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Record No. 1969 / 101

A Study of Observed Azimuths of New Guinea Earthquakes Recorded at Port Moresby

by

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SUMMARY

This study of large first arrivals recorded at Port Moresby from local earthquakes reveals lateral velocity contrasts in the upper mantle causing systematic changes in the P residual and the measured azimuth as observed from first-motion analysis.

Improvements in the epicentral location of local earthquakes, based on this analysis, are described. It was not possible to use these techniques for improving depth determinations.

1. INTRODUCTION

The azimuth of an earthquake with respect to the recording station can be estimated from the amplitudes of the first motions of the three components on the seismograms. By combining this result with the distance of the event obtained from the S-P time interval, an approximate epicentre can rapidly be obtained from the records of only one station.

In the Territory of Papua and New Guinea, where potentially destructive earthquakes occur frequently, it is important to be able to locate rapidly any large earthquakes that may take place so that Civil Defence authorities can be advised promptly of any remote areas likely to need assistance. Inadequacies in the telecommunication arrangements at present existing in the Territory preclude the rapid transfer of P and S readings from local seismic stations, and it may take up to 24 hours to obtain from Honiara, Rabaul, Charters Towers, and other neighbouring observatories, arrival time necessary to compute an accurate epicentre. Usually the recordings at one station - in this case Port Moresby - provide the only available information on which to base an epicentral determination.

This study was undertaken to improve the accuracies of epicentres located in this manner and to investigate any possible lateral velocity discontinuties which may affect the azimuth of the first arrival as measured at this recording station.

2. METHOD

All the Worldwide Standard Seismograph Network (WWSSN) records from the beginning of 1963 through May 1968, apart from those out of the country for micro-filming, were closely examined for large local events that gave clear impulsive arrivals on all three components of the short-period instruments. In order for the event to be acceptable for this analysis four requirements had to be fulfilled; these were:

1. The epicentre of the earthquake had to be determined by the United States Coast and Geodetic Survey (USCGS) or the International Seismological Centre (ISC).

2. The times of the first motions on all three components had to agree to within the reading error of 0.1 second.

3. The times of the first peaks of all three components had to agree to within the reading error of 0.1 second.

4. The amplitude of at least one of the horizontal components had to be at lease 5.0 mm; sometimes this requirement was relaxed somewhat when the background noise was very low.

The amplitudes were normalised to correct for the different magnifications of each component, and the azimuth and angle of incidence of the first arrival were computed. Plate 1 shows how these quantities are defined.

3. ANALYSIS OF ERRORS

There are three errors involved when the azimuth computed from the epicentre of the earthquake (defined as the true azimuth) is compared with that measured from the amplitudes of the first motion of the three components (defined as the observed azimuth). These are:

(1) The error in the alignment of the seismometers.

(2) The error in the measurement of the amplitude due to to background noise and trace thickness.

(3) The error in the true azimuth (supplied by USCGS or ISC) due to the errors associated with the epicentral determination.

At Port Moresby the error in the alignments of the N-S and E-W seismometers is probably well within one degree. The instrument pier was accurately surveyed by officers of the Department of National Mapping, and the only errors likely to be present are due to the vibrational axis of the seismometer not coinciding with the geometrical axis. This error should be well within one degree.

An estimate of the error in the measurement of the azimuth due to background noise and trace thickness can easily be made as follows. The azimuth is given by:

$$\tan \theta = e/n \quad \ldots\ldots\ldots\ldots(1)$$

where e and n are the amplitudes of the first peaks on the E-W and N-S components.

Since the errors in e and n are independent of each other (phase-wise) the error in tan θ will be given to a first approximation by:

$$\frac{\delta(\tan\theta)}{\tan\theta} \simeq \sqrt{\left(\frac{\delta e}{e}\right)^2 + \left(\frac{\delta n}{n}\right)^2} \quad \ldots\ldots\ldots(2)$$

For ease of computations both δe and δn were taken as 0.5 mm. In some cases when the traces were very quiet the error is probably slightly smaller than this but taken as an average overall the measurement 0.5 mm is considered to be a good estimate. The error in the angle of incidence may be calculated by a similar process.

The error in the true azimuth is more difficult to estimate. Although limits for latitude and longitude are given in the USCGS PDE sheets these are really a measure of the consistency of the calculation rather than an error in the position of the epicentre. In general the error associated with the determination of an epicentre will depend on the number of stations that record the first arrival, the applicability of the travel time tables used, the distribution of the stations with respect to the epicentre, and the source function at the origin.

For ease of compution it was decided to adopt an error of $\pm$ 0.1 degree for the epicentres of all the earthquakes analysed. This is probably an optimistic estimate for the pre-1966 events, but should be of the right order of magnitude for the 1966-1968 results because of the establishment of more local stations in 1966.

4. RESULTS

Plate 5 shows the locations of all the earthquakes used in the analysis. Most of the events originate in the New Britain Arc region, where the first motion recorded at Port Moresby is predominantly a dilatation. Those associated with the New Guinea mainland trend (which dips in the opposite direction - to the south) predominantly give a compression at Port Moresby. The lack of events west of 144°E probably indicates that Port Moresby is near a nodal plane for earthquakes in that region.

Only three events deeper that 300 km were used; all three gave compressional first motions at Port Moresby, an opposite polarity to the earthquakes situated at shallower depths in the same trend. This change in observed polarity of first motion is typical of all deep shocks in the Papua-New Guinea region, and all earthquakes with a depth greater than 300 km that have been observed to date give a compressional first motion at Port Moresby.

Table 1 lists all the earthquakes analysed. The errors quoted were determined by the methods described in the previous section. The last column on the right gives the sources of the data. These were either USCGS Data Reports or ISC Bulletins.

Plate 2 shows the variation of P residual with the true azimuth of the arrival. The mean P residual when the results are averaged over the whole azimuth range is less than 0.1 seconds, but as can be seen from Plate 2 there is a definite P residual dependence on azimuth. Between 320 and 360 degrees and between 50 and 100 the residual is usually negative; between 20 and 50 degrees the residual is usually positive. Elsewhere the residual is approximately zero.

Only three residuals were greater than 2 seconds. These were due to two shallow events in New Britain for which residuals of +2.7 and +2.8 seconds were obtained, and a deep event in East New Guinea which gave a residual of -3.8 seconds. An inspection of the seismograms confirmed the readings made originally.

Plate 3 shows the azimuth correction (the difference: true minus observed azimuth) plotted against the true azimuth. Between 350 degrees and 60 degrees most of the points are well grouped, indicating a definite trend. The thick line is an estimate of the mean curve through the points. Between 320 and 350 degrees there are too few points to establish any definite trend but there is a suggestion of a discontinuity in the curve at about 350 degrees when the correction appears to change from about -7 degrees to +13 degrees.

The region of the curve between 10 degrees and 60 degrees can be explained if a lateral velocity contrast of about 4½ percent exists in the upper mantle between the W and E sides of the Owen Stanley Ranges, with the higher velocity on the western side. The negative difference in angles between 350 and 10 degrees and the possible discontinuity at 350 degrees has no obvious explanation; however, it is clear that lateral inhomogeneity in the upper mantle exists along the wave paths for earthquakes from these regions. Using the thick line as a mean difference curve a correction can be applied to the measured azimuth to give a better estimate of the location of the earthquake. Table 2 shows these results.

The S-P time interval gives an estimate of the distance of the shock, and the measured amplitudes give the direction. The estimate of the depth of an earthquake from a single station is a difficult problem. The apperance of the seismogram usually indicates whether the shock is shallow, and the location of the event in relation to known earthquakes that have previously occurred in the region gives a general indication of the depth, but an accurate quantitative estimate is difficult to obtain.

In an effort to improve this position the apparent angle of incidence was measured for each suitable earthquake listed in Table 1, and this was plotted against the distance of the earthquake from the recording station. If the mantle and crustal material is homogeneous then it should be possible to determine the depth of shock for a given angle of incidence at a given distance.

Plate 4 shows the results of the plot of angle of incidence against distance and it is clear that there is no simple relation for these earthquakes. This is probably due to lateral velocity changes in the crust and upper mantle and to the fact that the results represent earthquakes from a wide range of azimuth.

5. CONCLUSIONS

The study of large first arrivals recorded at the Port Moresby Geophysical Observatory indicates lateral changes of velocity in the crust and the upper mantle.

This results in a dependence of the P residual on the azimuth of the earthquake and also a difference between the observed azimuth as measured from the seismograms and the calculated azimuth as computed geometrically from the station and earthquake co-ordinates. A correction table has been developed for improving the epicentral locations based on the Port Moresby records but no appreciable improvement in depth determinations could be derived.

TABLE I

EARTHQUAKES ANALYSED

Date	Origin Time	Lat °S	Long °E	Depth km	CGS Mag	Δ°	Trace Amplitudes in mm. Z	N-S	E-W	Azimuth in Degrees Calculated by U.S.C.G.S.	Measured Azimuth	Difference	Angle of Incidence	P Residual Seconds	PDE No.
12.2.63	17 43 59.2	6.7	147.1	120	4.8	2.7	u *	s 44.5	e 2.0	358.8 ± 2.1	357.5 ± 0.6	+1.3 ± 2.2	-	+1.5	14
27.2.63	04 30 00.8	6.0	149.4	52	5.2	4.1	d 132.0	n 58.5	e 33.8	33.1 ± 1.4	30.3 ± .4	+2.8 ± 1.5	27.2 ± 0.4	-0.1	19
13.5.63	22 48 10.3	6.0	150.1	94	4.8	4.0	d *	n 15.5	e 11.2	40.9 ± 1.4	36.9 ± 1.5	+4.0 ± 2.0	-	-	-
20.11.63	04 07 22.6	5.5	148.2	201	5.2	4.0	u 74.0	s 30.7	w 7.6	14.6 ± 1.5	14.0 ± 0.9	+0.6 ± 1.7	23.6 ± 1.4	+0.6	95
06.12.63	01 56 42.8	5.8	150.3	61	5.3	4.7	d 18.0	n 6.3	e 5.5	41.2 ± 1.2	39.7 ± 3.4	+1.5 ± 3.5	35.0 ± 3.3	-0.1	102
27.12.63	11 57 27.4	6.1	146.9	102	5.4	3.3	u -	s 64.7	e 0.0	355.2 ± 1.7	360.0 ± 0.5	-4.8 ± 1.8	-	+1.2	104
12.1.64	11 13 19.6	5.4	146.8	229	5.6	4.0	d 21.0	n 8.8	e 0.2	355.0 ± 1.5	1.3 ± 3.2	-6.3 ± 3.5	24.6 ± 1.3	-0.2	6
24.1.64	02 40 00.1	4.2	154.2	416	4.3	8.7	u 32.0	s 8.3	w10.1	53.0 ± 0.7	50.7 ± 2.2	+2.3 ± 2.3	23.6 ± 1.6	+1.1	9
28.1.64	05 43 23	6.21	148.84	34	5.2	3.6	d 36.0	n 17.6	e 9.0	28.0 ± 1.6	27.0 ± 1.4	+1.0 ± 2.1	28.6 ± 1.5	+1.2	ISRC
24.4.64	05 56 10.1	5.1	144.2	100	6.3	5.21	u 12.5	s 8.0	e 5.0	325.8 ± 1.1	328.5 ± 3.0	-2.7 ± 3.2	38.0 ± 3.4	-0.9	ISRC
27.4.64	04 21 15.9	8.6	148.1	110	4.5	1.2	d 51.0	n12.0	e14.0	48.3 ± 4.7	48.8 ± 1.6	-0.5 ± 5.0	20.4 ± 1.1	0.0	39
4.6.64	11 17 10.4	6.03	149.77	28	4.4	4.24	d 23.0	n10.0	e 7.0	38.0 ± 1.3	34.8 ± 2.3	+3.2 ± 2.6	27.8 ± 2.1	+1.3	ISRC
13.6.64	14 01 40.2	3.9	154.3	474	5.5	9.0	u 12.5	s 3.0	w 3.8	52.3 ± 0.6	51.6 ± 6.0	+0.7 ± 6.0	21.2 ± 3.8	+1.1	48
20.6.64	03 44 30.6	8.68	148.15	119	-	1.2	d 35.0	n 7.7	e 9.7	53.7 ± 4.8	51.7 ± 2.3	+2.0 ± 5.3	20.0 ± 1.5	0	54
10.7.64	21 48 42.5	8.54	147.90	127	-	1.1	d *	n15.0	e14.0	40.6 ± 5.2	44.4 ± 1.4	-3.8 ± 5.4	-	0	56
11.7.64	01 36 16.6	7.22	147.89	64	5.1	2.29	u 45.5	s22.0	w 5.0	18.0 ± 2.5	13.4 ± 1.3	+4.6 ± 2.8	26.2 ± 2.3	0	ISRC
9.8.64	03 13 00.2	6.30	147.73	76	4.4	3.14	d 14.0	n 6.5	e 1.0	10.0 ± 1.8	8.8 ± 4.4	+1.2 ± 4.8	25.3 ± 3.3	-1.0	ISRC
23.8.64	15 24 03.7	6.01	149.54	55	5.3	4.12	d 54.0	n26.2	e 20.0	35.0 ± 1.4	37.3 ± 0.8	-2.3 ± 1.6	31.9 ± 0.8	+0.3	ISRC
25.8.64	05 46 12.4	5.44	147.14	203	4.9	3.94	d 72.0	n 31.0	e 1.8	0.0 ± 1.5	1.8 ± 1.5	-1.8 ± 2.1	23.5 ± 0.5	-0.5	ISRC
30.8.64	08 47 34.8	4.97	144.41	94	5.2	5.18	d 11.5	n 6.5	e 5.0	328.0 ± 1.1	323.0 ± 3.5	+5.0 ± 3.7	36.1 ± 2.5	-2.0	ISRC
5.9.64	02 53 50.6	5.80	154.00	69	6.4	7.7	d 28.5	n 6.3	e14.7	61.8 ± 0.7	66.8 ± 1.8	-5.0 ± 1.9	27.6 ± 1.2	-1.1	69
6.9.64	20 34 22.2	4.72	144.78	76	5.7	5.2	d 10.0	n 6.8	w 2.5	333.3 ± 1.1	339.7 ± 10.6	-6.4 ± 10.7	36.3 ± 5.2	+0.1	70
12.9.64	12 43 19.0	4.42	144.02	120	6.3	5.9	d 12.5	n 6.8	w 4.0	328.0 ± 1.0	329.7 ± 3.6	-1.7 ± 3.7	32.5 ± 2.5	-3.8	75

EARTHQUAKES ANALYSED (cont'd)

Date	Origin Time	Lat ° S	Long ° E	Depth km	CGS Mag	Δ°	Trace Amplitudes in mm Z	N-S	E-W	Azimuths in Degrees: Calculated by U.S.C.G.S.	Measured Azimuth	Difference	Angle of Incidence	P Residual Seconds	PDE No.
12.10.64	20 13 54.0	5.55	147.13	195	5.5	3.8	d 28.0	n 11.7	e 0.8	359.7 ± 1.5	4.0 ± 2.5	-4.3 ± 2.9	23.2 ± 1.2	-0.7	81
05.11.64	04 19 39.5	5.46	147.16	197	4.9	3.9	d 78.5	n 14.8	e 0.8	0.1 ± 1.5	3.1 ± 2.0	-3.0 ± 2.5	10.5 ± 0.6	-	92
14.11.64	16 54 50.7	5.34	146.81	228	4.3	4.1	u 19.5	s 9.0	e 0	355.3 ± 1.4	0.0 ± 3.2	-4.7 ± 3.5	24.8 ± 1.3	-0.1	91
17.11.64	08 15 39.3	5.71	150.70	45	6.7	5.1	d 69.5	n 29.7	e 26.8	43.5 ± 1.1	42.5 ± 0.7	+ 1.0 ± 1.3	29.5 ± 0.4	-	92
18.11.64	14 34 54.5	6.00	148.22	49	6.1	3.5	d 92.0	n 57.5	e 14.0	17.3 ± 1.6	14.2 ± 0.5	3.1 ± 1.7	32.0 ± 0.3	+0.4	92
19.11.64	23 35 06.0	5.98	150.79	03	6.0	5.0	d 30.0	n 13.8	e 13.5	46.4 ± 1.2	45.5 ± 1.5	-0.9 ± 1.9	32.4 ± 1.0	+2.7	95
7.12.64	15 43 29.7	5.10	145.92	219	5.0	4.5	d 20.5	n 9.5	w 5.5	344.1 ± 1.3	329.9 ± 2.6	14.2 ± 2.9	28.3 ± 1.8	-0.6	97
10.1.65	07 37 35.1	5.78	147.30	113	6.5	3.6	u 39.0	s 18.2	w 0.5	2.5 ± 1.6	1.6 ± 1.6	+0.9 ± 2.3	25.0 ± 0.9	-0.7	3
14.1.65	08 28 45.3	6.16	149.88	63	5.6	4.2	d 32.0	n 12.6	e 7.7	39.8 ± 1.4	31.6 ± 1.0	+8.2 ± 1.7	24.7 ± 1.1	-0.4	4
4.3.65	01 48 54.1	5.39	146.97	191	6.4	4.0	d 55.0	n 32.7	w 0.0	357.3 ± 1.5	0 ± 1.2	-2.7 ± 1.9	28.7 ± 0.5	-0.6	24
6.5.65	14 24 04.3	6.05	149.13	74	6.0	3.9	d 50.0	n 19.5	e 12.7	30.3 ± 1.5	32.2 ± 1.0	-1.9 ± 1.8	24.8 ± 0.7	-0.1	45
19.7.65	08 51 35.0	6.88	147.37	62	5.7	2.5	u *	s 20.3	w 1.7	04.8 ± 2.3	04.8 ± 1.4	0 ± 2.7	-	1.1	61
5.8.65	00 07 50.5	5.27	151.70	47	6.3	6.1	d *	n 65.0	e 94.5	47.3 ± 0.9	54.7 ± 0.4	-7.4 ± 1.0	-	0.5	65
9.8.65	17 26 42.9	5.69	148.54	130	5.1	3.9	u 23.5	s 8.8	w 2.2	20.3 ± 1.5	14.2 ± 3.2	+6.1 ± 3.5	21.6 ± 1.5	-0.3	66
18.9.65	04 13 02.9	6.9	147.5	116	5.3	2.5	u 19.5	s 9.5	w 0.8	8.0 ± 2.3	4.8 ± 3.0	3.2 ± 3.8	26.0 ± 1.7	-	75
4.10.65	00 13 25.8	6.40	147.37	75	5.8	3.0	u *	s 31.8	w 2.5	4.1 ± 1.9	4.5 ± 0.9	-0.4 ± 2.1	-	-0.2	77
13.10.65	12 44 42.8	6.07	149.85	54	-	4.3	d 23.0	n 7.2	e 4.7	38.7 ± 1.3	33.3 ± 3.2	5.4 ± 3.4	21.9 ± 1.7	0.4	80
17.10.65	18 56 08.0	5.00	151.05	175	5.0	5.8	d 24.0	n 7.8	e 5.8	41.2 ± 1.0	36.8 ± 2.8	4.4 ± 3.0	14.5 ± 1.1	0.3	80
27.11.65	01 29 49.5	6.09	148.54	56	5.8	3.6	d 38.0	n 20.0	e 4.8	22.4 ± 1.6	13.3 ± 1.4	9.1 ± 2.1	27.9 ± 0.8	0.4	88
26.12.65	03 53 16.6	5.47	151.39	133	6.0	5.7	d 38.0	n 20.0	e 23.0	46.8 ± 1.0	49.9 ± 1.0	-3.1 ± 1.4	39.4 ± 1.9	-	95
22.2.66	05 02 37.2	5.40	151.55	28	6.2	5.9	d *	n 9.5	e 9.6	47.4 ± 1.0	45.2 ± 2.0	2.2 ± 2.2	-	2.8	12
24.2.66	20 08 57.0	6.10	147.44	59	5.5	3.3	d 29.5	n 16.8	e 1.0	5.0 ± 1.7	3.4 ± 1.6	1.6 ± 2.3	29.0 ± 1.0	-0.5	12
27.2.66	20 25 36.3	5.81	148.48	123	5.0	3.8	d 11.5	n 6.5	e 1.8	20.1 ± 1.5	15.3 ± 4.2	4.8 ± 4.4	29.6 ± 2.7	-0.7	12
16.3.66	10 58 53.9	6.19	149.07	56	5.0	3.7	u 10.0	s 5.1	w 3.0	30.5 ± 1.2	30.6 ± 4.8	-0.1 ± 4.9	31.4 ± 1.3	0.3	17
26.3.66	22 13 22.2	5.74	149.31	110	5.0	4.2	u 31.0	s 13.0	w 4.5	30.2 ± 1.4	20.1 ± 2.2	10.1 ± 2.6	24.7 ± 1.2	-0.2	18

EARTHQUAKES ANALYSED (cont'd)

Date	Origin Time			Lat ° S	Long ° E	Depth km	CGS Mag	Δ°	Trace Amplitudes in mm Z	N-S	E-W	Azimuths in Degrees Calculated by USCGS	Measured Azimuth	Difference	Angle of Incidence	P Residual secs	PDE No.
1.4.66	05	21	09.7	5.78	149.13	112	6.1	4.1	d 12.0	n 4.7	e 1.7	28.4 ± 1.4	19.7 ± 6.4	8.7 ± 6.6	23.1 ± 3.0	-0.2	20
5.4.66	18	59	54.1	5.94	147.61	61	5.2	3.5	d 13.0	b 6.6	e 1.2	7.4 ± 1.5	10.2 ± 4.2	-2.8 ± 4.5	27.9 ± 2.6	-0.6	21
2.5.66	09	52	48.5	5.98	149.72	52	5.2	4.3	d 33.0	n 12.0	e 9.0	36.5 ± 1.3	37.8 ± 1.9	-1.3 ± 2.3	23.9 ± 1.0	+0.4	27
10.6.66	12	15	05.7	6.11	149.81	53	5.0	4.2	d 11.0	n 4.0	e 4.7	38.6 ± 1.4	50.0 ± 4.2	-11.4 ± 4.4	23.2 ± 2.5	+0.9	40
26.8.66	12	01	17.8	7.34	147.59	68	5.1	2.1	d 13.0	n 5.7	e 1.5	11.8 ± 2.7	14.1 ± 3.0	-2.3 ± 4.0	24.7 ± 2.7	0.7	61
11.9.66	07	03	18.1	6.28	147.34	78	5.3	3.1	d 17.0	n 10.7	w 0	3.4 ± 1.8	0 ± 3.7	3.4 ± 4.1	29.3 ± 1.7	-1.0	66
6.10.66	03	11	03.3	6.24	146.38	113	5.5	3.2	u *	s 36.2	e 18.9	346.3 ± 1.8	332.7 ± 0.6	13.6 ± 1.9	-	-0.9	71
25.10.66	00	26	36.5	6.64	147.23	67	5.3	2.8	d 22.5	n 12.9	w 0	1.7 ± 2.0	0 ± 3.0	+1.7 ± 3.6	29.8 ± 1.4	-	78
27.10.66	22	26	20.5	7.40	146.89	137	5.1	2.0	d 47.0	n 21.5	w 0.5	352.7 ± 2.9	1.4 ± 1.4	-8.7 ± 3.2	24.6 ± 0.5	-0.5	77
25.11.66	20	57	56.7	8.44	147.67	14	-	1.1	u 44.0	s 30.6	w 15.6	27.9 ± 5.1	27.5 ± 0.8	+0.4 ± 5.2	37.4 ± 0.6	0.0	87
22.1.67	14	21	44.0	8.00	147.85	87	5.3	1.6	u 18.5	s 7.2	w 3.6	26.0 ± 2.2	26.5 ± 3.5	-0.5 ± 4.1	23.9 ± 1.9	-0.1	7
3.2.67	16	27	45.0	5.45	146.95	198	4.7	3.9	d 16.0	n 7.0	e 0.5	357.0 ± 1.5	4.3 ± 4.3	-7.3 ± 4.6	22.2 ± 2.0	-0.5	18
18.2.67	02	39	19.4	5.90	153.17	41	5.5	6.9	u 13.5	s 3.0	w 6.0	59.3 ± 0.8	61.9 ± 4.0	-2.6 ± 4.1	26.4 ± 2.5	-0.6	12
20.3.67	08	47	47.5	6.19	148.26	52	5.1	3.4	u 13.5	s 6.3	w 1.0	18.8 ± 1.7	9.2 ± 4.6	9.6 ± 4.9	25.3 ± 2.5	+0.2	20
24.4.67	18	52	21.3	6.05	148.54	63	5.1	3.6	d 13.0	n 6.0	e 2.5	22.3 ± 1.6	22.6 ± 4.4	-0.3 ± 4.7	26.3 ± 2.5	+0.3	28
13.6.67	15	39	29.7	5.58	148.12	213	5.4	3.9	d 20.0	n 6.8	e 2.0	14.0 ± 1.5	15.3 ± 3.8	-1.3 ± 4.1	19.5 ± 1.8	0.2	39
22.6.67	14	04	23.9	5.78	147.66	33	5.3	3.6	d 9.0	n 5.0	e 0.5	7.8 ± 1.6	5.4 ± 5.5	2.4 ± 5.7	30.1 ± 3.6	0.5	42
26.6.67	15	35	20.4	7.83	147.27	32	5.4	1.6	u *	s 52.0	e 2.7	4.1 ± 2.2	2.6 ± 0.5	1.5 ± 2.2	-	1.0	44
14.11.67	05	28	36.9	5.43	147.01	201	5.8	4.0	d(at CGS)	n 26.8	e 4.8	358.8 ± 1.5	10.1 ± 1.0	-12.3 ± 1.8	-	0.8	69
17.11.67	09	19	21.0	6.30	154.95	60	5.1	8.3	d 7.0	n 1.0	e 3.8	67.7 ± 0.7	75.2 ± 9.0	-7.5 ± 9.0	29.5 ± 5.0	-0.5	79
21.11.67	07	01	42.0	5.47	147.05	204	4.7	3.9	d 9.5	n 4.8	e 0.2	358.5 ± 1.5	2.4 ± 5.9	-3.9 ± 6.1	26.8 ± 3.4	-0.8	78
13.12.67	20	48	02.2	5.03	149.71	382	4.9	5.0	u 15.0	s 4.8	w 2.9	30.1 ± 1.1	31.4 ± 5.2	-1.3 ± 5.3	20.4 ± 2.0	0.8	76
14.12.67	23	27	39.7	5.09	151.15	150	5.1	5.8	d 18.5	n 6.0	e 6.2	42.5 ± 1.0	46.2 ± 3.2	-3.7 ± 3.4	25.0 ± 1.9	-0.4	77
25.12.67	01	23	33.6	5.28	153.67	64	5.7	7.7	d 29.5	n 9.0	e 17.0	57.2 ± 1.7	62.1 ± 1.5	-4.9 ± 2.3	29.9 ± 1.0	-0.6	81
7.1.68	09	56	40.3	5.07	153.93	118	5.6	8.0	d 17.0	n 5.0	e 9.0	56.9 ± 0.7	61.1 ± 2.8	-4.2 ± 2.8	31.3 ± 1.8	+0.7	2

EARTHQUAKES ANALYSED (cont'd)

Date	Origin Time			Lat °S	Long °E	Depth km	CGS Mag	Δ°	Trace Amplitudes, mm Z	N-S	E-W	Azimuths in Degrees: Calculated by USCGS	Measured Azimuth	Difference	Angle of Incidence	P Residual secs	PDE No
21.1.68	22	55	35.8	5.02	150.81	185	5.0	5.7	d 40.0	n 13.0	e 10.3	39.6 ± 1.0	39.2 ± 1.7	+0.4 ± 2.0	23.2 ± 0.9	1.1	6
22.1.68	18	16	49.8	9.85	148.96	27	5.3	1.8	d 59.0	s 8.8	e 28.5	103.5 ± 3.2	106.5 ± 0.9	-0.8 ± 3.3	27.9 ± 0.5	-0.8	6
9.3.68	03	19	23.7	5.56	154.01	86	5.7	7.8	d 29.5	n 5.2	e 14.0	60.2 ± 0.8	68.6 ± 2.0	-8.4 ± 2.2	26.5 ± 1.1	-0.8	12
4.4.68	09	12	10.5	5.30	154.00	96	4.9	8.8	d 15.5	n 3.9	e 7.0	62.5 ± 0.7	59.1 ± 3.7	+3.4 ± 3.8	27.3 ± 2.1	-	20
13.4.68	17	33	11.0	5.44	146.86	225	5.0	4.0	d 12.0	n 5.5	0	355.8 ± 1.5	[illegible].0 ± 6.9	-4.2 ± 7.0	24.7 ± 3.2	-1.4	20

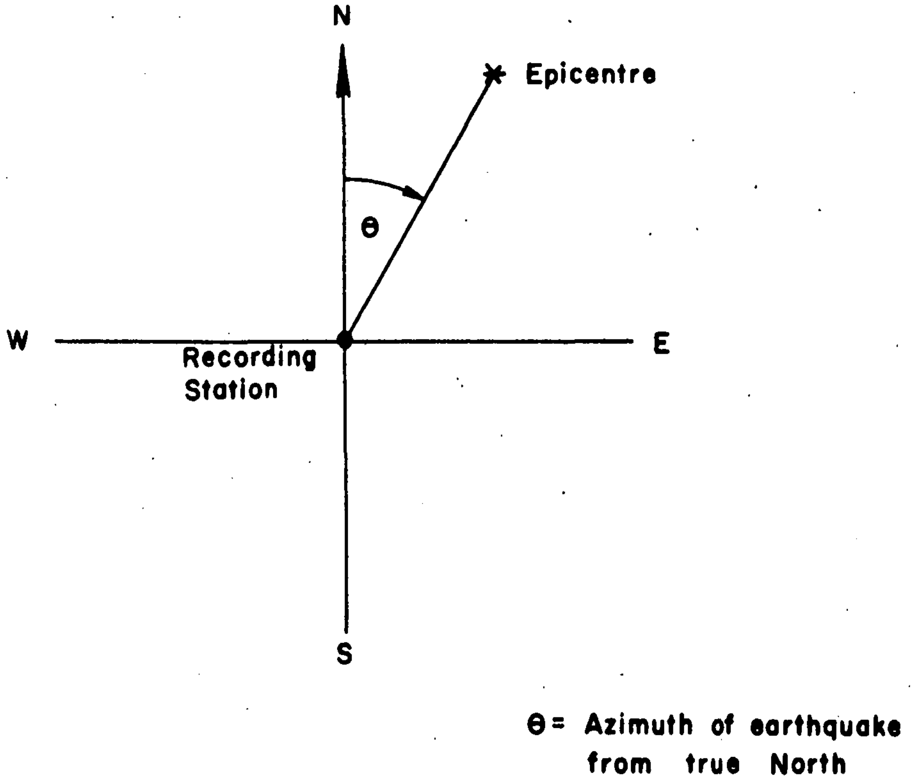
* : Trace off Record

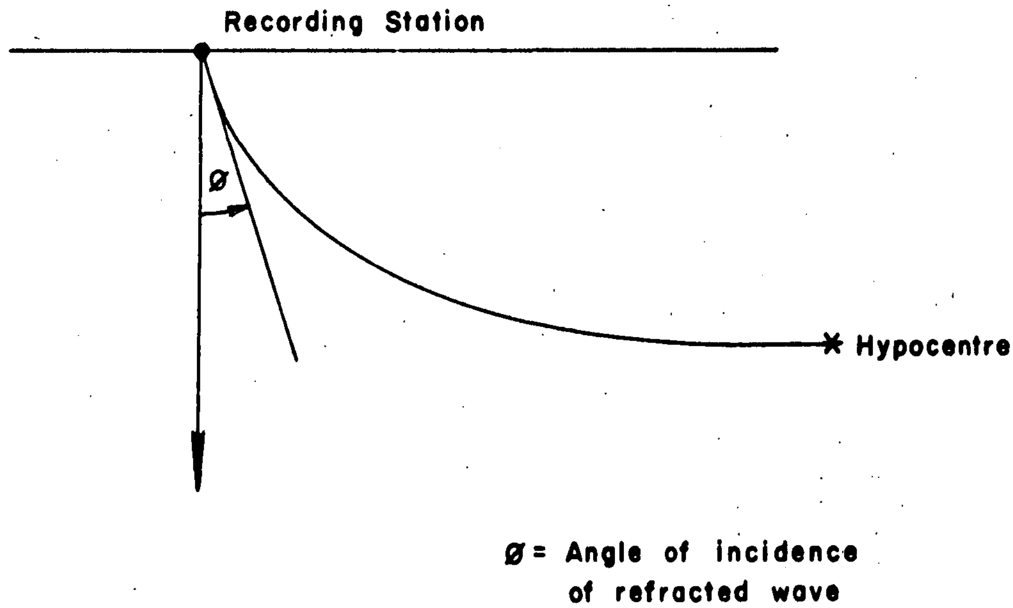
TABLE 2

CORRECTION TO BE APPLIED TO OBSERVED AZIMUTH

All readings in degrees		
Observed Azimuth from 1st Motion Measurements	Correction	Corrected Azimuth
345	+7	352
350	+5	355
355	+3	358
360	+1	01
05	0	05
10	-1	09
15	-2	13
20	-3	17
25	-4	21
30	-5	25
35	-4	34
40	-1	39
45	+2	47
50	+5	55
55	+6	61

PLATE 1





Azimuth angle and angle of incidence

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P residual dependence on azimuth

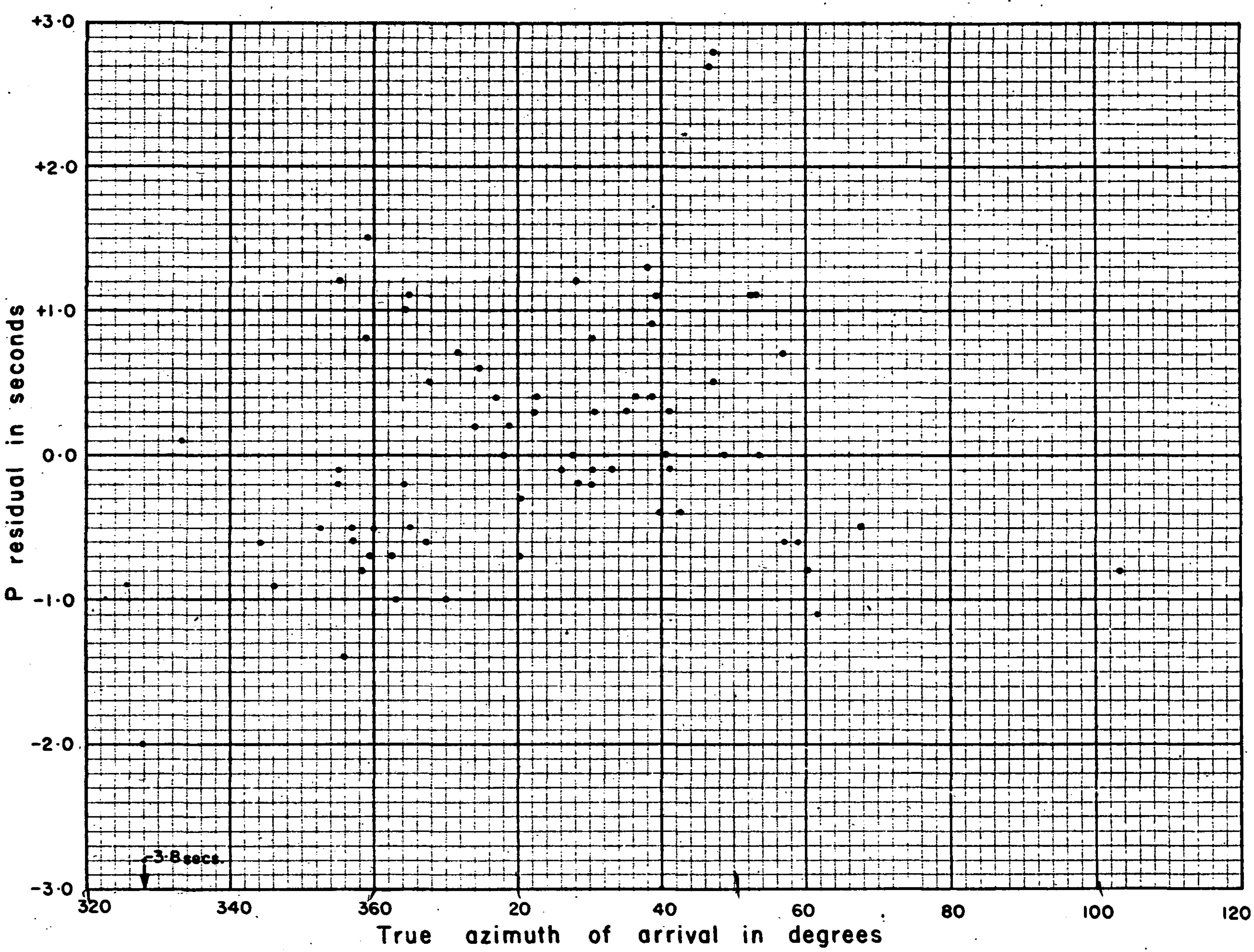

PLATE 2

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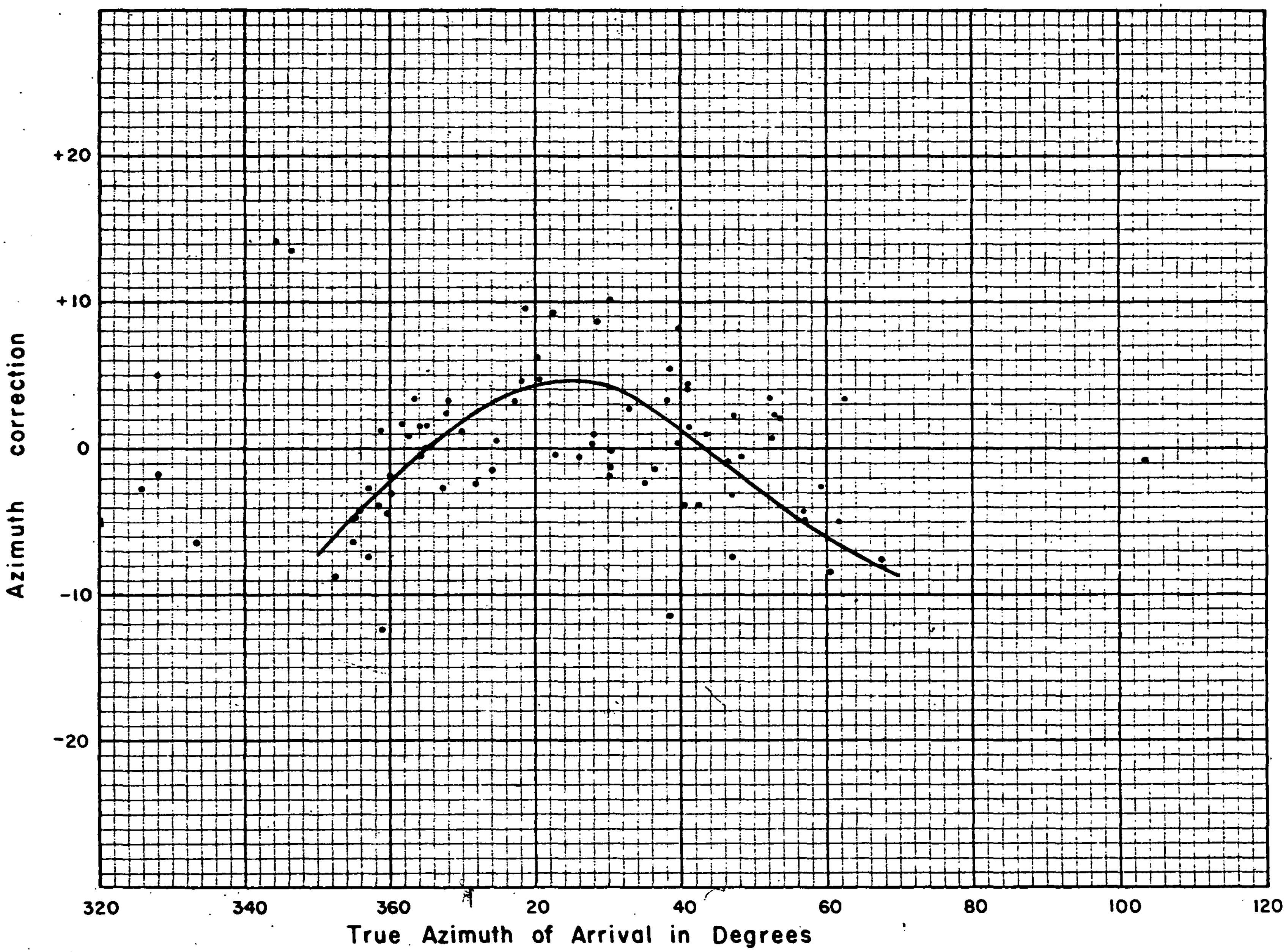

Plot of azimuth correction versus azimuth

PLATE 3

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Plot of observed angle of incidence against distance

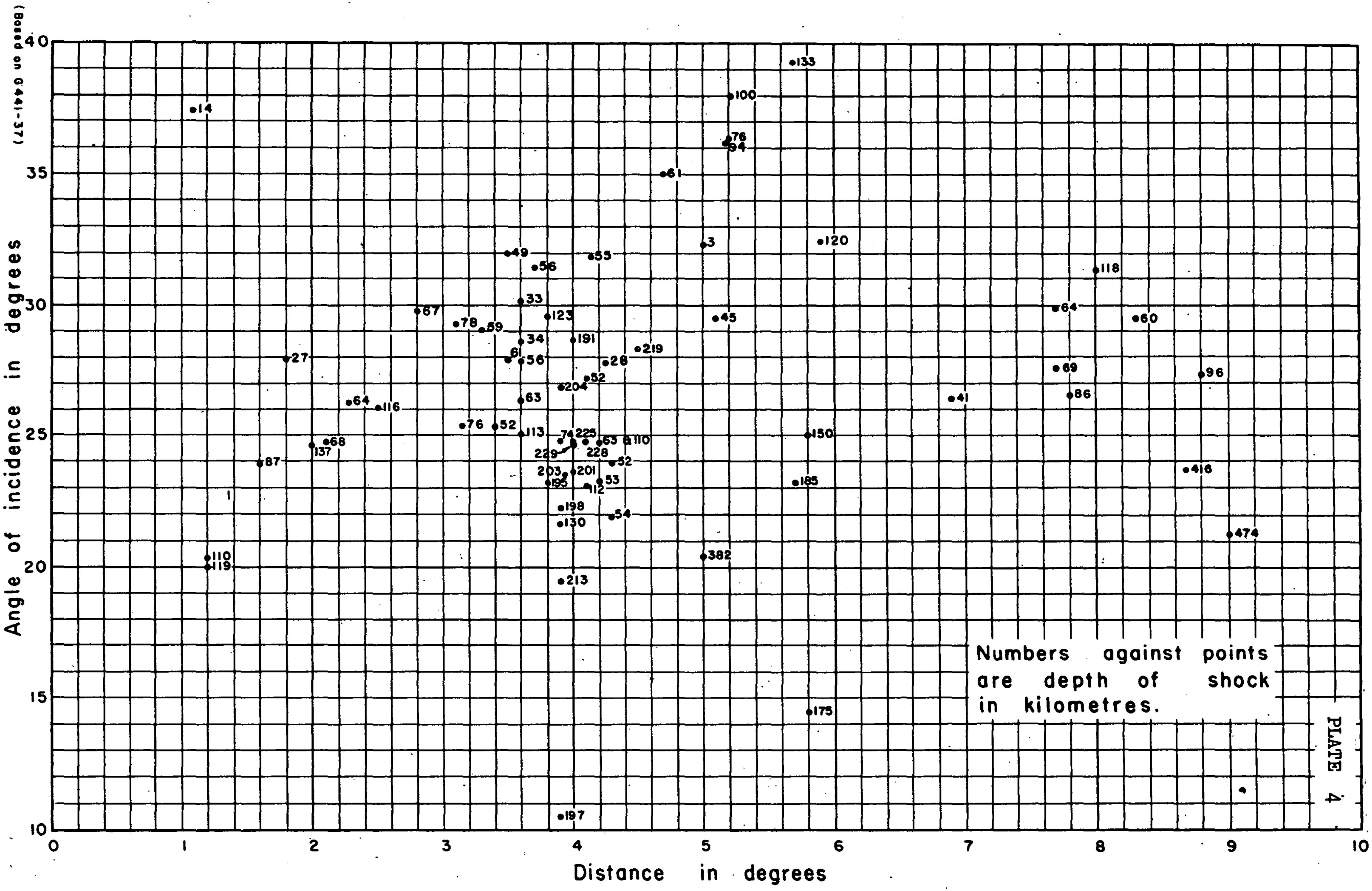

PLATE 4

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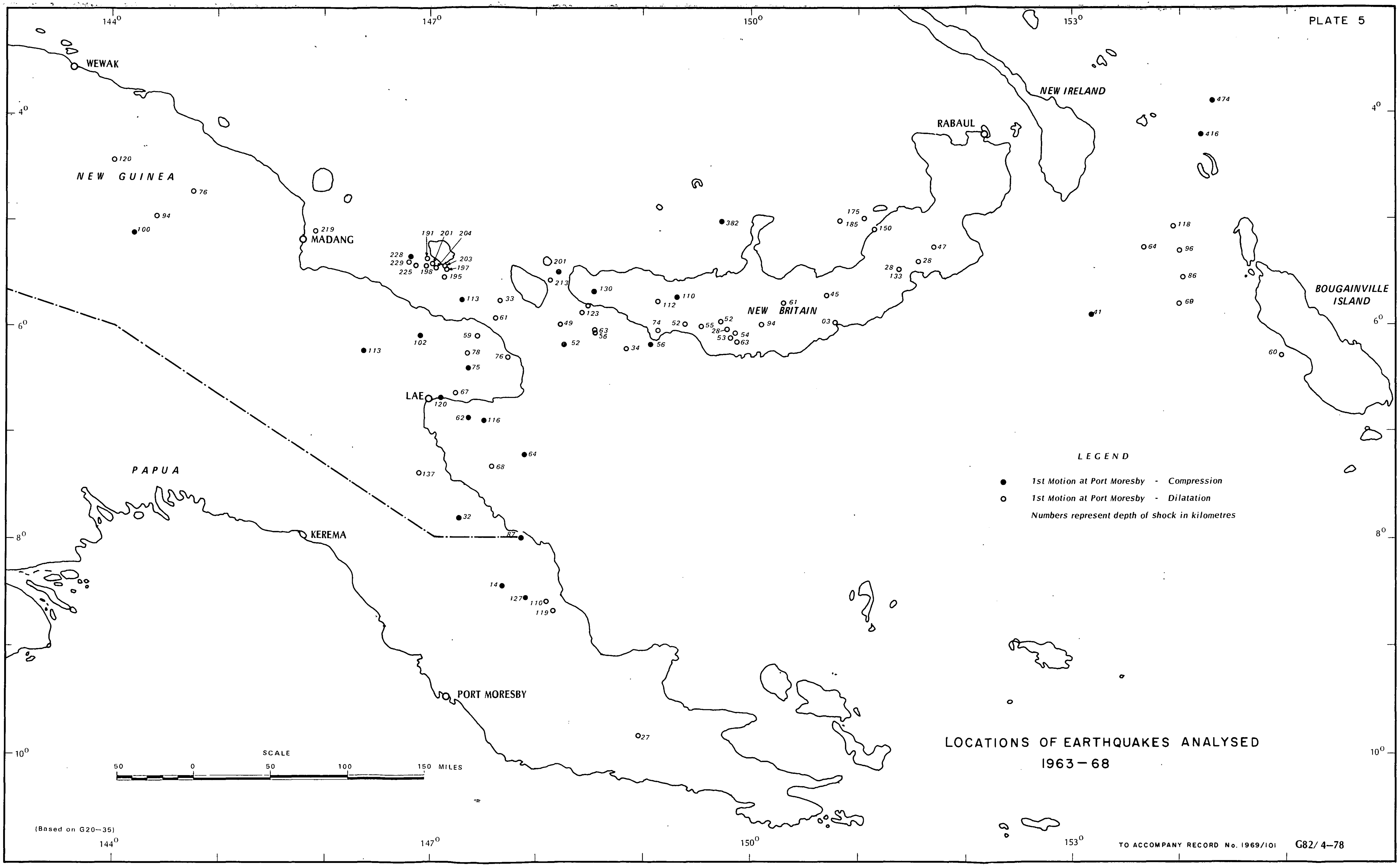
PLATE 5



LOCATIONS OF EARTHQUAKES ANALYSED
1963 – 68

TO ACCOMPANY RECORD No. 1969/101 G82/4-78