95. On the Mechanism of a Deep-seated Earthquake as Revealed by the Distribution of the Initial Motions at Stations throughout the World.¹)

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Studies of distant earthquakes have hitherto been confined mostly to problems connected with time-distance curves. An epoch-making investigation, however, has been carried out by L. Geiger and B. Gutenberg, who, following the ingenious method of K. Zöppritz and studying the ratio of the amplitudes of the direct and reflected seismic waves, have thrown light on the internal structure of the earth. Their investigations, however, involved the serious assumption that the seismic energy is emitted uniformly in all directions from the hypocentre, an unsatisfactory assumption in view of the present knowledge concerning initial earthquake motions, so that it has now become necessary to examine the results of their previous investigation. There is moreover the other important problem as to whether it is possible to deduce the mechanism of earthquakes from tele-seismic observations as has already been done from observations of near earthquakes. In the course of our studies on earthquake mechanism as deduced from observations of near earthquakes, one of us noticed that the mechanism of the deep-seated earthquake of Feb. 20, 1931, could be explained either by means of model A, which has a conical surface as node, or by B, which has two perpendicular nodal planes, but were handicapped through not being in possession of seismograms obtained at more distant stations than were at our disposal. We accordingly started to collect the seismograms; 74 foreign stations having complied with our wishes besides 17 Japanese stations. With these data in hand the various problems were studied, the present note being a description of one of the results thus obtained. We wish to take this opportunity of expressing our sincere thanks to all the institutions who have so generously supplied us with the results of their invaluable observations. Our thanks are also due to Professor M. Ishimoto, who kindly encouraged us to carry out the present work.

¹) Preliminary note to a paper that will shortly appear in the Bulletin of the Earthquake Research Institute.
The earthquake in question was first studied by T. Isikawa; then by F. J. Scrase, who published his detailed paper in which he had investigated the time-distance curves of various phases of the earthquake. Lastly, K. Wadati also published an investigation on the position of the hypocentre as deduced from the results of observations made by near stations.

We have determined the position of epicentre of this earthquake by means of the method of least squares. Utilizing the arrival times of the P-wave at 135 stations scattered throughout the world, the epicentre came out as $\varphi = 44^\circ 29' \pm 1.3^\prime$ N, $\lambda = 135^\circ 43' \pm 1.4^\prime$ E. The time-distance curve on the mean spherical earth was next constructed, with due corrections for the ellipticity\(^1\) of the earth to the distance and travel times. The times of arrival at short epicentral distances were derived from

$$T_P(\Delta_2 - \Delta_1) = T_{pP}(\Delta_2) - T_P(\Delta_1) + T_0$$

where $\Delta_1$ and $\Delta_2$ are epicentral distances, $\left(\frac{dT_P}{d\Delta}\right)_{\Delta_1} = \left(\frac{dT_{pP}}{d\Delta}\right)_{\Delta_2}$, and $T_0$ is the time of occurrence at the hypocentre. $T_0$ was determined from the relation

$$T_0 = \frac{3}{2} T_P \left(\frac{\Delta_0}{3}\right) - \frac{1}{2} T_{pP}(\Delta_0)$$

where $\Delta_0$ is the minimum distance at which $pP$ makes its appearance.\(^2\) Taking the observations at Taihoku, $T_0$ came out as 5 h 33 m 24 s. Again, on comparing the travel times with the Tables now in use, the hypocentral depth came out as 328 km.

It will be possible now to find from formula $i = \sin^{-1}\left\{\frac{dT}{d\Delta}/\left(\frac{dT}{d\Delta}\right)_{\text{max}}\right\}$ the angle $i$ subtended by the seismic vertical and a seismic ray which emerges at a point on the earth's surface whose epicentral distance is $\Delta$. We can therefore calculate the amplitude for any kind of earthquake mechanism.

We shall now examine the results of actual observations. The initial motions in our seismograms conspicuously show systematic dis-

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1) After completing our work, we came into receipt of a paper by B. Gutenberg and C. F. Richter discussing the same problem. Beitr. z. Geophys., 40 (1933), 380–389.

2) In practice, we seldom have observations at such a distance as $\Delta_0$, but if we have observations at $\Delta_0 + \epsilon$, we can then also apply the formula with the negligibly small error of $-\frac{1}{3!} \frac{4}{9} \left(\frac{d^3T}{d\Delta^3}\right)_{\Delta_0} \epsilon^3$, which amounts usually to 0.1 sec. for $\epsilon$ when it is as large as $3^\circ$. 
Fig. 1.

tribution (Fig. 1). The predominance and simple character with almost constant period of the P and S phases, howsoever the epicentral distances may differ, and the regular distribution of the initial motions seem to suggest the slightness of the dispersive effect of seismic waves in the earth's interior. The character of the distribution rules out the efficacy of model A in favour of B. The thick curves in Fig. 1 indicate the calculated intersections of the nodal surface (planes at hypocentre and modified by the crustal structure) with the earth's surface, the angle subtended at the hypocentre by these nodal planes being 78°. It is obvious that this angle may be an arbitrary one as viewed from the standpoint of the elastic theory, while there is an uncertainty as to whether the angle thus obtained is correct or whether it requires a correction through inaccuracy in the time-distance curve. The initial motions of reflected waves pP or PP also confirm this interpretation. In the figure the nodal lines (calculated) of reflected waves are indicated with broken (pP) and dotted (PP) lines.

If this interpretation be correct, we may expect the presence of four points on the earth's surface where S-waves do not appear (where only P-waves appear with maximum amplitude). L, M, N, and O are such points. Our seismograms show that Aomori is near L, while Palau and Amboina are near M (Fig. 2). Moreover, as may be expected
from this mechanism, the initial motions of the S-wave at almost all the stations throughout the world seem to diverge from point L or N and converge towards M or O. The largeness of $P$ and $pP$ in Europe and smallness of $P$ and $PP$ in North America accord well with the foregoing considerations. We may therefore conclude that this earthquake occurred according to the mechanism of model B, possibly due to two pairs of doublet without moment, the plane of which dips at $56^\circ.3$ and strikes at N $35^\circ.5$ W.

In conclusion the writers wish to express their cordial thanks to Professor A. Imamura for the kindness bestowed on them in the publication of this paper.