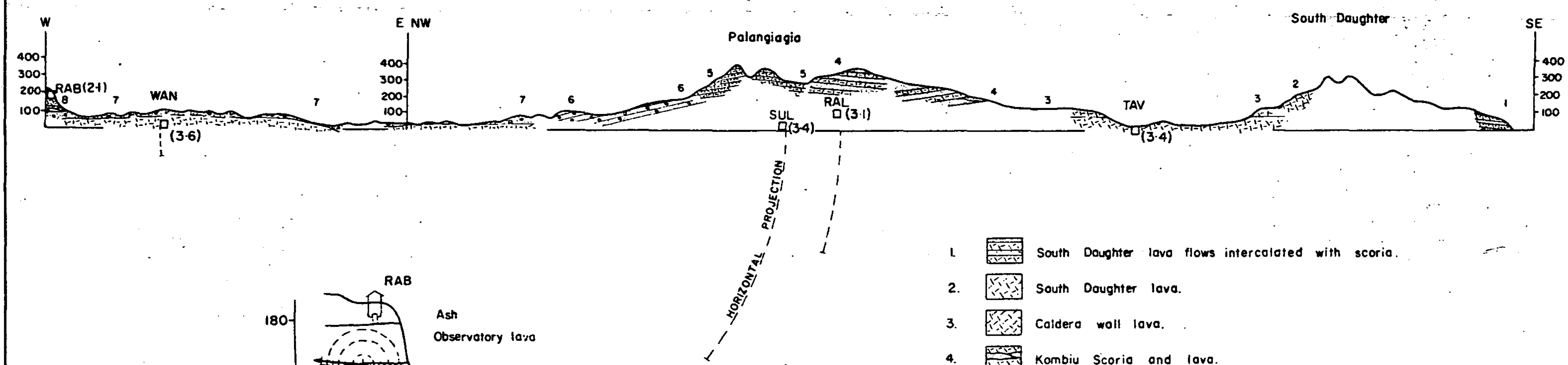
To accompany Note on Investigation 70502

22·37
M(G)152

PLATE 3

RABAUL CALDERA PROFILES

Seismic velocities from N.B. Quarry blast (1st May 1970)



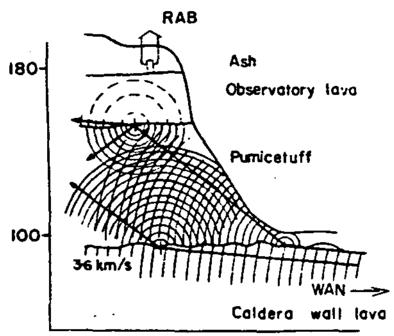


Fig.1 Not to scale

0 ½ 1 Km

SCALE $\frac{V}{H}$ = 1·25

1. South Daughter lava flows intercalated with scoria.
2. South Daughter lava.
3. Caldera wall lava.
4. Kombiu Scoria and lava.
5. Palangiangia lavas
6. Kombiu ash and pumices.
7. North Daughter pumicetuffs overlying caldera wall lava.
8. Observatory lava flow.

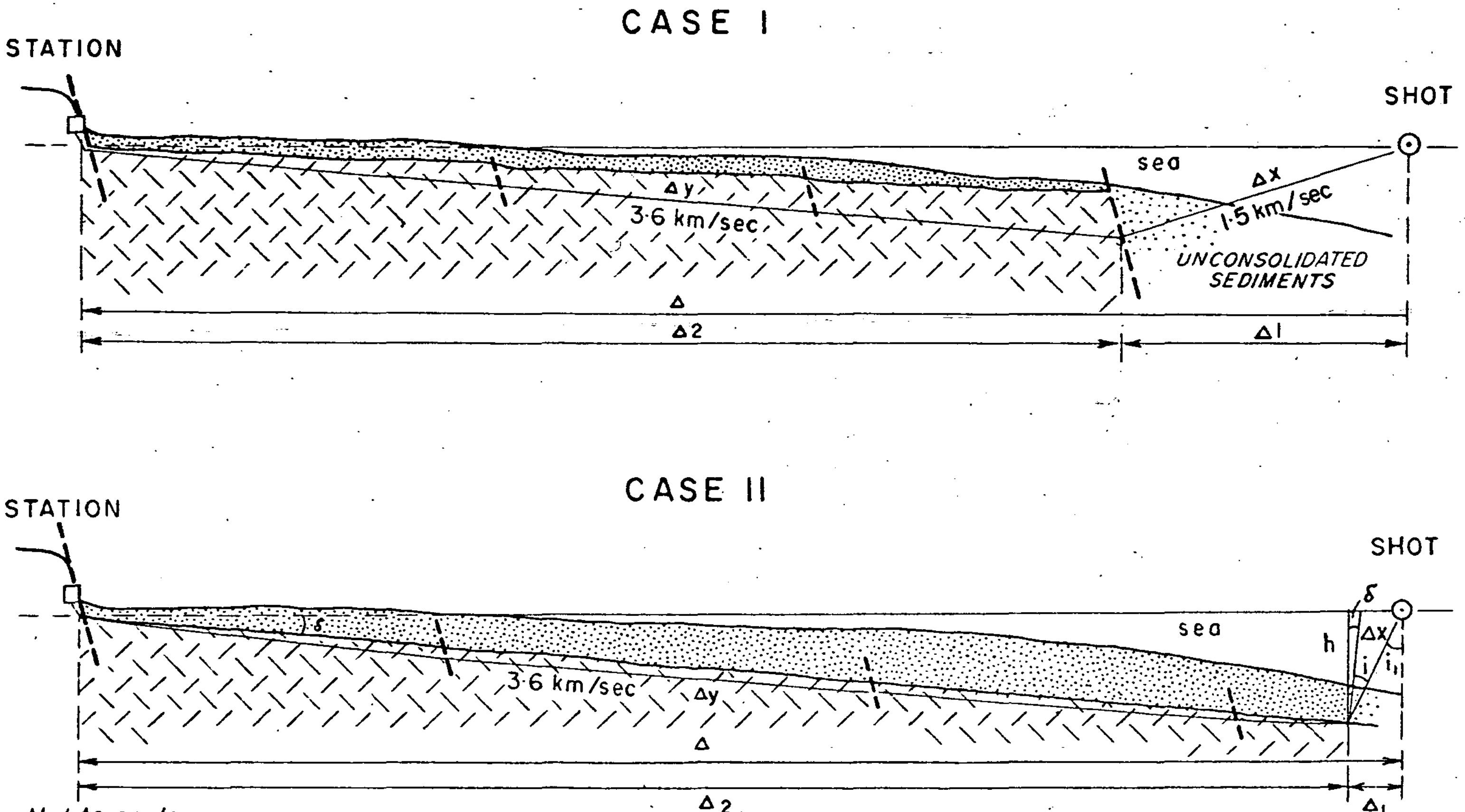
RAB Recording station

□(2.1) Longitudinal wave apparent velocity km/s

To accompany Note on Investigation 70502

B 56/A2/77

PLATE 4



Not to scale

Δ *Distance shot-station*

Δ_x *Path length in water and unconsolidated sediments* $\Delta_1 = \Delta x$ *horizontal projection*

Δ_y *Path length in bedrock* $\Delta_2 = \Delta y$ *horizontal projection*

h *Refractor depth at refraction point*

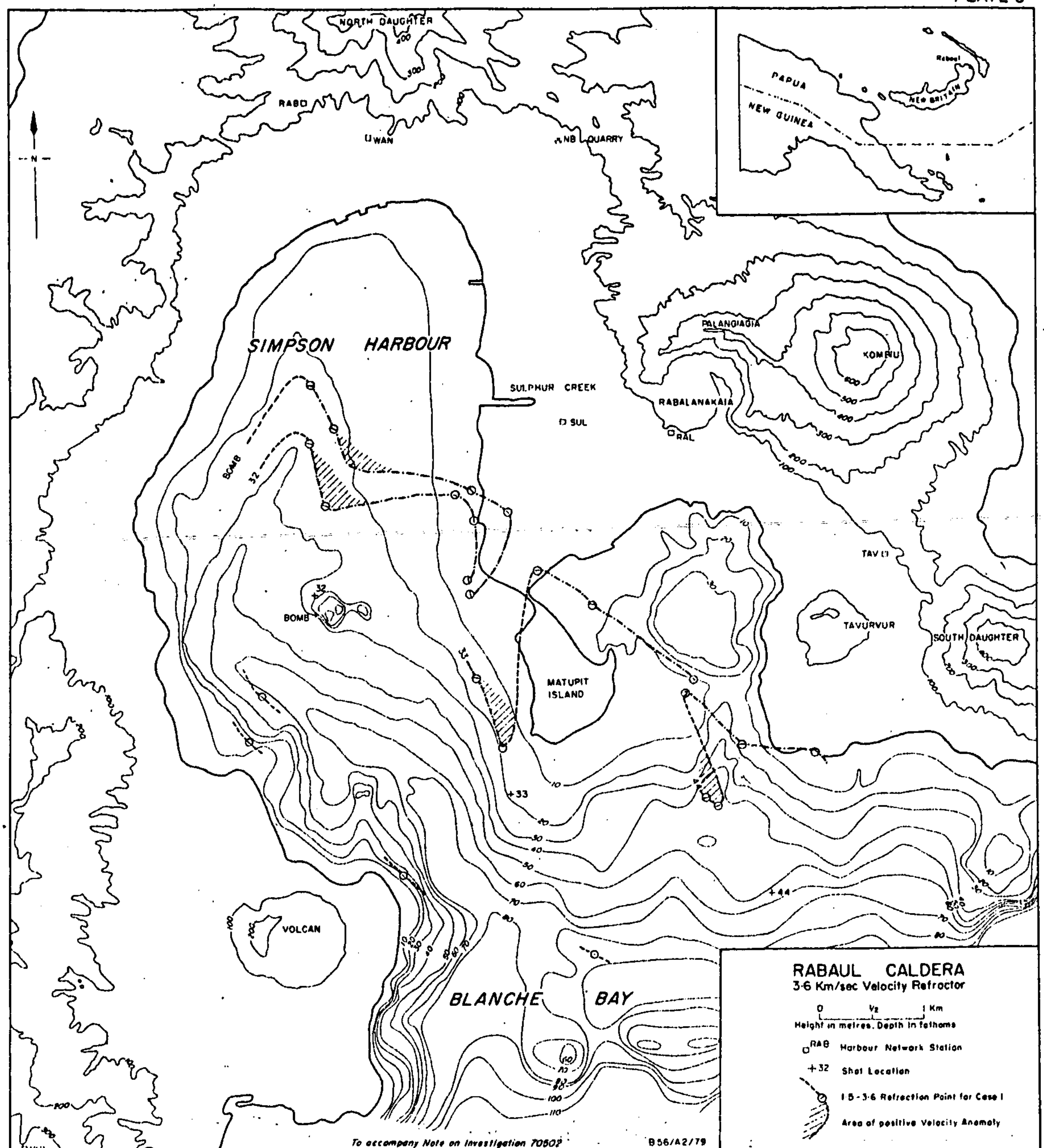
δ *Bedrock dip angle,* i *- refraction angle,* i_1*-wave ray emergent angle*

One or both cases are assumed to occur in the Rabaul Caldera

To accompany Note on Investigation 70502

B56/A2/78

PLATE 5



NORTH DAUGHTER
RABO
WAN
NB QUARRY
SIMPSON HARBOUR
SULPHUR CREEK
SUL
PALANGIAGIA
KOMBIU
RABALANAKAIA
RAL
TAV
TAVURVUR
SOUTH DAUGHTER
MATUPIT ISLAND
BOMB
VOLCAN
BLANCHE BAY
VUL
PAPUA
NEW GUINEA
NEW BRITAIN
Rabaul
RABAUL CALDERA
3·6 Km/sec Velocity Refractor
0 ½ 1 Km
Height in metres. Depth in fathoms
RAB Harbour Network Station
+32 Shot Location
1·5 - 3·6 Refraction Point for Case I
Area of positive Velocity Anomaly
To accompany Note on Investigation 70502
B56/A2/79

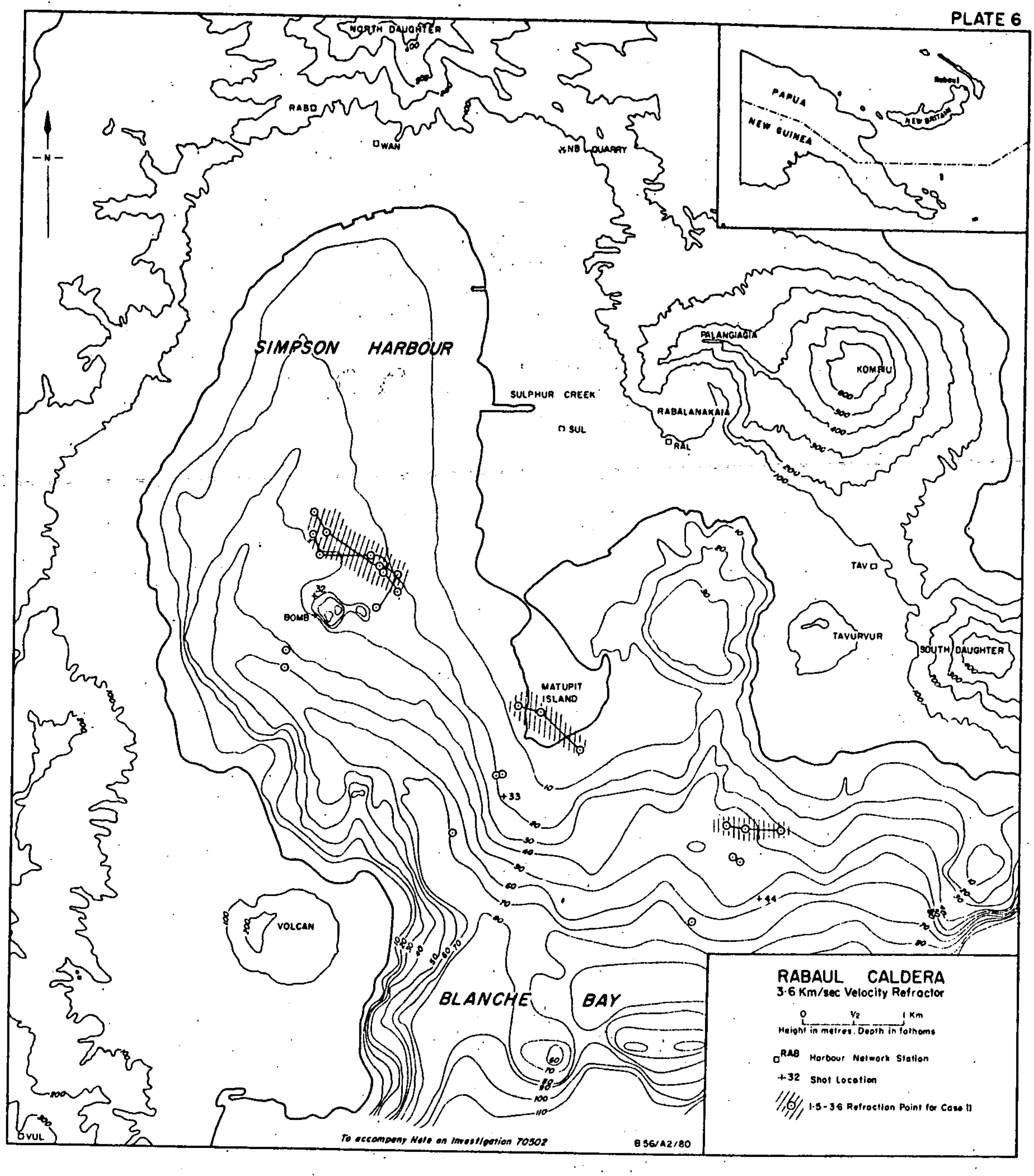


PLATE 6
PAPUA
NEW GUINEA
NEW BRITAIN
Rabaul
NORTH DAUGHTER
RABO
WAN
NB QUARRY
N
SIMPSON HARBOUR
SULPHUR CREEK
SUL
PALANGIAGIA
RABALANAKAIA
RAL
KOMBIU
TAV
TAVURVUR
SOUTH DAUGHTER
BOMB
MATUPIT ISLAND
+33
+44
VOLCAN
BLANCHE BAY
VUL
RABAUL CALDERA
3·6 Km/sec Velocity Refractor
0 ½ 1 Km
Height in metres. Depth in fathoms
RAB Harbour Network Station
+32 Shot Location
1·5-3·6 Refraction Point for Case II
To accompany Note on Investigation 70502
B 56/A2/80