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PROPOSED INVESTIGATIONS OF CRUSTAL STRUCTURE IN NEW GUINEA

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CONTENTS

ILLUSTRATIONS

SUMMARY

It is proposed to investigate the crustal structure of New Guinea by observing and analysing the phase-velocity dispersion characteristics of Rayleigh waves from distant earthquakes. Data must be observed with the highest possible precision to ensure close evaluation of crustal parameters by the numerical inversion method of Dorman and Ewing.

Auxiliary data to use when interpreting phase velocities are being sought through a synoptic study of local earthquake arrival times and group-velocity dispersion. The first results of this study, relating to mainland New Guinea, are analysed. These indicate a considerable crustal thickening under the axis of the main mountain range.

There are indications also of regional variations of P_n velocity to which close attention will be necessary in the future.

1. INTRODUCTION

The substance of this Record was presented by one of the authors (JAB) at the Symposium on Crustal Seismology, University of Tasmania, in August 1964.

So far, few publications have dealt quantitatively with the gross crustal structure of New Guinea. Most of what is known has emerged as a by-product of extensive geological and geophysical survey work undertaken both in the western and eastern sections of the island, and is mainly confined to the upper five kilometres or so of the Earth's crust.

Of special interest is a hypothetical profile of the lower crustal boundary from the southern to the northern coast of West New Guinea (Visser & Hermes, 1962) inferred from Bouguer gravity anomalies. Regional anomalies range from about +100 to less than -100 milligals and are associated with crustal thicknesses ranging from 10 to 20 kilometres off the north coast to about 40 kilometres under the Van Rees Mountains and the central range areas, thinning to 30 kilometres or more under the plains of southern New Guinea.

Extensive thicknesses of sediments extending to the top of the crystalline basement at depths of five or more kilometres are known (loc. cit.). Similar extensive sedimentary basins also predominate in Papua south of the Highlands (Australasian Petroleum Company Pty Ltd, 1961).

Thus, apart from the overall picture of regional instability apparent from the high seismicity, there is already enough evidence to suggest extensive variations in gross crustal structure within New Guinea.

Almost no deductions have yet been made from a study of earthquake waves within the region.

Some inferences as to the probable broad characteristics of the crust both north and south of New Guinea have been drawn. The areas immediately to the north and south of the island are marginal to the main Pacific Basin. Kuo et al (1962), in discussing broad categories of crustal structure in the Pacific Basin that are inferred from Rayleigh wave group-velocity analyses, commented that the Melanesian-New Zealand area west of the Andesite Line showed distinctly different characteristics from the Pacific Basin proper. Specifically, they noted that the path between the Banda Sea and Fiji represented neither a typically oceanic nor a typically continental structure.

A comprehensive study of group-velocity dispersion observed over a number of intersecting paths in and around the Pacific led Santo (1963) to infer that the crust immediately to the north and south of New Guinea was chiefly continental in broad characteristics.

Neither survey provided enough data for the authors to make quantitative estimates of crustal thickness.

Doyle and Webb (1963) studied the residuals of P_n arrivals at both Rabaul and Port Moresby from Pacific nuclear explosions and concluded that these data were consistent with a 'continental type' crust beneath Port Moresby and an 'island type' crust beneath Rabaul.

The most economical means to seek further quantitative information on the gross crustal structure in the areas is to make use of earthquake surface waves, and therefore it is proposed to study the crustal structure throughout the Territory of Papua and New Guinea by observing the dispersion of, primarily, the phase velocities of Rayleigh wave trains from distant earthquakes and by determining the characteristics of the crustal layers that best fit these observations.

The necessary equipment for the project is now being assembled and the purpose of this paper is to discuss the design of the experiment and the factors governing the interpretation of results, and to offer an early comment on body wave and group-velocity data now being collected.

2. METHODS OF ANALYSIS

Earthquake surface wave dispersion data are useful for two main purposes :

(1) They describe the transmission characteristics of a portion of the Earth and thus assist deductions that depend on wave transmission through that region; otherwise, the transmission characteristics must be assumed.

(2) Crustal dimensions can be evaluated from them fairly accurately, provided some independent knowledge of the density and velocity distributions is available.

The dispersive characteristics of Rayleigh waves with periods below about 60 seconds are governed by the elastic properties of each of the crustal layers and the underlying upper mantle, which together form their wave guide.

In the case of (m-1) layers overlying an infinitely thick mantle, the phase velocity is

$$c = f(T, h_j, \alpha_j, \beta_j, \rho_j, \alpha_m, \beta_m, \rho_m); \quad j = 1 \ldots (m-1)$$

where T is the wave period
h_j is the thickness of crustal layer j
α_j is the compressional velocity of layer j
β_j is the shear velocity of layer j
ρ_j is the density of layer j

The subscript m refers to the 'bottom layer' - in this case the upper mantle.

The group velocity U is related to c in the following way:

$$U = c - T(dc/dT)$$

Curves of c(T) can be observed and U(T) calculated from a single seismogram, although it is preferable to measure c using at least two stations when regions of limited size are being studied.

Methods of interpreting these curves in terms of the remaining parameters involve computation of theoretical dispersion curves for a variety of possible or likely crustal models until a good fit with the observations is obtained. It is evident that the theoretical dispersion curves can differ quite markedly for apparently slight changes in model parameters (Plate 1).

Several procedures have been developed to permit the computation of theoretical dispersion curves, e.g. Haskell (1953) and Bolt and Butcher (1960). The algebra is very involved but a number of computer programmes are now available to evaluate complex models involving many layers. It has been shown by Knopoff (1961) that an infinite variety of theoretical solutions is possible to fit observed Love wave data equally well. Dorman and Ewing (1962) have assumed that this conclusion applies equally well to Rayleigh waves, and this appears to leave the problem of finding a unique fit to any one set of observations insoluble.

However, Dorman and Ewing point out that this is so only if the α, β, and ρ parameters are regarded as arbitrary functions of depth. If the variations in these parameters are permitted only at a discrete number of discontinuities corresponding to large-scale layering within the crust, unique resolution apparently can be approached within surprisingly small limits.

This problem, together with a summary of the limitations of resolution of crustal thickness inherent in earlier trial and error methods of analysis are discussed in two excellent articles by Oliver, Kovach, and Dorman (1961) and Dorman and Ewing (1962). Certainly the assumption of constant parameters within each layer is consistent with the understanding of crustal structure deduced by other methods (all of which are limited in accuracy), and the high resolution of the inversion method of analysis of phase-velocity data proposed by Dorman and Ewing would appear to offer results that compare more than favourably with data from explosion seismology refraction measurements, in terms of accuracy and reliability.

Early interpretation of phase-velocity data in terms of crustal thickness, e.g. Press (1956) rested largely on the assumption that the effect of thickness variations on c was relatively much greater than that of velocity or density variations. However, it has been shown (Oliver, Kovach, & Dorman, 1961) that errors of up to 25% in crustal thickness can result if deductions are made on the basis of direct visual comparison with theoretical curves based on incorrectly assumed velocity and density values. This error can be reduced by about half if some knowledge of the average velocity and density values that apply over a particular region is available (Oliver et al, 1961).

A useful guide to the validity of a particular model is given by the degree of similarity of the form of the theoretical dispersion curve with that derived from observations of phase velocity, over as wide a period range as possible, i.e., whether or not the theoretical and observed curves are parallel. For example, when sediments are present, the shape of the curve at the high-frequency end (T = 10 to 20 seconds) is affected, owing to the relatively high sensitivity of this portion of the curve to shear-velocity variations in the upper crust. On the other hand, shear-velocity variations in the upper mantle are likely to affect the low-frequency end of the curve. The dispersion curves are most sensitive to changes in the thickness of crustal layers at periods of about 22 to 32 seconds (Dorman & Ewing, 1962, Figure 4). Thus, even in the absence of independent crustal data, certain models can be rejected as unsuitable for a particular region.

The numerical inversion method proposed by Dorman and Ewing (1962) to interpret phase-velocity dispersion, which so far seems the most suitable for processing the New Guinea data, requires one to postulate as closely as independently observed data will allow, the most suitable average crustal model for the area under investigation. The theoretical dispersion curve corresponding to this model is then compared with the observed phase velocity at each observed period, and crustal parameters h, α, β, and ρ can be successively varied until the sum, over all periods, of the squares of residuals of each observed value of phase velocity is a minimum. In practice, although the total number of parameters to be varied is 4n - 1 (for n layers), it is not necessary to vary them all, but only those that are unknown or doubtful, or when small changes in them will affect the dispersion curve, i.e., parameters h, α, β, and ρ for each layer can be designated 'active' or 'passive', and only the active parameters are subject to revision to ahcieve the minimum condition mentioned above. Partial derivatives of c with respect to each active parameter are computed and become the coefficients of simultaneous equations relating observed and calculated phase velocities. The method proposed by Dorman and Ewing was tested by them by computing a theoretical curve for a hypothetical structure. Variations of the known parameters up to 0.6 g/cm^3 im density and 0.1 km/s in shear velocity were then introduced to construct a trial model, which was compared with the original by the inversion process described above, and the original values of h, α, β, and ρ were recovered exactly.

In practical applications of the method, standard deviations of α and β as low as 0.04 km/s are claimed. The higher the precision of the observed values the more complex the model that can be fitted with a given uncertainty.

According to Dorman and Ewing, therefore, the resolution of the method is largely governed by the precision of the original observed data over as wide a period range as possible from 10 to 100 seconds. It is, therefore, most important that the observations of phase velocity be made with the highest degree of precision.

The quality of the observed data depends chiefly on :

(1) Accurate recording and timing. This is especially important for small networks.

(2) Choice of the most suitable events for reduction. It is best to group the observations selectively from a number of earthquakes. The quality of individual recordings will also be important.

(3) Precise computation of phase velocities from recordings.

3. THE NEW GUINEA PROGRAMME

This project has been designed with the knowledge that not only are operating conditions in the New Guinea area more difficult than are usually met with elsewhere, but also that only limited information concerning crustal parameters is available. These difficulties, in a sense, increase the value of the survey if means can be found to overcome them.

Phase velocities can be determined from corresponding waves formed by the passage of wave fronts across a network of suitably distributed stations. Well-dispersed wave trains are the most suitable for these studies. These are best generated over long oceanic paths. Triangular networks (Plate 2) are to be established in turn throughout the Territory of Papua and New Guinea during the next few years. It is expected that three or four months' recording will be sufficient over each network. The first four networks will be confined to the area northwest of Port Moresby.

The choice of station locations is largely governed by the dimensions of the land mass and the distribution of outstations where power is available. Evernden (1953) first discussed the optimum dimensions of such a network. The spacing must be at least the order of one wavelength apart (say 100 kilometres), otherwise the normal limits of timing accuracy are too large to permit the calculation of phase velocities to the required accuracy. On the other hand, if networks are more than a few wave-lengths in linear dimension, there is a risk that correlation of wave trains would be too difficult because of the difficulty of correlation of network records.

Having regard to the operating difficulties, the location of each network has been chosen to ensure that any major variation in crustal thickness throughout the Territory of Papua and New Guinea will ultimately be found.

Four networks are involved in the first stage of the experiment. Three of these, networks 1, 3, and 4 (Plate 2) will progressively cover the main axis of the Owen Stanley Range from the Mount Victoria region north-westward to the Eastern Highlands. Network 2 is designed to examine crustal structure under the Papuan coastal region. It is not yet decided whether network 2a will be occupied immediately after network 2 orlater in the programme. The results for network 2a could indicate whether there are extensive sedimentary layers over that part of the Gulf of Papua. An additional network, Kerema-Daru-Kikori, could be formed to examine this point further if necessary. However, the quantitative estimation of total thickness of sedimentary layers may be beyond the limits of resolution of the method, as envisaged at this stage.

Stage 2 will examine structure in the region of the Bismark Archipelago. Although it is impossible to arrange any of the three networks 5, 6, and 7 across uniform topography, results from these networks should indicate the extent of any regional variations that may exist. Network 8 is rather larger than desirable, but is worth testing in view of the topographic uniformity of the area and its proximity to an active seismic area.

Details of stage 3 will be decided later, but if stages 1 and 2 are completed successfully in the estimated time of about three years, it is intended to extend the survey to other parts of the Territory of Papua and New Guinea. Choice of networks may be determined by the results found in the early stages.

Initially it is proposed to make record comparisons visually and to compute phase velocities graphically with the best available model curves in order to yield approximate data.

A seismogram of a surface wave train may be described as the superimposed effect of a number of travelling plane waves. The phase and period of the whole disturbance are related to the phase and period of each of the travelling wave components (Brune et al, 1960). After the initial rough analysis, therefore, selected records will be digitised and subjected to a Fourier analysis to recover frequency and corresponding phase angle for a range of periods. Computation of phase velocity should follow immediately from a knowledge, at a specified time, of the difference in phase angle of waves of corresponding period, recorded at each station.

4. EQUIPMENT

The equipment consists of a long-period seismometer, a visual pen-recorder that includes a filter network to accomplish the desired system response, a timing and power unit, and batteries and battery charger (Plate 3). The system is designed to record at a maximum magnification of 4,000 times ground motion at a period of 30 seconds. The filter characteristics simulate very closely the response of a 90-second galvanometer. The response curves of the seismometer and the recorder are shown in Plate 3.

Press-Ewing SV282 seismometers have been chosen, mounted on special bases to facilitate portable operation. These instruments are very sensitive to small temperature changes and will be installed under foam polystyrene covers. To facilitate complete portability, special fibre-glass insulated 'vaultlets' have been built to house the seismometers below ground level where necessary, thus ensuring an optimum temperature environment.

The ER-230 visual recorder has only recently been developed by the Geomeasurements Division of United Electro Dynamics Corporation and is especially suited to long-period work where phase characteristics ofthe records are important. The recorder is transistorised throughout and consists of four parts:

(a) A d.c. amplifier. A differential input signal from the seismometer coil (the input impedance providing damping for the signal source) is applied to the amplifier, which has an overall voltage gain of 1000. The amplifier utilises heavy negative feedback for stability.

(b) A filter, which consists of a simple R-C network having a large time-constant and provision for variation of the time-constant to adjust the phase response of the system. It is important to ensure that the phase response is identical at each station of the network, otherwise observed phase differences will not be entirely a result of crustal structure.

(c) A servo pen drive that operates on the null balance potentiometer principle. After passing through the attenuator and input filter the signal is applied to the measuring circuit, where it is cancelled by an internally generated voltage. The difference, or error, signal is applied to the chopper, and the a.c. output of this unit is amplified and applied to the servo-motor control, which operates the pen and concurrently reduces the error signal to zero.

(d) A drum recorder. The pen is mounted over a conventional recording drum driven at a peripheral speed of 60 millimetres per minute. Pen response is fast, full-scale balance time being only half a second, which makes the equipment quite suitable for recording at the frequencies required (0.1-0.01 c/s).

The NCD2 timing equipment (see Plate 4) has been designed in the laboratories of the Bureau of Mineral Resources at Footscray. It is essentially a crystal-controlled (100 kc/s) clock providing both time display and relay operations at programmed intervals. It also includes a power amplifier capable of delivering up to 30 watts at 250 volts and 50 c/s to operate external equipment. A feature of the timing unit is the facility to display time errors of ± 10 milliseconds between the clock and a reference source, determined in a pulse-counting circuit. The unit is fully transistorised and can be operated from a 11-17 volts d.c. source. The maximum input current required is 6 amps.

The whole recording system has been chosen to meet the requirements of accuracy demanded by the programme and the operational requirements imposed by the extreme field conditions (for long-period seismic equipment) that will be encountered in the Territory of Papua and New Guinea.

Factors that required consideration included:

(a) The equipment will be located at remote outstations where electric power is limited. Untrained station personnel will be asked to perform daily routines that must be simple, both in their interests and ours.

(b) Regular maintenance visits by technical staff will be infrequent.

(c) Costly equipment-housing had to be avoided.

5. AUXILIARY DATA

Apart from a study of the published data, a synoptic study of regional earthquake arrivals and regional group-velocity dispersion characteristics has been commenced in order to seek information on shear and compressional velocities and the general nature of crustal structure. The data below are presented chiefly to illustrate the methods being adopted. Although it is intended to make some interpretation of the data as it stands for the purpose of this record, it is important to stress that more information is required before this would normally be attempted.

Published data

A thorough search of the publications of the results of geological and geophysical surveys is under way and useful data on sedimentary thickness, densities from drill cores, and seismic velocities are being accumulated, which will assist greatly in forming a picture of the average velocity and density distribution in some areas.

Local earthquake seismology

The first efforts to deduce crustal compressional and shear velocities are being confined to Papua and N.E. New Guinea as this will be the first area subjected to the phase velocity analysis. Velocities to use in models of the Bismark Archipelago region will be determined from a search of Rabaul records.

At present there are only two permanent seismic stations in the whole of the Territory of Papua and New Guinea, viz., Port Moresby and Rabaul, which are separated by about 800 kilometres. In 1965 a permanent station at Manam Island should begin operations and P and S arrival times will usefully supplement the Port Moresby data for the mainland area.

Plate 5 illustrates travel-time curves from earthquakes with mainland epicentres at focal depths of 30 to 35 kilometres. Epicentral distances range from 300 to 1000 kilometres. Basic data have been extracted from the U.S.C.G.S. data reports. Although local and near earthquake activity is prolific in this region, foci are commonly located at depths exceeding 50 kilometres. (Few are shallower than 30 kilometres).

To improve consistency of results, care has been taken to select only those earthquakes with land epicentres and shallow depths of focus. It is suspected that readings from epicentres in the Bismarck Sea are anomalous.

The P_n data were derived from earthquakes solved by readings at more than ten stations so that the bias introduced by the Port Moresby contribution to the data is minimised. For other waves, no such restriction was imposed. These preliminary data yield the following results:

P_n : $t = (2.5 \pm 0.8) + \Delta/(7.82 \pm 0.16)$ seconds; 11 observations.
P_1 : $t = (-0.6 \pm 1.2) + \Delta/(6.52 \pm 0.20)$ seconds; 11 observations.
S_n : $t = (11.42 \pm 2.9) + \Delta/(4.73 \pm 0.11)$ seconds; 9 observations.
S_1 : (Approximately 3.4 km/s); 5 observations

where Δ is the epicentral distance in kilometres.

More significance can be attached to these results as data are added. At present there are too few observations to warrant substantial discussion. Ultimately it is intended to request recomputation by U.S.C.G.S. of a large number of selected earthquakes, omitting the Port Moresby or, when appropriate, the Rabaul arrivals, to ensure complete removal of this bias on the coordinates and origin times of the earthquakes used.

The P_1 velocity is higher than expected for a granitic layer and is more characteristic of a gabbro. Refraction results from oil exploration surveys in West New Guinea list velocities of between 5 and 6 km/s in the crystalline basement underlying deep sedimentary basins (Visser & Hermes, 1962). Observations of phases from an upper granitic layer are more likely to be observed from earthquakes shallower than those considered above. From past statistics few very shallow earthquakes occur in this region.

The time intercepts for P_n and S_n are inconsistent but, again, further results must be awaited before this can be confirmed. The S_n intercept is consistent with a 'continental type' crustal thickness expected by Doyle and Webb (1963). If the small P_n intercept is confirmed, the explanation might be sought in terms of delay caused by the presence of a mountain root system affecting the more distant arrivals.

Regional variations of P_n velocity would most certainly influence the P_n residuals and some evidence of this is seen in Plate 6, which illustrates the distribution of positive and negative residuals observed at Port Moresby since August 1962, for earthquakes of a nominal depth of 30 kilometres. The residuals are plotted in the sense : computed minus observed travel times.

Although further data are needed, a regional distribution is beginning to emerge to the east and west of Port Moresby. The P_n travel-time curve discussed above was computed from earthquakes having land epicentres in the north-west quadrant from Port Moresby. The more distant of these ($\Delta \approx 9^\circ$ to 10°) are located in an area where residuals tend to become negative (i.e., where the arrivals are later than predicted), in contrast to the closer earthquakes. Thus a combination of travel times from these two zones would have an effect on the P_n travel-time curve consistent with the low intercept observed. However, it is difficult to see why the S_n results, although less accurate, should not be affected in the same way. More data are needed before the matter can be taken further, but a denser network of short-period vertical stations should yield very interesting data.

Rayleigh wave group velocities

The extent to which the New Guinea structure can be considered typically continental is being examined by comparing group-velocity dispersion data for paths across the Australian continent with those for internal paths within New Guinea. A synoptic study of all these data recorded at Port Moresby has begun.

The procedure to determine group velocity from seismograms is a simple one and was first described by Ewing and Press (1952). They used very long paths and no instrumental corrections were necessary. Thomson and Evison (1962) discussed the effect of instrumental phase-shift on the period of recorded ground motion in cases where the path lengths (2000 kilometres or so) were somewhat shorter than those used by Ewing and Press, and found it necessary to apply small corrections to the observed period to obtain true ground period.

Internal paths within New Guinea are shorter than 2000 kilometres, and it transpires that for these short paths where the rate of change of period at the beginning of the wave train (longest periods)

TABLE 1

Group velocities at observed and corrected periods

Observed T	Path A 2760 km		Path B 2930 km		Path C 1002 km		Path D 1002 km		Path E 1234 km		Path E-C 684 km	
(Seconds)	Corrected T	U	Corrected T	U	Corrected T	U	Corrected T	U	Corrected T	U	Corrected T	U
	(Seconds)	(km/s)	(Seconds)	(km/s)	(Seconds)	(km/s)	(Seconds)	(km/s)	(Seconds)	(km/s)	(Seconds)	(km/s)
65	-	-	-	-	-	-	-	-	54.4	3.88	-	-
60	-	-	-	-	-	-	-	-	52.0	3.81	-	-
55	-	-	-	-	-	-	-	-	49.8	3.75	-	-
50	-	-	-	-	-	-	-	-	45.9	3.65	-	-
45	-	-	-	-	-	-	-	-	42.0	3.51	-	-
40	38.7	3.76	-	-	36.8	3.53	37.6	3.43	37.8	3.36	37.8	3.23
35	34.0	3.59	34.4	3.51	32.7	3.35	33.3	3.23	33.8	3.17	33.8	3.00
30	29.4	3.42	29.6	3.30	28.4	3.22	28.9	3.01	29.3	2.95	29.3	2.74
25	24.6	3.21	24.8	3.05	24.2	3.05	24.3	2.81	-	-	-	-
20	19.8	3.03	-	-	19.7	2.75	-	-	-	-	-	-
15	14.8	2.91	-	-	-	-	-	-	-	-	-	-

is fairly rapid, the instrumental phase-lag causes the recorded period at any instant to be slightly greater than the ground period.

In particular, if θ = phase angle of the ground
ϕ = instrumental phase-shift
T = true ground period
T' = recorded wave period
t = time

then $T = 2\pi dt/d\theta$ and $T' = 2\pi dt/d(\theta + \phi)$

and it follows that $1/T = 1/T' - (1/2\pi)(d\phi/dT)\ (dT/dt)$

In the case of paths A to E (Plate 7), significant corrections were necessary for paths C, D, and E at long periods, and amounted to 11 seconds at T' = 65 in one instance. Table 1 gives details of all corrections made. In Plate 8 the group velocities are plotted against observed periods, and in Plate 9 they are plotted against periods that have been corrected for instrumental phase-shift.

There are insufficient observations to make a numerical interpretation of average crustal thickness along these paths, but the group velocities show some general features that are worth pointing out:

(a) There is a general tendency for the trend of the observed curves to intersect rather than run parallel to those corresponding to the models considered here (Plate 1), although this tendency is reduced when phase-shift corrections are applied to observed periods. The effect could be explained if the shear-velocity structure of the models does not quite represent the conditions along the paths being studied, for example, lower velocities both in the upper crust and upper mantle might improve the match of the models.

(b) There is a general tendency for crustal thickness to increase from path A to path E. This effect is probably sufficiently strong to remain even when changes in structure between each path can be taken into account. The maximum difference in average thickness between paths may amount to 15 to 20 kilometres.

(c) Path A indicates higher group-velocities at periods of 25 seconds or less, than do paths C, D, and E. This would be consistent with the effect of a low velocity sedimentary layer overlying the latter paths and is demonstrated by a comparison of the curve for model III (Plate 1), which includes such a layer, and model I, which is similar in most other respects but omits this layer. The existence of a sedimentary layer of considerable thickness over most of path C has been well established by oil search results (Visser & Hermes, 1962; Australian Petroleum Company Pty Ltd, 1961). Therefore, of the models considered here, it seems better to compare path A with model I and the remainder with model III. The velocity structure of model III is not inconsistent with the P and S wave crustal velocities so far found for mainland New Guinea. One exception may be velocities from immediately below the Mohorovicic layer (P_n and S_n). These are likely to affect the portion of the curve above 40 seconds and, in this part of the spectrum, model I seems more suited to New Guinea (P_n = 7.8 km/s), an observation supported by the group-velocity dispersion characteristics for path E.
The general form of dispersion over path A is consistent with model I - a model for a typical continental structure (Press, 1960). It is interesting to compare the velocity structure for model I with that found by Bolt <u>et al</u> (1958)

for the southern portion of the Australian continent. The dispersion curve II (after Bolt and Butcher, 1960) was designed for this velocity structure. The dispersion observed over path A does not fit this model at all well, which leaves the impression that differences may exist between the structure across the northern and southern parts of the continent.

(d) Paths D and E were very close together, but the proportion of path E under the main mountain range is higher. This is reflected in the respective group-velocity curves. The majority of path C traverses an area of very low topographic relief and a clearly thinner crust is indicated here. The effect of the path C dispersion along that portion (550 kilometres) of path E of corresponding relief, has been removed from the path E data, and assuming the average velocity and density distributions to be the same for both paths, the resulting dispersion curve labelled E-C should give some indication of the order of crustal thickening under the main axis of the range. This appears to be about 15 kilometres.

(e) Although path B is entirely across water, except for a small part of it over Timor, the group-velocity dispersion strongly indicates a continental type rather than an oceanic type crust.

(f) One observation interpreted as a point on a higher mode disperison curve was made for path D. The point ($T = 6$, $U = 3.6$) is not plotted and the interpretation is difficult to confirm.

6. CONCLUSIONS

Although it has been possible to consider only a very limited amount of data here, significant information relevant to the future crustal structure investigation project is beginning to emerge.

There are fairly strong indications from the group-velocity data of a relatively sudden crustal thickening under the central mountain ranges of New Guinea. More specific information on this point will emerge from the phase-velocity results.

The extensive thickness of sediments known to exist in the southern part of the island seems to affect the group-velocity dispersion curves. Apart from this, the dispersion curves so far tend to support the view that, at least in major respects, the gross crustal structure of the southern New Guinea area is similar to that across northern Australia and between the two land masses. No indications have yet emerged of an oceanic type crust north of Australia, although not enough data have yet been analysed to be sure of this.

There are some indications also that a low velocity layer is present in the upper mantle. Group-velocity dispersion over both paths A and E tends to support this, although more data at longer periods (50 to 100 seconds) would provide better evidence. This general conclusion was reached independently by Brooks (1962).

The crustal and upper mantle velocity structure is not well known within the Territory of Papua and New Guinea. In time, this will be improved by results from the frequent regional earthquakes, but it is unfortunate that there are insufficient short-period vertical stations to take better advantage of this activity.

The indications of regional variations in P_n velocity that are beginning to emerge from a study of residuals foreshadow important problems in securing adequate information on velocities generally, and point to the need for close attention to this question when reducing phase-velocity data. It will be interesting to see if these variations are reflected in crustal velocities as well.

This study of crustal phases from local earthquakes and average characteristics of regional crustal structure is beginning to produce interesting and useful data, but more results are needed to provide adequate supporting data to permit reduction of the phase-velocity dispersion data to a higher degree of resolution.

Notwithstanding the present limited knowledge of crustal velocities, the numerical inversion method of Dorman and Ewing offers the best approach yet to the interpretation of crustal structure and should be quite a feasible method. No more can be said until some practical experience has been gained.

Because of the nature of the problem, interpretation of wave dispersion in terms of many crustal parameters is basically a problem of successive approximation. Data are periodically subject to reinterpretation in the light of new information and data processing procedures and this will persist for some time. Therefore, it is most important that the original observations be made to the highest precision. This applies with greater significance in the case of field observations in New Guinea, where, because of the logistic problems, observations cannot easily be repeated.

7. REFERENCES

AUSTRALASIAN PETROLEUM COMPANY PTY LTD 1961 Geological results of petroleum exploration in Western Papua, 1937-1961. J.Geol.Soc.Aust., 8(1), p 133.

BOLT, B. A. and BUTCHER, J. C. 1960 Rayleigh wave dispersion for a single layer on an elastic half space. Aust.J.Phys., 13, 498-504.

BOLT, B. A., DOYLE, H. A., and SUTTON, D. J. 1958 Seismic observations from the 1956 atomic explosions in Australia. Geoph. J. 1, 135-145.

BROOKS, J. A. 1962 Seismic wave velocities in the New Guinea-Solomon Islands region. Amer.Geophys.Un.,Monogr.No. 6, 2-10.

BRUNE, J. N., NAFE, J. E., and OLIVER, J. E. 1960 A simplified method for the analysis and synthesis of dispersed wave trains. J.Geophys.Res., 65(1), 287-304.

DORMAN, J. and EWING, M. 1962 Numerical inversion of seismic surface wave dispersion data and crust-mantle structure in the New York-Pennsylvania area. J.Geophys.Res., 67(13), 5227-5241.

DOYLE, H. A. and WEBB, J. P. 1963 Travel times to Australian stations from Pacific nuclear explosions in 1958. J.Geophys.Res., 68(4), 1115-1120.

EVERNDEN, J. F. 1953 Direction of approach of Rayleigh waves and related problems (Part 1). Bull.Seis.Soc.Amer., 43, 335-374.

EWING, M. and PRESS, F. 1952 Crustal structure and surface-wave dispersion. Part II - Solomon Islands Earthquake of July 29, 1950. Bull.Seism.Soc.Amer., 42, 315-325.

HASKELL, N. A. 1953 The dispersion of surface waves on multilayered media. Bull.Seism.Soc.Amer., 43, 17-34.

KNOPOFF, L. 1961 Green's function for eigenvalue problems and the inversion of Love wave dispersion data. Geophys.J., 4, 161-173.

KUO, J., BRUNE, J., and MAJOR, M. 1962 Rayleigh wave dispersion in the Pacific Ocean for the period range 20 to 140 seconds. Bull.Seism.Soc.Amer., 52(2), 333-357.

OLIVER, J., KOVACH, R., and DORMAN, J. 1961 Crustal structure of the New York-Pennsylvania area. J.Geophys.Res., 66(1), 215-225.

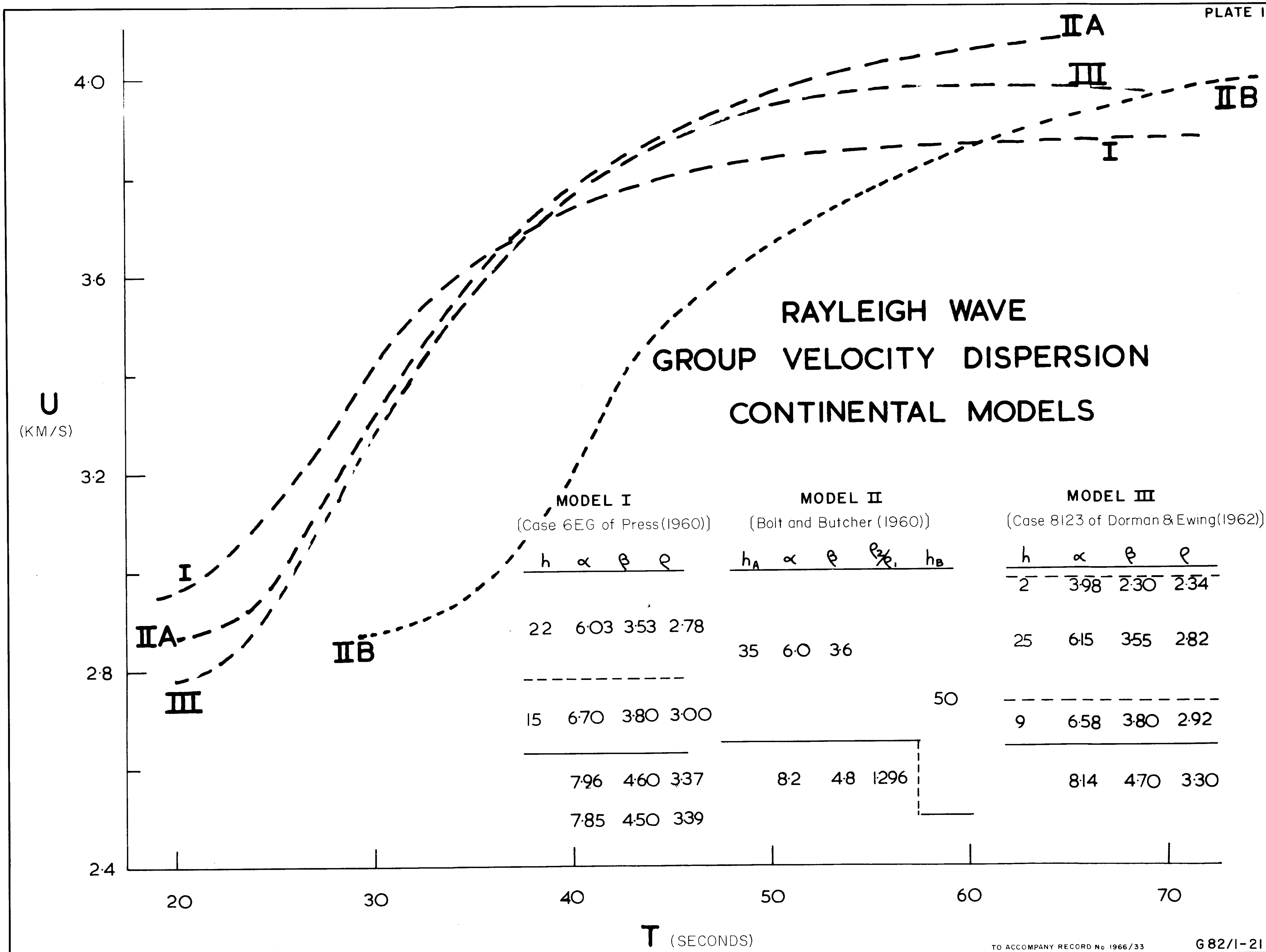
PRESS, F. 1956 Determination of crustal structure from phase velocity of Rayleigh waves, Part I : Southern California. Geol.Soc.Amer.Bull., 67, 1647-1658.

PRESS, F. 1960 Crustal structure in the California-Nevada region. J.Geophys.Res., 65(3), 1039-1051.

SANTO, T. 1963 Division of the Pacific area into seven regions in each of which Rayleigh waves have the same group velocities. Earthq.Res.Inst.Bull.Uni. Tokyo, 41(4), 719-741.

THOMSON, A. A. and EVISON, F. F. 1962 Thickness of the Earth's crust in New Zealand. <u>N.Z. J.Geol.Geophys.</u>, 5, 29-45.

VISSER, W. A. and HERMES, J. J. 1962 GEOLOGICAL RESULTS OF THE EXPLORATION FOR OIL IN NETHERLANDS NEW GUINEA. Staatsdrukkerij-En Uitgeverijbedrijf.



MODEL I (Case 6EG of Press (1960))

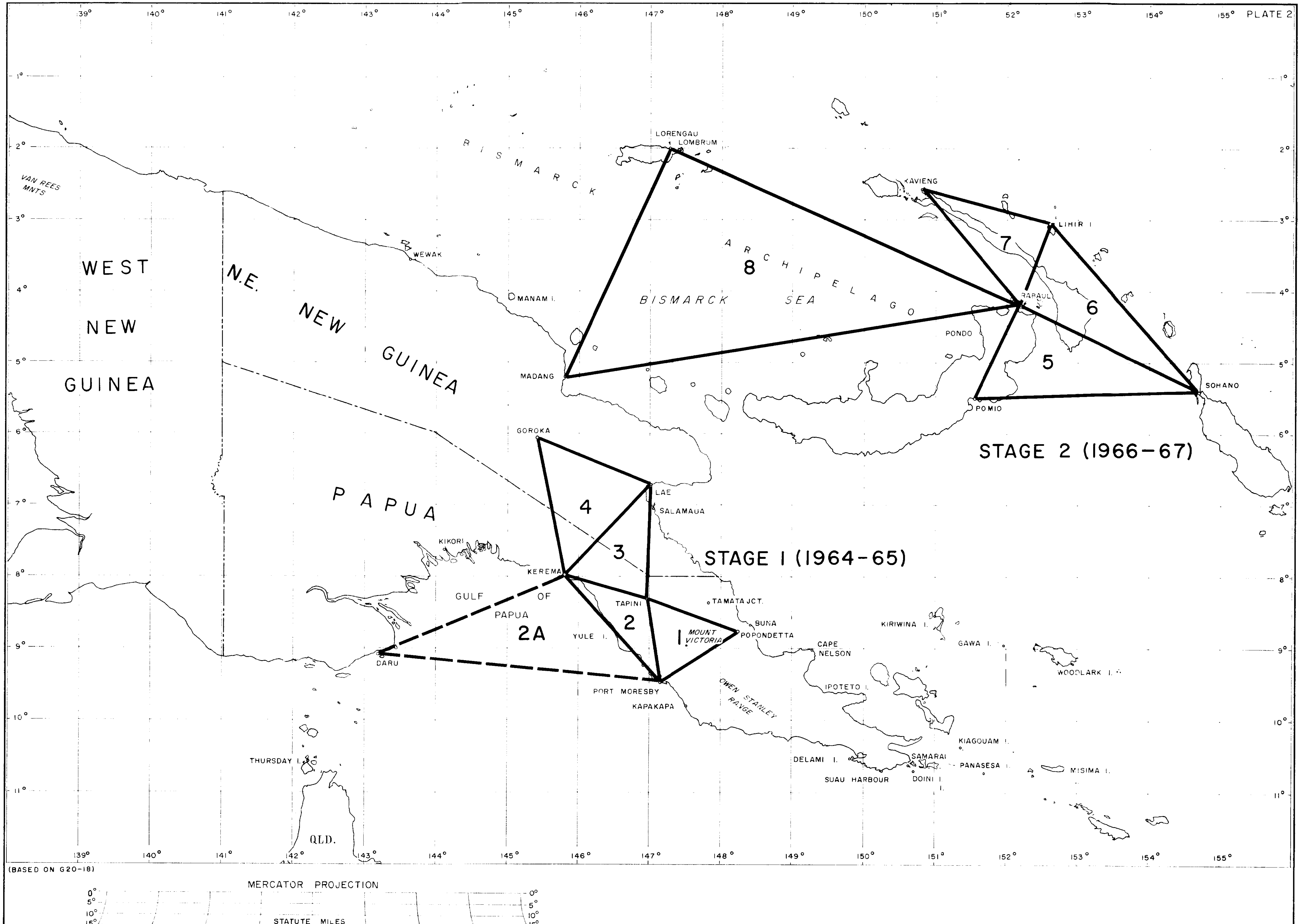
h	α	β	ρ
22	6·03	3·53	2·78
15	6·70	3·80	3·00
	7·96	4·60	3·37
	7·85	4·50	3·39

MODEL II (Bolt and Butcher (1960))

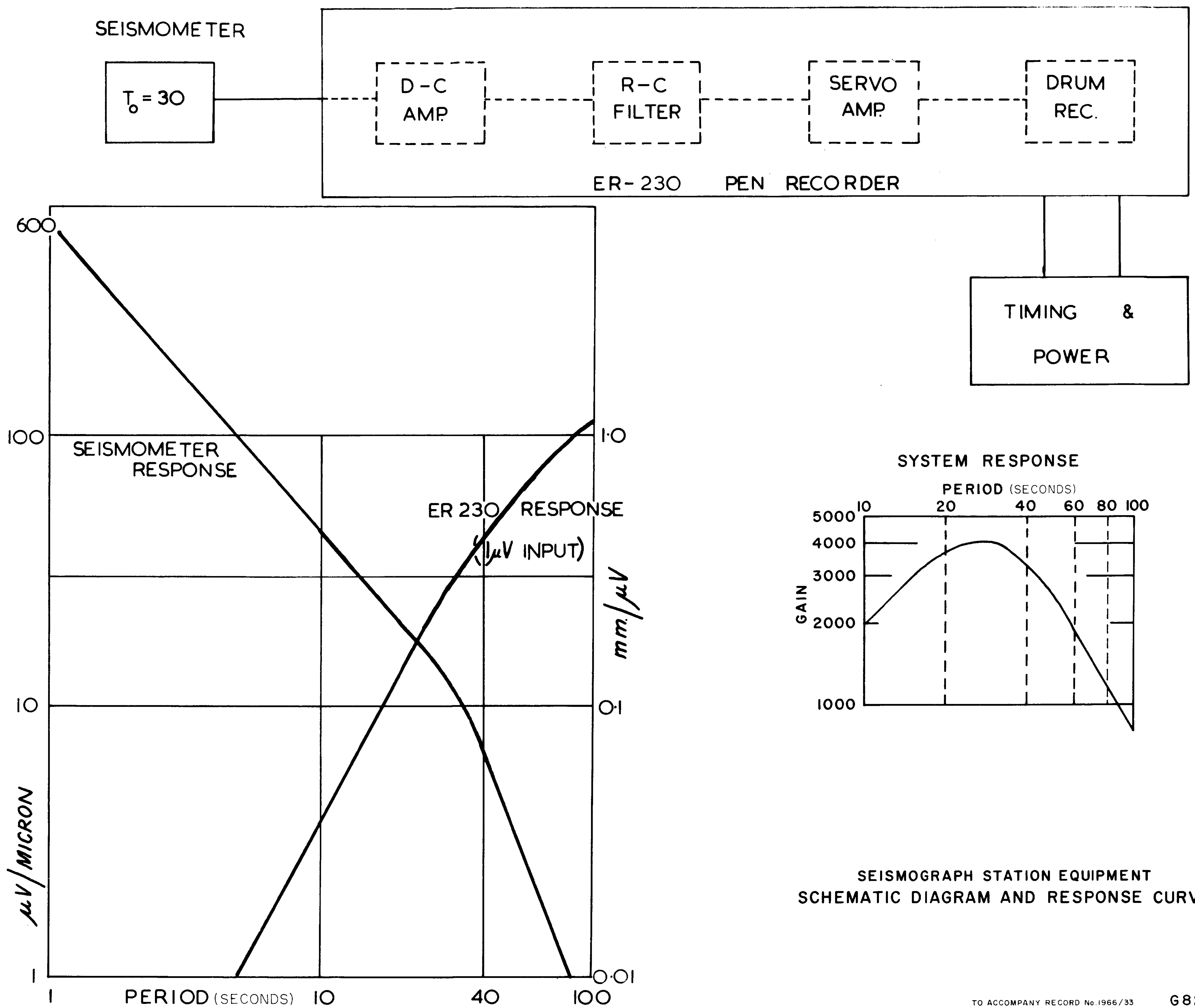
h_A	α	β	ρ_2/ρ_1	h_B
35	6·0	3·6		
				50
	8·2	4·8	1·296	

MODEL III (Case 8123 of Dorman & Ewing (1962))

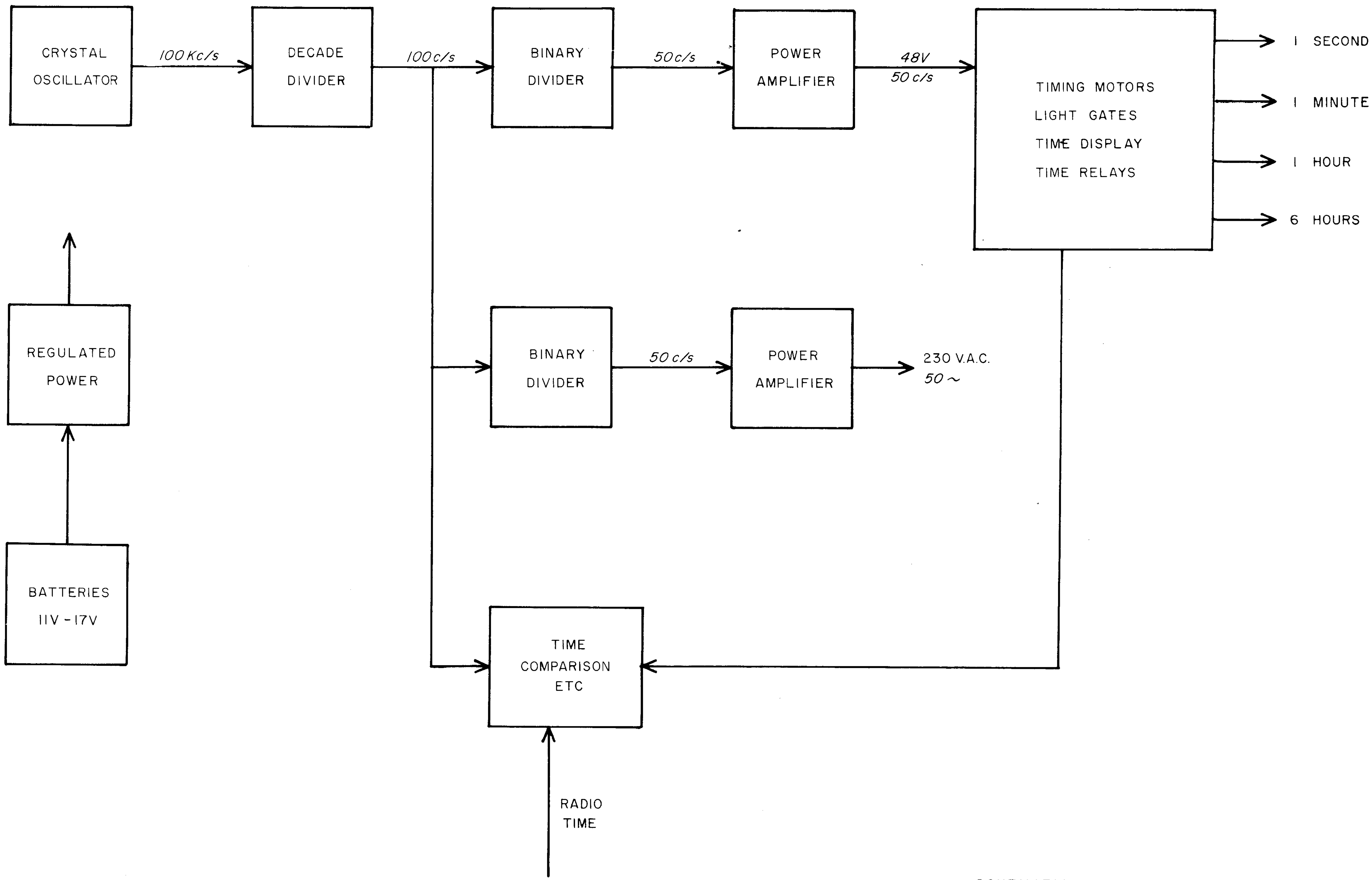
h	α	β	ρ
2	3·98	2·30	2·34
25	6·15	3·55	2·82
9	6·58	3·80	2·92
	8·14	4·70	3·30



SEISMOGRAPH NETWORK



SEISMOGRAPH STATION EQUIPMENT
SCHEMATIC DIAGRAM AND RESPONSE CURVES

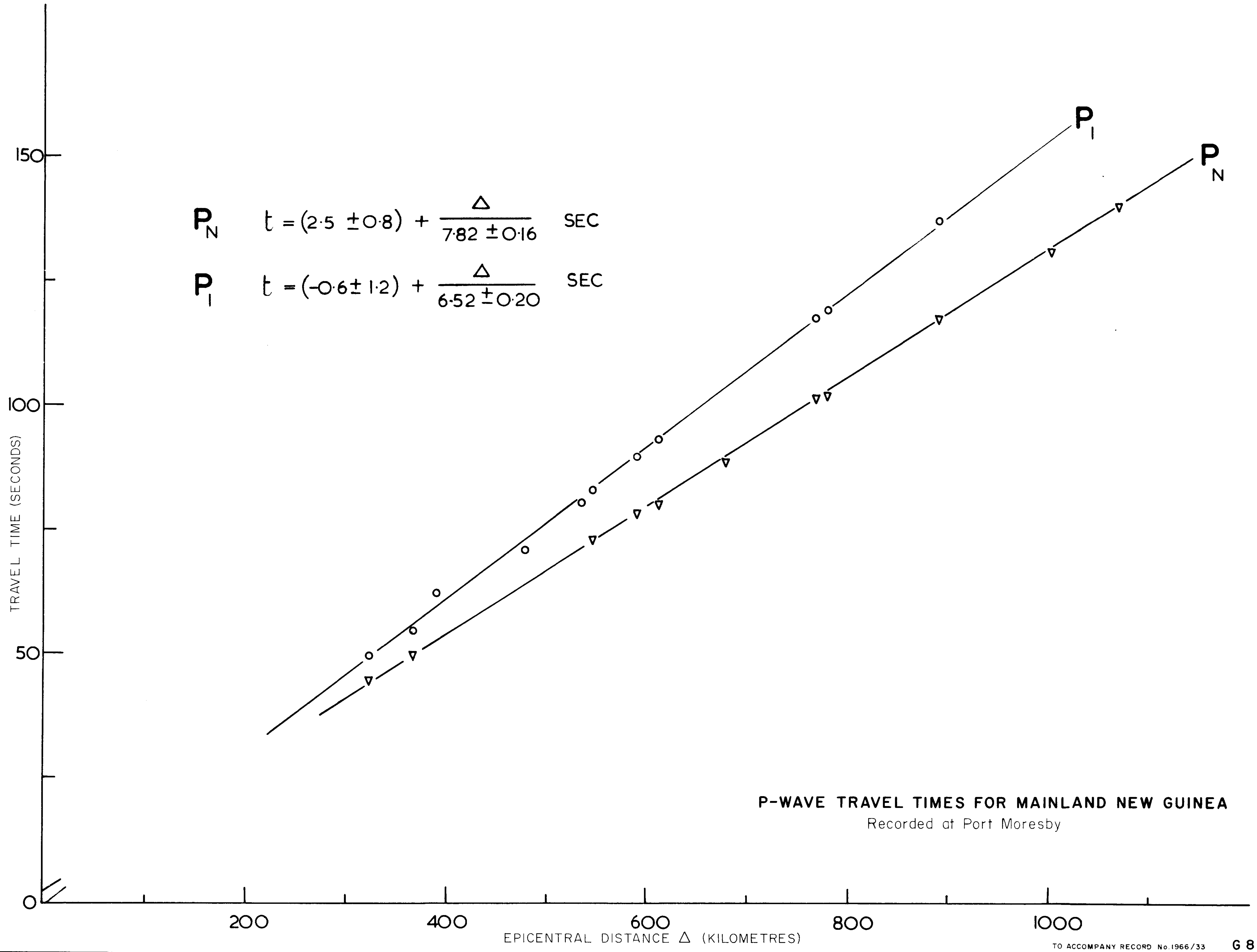


SCHEMATIC DIAGRAM

N C D 2 TIMING UNIT

TO ACCOMPANY RECORD No.1966/33

G 82/1-24



P-WAVE TRAVEL TIMES FOR MAINLAND NEW GUINEA
Recorded at Port Moresby

TO ACCOMPANY RECORD No. 1966/33 G 82/1-18

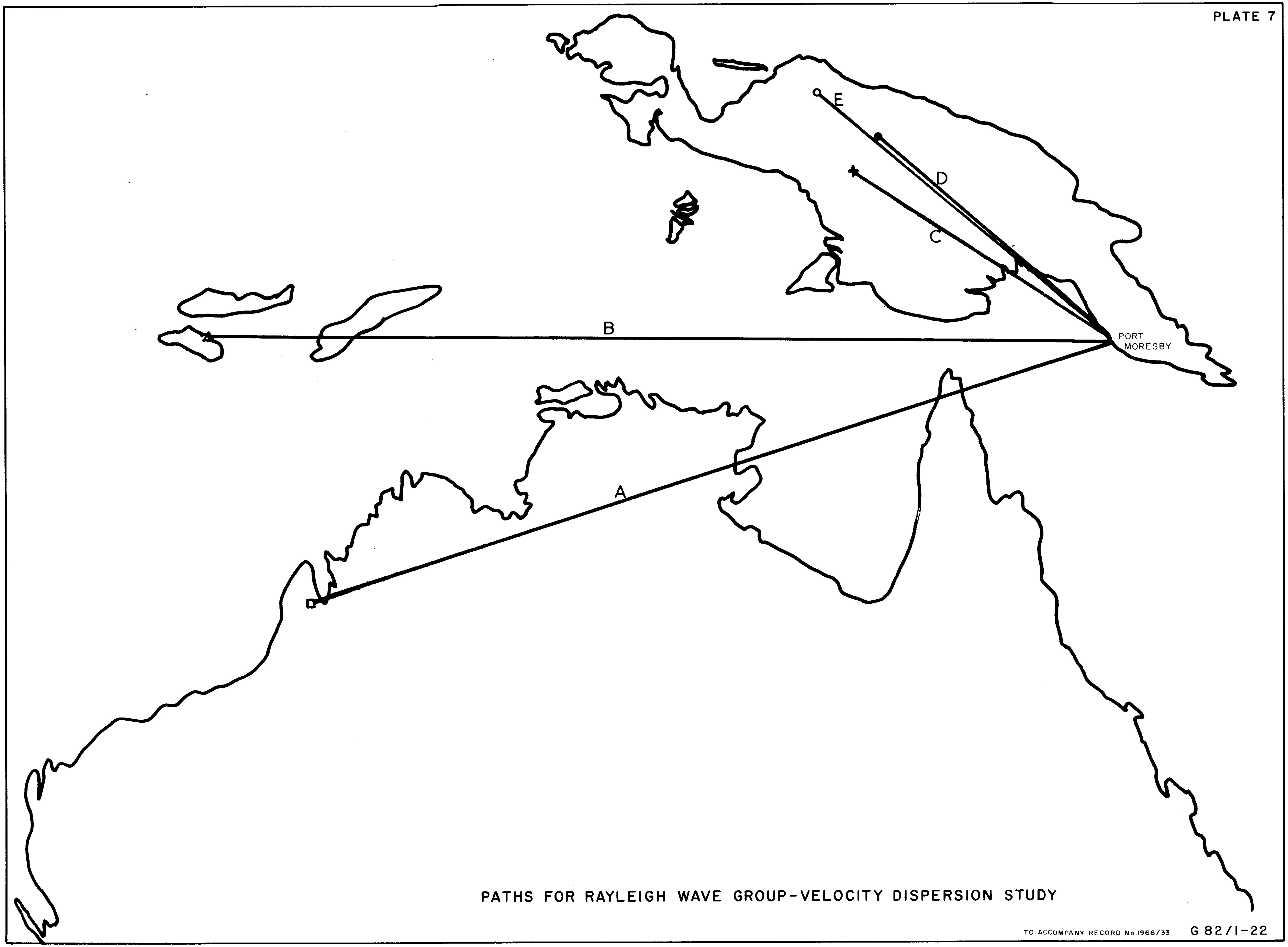
DISTRIBUTION OF P_n RESIDUALS OBSERVED AT PORT MORESBY FROM AUGUST 1962 TO MARCH 1964 AS LISTED IN USCGS EARTHQUAKE DATA REPORTS

Residuals are computed travel times minus observed travel times

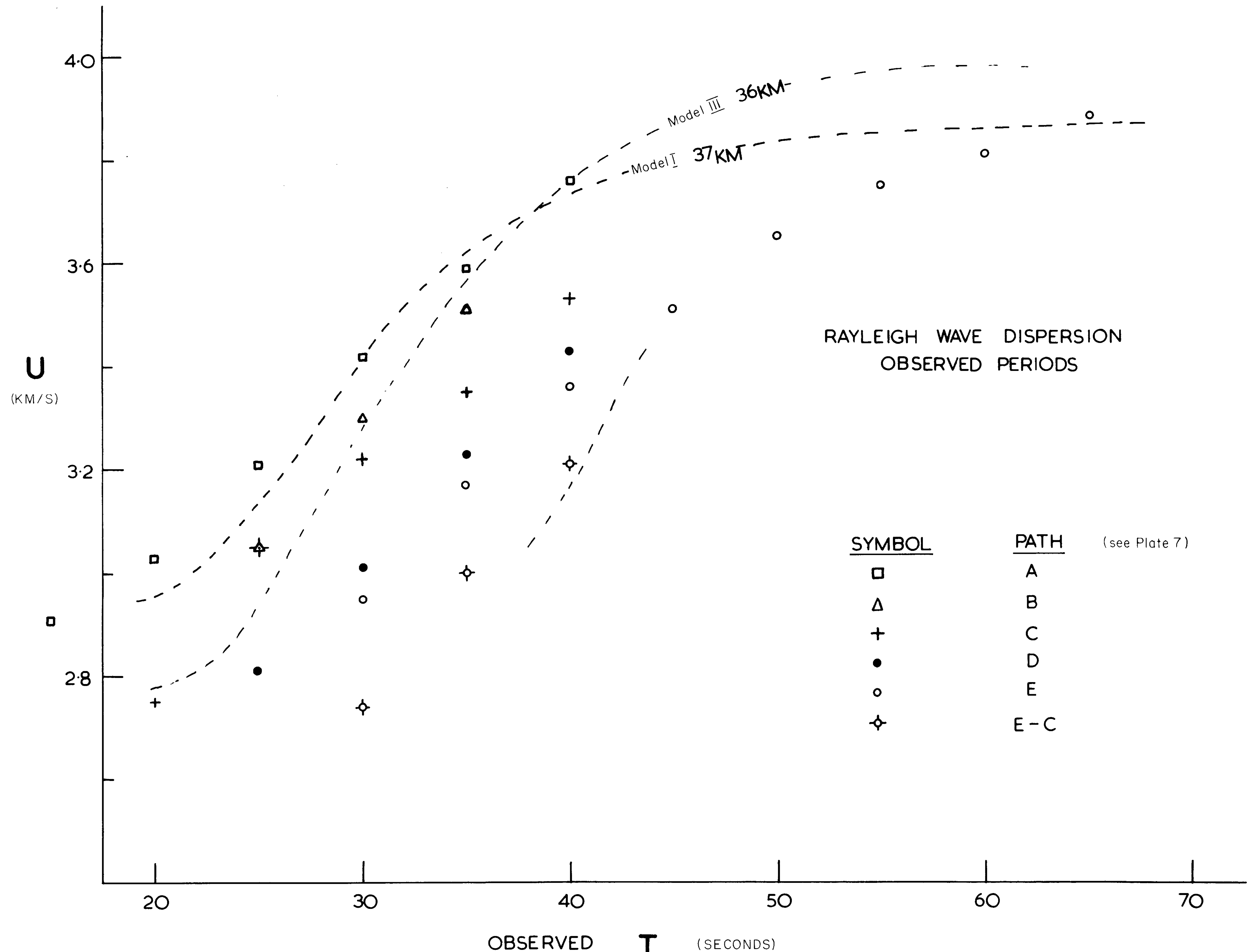
Focal depth approximately 30 km

TO ACCOMPANY RECORD No. 1966/33
Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics. G82/1-16

(BASED ON G20-13)



PATHS FOR RAYLEIGH WAVE GROUP-VELOCITY DISPERSION STUDY



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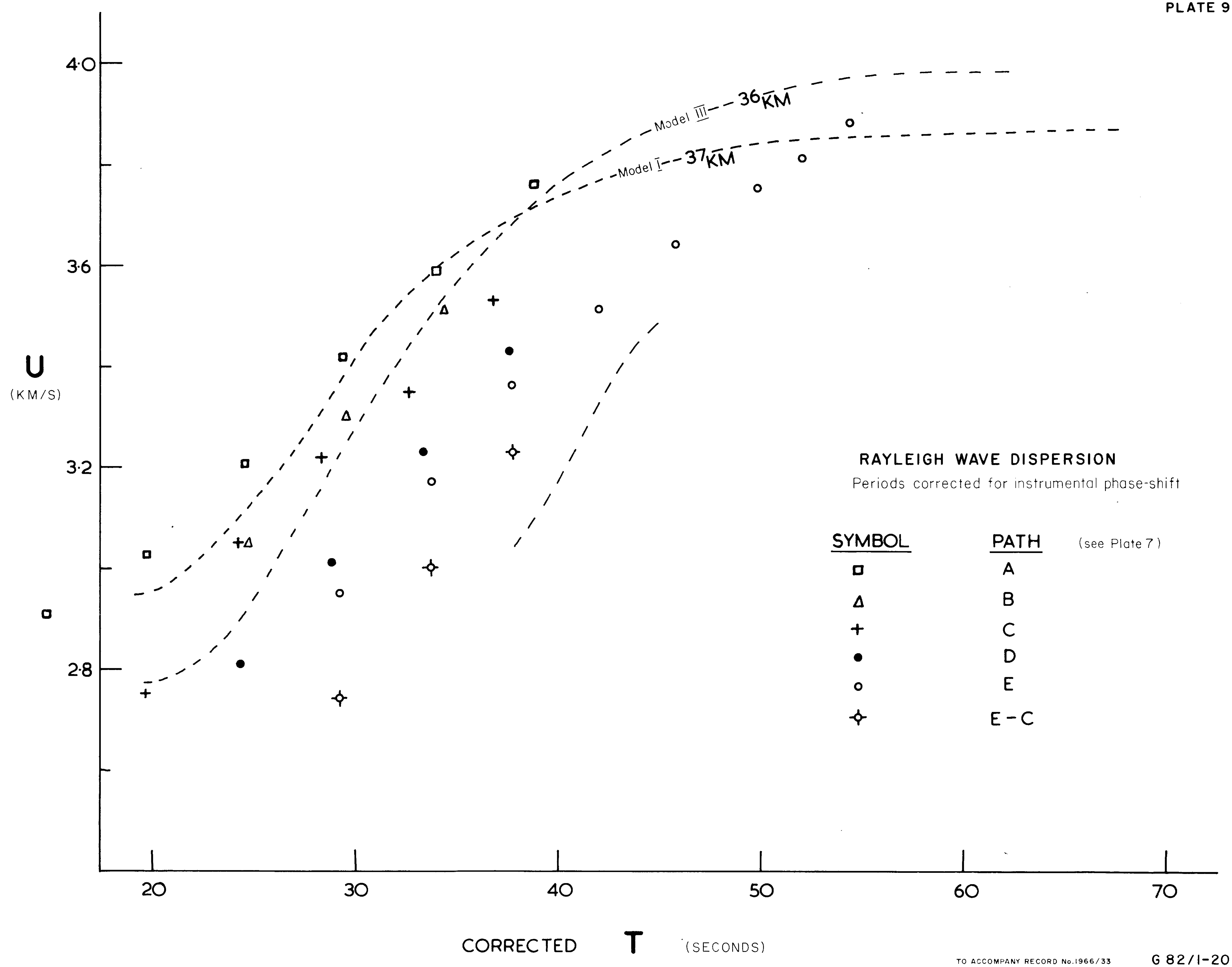
G 82/1-19



4·0
3·6
3·2
2·8
U
(KM/S)
Model III 36 KM
Model I 37 KM
RAYLEIGH WAVE DISPERSION
Periods corrected for instrumental phase-shift
SYMBOL
PATH
(see Plate 7)
A
B
C
D
E
E – C
20
30
40
50
60
70
CORRECTED T (SECONDS)