copy 3

COMMONWEALTH OF AUSTRALIA

DEPARTMENT OF NATIONAL DEVELOPMENT

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

Record No. 1969 / 83

A Graphical Method for Preliminary Location of Earthquakes in the New Guinea - Solomon Islands Region

by

R.J.S. Cooke

Note: The original Record contains overlays for plate/s 3. If you wish to view the original, please contact the N.H. (Doc) Fisher Geoscience Library.

Mail

N.H. (Doc) Fisher Geoscience Library
GPO Box 378
Canberra ACT 2601
Australia

Email

library@ga.gov.au

Telephone

Within Australia: 02 6249 9567

International: +61 2 6249 9567

Fax

Within Australia: 02 6249 9989

International: +61 2 6249 9989

Record No. 1969 / 83

A Graphical Method for Preliminary Location of Earthquakes in the New Guinea-Solomon Islands Region

by

R.J.S. Cooke

CONTENTS

ILLUSTRATIONS

Record 1969/83

SUMMARY

A method of locating earthquakes, using P-wave arrival-time differences between stations of selected pairs, is described. It is applied to locations in the East New Guinea-Solomon Islands region using stations Port Moresby, Rabaul, Honiara, and Charters Towers. A set of hyperbolic curves is presented which allows almost instant location of shallow earthquakes. Graphed corrections to allow extension of the method to deep earthquakes are also presented. The accuracy of the epicentres varies considerably with location and depth, because of the station distribution. In the best areas, accuracies for shallow shocks are as good as or better than those of routine published epicentres.

1. INTRODUCTION

This Record is based on work done in early 1961. There is an early draft of the Record in the library of the Port Moresby Geophysical Observatory (P.M.G.O. Report No. 5); that version contains only a roughly drawn set of curves at a smaller scale than that used in the present record, and based upon a map on a different projection.

The principle of the method of earthquake location to be described is not original, but it seems to have been seldom used in a form as highly developed as that shown here. Standard text books on seismology mention the method either briefly (Richter, 1958, p.320), or not at all (Byerly, 1942; Bullen, 1963). It has considerable value, however, in easily providing a starting point for more accurate location by other methods. It can also provide a position rapidly for inclusion in newspaper reports of felt earthquakes, a requirement which arises frequently in Papua-New Guinea.

2. PRINCIPLE OF LOCATION METHOD

Two seismological stations that are equidistant from an earthquake will record P-phases at the same time. Earthquakes equidistant from these same two stations must have epicentres that lie on one great circle passing between the stations. Thus this great circle is the epicentral locus of earthquakes registering the same arrival times at these stations. This condition may be represented as

$$\Delta P = 0$$

where ΔP symbolises the time difference between P arrivals at the two stations.

On the other hand, an earthquake with epicentre lying on a great circle passing through both stations will produce a maximum ΔP under certain circumstances. These circumstances will be better appreciated if a simplified situation is considered.

Suppose both stations and all earthquakes are located within so restricted a zone of the Earth that surface planarity is a reasonable approximation. Suppose also that P-wave velocity is constant, and that all earthquakes occur at the surface. Then ΔP will have a constant maximum value for earthquakes anywhere along the straight line passing through both stations, except the part between the stations. This situation is illustrated in Figure 1, where the two stations are O and Q. The value of maximum ΔP is determined by the distance between the stations and the P velocity.

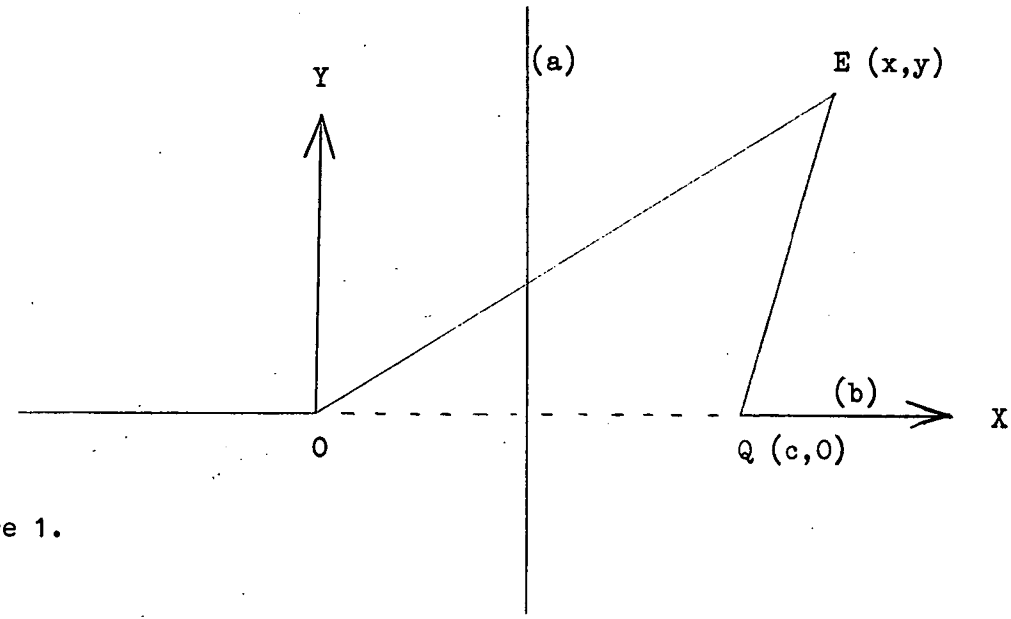


Figure 1.

Evidently, earthquakes producing ΔP values between zero and the maximum, such as E of Figure 1, are located on one of a family of curves lying between the limiting straight lines (a) and (b), and must be symmetrical about both (a) and (b).

The form of these curves is derived in the Appendix with reference to Figure 1 for the simplified case, and is seen to be hyperbolic.

P readings from a minimum of three stations are necessary to define two hyperbolas, whose intersection represents the epicentre of the earthquake. A fourth station reading is desirable, as it defines a third hyperbola which serves as a check on the two-part intersection.

3. PRACTICAL APPLICATION

The method was originally intended for use in the location of the smaller earthquakes in the East New Guinea-Solomon Islands region: earthquakes well-recorded locally, but not large enough to appear on routine lists of preliminary epicentres, such as that published by the United States Coast & Geodetic Survey.

The usefulness of the method in practice, and the details of the way in which it may be applied, depend on how well the simplifying assumptions hold. Four well-distributed stations covering the area were in operation: Port Moresby, Rabaul, Honiara, and Charters Towers. The area is thus sufficiently small for departures from planarity to be minor.

Of the other assumptions used, that restricting earthquakes to surface focus does not hold, since it is well known that focal depths in this region extend to 500 km or more (e.g. Brooks, 1965). The effect of depth on the use of the method will be considered in a later section.

The remaining assumption that P velocity is constant must be examined. One obvious departure from general constancy is to be found in P-waves (P1) from crustal earthquakes at short distances (up to about 120 km), which travel entirely within the crust at velocities several km/s lower than do waves (Pn) from events at greater distances. Other velocity variations, smaller by an order of magnitude, also occur. For instance, Brooks (1962) has produced evidence for a low-velocity layer in the upper mantle which affects Pn arrival times within the epicentral distance range of interest here. Further, Brooks and Ripper (1966) indicate that there may be regional variations of Pn velocity in the area. In fact these latter, smaller variations are unlikely to affect epicentral determinations seriously (locations are only approximate anyway), and provided that arrivals from very short distances are not used for ΔP determinations, velocity constancy may be reasonably assumed.

For the purposes of approximate location, the velocities adopted by Jeffreys and Bullen (1948) in their standard seismological tables are regarded as sufficient. Plate 1 shows travel-times from these tables for several depths. It is seen that, while the apparent velocity increases with source depth, the velocity is sensibly constant for each depth, from distances of about one degree to fifteen degrees. In fact, recent work (e.g. Sutton and White, 1966) shows that observed travel-times are linear to about 18½ degrees. This distance limit for velocity constancy is not exceeded for the seismic zone and stations considered here. The Jeffreys-Bullen velocity for "normal" depth (0.00r) is adopted here for calculations.

Port Moresby station, being that of principal concern, was chosen as base station. Distances from Port Moresby to each of Rabaul, Honiara, and Charters Towers were calculated, and were converted to equivalent times by applying the adopted velocity. These times then represent maximum Δ P for each station pair. In practice, these values were rounded off to the nearest two and a half seconds.

This step involved changes of only one second or less in each case. It was believed that significant accuracy would not be lost, as individual station readings were usually only reliable to about one second at best, and the simplifying assumptions regarding velocity might lead to errors of the same order. For the same reasons, the hyperbolas were computed at intervals of five seconds in Δ P. Computation involved use of the formula derived in the Appendix with equivalent times instead of distances, and was carried out point-by-point on a desk calculator.

Since the hyperbolas are computed on the assumption of planarity, the most suitable map projection must be chosen for use with them. This is believed to be the two-point equidistant projection (Steers, 1950), as the principle is the same as that used in the derivation of the hyperbolas; i.e. distances (travel-times) from any point (an epicentre) to two base stations (seismological observatories) are accurately represented. A latitude-longitude grid was calculated for each of the three station pairs used, and the three grids were meaned. This is the grid shown with the hyperbolas in Plate 3. Errors resulting from the meaning are negligible compared with others already discussed.

4. TREATMENT OF DEEP FOCUS

As has been already pointed out, the hyperbolas of Plate 3 are strictly applicable only for shallow shocks (depth $<$ 50 km). For deeper focus, the P velocity becomes higher and less linear. Thus it becomes no longer possible to use the simple formula, since Δ P is dependent not only on the difference in epicentral distances from the shock to the two stations but also on the distances themselves. Every point on the curves (no longer hyperbolas) would have to be separately calculated without use of the formula.

However, if a poor crossover is obtained on the assumption of shallow depth, or depth is suspected from other evidence, a simple method of successive approximation may be used to obtain an epicentre. From this first rough crossover, the effects of depth on P arrivals at the appropriate distances and thus on Δ P may be estimated. Plate 2 shows corrections to the P travel-times (depth 0.00r) for various depths (from Jeffreys & Bullen, 1948), which may be used for this purpose. An adjustment to Δ P for a station pair may be made for several trial depths, such that

$$\left|\Delta P\right|_{\text{adjusted}} = \left|\Delta P\right|_{\text{observed}} + \left[2\right] - \left[1\right]$$

where $[1]$, $[2]$ are signed depth corrections as found from Plate 2 for the closer, and more distant, stations, respectively. A revised epicentre is then found from the adjusted Δ Ps. An improvement in the quality of the crossover represents an improvement in the epicentre.

The cycle may be repeated if necessary. In practice, depths and epicentres found by this method of adjustment tend to be biased relative to United States Coast & Geodetic Survey locations in the area, and are frequently not as accurate as the excellence of the adjusted crossovers would suggest, particularly for the deepest shocks.

Obviously, a station phase misidentification, or a timing error, may produce a false impression of depth by giving a poor crossover.

5. DISCUSSION

The method is not equally successful in all parts of the area covered by Plate 3. In the north-west portion, for instance, Rabaul and Honiara hyperbolas cross at very small angles, so that large error in position is possible. In the same area, the Charters Towers hyperbolas are not very discriminating because of large spacing for small time intervals in the vicinity of maximum ΔP. Another area in the vicinity of Rabaul is not well-covered, because of the short-distance velocity effect and the maximum ΔP uncertainty in the Rabaul hyperbolas.

Other parts, as for instance the triangle bounded by the three stations indicated, are particularly well-covered. The active zones of Bougainville, west New Britain, and the East Papuan islands are in this section.

6. ACKNOWLEDGEMENTS

The author is grateful to Dr D. Denham for directing his attention to the two-point equidistant projection.

7. REFERENCES

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

BROOKS, J.A., 1965 - Earthquake activity and seismic risk in Papua and New Guinea. Bur. Min. Resour. Aust. Rep. 74.

BROOKS, J.A., and RIPPER, I.D., 1966 - Proposed investigation of crustal structure in New Guinea. Bur. Min. Resour. Aust. Rec. 1966/33 (unpubl.).

BULLEN, K.E., 1963 - AN INTRODUCTION TO THE THEORY OF SEISMOLOGY. Cambridge, University Press.

BYERLY, P., 1942 - SEISMOLOGY. New York, Prentice-Hall.

JEFFREYS, H. and BULLEN, K.E., 1948 - SEISMOLOGICAL TABLES. British Association, Gray Milne Trust.

RICHTER, C.F., 1958 - ELEMENTARY SEISMOLOGY. San Francisco, Freeman and Co.

STEERS, J.A., 1950 - AN INTRODUCTION TO THE STUDY OF PROJECTIONS. London, University Press.

SUTTON, D.J., and WHITE, R.E., 1966 - A study of P travel-times for some Australian earthquakes. Aust. J. Phys. 19, p. 157

APPENDIX

Refer to Figure 1 (page 2)

Adopt straight line (a) as X-axis, and as Y-axis, a line through station O perpendicular to the X-axis.

OP = A, PQ = B, A - B = k = constant, OQ = C = constant

The aim is to find the locus f(x,y) of epicentre P for specified constant k.

$$A^2 = x^2 + y^2 = (B + k)^2 \qquad \ldots\ldots\ldots\ldots (1)$$

$$B^2 = (x - c)^2 + y^2 \qquad \ldots\ldots\ldots\ldots (2)$$

$$\therefore \left(\sqrt{x^2 + y^2} - k\right)^2 = (x - c)^2 + y^2 \qquad \text{from (1) in (2)}$$

$$\therefore x^2 + y^2 - 2k\sqrt{x^2 + y^2} + k^2 = (x - c)^2 + y^2$$

$$\therefore 2k\sqrt{x^2 + y^2} = k^2 - c^2 + 2cx$$

$$\therefore 4(c^2 - k^2)x^2 - 4c(c^2 - k^2)x + (c^2 - k^2)^2 = 4k^2y^2$$

$$\therefore (c^2 - k^2)(x^2 - cx + c^2/4 - k^2/4) = k^2y^2$$

$$\therefore \frac{(x - c/2)^2}{k^2/4} - \frac{y^2}{(c^2 - k^2)/4} = 1$$

EXPLANATION OF PLATES

The method of referring to depth in Plates 1 and 2 is that used by Jeffreys and Bullen in the "Seismological Tables", where r is the radius from the centre of the Earth to the bottom of the crust. The crust is taken nominally as 33 km thick. The conversion of depths from fractions of r to kilometres below the surface is as follows:

n(xr)	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08
km	33	95	160	230	295	360	430	495	560

Depths other than "normal" (33 km) are here taken to the nearest five kilometres.

In Plate 3, the stations shown are identified by U.S. Coast & Geodetic Survey symbols:

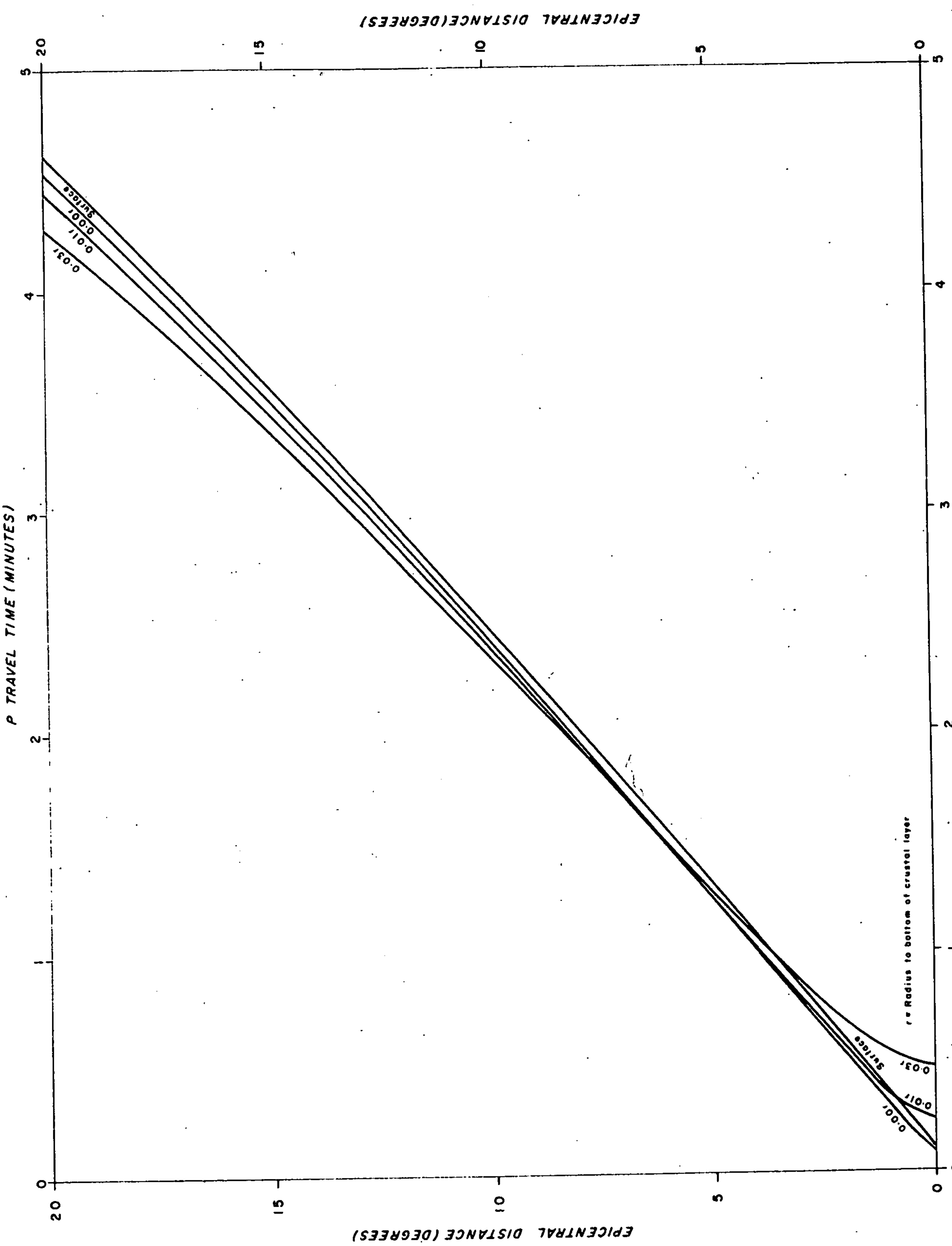
PMG	Port Moresby
RAB	Rabaul
HNR	Honiara.

Charters Towers is not within the area of the map, but to facilitate distance measurement, circular arcs at intervals from Charters Towers increasing by one degree of distance are shown.

The three sets of hyperbolas are identified by letters:

R	Rabaul-Port Moresby
H	Honiara-Port Moresby
C	Charters Towers-Port Moresby,

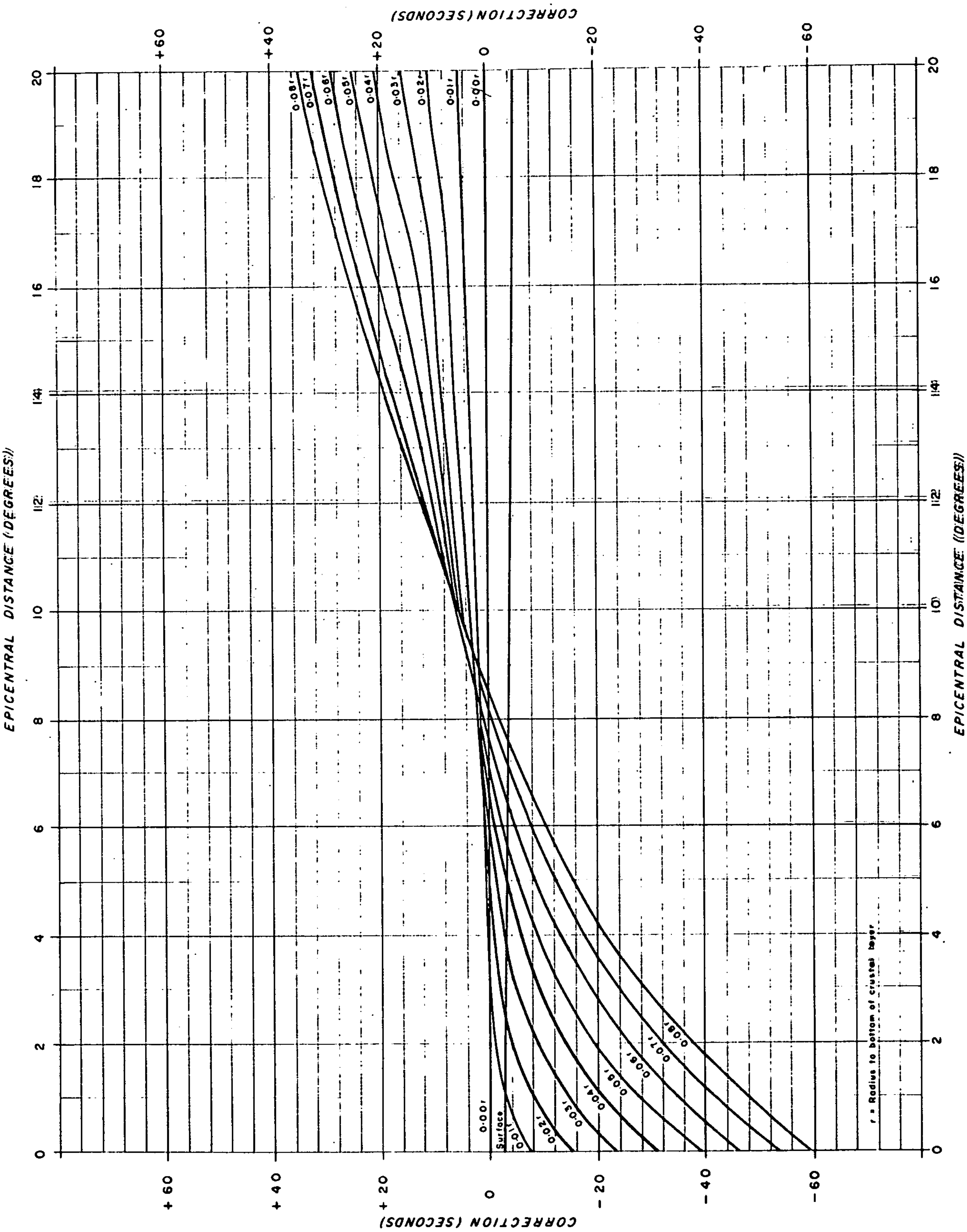
and figures, which are unsigned ΔP values in seconds.



TRAVEL TIMES FOR THREE FOCAL DEPTHS

(FROM JEFFREYS & BULLEN, 1948)

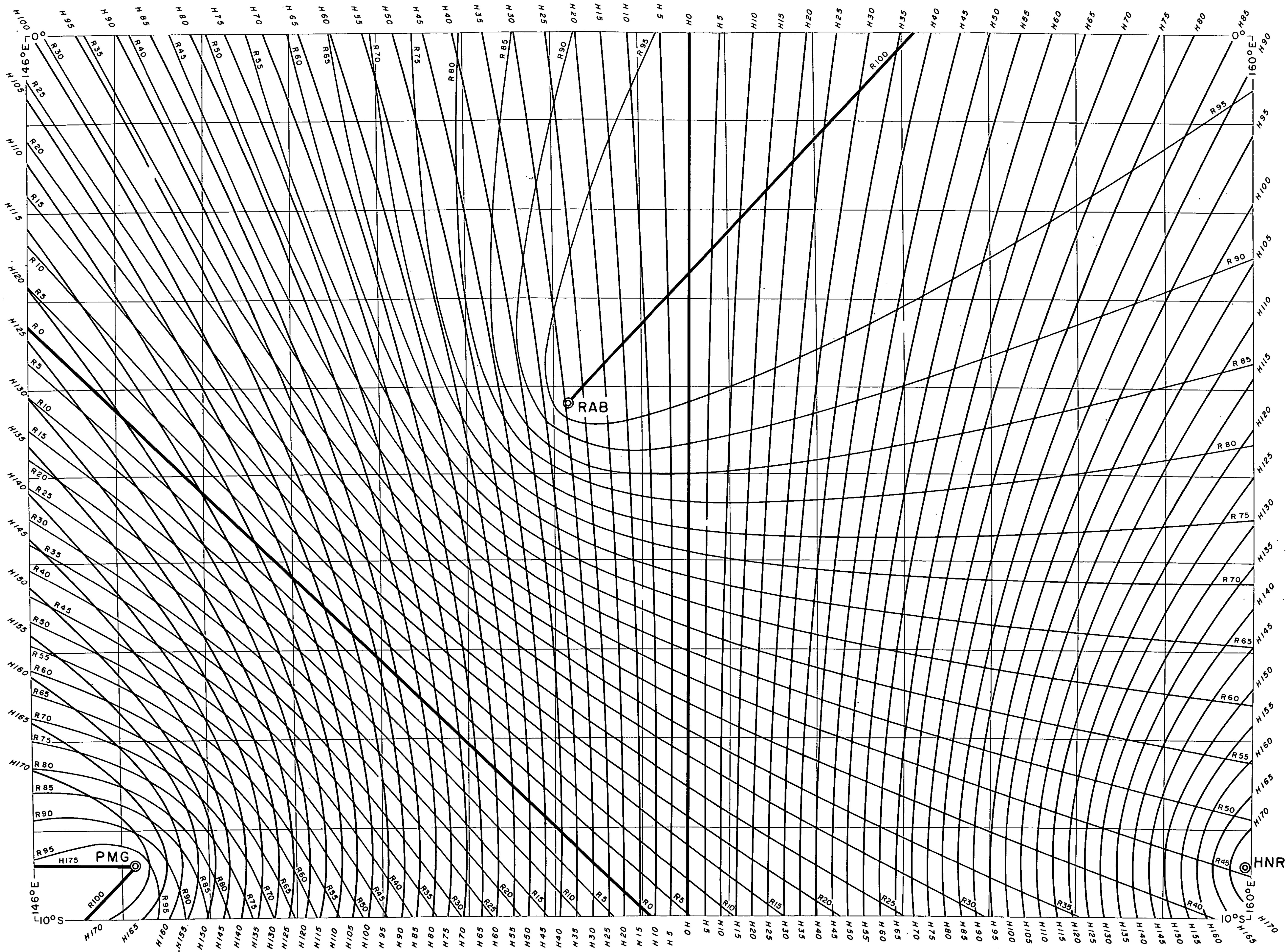
PLATE 2



DEPTH CORRECTIONS FOR P

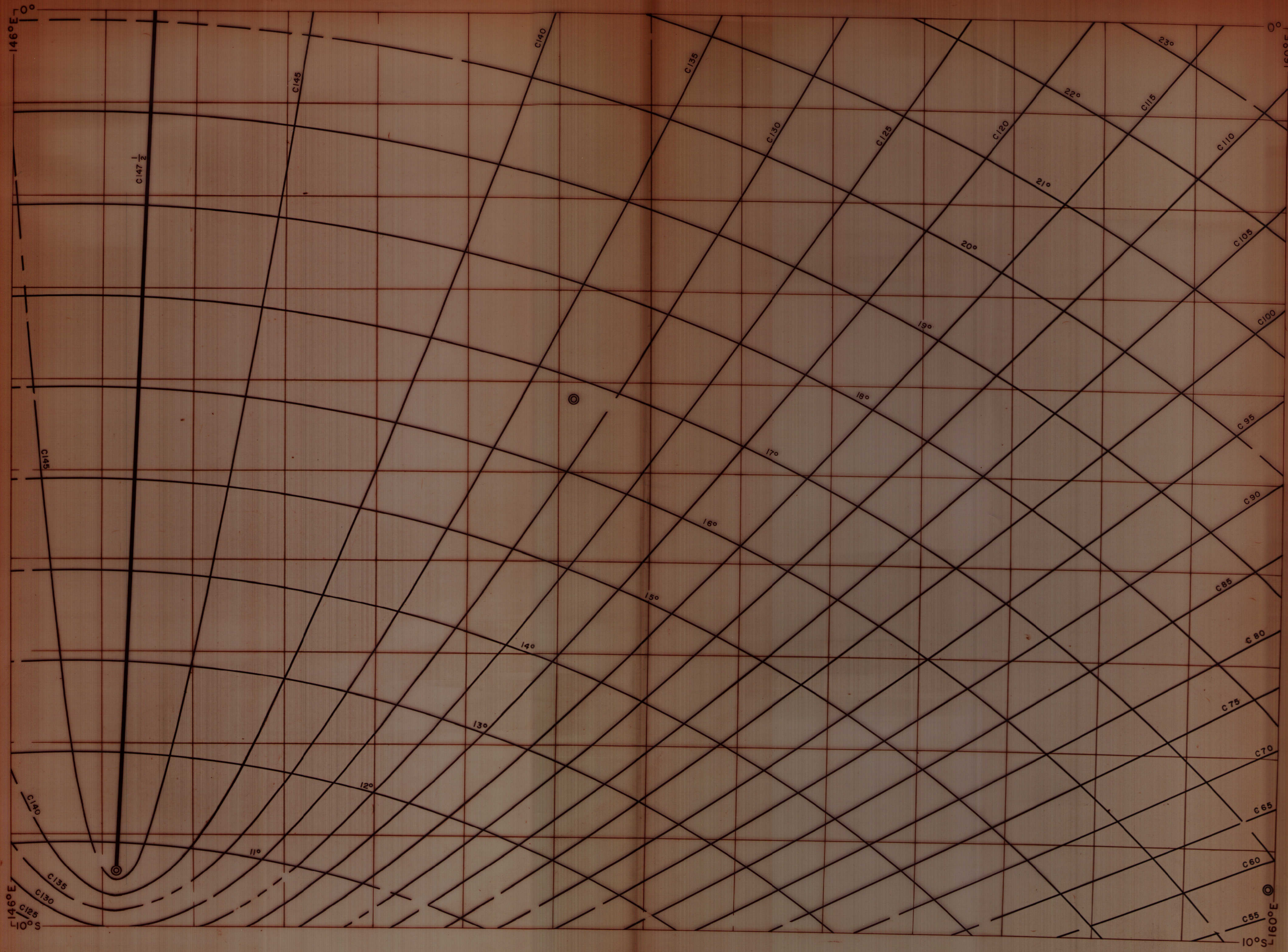
(FROM JEFFREYS & BULLEN, 1948)

TO ACCOMPANY RECORD No. 1969/83 G82/4—47



EARTHQUAKE LOCATION CHART
TERRITORY OF PAPUA & NEW GUINEA

G82/4—44



(OVERLAY TO G 82/4-44)