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Seismology in St. Louis University

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HISTORICAL OUTLINES.

THERE is perhaps no development in the broad fields of science, which has so completely captivated the attention of many of the keenest intellects of our age, and in so short a space of time, as the recent study of seismography. This new science opened so near the close of the last century, may justly be claimed by the present, twentieth century, as among its first excellent fruits. In a decade of years it has developed into gigantic proportions. Means and energy have not been spared in promoting it. Still, truly efficient work, as von Rebeur-Paschwitz pointed out in his able address to the Geographical Congress at London (1895), will be next to impossible until a complete chain of fully equipped seismological stations with a staff of reliable, interested, self-sacrificing observers will have been inaugurated in every part of the world. Dr. E. Wiechert, an acknowledged authority on seismology, voiced the same sentiments at the third International Conference for the Study of Seismology held at The Hague (1907). In every part of the world, "the gaps intervening between any two stations," he stated, "should be only 5000-6000 km." "This ideal," Dr. Hennig seems to think, "is at the present day still on the distant horizon."[1]

The urgent necessity was patent to all from the first. But recently, Prof. G. B. Rizzo, director of the Osservatorio di Messina, Istituto di Fisica Terrestre della R. Università, in his work "*Sulla Propagazione dei Movimenti Prodotti dal Terremoto di Messina del 28 Dicembre 1908*," which was published only last January, laments that "the observatories were not a little more numerous, and these all equipped with instruments which would permit us to distinguish with certainty, in their diagrams, the various phases of the movements." In this way alone, will it become possible to follow seismic disturbances at small intervals, in their progress around the globe. For this purpose, the already extensive "International Seismological Association" was formed in Europe. Its first assembly was held at Strassburg just ten years ago, two years after the earnest appeal for the founding of an "International Seismological Association" had been made by Gerland

[1] Dr. E. Hennig—*Erdbebenkunde*.

and his enthusiastic followers at the international "Geographical Congress" held at Berlin in 1899.

Strassburg was selected in 1903 by the "Second International Seismological Convention" to be the central bureau of the association, as it had already for several years enjoyed a like distinction among the Imperial German observatories. Prof. Dr. George Gerland, to whose able management was entrusted the important post of general director of the bureau, occupies the same position even at present.

The year 1907 witnessed another concourse of the world's learned seismologists. The "Third International Conference" included a representation which gathered from 22 States. At this period there existed 126 seismological observatories in different parts of the world, barring Japan. Germany possessed 15 in her own boundaries, and 3 in her dependencies. England and her colonies could boast of 60. "Milne" has become a household name among English seismologists, and must be identified with the rapid development of British seismology.

This brief sketch of the development of our science would, however, be sadly wanting in an essential feature, if we omitted to mention still a third nation, Japan, which deserves distinction not only as including within its borders the region of greatest seismicity, but for the active interest it has shown in the observation of seismic phenomena and that at a time when Europe was not yet awakened to its overwhelming importance. And it was her unique position that, as it were, forced Japan to take her bearings, and to accomplish what she has in the world of science. In 1880 a seismological association was formed. The results of its labors were issued in its own publications (Transactions and Seismological Journal). The University of Tokyo in the year 1886 incorporated a special department for the teaching of seismology under Prof. Sekiya, who was succeeded by Prof. Omori. Prof. Kikuchi makes mention of this with a spirit of honest pride when he says that "the chair of seismology in Japan is the only one of its kind in all the world." The famous earthquake of Mino-Owari in 1891 induced Prof. Kikuchi to establish a commission for the investigation of earthquakes (Shinsai Yobo Chosakwai or "Earthquake Investigation Committee"). An imperial edict of June 25th, 1892, signified the full approbation of the government in the establishment of the Committee. At the present day the country is literally covered with a network of over 1500 observing stations, of which number at least 70 are equipped with modern recording apparatus. Although much of prime importance, especially from the viewpoint of utility, was accomplished, the work was necessarily restricted. The narrow confines of the country impeded

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any great developments of scientific value, the like of which we have witnessed since seismology has become a study of such universal interest in the western world. With Japan, it must be admitted, it was a more immediate matter of physical self-protection.

Finally, the new science has found its way across the waters to our own land. There are, independently of the Jesuit Seismological Stations, some six or seven seismic observatories in the United States, mostly in the eastern States. About two years ago the United States joined the "International Association" and Mr. Harry Fielding Reid was appointed by the President as the representative for this country. Lately a Seismological Society of America has been organized with headquarters at Stanford University, Cal.

Rev. Fr. Algue, S. J., director of the Manila Observatory, in the Philippine Islands, suggested the question of the organization of a Jesuit Seismic Service, which was established five years afterwards. His interest in meteorology led Fr. Algue to confer with Rev. Fr. Odenbach, S. J., for many years director of the Meteorological Observatory of St. Ignatius College. The latter had made some more or less fruitful attempts at the observation of earthquake phenomena with machines of his own invention, as well as of the Omori type. It was mainly due to Father Algue's suggestion of spreading interest and calling out as many collaborators into the new field as possible, that Father Odenbach broached the great idea to his superiors with the petition for their approbation. At the same time he solicited their support towards the establishment of seismic instruments in all colleges under the control of members of the Society of Jesus in this country or at least in all such as already enjoyed the distinction of a meteorological observatory. These would doubtless be best fitted to lend a helping hand in the undertaking. Sixteen colleges, and among them St. Louis University, came thus to be equipped with seismological instruments of the Wiechert 80 kilogram type.

Fifteen stations are distributed through the United States as follows: Georgetown, D. C.; Brooklyn, N. Y.; Fordham, N. Y.; Worcester, Mass.; Buffalo, N. Y; Cleveland, O.; Mobile, Ala.; New Orleans, La.; Chicago, Ill.; Milwaukee, Wis.; St. Mary's, Kan.; Denver, Colo.; Santa Clara, Cal.; Spokane, Wash.; St. Louis, Mo. St. Boniface, Manitoba, in Canada, concludes the list of colleges which at this time installed seismic machines in America.

In other countries, too, the members of the Society of Jesus have given a practical proof of their devotion to seismology. It may be of interest to note that there are under the management of the Fathers of the Society the following meteorological observatories, many of which have already opened a department for seismological study, and all, no doubt, are looking forward to the day, when they, too, shall be enabled to subscribe their names to the daily increasing number of earnest and devoted seismologists: Bulawayo, Rhodesia; Stonyhurst, England; Cartuja (Granada), Spain; Madrid, Spain; Puebla, Mexico; Kalocsa (Pestmegye), Hungary; Gijon (Oviedo), Spain; Comillas (Santander), Spain; Galicia (Pontevedra), Spain; Tortosa (Tarragona), Spain; Orduña (Viscaya), Spain; Ambohidempona, (Tananarivo), Madagascar; Kildare, Ireland; Itù (Estado de S. Paulo), Brazil; Riverview, Sydney, Australia; Nova Friburgo (Estada de Rio Janeiro), Brazil; Cienfuegos, Cuba; Havana, Cuba; Manila, Philippine Islands; Calcutta (Bengal Presidency), East India; Specola Vaticana, Rome, Italy; Ksara (Beyrout), Syria; Zi-ka-wei, China; Boroma, Zambesi.

At the St. Louis University, the Department of Seismology was opened on October 22, 1909. On this day a seismograph of the Wiechert type (80 kilogram) was permanently erected in a vault under the administration building. The machine rests on a concrete pier 4 ft. x 4 ft. x 5.8 ft., constructed to be independent of the foundations of the buildings, and deep enough to eliminate the less violent disturbances. The pier stands on a few feet of loess underlain by Carboniferous, Silurian and Ordovician limestones, shales and sandstones, dipping toward the northeast. In an artesian well sunk somewhat less than four miles southwest of the university, the igneous substratum was reached at a depth of 986.08 metres below sea-level.

The effects of external changes in temperature and humidity are greatly restricted by two vestibules through which access is had to the instrument. They are separated by a doubly insulated wall with "refrigerator" door.

THE AIM OF OUR WORK.

The year's work has brought home to us the absolute necessity of accurate and systematic work. In this, as in other exact sciences, everything depends on reliable data and precise measurements. The data referred to are the records of earth motion propagated from centers of disturbance more or less distant. Since these vibratory movements are too faint to be directly perceptible, they can be studied only through the medium of a magnifying instrument. Such are the various types of seismographs. These instruments magnify the feeble tremors which

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pass through the earth beneath them, into measurable proportions, at the same time registering what has taken place.

If a mere catalogue of these phenomena and a rough estimate of their relative intensity were all that is desired, a sufficiently sensitive instrument would answer as equipment, and an examination and comparison of the daily records would be all the pains required. But the problems, with which the infant science of seismology finds itself confronted, will never have a satisfactory solution without a considerably greater outlay of painstaking labor. The most elementary of these problems is that of determining the velocity of transmission of seismic waves. Yet, little or nothing can be done towards its solution without (1) a recording instrument sensitive enough to register the beginning, at least, of the three chief phases; (2) means of ascertaining, to the minute and second, the times at which these were recorded.

Our station answers the first of these requirements in regard to a sufficiently large number of earthquakes, although in many of these instances the first preliminaries are missing or so indistinct that their beginning or initial impulse escapes recognition. As to the second requisite, we are sorry to say, that up to the present, it has not been realized fully. In no case could we be sure of the exact second, and often there was a doubtful margin of several seconds. Steps have been taken, however, to remedy this drawback.

This is one part of the task we have set ourselves. We are also trying to furnish our co-workers with a faithful record of the local disturbances registered. For a time we did this by reporting the maximum double displacements of the pen as recorded on the seismogram, i. e., the total amplitude $2a$, reckoned from turning point to turning point of the maximum vibration. This, it was thought, would be a reliable standard from which to judge of the effect produced at various stations by a given earthquake; but it was found unsatisfactory for several reasons: (1) It would have been necessary to have the various instruments of the network of stations concerned tuned, as it were, to the same pitch; that is, the constants on which the magnification depends, should be identical for all. Now, it was found impossible to fix the constants precisely at predetermined values and keep them unchanged for any length of time. (2) A more serious objection lies in the fact that there is no uniform correspondence between seismogram-amplitudes and those of the earth-tremors, except when the latter have a very short period compared with that of the instrument. In all other cases the magnification changes with the changing ratio of the two periods. Hence a large gram-amplitude is not necessarily indicative of a large earth displacement and vice versa. For these reasons it seemed advisable to change our method of reporting amplitudes. They are, therefore, now tabulated in our reports in terms of the earth amplitudes. This reduction of the recorded amplitudes to those of the earth motion entails a determination of the various constants of the instrument, which modify the magnification. After a brief description of the instrument and the working of the various parts we shall present, in concise form, the method we have found most practical for determining the value of the constants.

THE INSTRUMENT.

The seismograph consists essentially of a heavy mass poised on a stiff rod whose lower end terminates in a Cardanic hinge, which allows the mass to move freely in any horizontal direction. When the pier or support, on which the instrument rests, is set in motion by the tremblings of an earthquake, the Cardanic hinge and the frame of the machine, which rises to the level of the "stationary" mass, execute all the oscillations communicated to them, while the mass itself will tend to keep its position. It is the inertia of the mass which gives it stability, and hence the greater it can be made, consistently with the strength of the hinge, the better. Between the mass, which tends to remain stationary, and the frame which is more or less agitated by the feeblest earth tremors, we have a relative motion; and pens, projecting from the percussion centre of the mass to a smooth writing surface on the frame, would trace a record of the disturbance.

But the mass will not stand in this unstable position without some means of support. It must be attached to the frame, without being so bound to it, that it may not remain stationary when the frame oscillates. This is effected by two thrust rods, which meet in the centre of oscillation of the mass at an angle of 90° and thence extend, each to the short arm of a lever, whose fulcrum is rigidly fixed to the frame, and whose long arm works against a spring. The pressure of these two springs opposes the pull of gravity acting on the mass, which is slightly displaced from the vertical position. The mass, therefore, will find its position of equilibrium at a point in which the acting components of the two accelerations, g and ϕ (gravity and spring) are just equal and opposite. When the mass is displaced from this position, the components of both ϕ and g are changed. If moved farther from the vertical, both are increased; if nearer, both are diminished.

If they change at the same rate, there will be no fixed point of equilibrium, and the mass will stand in any position whatever. Hence ϕ and g must be so related that, in whatever direction the mass is displaced, a restoring force will be set up tending to bring it back to the equilibrium point; in short, it must be made to act like a pendulum. This will obtain if the component of ϕ increases more rapidly than that of g, when the mass is deflected from the vertical; and decreases more rapidly than the g-component when deflected towards the vertical.

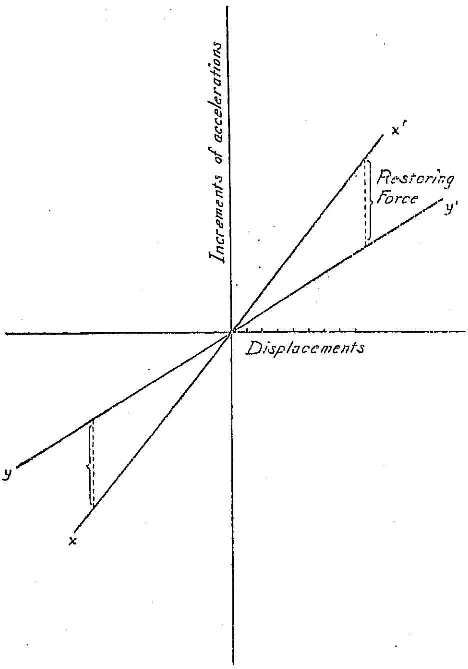

FIG. 1.

The restoring force might be represented graphically, by plotting, as abscissae, the displacements of the mass; as ordinates, the corresponding increments in the ϕ and g-components. (See Fig. 1.) These sets of points will determine two straight lines, xx' representing the successive increments of the ϕ-component; and yy' those of the g-component. xx' is a straight line because all harmonic motions vary directly with the displacement; and the same holds for yy', because of the very short range, never more than 2 mm., within which the movement of the mass is confined. The difference between the ordinates at any point will represent the resultant acceleration or restoring force which drives the mass back to the equilibrium point, represented by the origin of co-ordinates, where the components of ϕ and g are equal and opposite. If the mass is displaced, the restoring force will carry it back to and beyond the point of equilibrium by virtue of the kinetic energy developed. Hence the mass, like a pendulum, will execute harmonic motion, and will have its own definite period. This, however, may be changed at will by adjusting the leverage through which the spring acts on the mass. Shortening the arm connected with the latter, lessens the distance through which the mass must move to set up a given force of restitution, and hence shortens the period; while lengthening this arm has the opposite effect.

These levers serve another purpose. It is through them that the desired magnification on the gram is secured. The long arm in each case operates one of the recording pens, and hence, any movement transmitted to the latter will be multiplied on the record in the ratio of the long to the short arm of the lever system. This we might style the lever magnification. It remains practically constant. Fluctuations in magnification are due to other causes.

The pens are delicately balanced so that the pressure on the smoked paper amounts to about 1 milligram. The paper is carried around on a revolving drum at a uniform rate of 1 cm. per minute. The hours and minutes are automatically registered by an electro-magnet connected with the contact clock. The instrument is now ready to record an impulse from any direction. An impetus traveling parallel to the one of the thrust rods will affect only the pen connected with it, leaving the other undisturbed. Hence the mass is really equivalent to two distinct pendulums; there are two planes of independent vibration, viz.: the vertical planes passing through the thrust rods, and cutting each other at right angles. Vibrations parallel to neither of the thrust rods, will be split into two components, each of which will be recorded by the corresponding pen. The relative magnitudes on the record will depend on the angle formed by the direction of the vibrations with the independent planes, which, in our instrument, pass through the cardinal points of the compass.

One more adjunct, well-nigh essential to the proper working of the instrument, deserves mention before we pass on to the discussion of the constants. This is the damping contrivance. Its purpose is to "damp out" the vibrations due to the proper period of the pendulum, which would be set up by a sudden, strong impulse. Strong impulses, unless checked, would keep the mass in motion for a considerable time, and hence obliterate or accentuate any earth tremors, which might follow, thus falsifying the record. Such a disturbing element must be eliminated. The damping holds the mass in check, preventing it, to a great extent, from executing its own vibrations, and tending to keep it approximately at rest. The device consists of a cylindrical air chamber, in which moves to and fro, a piston connected by a rod to the lever system. The resistance of the air in the chamber opposes and minimizes the pendulum's independent action. This is different from friction in the ordinary sense of the term, which must always be kept at a minimum. The friction is a constant quantity, so that, if it curtails the stroke of the pen in one direction by 2 mm., it will curtail it by the same amount on the return stroke, etc. Not so the damping. This is not constant in amount, and is called forth by, and varies with the acceleration of the motion it is to oppose. Hence it will shorten the successive strokes of the pen by a constantly decreasing amount—the successive amplitudes will be a decreasing geometrical series. Thus the mass keeps itself from being thrown into violent swinging by strong earth disturbances, without losing, to any great extent, its sensitiveness to minute tremors.

THE PHYSICS OF THE SEISMOGRAPH.

Since the seismograph record is not a reliable index, of the intensity of a seismic disturbance, it is desirable to go back to the earth-motion itself. But the reduction of the recorded amplitudes to those of the actual earth-waves, involves a knowledge of several characteristic physical constants on which the magnifying power of the instrument depends. The term "constants" may be a bit misleading, for the factors in question are not constant in the sense that they may be measured once for all. Owing to changes produced by fluctuations in temperature and humidity, or, by violent earth shocks, etc., they are subject to variation, and hence, must be determined from time to time, especially after any readjustment.

The seismograph, as we have said, is an inverted pendulum; hence, it has a free period of its own, T_0. This is one of the constants, and is the time required for a complete oscillation of the pendulum set in motion, and left to itself, free from all exterior hindrances, such as damping, etc. Since the period is comparatively long, there is no difficulty in obtaining it by direct observation, provided the damping can be thrown out. The interval required for three, four or five oscillations of the pen, can be read off on a stop-watch. This number of seconds divided by the number of complete oscillations, will give the period quite accurately. The average of several such results may be taken as final. This, of course, must be repeated for each component.

Now, the seismograph pendulum is kept in equilibrium, by springs, as it could not oscillate, because of its inverted position, if the force of gravity were in control. We can not, therefore, apply to it the formula, $T = 2\pi\sqrt{\frac{l}{g}}$. For, instead of g we have an acceleration $(\phi - g)$, which is the resultant of the two opposing accelerations, gravity (g)

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and the spring (ϕ). Hence the above formula must be changed to; $T_0 = 2\pi\sqrt{\dfrac{l}{\phi - g}}$ (1). Both ϕ and g are accelerations of the same character (harmonic), and therefore, their difference is harmonic, and may be expressed in cm/sec ^{2}. ϕ can not be equal to g, for an infinite period would result; that is, the pendulum, if deflected, would remain deflected. ϕ is, therefore, greater than g.

If ϕ is unknown, then $\phi - g$ is also unknown, and, hence, observing T_0 can not give l, the length of the actual seismograph pendulum. We may, however, infer the following: Let it be assumed that $\phi - g$ is wholly gravitational. Then: $T_0 = 2\pi\sqrt{\dfrac{L}{g}}$ (2), that is, some length, L, can be found, having the period T_0, upon the assumption that g is the acceleration. This L is the length of the equivalent mathematical pendulum. Therefore, our machine is "equivalent" to a simple gravitational pendulum of Length L, and period T_0. This equivalent length L is another of the constants.

In Figure 2, let CM represent the equivalent pendulum, which is suspended at C, and whose mass is concentrated at M. To make the simple pendulum record its vibrations with the same magnification as the actual seismograph, imagine a long pointer P (without mass), to be attached to M (thus prolonging L), so that it can be made to trace a line on the surface "S," when M moves to M'. Call the distance $L + P$, I. If I is given the proper length, the trace SS' on the surface "S" will equal the throw a of the pen on the actual seismograph for equal displacements of the two masses. Let this displacement be MM'. Now, from similar triangles, I is to L, as SS' is to MM'; but the ratio of SS' to MM' is the number expressing how many times larger SS' is than MM'. It is, therefore, the magnification; call it V. Then $V = \dfrac{I}{L}$ (3). Hence to determine the magnification, we need only the values of L and I. L, as we have said, can be determined from the observed period of the actual seismograph. I may also be found experimentally in the following manner:

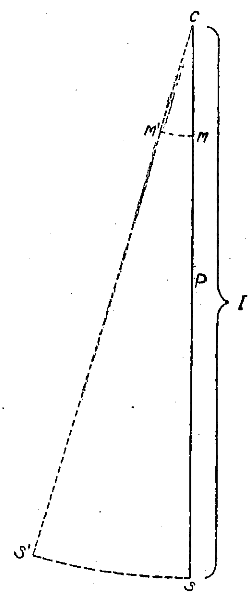

FIG. 2.

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In Figure 3, which is exaggerated for the sake of clearness, let H be the distance in the actual seismograph from the center of gravity M' of the pendulum to the center of suspension C in the cardanic spring system.

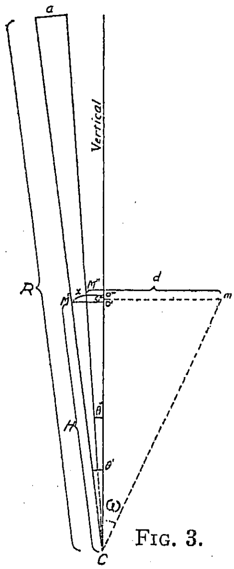

FIG. 3.

Now if the center of gravity m of a small weight be placed at a known distance d from the line CM', the pendulum will shift to a new position of equilibrium, so that the center of gravity will now be at M'', and a certain throw a of the pen will be observed. Since all displacements of M from the vertical are small, the arcs = sines = tangents approximately. For the same reason $O'C = O''C = O'''C = H$, and $mO' = d$ approximately.

In position M', the moment about $C = M\ (\phi - g) \cdot H \tan \theta'$.

In position M'', the moment about $C = M\ (\phi - g) \cdot H \tan \theta''$.

The difference is caused by mg, whose moment is $mg \cdot H \tan \omega$.

Hence, $M\ (\phi - g) \cdot H\ (\tan \theta' - \tan \theta'') = mg \cdot H \tan \omega$.

Or, $M\ (\theta' - \theta'') = m \tan \omega \dfrac{g}{\phi - g}$.

Since angle $(\theta' - \theta'') = \dfrac{x}{H}$, and $\tan \omega = \dfrac{d}{H}$, $M \dfrac{x}{H} = m \dfrac{d}{H} \cdot \dfrac{g}{\phi - g}$. (4).

Now, suppose the pen, instead of being operated by the compound lever system, were at the end of a long pointer CM' and CM'' produced to a length R such that the arc sweep through by the pen-tip would be exactly equal to a (see above), the throw of the actual pen observed when operated by the lever system.

Then $\dfrac{x}{H} = \dfrac{a}{R}$.

Substituting $M \dfrac{a}{R} = m \dfrac{d}{H} \cdot \dfrac{g}{\phi - g}$,

Or $\dfrac{M \cdot H \cdot a}{m \cdot d} = \dfrac{g}{\phi - g} \cdot R$ (5).

But, $\dfrac{L}{g} = \dfrac{T_0^2}{4\pi^2} = \dfrac{l}{\phi - g}$, (from (1) and (2) above).

Hence, $\dfrac{g}{\phi - g} = \dfrac{L}{l}$.

Substituting in (5) $\dfrac{M \cdot H \cdot a}{m \cdot d} = \dfrac{L}{l} R$ (6).

Since the center of suspension and the center of percussion (call it P, see Fig. 4) in any pendulum are interchangeable, if C is moved rapidly P will remain stationary. And as the writing plane moves with C, $\frac{a}{x} = \frac{C'S''}{CP}$ (from similar triangles). Now, $\frac{a}{x}$ is the magnification which we called V, $C'S''$ is R and CP is l.

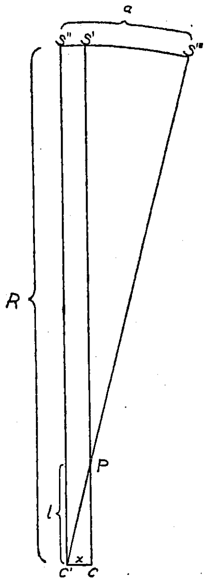

FIG. 4.

$$\text{Hence, } V = \frac{R}{l}\cdot$$

$$\text{But we said above, } V = \frac{I}{L}$$

$$\text{therefore, } \frac{R}{l} = \frac{I}{L}$$

$$\text{and, } \frac{RL}{l} = I.$$

$$\text{substituting in (6) } \frac{M \cdot H \cdot a}{m \cdot d} = I \ (7).$$

Hence, we can determine I experimentally from the known quantities, M, H, m, d and the resulting throw a of the pen (not riding on the smoked paper). Hence, we can find V. Since, however, on account of the mode of suspension, the single seismograph is equivalent to two pendulums, swinging at right angles, I (and hence V) must be found for each component. But one experiment will suffice if the small mass is placed in the plane bisecting the angle formed by the vertical planes passing through the thrust-rods, and the pen-throws a_E and a_N read off. The above formula then becomes $I = \frac{M \cdot H \cdot a}{.707 \ m \cdot d}\cdot$

Now V is the magnification only when the ratio $\frac{T_e}{T_0}$ (earth-period to machine period) is very small. That V is not the magnification for all values of T_e may be seen from the following consideration:

In Figure 5 a coiled spring is shown, supporting a mass W. If the point of support A is suddenly raised or lowered and then held fixed again, W will begin to oscillate with its own "free period," the amplitude depending on the permanent displacement of A.

If A is very suddenly raised or lowered, and as suddenly returned to position again, no matter how often in succession, provided this

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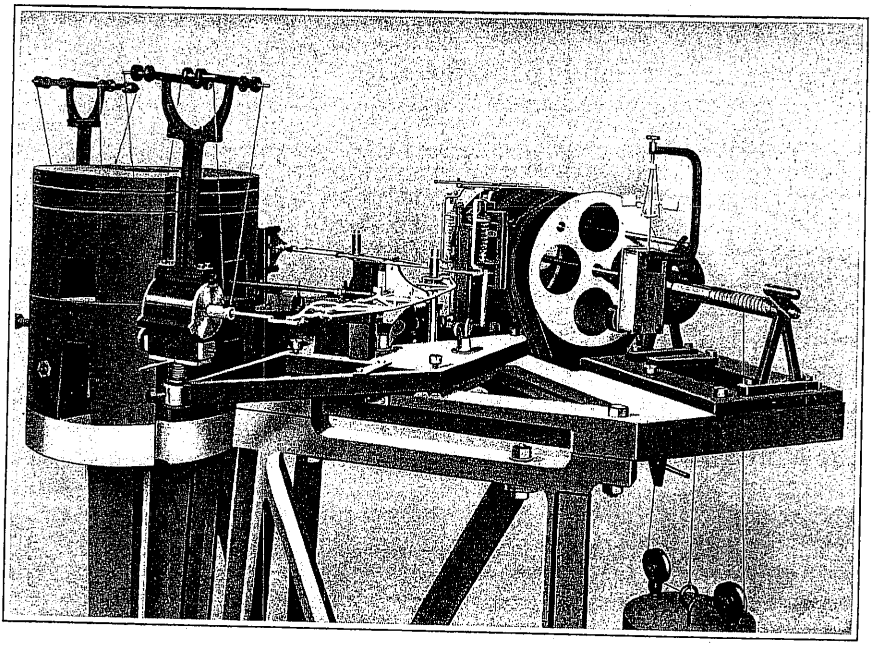

Magnifying and Registering Apparatus.

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vibration of A is of very short time-period compared to the "free" period of W, W will not be set in motion appreciably. It will begin to oscillate when A is vibrated more slowly. But the period of W will not be its "free" period nor that of A; neither will the amplitudes of W differ greatly from those of A. When the A vibration gets within about 99% of the free period, W will begin to plunge violently. The phenomenon therefore, appears rather suddenly, as it depends on small changes in the difference of the two periods. Moreover, the excursions of W will not be of constant amplitude; W will run up to a maximum excursion—then gradually diminish, and for an instant come to a full stop (of course, A is supposed to be kept moving steadily with fixed amplitude and period). Then W begins the performance over again. The action resembles that of "beats" in acoustics. The "beat" has a period of its own.

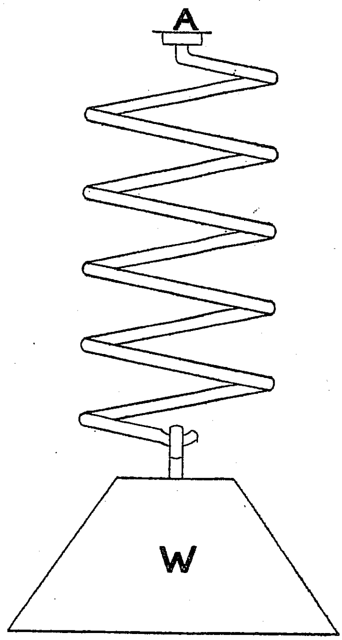

FIG. 5.

Let A be now moved with a period equal to the "free" period of W. W promptly falls into 1/2 phase with A, and the "beat" becomes infinitely long. That is, the amplitude of W goes on increasing indefinitely. Meantime A need not move with anything like large amplitude.

This effect is the well-known phenomenon called resonance.

As soon as the period of A becomes ever so little greater than the W "free" period, the latter will again be hampered in its vibrations. And should A move up and down much more slowly than the W period, W will simply begin to go up and down with A.

Applied to the seismograph, the frame and support will correspond to A, and the stationary mass to W. Hence, the "stationary" mass will only remain stationary when earth periods are very small. This is the only condition in which V will give the true magnification, which we may call $\mathfrak{V}$. When T_e approaches T_0, $\mathfrak{V}$ will become greater and greater, and when the two periods coincide $\mathfrak{V}$ would be theoretically infinite. When T_e becomes greater than T_0, $\mathfrak{V}$ decreases very rapidly and even falls far below V. This irregularity in the values of $\mathfrak{V}$ is another phase of the difficulty which makes necessary the introduction of damping. Small earth motions of a period near that of the machine are exaggerated beyond all proportion, while vibrations of greater amplitude, but also of longer period, are nearly suppressed. Damping tends to reduce "resonance" to a minimum, and hence to equalize the magnification curve.

In this case the true magnification $\mathfrak{V}$ for a given earth period may be found from Dr. Wiechert's formula:[2]

$$\mathfrak{V}=\frac{V}{\sqrt{\left[1-\left(\frac{T_e}{T_0}\right)^2\right]^2+4\left(\frac{T_0}{2\pi\tau}\right)^2\left(\frac{T_e}{T_0}\right)^2}}$$

τ being the time required for the amplitude of free vibrations to fall to $\frac{1}{e}$ of their original value, *i. e.*, to a fraction of the original value equal to the reciprocal of e, the base of the natural logarithms. Since $T_0=\frac{T}{\sqrt{1+\left(\frac{T}{2\pi\tau}\right)^2}}$ and log. nat. $\epsilon=\frac{T}{2\tau}$, (T being the period of the instrument when damped), the above formula may be reduced to the following:

$$\mathfrak{V}=\frac{V}{\sqrt{\left[1-\left(\frac{T_e}{T_0}\right)^2\right]^2+4\frac{(\text{log. nat. }\epsilon)^2}{\pi^2+(\text{log. nat. }\epsilon)^2}\cdot\left(\frac{T_e}{T_0}\right)^2}}$$

In this formula ϵ is the damping measured in terms of the ratio of two succeeding pen-amplitudes. This may be determined in the following manner:

Let the zero or mid-point of a graduated arc be made to coincide with the zero-line or neutral position of the pen, balanced so as to swing clear of the scale beneath. An impulse given to the lever controlling the pen will set the mass and pen in motion, and the displacement to either side may be read from the scale. Three such readings suffice; let them be a_1 to the right of 0; a_2 to the left of 0; a_3 to the right of 0 again. Then $\epsilon=\frac{a_1+a_2}{a_2+a_3}$, or with pen writing on the paper $\epsilon=\frac{a_1+a_2-2r}{a_2+a_3+2r}$, where r is the "maximum friction amplitude," i. e., the maximum distance to which the pen-point may be displaced

[2] Dr. E. Wiechert — *Die Theorie der Automatischen Seismographen*,— Abhand d. K. Gesellsch. d. Wiss. zu Göttingen, Math.-Phys. Kl., 1903.

without setting up a restoring force sufficient to overcome the friction opposing its return to the line of rest. We may obtain r independently by the following formula:

$r = \frac{1}{2} \frac{l_1^2 - l_0 l_2}{l_0 - l_2}$, where l_0, l_1, l_2, are successive double amplitudes from turning point to turning point (pen writing on paper). This formula can only be applied if the damping can be thrown out. The advantage of the latter method is that a permanent record of the damping test is obtained.

The constants T, L, I, V, ϵ, r definitely characterize an instrument as to its magnifying effect on a given earth motion. Hence, if they are known, any recorded seismic disturbance can be described in terms of the actual earth motion. This leads us to the practical working out of the seismogram.

THE PHASE ANALYSIS OF THE DIAGRAM.

Before taking up this subject, however, we must premise a few remarks on the nature of earthquakes in general. The theory of earthquake propagation most widely accepted, at present, is that of Dr. E. Wiechert [3]. It would lead us beyond the scope of these pages, to enter into a discussion of the facts and hypotheses upon which this theory is based. Suffice it to say, that he is led, mainly by astronomical reasons, to the assumption of a rock mantle increasing in density with increasing depth, and finally merging into a uniform metallic nucleus. Now, if a disturbance be set up in such an elastic medium, two sets of waves will necessarily be sent out in all directions. One of these wave-trains will be longitudinal, like sound vibrations in air; the other, transverse, like those of light. Upon reaching the surface these vibrations will transform part of their energy into a complicated series of surface waves. Of these disturbances the longitudinal waves will necessarily travel fastest, the surface waves least rapidly. Hence the order at which they will arrive at a distant point on the surface will be first longitudinal, then transverse, then surface waves, among the latter of which the first to appear will be the so-called long or "Rayleigh" waves. These three sets of waves will be recognized on the seismograph record as the first preliminary, second preliminary and main phases of the disturbance. Again, the longitudinal and transverse elastic waves travel faster, the denser the medium through which they

[3] E. Wiechert and K. Zöppritz — *Ueber Erdbebenwellen I und II.* Nachr. d. K. Gesellsch. d. Wiss. zu Göttingen, Math.-Phys. Kl., 1907.

pass. Therefore, on the assumption made in the theory of Wiechert, their velocity should increase with their depth. Hence if a plane wave front (such as a small element—e. g., a_1 b_1, a_2 b_2, a_3 b_3, etc.—Cfr. Fig. 6—of the actual ovoidal wave front may be considered to be), traverses any other path than a diameter, one side will at first be passing through a denser medium than the other. As a consequence, this side will travel faster than the other, and the whole wave front will be swung around. In the middle core, however, both sides of the wave front will be traversing a medium of equal density, and the wave front will remain parallel to itself. Thus the ray or normal to the wave surface will describe a curved line in the rock mantle, and a straight line in the metallic core.

Furthermore, each of these disturbances will produce its effect independently of all the rest. Hence, whenever a longitudinal or transverse wave reaches the surface, it will be reflected independently, according to the laws which govern elastic waves[4].

(A) A longitudinal wave striking the surface will be reflected in two components, one longitudinal with the angle of reflection equal to the angle of incidence; the other, transverse, with a lesser angle of reflection. The sines of the two angles are directly proportional to the velocities of the corresponding waves (in the same medium, of course).

(B) There are two cases possible in the reflection of transverse waves:

(a) When the vibration takes place perpendicularly to the plane of incidence (i. e., the plane which contains the normal to the surface, the angle of incidence and the angle of reflection), only one wave, similar to the incident one is reflected, and this at an angle equal to the angle of incidence.

(b) When, however, the transverse wave is vibrating in the plane of incidence a resolution of component motions will take place at the surface. And, if the angle of incidence i is smaller than the *critical* value ($\sin i = \left(\frac{\textit{velocity of transverse wave}}{\textit{velocity of longitudinal wave}} \right)$, two waves will be reflected, the one transverse, at an angle equal to the angle of incidence, the other longitudinal at a much greater angle, the sines of the two angles being again directly proportional to their velocities. If, on the other hand, the incident ray makes an angle with the normal greater than the critical value, then no longitudinal wave can be reflected, but very complex surface-disturbances will be set up instead.

[4] See Wiechert, Note 3.

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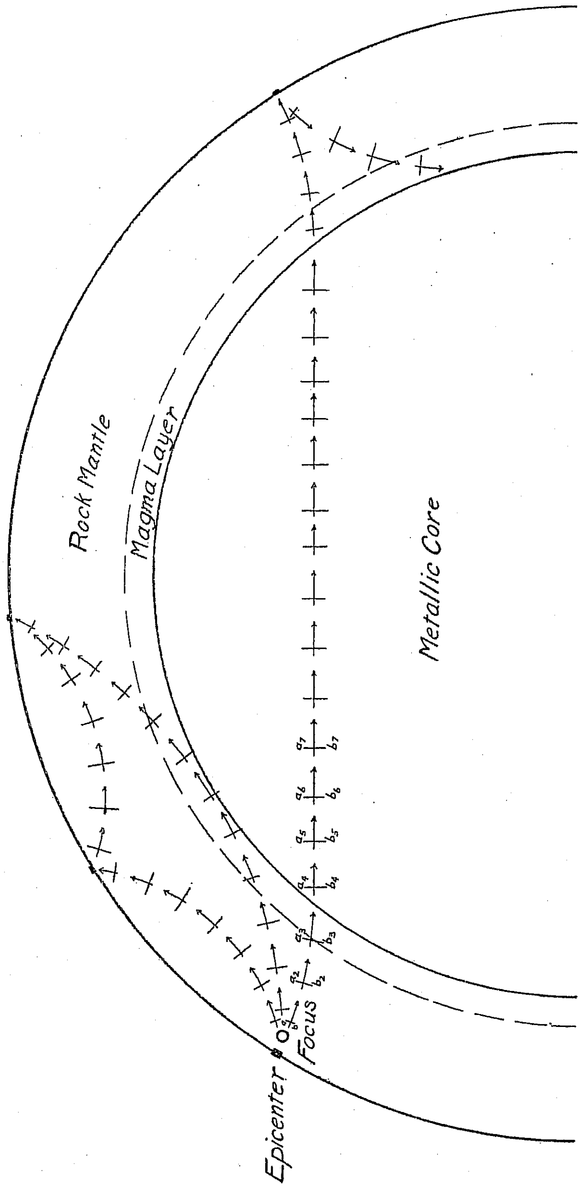

FIG. 6.

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Now it is evident, that if the paths and velocities of the direct waves in the preliminary phases are known, the velocities of the reflected and transformed waves may be derived from them. An absolutely necessary requisite to further progress, therefore, is to obtain arrival curves for the principal phases which will be as accurate as possible. Such curves were constructed by Milne (1903), Benndorf (1905), Oldham (1906) and others, but the most reliable results so far obtained, are those contained in the Göttingen curves and tables[5]. The original tables gave the time in seconds required by each phase to travel from the epicenter to successive stations one-half megameter (1 megameter = 1000 km.) apart up to a distance of 13 megameters. The following is an arrangement of these tables giving time-differences in minutes and seconds and embodying interpolations to 100 km. of Dr. Conrad[6] and some of our own.

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[5] See Note 3, and K. Zöppritz and L. Geiger — *Über Erdbebenwellen III.* Nachr. d. K. Gesellsch. d. Wiss. zu Göttingen, Math.-Phys. Kl., 1909.

[6] Dr. V. Conrad — *Seismische Registrierungen in Wien*, K. k. Akad. d. Wiss., Neue Folge., No. 39.

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I. TABLE FOR DISTANCES.

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Distance	Epicenter by Stereographic Projection		Distance		PHASES										Angle of Emergence	
Statute Miles	"d" St. Louis	"r" St. Louis	Angular	Mega-Meters	S—P	R_1P—P	R_2P—P	R_3P—P	PS—S	R_1S—S	R_2S—S	R_3S—S	eL—P	eL—S	P	S
					m s	m s	m s	m s	m s	m s	m s	m s	min	min		
100	.4810	.00967	54′	0.1	....	....	....	....	....	....	....	....	....	....	....	....
	.4811	.01934	1°48′	.2	....	....	....	....	....	....	....	....	....	....	....	....
200	.4813	.02902	2°42′	.3	....	....	....	....	....	....	....	....	....	....	....	....
	.4815	.0387	3°36′	.4	....	....	....	....	....	....	....	....	....	....	....	....
300	.4818	.04839	4°30′	.5	....	....	....	....	....	....	....	....	....	....	....	....
400	.4822	.05809	5°24′	.6	....	....	....	....	....	....	....	....	....	....	....	....
	.4827	.06781	6°18′	.7	....	....	....	....	....	....	....	....	....	....	....	....
500	.4833	.07753	7°12′	.8	....	....	....	....	....	....	....	....	....	....	....	....
	.4839	.08728	8° 6′	.9	....	....	....	....	....	....	....	....	....	....	....	....
600	.4846	.09704	9° 0′	1.0	1 48	....	....	....	....	....	....	....	1.9	.1	20°42′	20°42′
700	.4854	.1068	9°54′	1.1	1 58	....	....	....	....	....	....	....	2.1	.1	22°29′	22°29′
	.4862	.1166	10°48′	.2	2 8	....	....	....	....	....	....	....	2.3	.2	24°16′	24°16′
800	.4872	.1265	11°42′	.3	2 17	....	....	....	....	....	....	....	2.5	.2	26° 3′	26° 3′
	.4882	.1363	12°36′	.4	2 27	....	....	....	....	....	....	....	2.7	.2	27°50′	27°50′
900	.4892	.1462	13°30′	.5	2 37	....	....	....	....	....	....	....	2.9	.3	29°37′	29°37′
1,000	.4904	.1561	14°24′	.6	2 46	....	....	....	....	....	....	....	3.1	.3	31° 9′	31° 9′
	.4916	.1661	15°18′	.7	2 55	....	....	....	....	....	....	....	3.4	.5	32°40′	32°40′
1,100	.4930	.1761	16°12′	.8	3 5	....	....	....	....	....	....	....	3.6	.5	34°12′	34°12′
1,200	.4944	.1861	17° 6′	.9	3 14	....	....	....	....	....	....	....	3.8	.6	35°43′	35°43′
	.4959	.1961	18° 0′	2.0	3 23	0 15	0 18	0 19	....	0 28	0 34	0 36	4.0	.6	37°15′	37°15′
1,300	.4974	.2063	18°54′	.1	3 31	0 17	0 21	0 22	....	0 32	0 39	0 42	4.3	.8	38°32′	38°32′
	.4991	.2164	19°48′	.2	3 40	0 19	0 24	0 25	....	0 35	0 44	0 48	4.5	.8	39°49′	39°49′
1,400	.5008	.2266	20°42′	.3	3 48	0 22	0 27	0 28	....	0 39	0 48	0 54	4.8	1.0	41° 6′	41° 6′
1,500	.5027	.2369	21°36′	.4	3 57	0 23	0 30	0 31	....	0 42	0 53	1 0	5.0	1.0	42°23′	42°23′
	.5046	.2472	22°30′	.5	4 5	0 25	0 33	0 34	....	0 46	0 58	1 6	5.3	1.2	43°40′	43°40′
1,600	.5066	.2575	23°24′	.6	4 13	0 28	0 36	0 37	....	0 51	1 5	1 13	5.5	1.3	44°45′	44°45′
1,700	.5087	.2679	24°18′	.7	4 20	0 31	0 40	0 41	....	0 56	1 11	1 21	5.8	1.5	45°49′	45°49′
	.5109	.2784	25°12′	.8	4 28	0 34	0 43	0 44	....	1 1	1 18	1 28	6.0	1.5	46°54′	46°54′
1,800	.5131	.2890	26° 6′	.9	4 35	0 37	0 47	0 48	....	1 6	1 24	1 36	6.3	1.7	47°58′	47°58′
1,900	.5155	.2996	27° 0′	3.0	4 43	0 40	0 50	0 51	....	1 11	1 31	1 43	6.5	1.8	49° 3′	49° 3′
	.5180	.3103	27°54′	.1	4 50	0 43	0 55	0 56	....	1 17	1 39	1 51	6.8	2.0	49°54′	49°57′
2,000	.5206	.3210	28°48′	.2	4 57	0 46	0 59	1 1	....	1 23	1 47	1 59	7.1	2.1	50°44′	50°51′
2,100	.5232	.3318	29°42′	.3	5 3	0 49	1 4	1 6	....	1 29	1 54	2 8	7.3	2.2	51°35′	51°45′
	.5260	.3428	30°36′	.4	5 10	0 52	1 8	1 11	....	1 35	2 2	2 16	7.6	2.4	52°25′	52°39′
2,200	.5289	.3537	31°30′	.5	5 17	0 55	1 13	1 16	....	1 41	2 10	2 24	7.9	2.6	53°16′	53°32′
	.5319	.3648	32°24′	.6	5 23	0 58	1 17	1 21	....	1 47	2 18	2 33	8.2	2.8	53°58′	54°17′
2,300	.5350	.3760	33°18′	.7	5 29	1 4	1 22	1 26	....	1 53	2 26	2 41	8.4	2.9	54°40′	55° 4′
2,400	.5382	.3873	34°12′	.8	5 35	1 5	1 26	1 32	....	1 59	2 33	2 50	8.7	3.1	55°23′	55°49′
	.5415	.3986	35° 6′	.9	5 41	1 9	1 31	1 37	....	2 5	2 41	2 58	9.0	3.3	56° 5′	56°35′
2,500	.5449	.4101	36° 0′	4.0	5 47	1 12	1 35	1 42	....	2 11	2 49	3 7	9.3	3.5	56°47′	57°20′
	.5486	.4216	36°54′	.1	5 53	1 16	1 40	1 47	....	2 17	2 58	3 17	9.6	3.7	57°26′	57°59′
2,600	.5523	.4333	37°48′	.2	5 59	1 20	1 45	1 53	....	2 24	3 7	3 27	9.9	3.9	58° 5′	58°37′
2,700	.5561	.4451	38°42′	.3	6 4	1 24	1 49	1 58	....	2 30	3 16	3 36	10.2	4.1	58°43′	59°16′
	.5600	.4570	39°36′	.4	6 10	1 28	1 54	2 4	....	2 37	3 25	3 46	10.5	4.3	59°22′	59°54′
2,800	.5641	.4690	40°30′	.5	6 16	1 32	1 59	2 9	....	2 43	3 34	3 56	10.8	4.5	60° 1′	60°33′
	.5684	.4811	41°24′	.6	6 21	1 35	2 4	2 15	....	2 50	3 43	4 7	11.1	4.7	60°34′	60°54′
2,900	.5727	.4934	42°18′	.7	6 26	1 38	2 9	2 21	....	2 57	3 53	4 18	11.4	5.0	61° 8′	61°14′
3,000	.5772	.5058	43°12′	.8	6 31	1 42	2 13	2 26	....	3 3	4 2	4 29	11.7	5.2	61°41′	61°35′
	.5819	.5184	44° 6′	.9	6 36	1 45	2 18	2 32	....	3 10	4 12	4 40	12.0	5.4	62°15′	61°55′
3,100	.5867	.5311	45° 0′	5.0	6 41	1 48	2 23	2 38	0 11	3 17	4 21	4 51	12.3	5.6	62°48′	62°16′
	.5917	.5439	45°54′	.1	6 47	1 52	2 29	2 44	0 12	3 23	4 30	5 2	12.6	5.8	63°11′	62°18′
3,200	.5968	.5569	46°48′	.2	6 52	1 56	2 35	2 51	0 14	3 29	4 40	5 13	12.9	6.0	63°34′	62°20′
3,300	.6021	.5701	47°42′	.3	6 58	1 59	2 40	2 57	0 15	3 34	4 49	5 24	13.3	6.3	63°56′	62°23′
	.6076	.5834	48°36′	.4	7 3	2 3	2 46	3 4	0 17	3 40	4 59	5 35	13.6	6.5	64°19′	62°25′
3,400	.6133	.5969	49°30′	.5	7 9	2 7	2 52	3 10	0 19	3 46	5 8	5 46	13.9	6.7	64°42′	62°27′
3,500	.6191	.6106	50°24′	.6	7 14	2 10	2 57	3 17	0 20	3 52	5 17	5 56	14.2	7.0	64°43′	62°31′
	.6252	.6245	51°18′	.7	7 20	2 14	3 3	3 24	0 22	3 57	5 26	6 6	14.5	7.2	64°44′	62°35′
3,600	.6314	.6386	52°12′	.8	7 25	2 17	3 8	3 30	0 23	4 3	5 34	6 16	14.8	7.4	64°45′	62°40′
3,700	.6378	.6519	53° 6′	.9	7 31	2 21	3 14	3 37	0 24	4 8	5 43	6 26	15.1	7.6	64°46′	62°44′
3,800	.6444	.6673	54° 0′	6.0	7 36	2 24	3 19	3 44	0 25	4 14	5 52	6 36	15.5	7.9	64°47′	62°48′
	.6513	.6821	54°54′	.1	7 41	2 27	3 24	3 50	0 27	4 19	6 0	6 47	15.8	8.1	64°49′	62°51′
3,900	.6584	.6971	55°48′	.2	7 47	2 30	3 29	3 56	0 29	4 23	6 8	6 57	16.1	8.3	64°52′	62°55′
	.6658	.7123	56°42′	.3	7 52	2 33	3 35	4 2	0 30	4 28	6 17	7 8	16.5	8.6	64°54′	62°58′
4,000	.6733	.7277	57°36′	.4	7 58	2 36	3 40	4 8	0 32	4 32	6 25	7 18	16.8	8.8	64°57′	63° 2′

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Distance	Epicenter by Stereographic Projection		Distance		PHASES										Angle of Emergence	
Statute Miles	"d" St. Louis	"r" St. Louis	Angular	Mega-Meters	S—P	R_1P—P	R_2P—P	R_3P—P	PS—S	R_1S—S	R_2S—S	R_3S—S	eL—P	eL—S	P	S
					m s	m s	m s	m s	m s	m s	m s	m s	min	min		
	.6812	.7434	58°30′	.5	8 3	2 39	3 45	4 14	0 33	4 37	6 33	7 29	17.1	9.0	64°59′	63° 5′
4,100	.6892	.7594	59°24′	.6	8 8	2 42	3 50	4 20	0 33	4 41	6 41	7 39	17.4	9.3	65° 3′	63°11′
4,200	.6976	.7757	60°18′	.7	8 13	2 45	3 55	4 26	0 34	4 45	6 48	7 48	17.7	9.5	65° 7′	63°16′
	.7062	.7922	61°12′	.8	8 19	2 47	4 0	4 31	0 34	4 50	6 56	7 58	18.0	9.7	65°11′	63°22′
4,300	.7152	.8091	62° 6′	.9	8 24	2 50	4 5	4 37	0 35	4 54	7 3	8 7	18.3	9.9	65°14′	63°27′
4,400	.7244	.8262	63° 0′	7.0	8 29	2 53	4 10	4 43	0 35	4 58	7 11	8 17	18.6	10.1	65°18′	63°33′
	.7340	.8437	63°54′	.1	8 34	2 55	4 14	4 49	0 35	5 1	7 19	8 27	18.9	10.3	65°23′	63°39′
4,500	.7439	.8616	64°48′	.2	8 39	2 57	4 18	4 54	0 35	5 5	7 27	8 37	19.3	10.6	65°28′	63°45′
4,600	.7541	.8798	65°42′	.3	8 44	2 59	4 22	5 0	0 36	5 8	7 35	8 47	19.6	10.9	65°32′	63°50′
	.7647	.8984	66°36′	.4	8 49	3 1	4 26	5 5	0 36	5 12	7 43	8 57	20.0	11.2	65°37′	63°56′
4,700	.7757	.9174	67°30′	.5	8 54	3 3	4 30	5 11	0 36	5 15	7 51	9 7	20.3	11.4	65°42′	64° 2′
	.7871	.9368	68°24′	.6	8 59	3 6	4 34	5 17	0 36	5 18	7 58	9 16	20.6	11.6	65°48′	64° 9′
4,800	.7989	.9566	69°18′	.7	9 5	3 8	4 39	5 23	0 37	5 21	8 4	9 25	20.9	11.8	65°54′	64°16′
4,900	.8111	.9769	70°12′	.8	9 10	3 11	4 43	5 28	0 37	5 23	8 11	9 33	21.3	12.1	65°59′	64°22′
	.8238	.9976	71° 6′	.9	9 16	3 13	4 48	5 34	0 38	5 26	8 17	9 42	21.6	12.3	66° 5′	64°29′
5,000	.8369	1.0189	72° 0′	8.0	9 21	3 16	4 52	5 40	0 38	5 29	8 24	9 51	21.9	12.5	66°11′	64°36′
	.8506	1.0407	72°54′	.1	9 26	3 18	4 56	5 46	0 39	5 32	8 31	10 0	22.2	12.8	66°18′	64°44′
5,100	.8648	1.0630	73°48′	.2	9 31	3 19	5 0	5 51	0 40	5 34	8 38	10 10	22.5	13.0	66°25′	64°51′
5,200	.8795	1.0859	74°42′	.3	9 35	3 21	5 3	5 57	0 40	5 37	8 45	10 19	22.9	13.3	66°31′	64°59′
	.8948	1.1093	75°36′	.4	9 40	3 22	5 7	6 2	0 41	5 39	8 52	10 29	23.2	13.5	66°38′	65° 6′
5,300	.9107	1.1440	76°30′	.5	9 45	3 24	5 11	6 8	0 42	5 42	8 59	10 38	23.5	13.7	66°45′	65°14′
	.9272	1.1583	77°24′	.6	9 50	3 26	5 15	6 13	0 43	5 44	9 5	10 47	23.8	14.0	66°52′	65°22′
5,400	.9444	1.1838	78°18′	.7	9 55	3 28	5 19	6 19	0 43	5 47	9 11	10 56	24.1	14.2	67° 0′	65°30′
5,500	.9623	1.2100	79°12′	.8	10 0	3 29	5 23	6 24	0 44	5 49	9 17	11 4	24.5	14.5	67° 7′	65°39′
	.9810	1.2370	80° 6′	.9	10 6	3 31	5 27	6 30	0 44	5 52	9 23	11 13	24.8	14.7	67°15′	65°47′
5,600	1.0005	1.2650	81° 0′	9.0	10 11	3 33	5 31	6 35	0 45	5 54	9 29	11 22	25.1	14.9	67°22′	65°55′
5,700	1.0208	1.2936	81°54′	.1	10 16	3 35	5 35	6 40	0 46	5 56	9 35	11 31	25.4	15.1	67°30′	66° 4′
	1.0420	1.3233	82°48′	.2	10 21	3 37	5 38	6 45	0 47	5 58	9 41	11 39	25.8	15.4	67°38′	66°13′
5,800	1.0639	1.3540	83°42′	.3	10 25	3 40	5 42	6 51	0 49	6 1	9 47	11 48	26.1	15.7	67°47′	66°23′
	1.0872	1.3856	84°36′	.4	10 30	3 42	5 45	6 56	0 50	6 3	9 53	11 56	26.5	16.0	67°55′	66°32′
5,900	1.1114	1.4183	85°30′	.5	10 35	3 44	5 49	7 1	0 51	6 5	9 59	12 5	26.8	16.2	68° 3′	66°41′
6,000	1.1369	1.4523	86°24′	.6	10 40	3 45	5 53	7 6	0 52	6 7	10 5	12 13	27.1	16.4	68°12′	66°51′
	1.1634	1.4875	87°18′	.7	10 44	3 46	5 57	7 11	0 54	6 8	10 11	12 22	27.4	16.7	68°21′	67° 0′
6,100	1.1912	1.5240	88°12′	.8	10 49	3 47	6 2	7 15	0 55	6 10	10 17	12 30	27.8	17.0	68°30′	67°10′
	1.2204	1.5620	89° 6′	.9	10 53	3 48	6 6	7 20	0 57	6 11	10 23	12 39	28.1	17.2	68°39′	67°19′
6,200	1.2511	1.6011	90° 0′	10.0	10 58	3 49	6 10	7 25	0 58	6 13	10 29	12 47	28.4	17.4	68°48′	67°29′
6,300	1.2834	1.6427	90°54′	.1	11 2	3 50	6 13	7 31	0 59	6 16	10 35	12 56	28.7	17.7	68°57′	67°39′
	1.3174	1.6855	91°48′	.2	11 7	3 50	6 16	7 36	1 0	6 19	10 40	13 4	29.1	18.0	69° 6′	67°50′
6,400	1.3532	1.7303	92°42′	.3	11 11	3 51	6 20	7 42	1 0	6 21	10 46	13 13	29.4	18.2	69°16′	68° 0′
	1.3910	1.7771	93°36′	.4	11 16	3 51	6 23	7 47	1 1	6 24	10 51	13 21	29.8	18.5	69°25′	68°11′
6,500	1.4310	1.8260	94°30′	.5	11 20	3 52	6 26	7 53	1 2	6 27	10 57	13 30	30.1	18.8	69°34′	68°21′
6,600	1.4732	1.8774	95°24′	.6	11 24	3 54	6 30	7 58	1 3	6 29	11 2	13 39	30.4	19.0	69°44′	68°32′
	1.5172	1.9313	96°18′	.7	11 28	3 55	6 34	8 3	1 4	6 31	11 8	13 47	30.8	19.3	69°54′	68°42′
6,700	1.5654	1.9880	97°12′	.8	11 33	3 57	6 37	8 8	1 6	6 33	11 13	13 56	31.1	19.5	70° 3′	68°53′
	1.6198	2.0476	98° 6′	.9	11 37	3 58	6 41	8 13	1 7	6 35	11 19	14 4	31.5	19.9	70°13′	69° 3′
6,800	1.6694	2.1110	99° 0′	11.0	11 41	4 0	6 45	8 18	1 8	6 37	11 24	14 13	31.8	20.1	70°23′	69°14′
6,900	1.7266	2.1772	99°54′	.1	11 45	4 1	6 49	8 23	1 10	6 40	11 29	14 19	32.1	20.3	70°34′	69°26′
	1.7876	2.2477	100°48′	.2	11 49	4 2	6 52	8 27	1 11	6 43	11 35	14 25	32.5	20.7	70°44′	69°38′
7,000	1.8530	2.3226	101°42′	.3	11 53	4 3	6 56	8 32	1 13	6 45	11 40	14 32	32.8	20.9	70°55′	69°49′
7,100	1.9230	2.4022	102°36′	.4	11 57	4 4	6 59	8 36	1 15	6 48	11 46	14 38	33.2	21.2	71° 6′	70° 1′
	1.9982	2.4872	103°30′	.5	12 1	4 5	7 3	8 41	1 16	6 51	11 51	14 44	33.5	21.5	71°17′	70°13′
7,200	2.0793	2.5780	104°24′	.6	12 5	4 7	7 6	8 46	1 18	6 54	11 56	14 54	33.8	21.7	71°28′	70°25′
7,300	2.1669	2.6754	105°18′	.7	12 9	4 9	7 9	8 50	1 20	6 57	12 2	15 4	34.2	22.0	71°39′	70°37′
	2.2612	2.7802	106°12′	.8	12 13	4 12	7 12	8 55	1 22	7 1	12 7	15 15	34.5	22.3	71°51′	70°49′
7,400	2.3654	2.8941	107° 6′	.9	12 17	4 14	7 15	8 59	1 24	7 4	12 13	15 25	34.9	22.6	72° 2′	71° 1′
7,500	2.4770	3.0156	108° 0′	12.0	12 21	4 16	7 18	9 4	1 26	7 7	12 18	15 35	35.2	22.8	72°13′	71°13′
	2.5999	3.1496	108°54′	.1	12 25	4 17	7 22	9 9	1 28	7 10	12 24	15 44	35.5	23.1	72°25′	71°25′
7,600	2.7349	3.2938	109°48′	.2	12 28	4 19	7 25	9 15	1 31	7 14	12 30	15 52	35.9	23.4	72°36′	71°38′
	2.8834	3.4527	110°42′	.3	12 32	4 20	7 29	9 20	1 33	7 17	12 35	16 1	36.2	23.7	72°48′	71°50′
7,700	3.0483	3.6280	111°36′	.4	12 35	4 22	7 32	9 26	1 36	7 21	12 41	16 9	36.6	24.0	72°59′	72° 3′
7,800	3.2320	3.8222	112°30′	.5	12 39	4 23	7 36	9 31	1 38	7 24	12 47	16 18	36.9	24.2	73°11′	72°15′
	3.4377	4.0386	113°24′	.6	12 42	4 25	7 39	9 36	1 40	7 28	12 53	16 26	37.3	24.6	73°22′	72°27′
7,900	3.6696	4.2812	114°18′	.7	12 46	4 27	7 42	9 41	1 42	7 32	12 58	16 34	37.6	24.8	73°34′	72°40′
	3.9333	4.5557	115°12′	.8	12 49	4 29	7 46	9 45	1 45	7 35	13 4	16 41	38.0	25.2	73°45′	72°52′
8,000	4.2353	4.8685	116° 6′	.9	12 53	4 31	7 49	9 50	1 47	7 39	13 9	16 49	38.3	25.4	73°57′	73° 5′
8,100	4.5845	5.2290	117° 0′	13.0	12 56	4 33	7 52	9 55	1 49	7 43	13 15	16 57	38.7	25.8	74° 9′	73°17′

The phase analysis of diagrams is greatly facilitated by such an arrangement of the tables. To use them, we determine approximately the beginning of the three principal phases of the earthquake recorded on the diagram, and obtain the time differences, S-P, eL-P, and eL-S, in minutes and seconds. With these we enter the respective columns of the table, and note the corresponding distances. If they agree approximately, we may suppose that we have rightly identified the phases as present on our record. In that case we need only make sure that our time determinations are correct; and the epicentral distance thus obtained, may be considered fairly certain. If, however, the distances obtained for the three time differences do not agree, then, either we have mistaken the phases, or, some phase or part of phase is missing from our diagram. The latter is not at all improbable, for scarcely one-fourth of the seismograms obtained in the course of a year, will be complete. The correct interpretation of such an imperfect record, is by no means an easy matter, and will require careful comparison and study. To avoid complications, let us suppose that the diagram before us is a perfect one, and the epicentral distances agree. We then run through the entire line, corresponding to the distance we have found in the table, and note the time-difference for each reflection. With these we go back to the diagram, and examine it carefully. If any or all of the reflections actually appear at the time indicated, this will be an additional confirmation of the determined epicentral distance. The relative values of the vertical and horizontal impulses may also be of assistance in estimating the distance, and for this reason, we have added the tables of angles of emergence, derived by linear interpolation and subtraction from 90°, according to Dr. Geiger's table of angles of incidence[7].

But even with the distance accurately determined, the position of the earthquake epicenter is by no means fixed. Call the distance "Δ". Then the locus of epicenters is the circumference of a circle, whose arcual radius is "Δ". If, however, we could ascertain the direction or azimuth of the epicenter, then, evidently, its position would be absolutely fixed; for it would be the point of intersection of the locus and the line of azimuth. Now, on some records, the first preliminary tremors begin with a well-defined impetus, and, as these waves are longitudinal in character, this impulse must have traveled along the line of propagation of the wave itself. Hence, if we know the specific

[7] See Note 5.

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behavior of our seismograph, under an impulse from each of the cardinal points, we can conclude to the direction, by applying the principle of the parallelogram of forces to the impulses on each component. This method, however, applies only to the cases mentioned which begin with a sudden impulse, and even then is somewhat uncertain. For we can never be quite sure, in the case of distant earthquakes, that the very first impulse was recorded. Besides, the direction thus obtained, is the direction from which the wave was coming, the moment it reached the instrument, not necessarily that of the epicenter. But for the sake of the probable estimate, which can often be made thus, it is of advantage to have a map, on which lines of equal distance and like direction from the seismograph are drawn. Such maps were constructed for Ischia, Rome, Laibach, Hamburg, Uccle, Jugenheim[8].

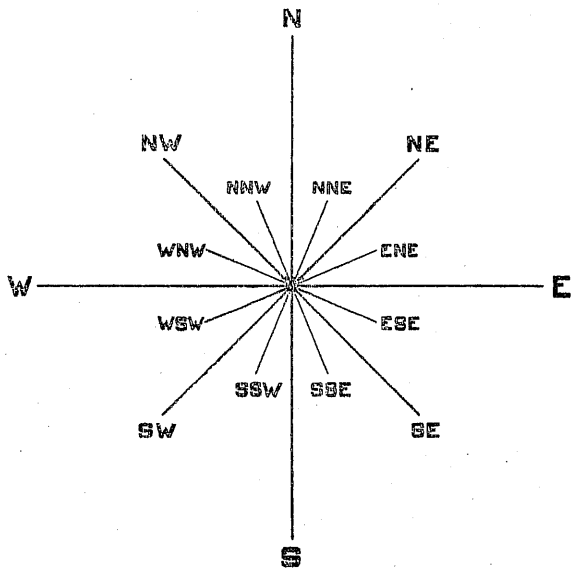

FIG. 7.

To construct the map, the directions shown in the accompanying figure (Fig. 7) were chosen and the geographical positions computed for points along each of these lines, 1000 km., 2000 km., etc., up to 20000 km. distant from St. Louis.

[8] Dr. C. Zeissig—*Koordinaten-Tafeln für d. Seismische Station Darmstadt-Jugenheim*, 1909.

The accompanying table contains the co-ordinates of these points. 1000 km. was taken as 9°, and the co-ordinates of St. Louis roundly as 38° 38′ N. Lat. and Long. 90° 14′ W.

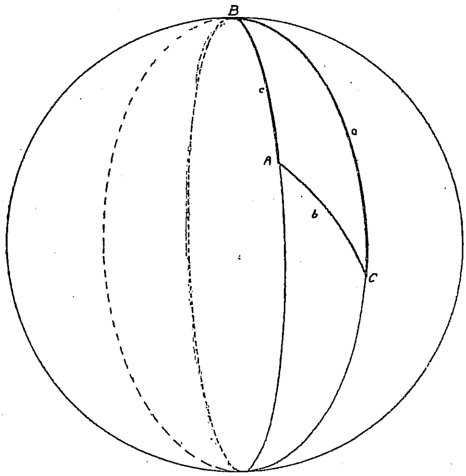

FIG. 8.

In the figure (Fig. 8) let *A* be St. Louis, *B* the North Pole, *C* one of the points whose co-ordinates are to be found. Then in the spherical triangle *ABC* the side *c* is known, being the polar distance of St. Louis (90°—ϕ); *b* is the arcual distance chosen, and *A* is the angle included between the distance chosen and the meridian *N.* of St. Louis. With these three quantities chosen, we can compute *a*, the polar distance of the point whose co-ordinates are sought; and *B*, the difference in longitude, by means of the trigonometric formulas:

$$\tan \frac{1}{2}(B+C) = \frac{\cos \frac{1}{2}(b-c)}{\cos \frac{1}{2}(b+c)} \cot \frac{1}{2} A$$

$$\tan \frac{1}{2}(B-C) = \frac{\sin \frac{1}{2}(b-c)}{\sin \frac{1}{2}(b+c)} \cot \frac{1}{2} A$$

$$\cos \frac{1}{2} a = \frac{\cos \frac{1}{2}(b+c)}{\cos \frac{1}{2}(B+C)} \sin \frac{1}{2} A$$

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II. COÖRDINATES FOR ST. LOUIS.

Distance from St. Louis	N		NNW		NW		WNW	
	Latitude	Longitude	Latitude	Longitude	Latitude	Longitude	Latitude	Longitude
1,000......	47°38′ N	90°14′ W	46°48′ N	95°15′ W	44°46′ N	99°11′ W	41°30′ N	101°22′ W
2,000......	56°38′ N	90°14′ W	55° 0′ N	102° 4′ W	49°58′ N	110° 3′ W	43°22′ N	113°21′ W
3,000......	65°38′ N	90°14′ W	61°58′ N	112° 2′ W	53°48′ N	123°10′ W	43°48′ N	125°46′ W
4,000......	74°38′ N	90°14′ W	67°46′ N	127°45′ W	56° 6′ N	138°22′ W	42°50′ N	138° 5′ W
5,000......	83°38′ N	90°14′ W	72° 6′ N	152° 8′ W	56°12′ N	154°34′ W	40°44′ N	149°49′ W
6,000......	87°22′ N	90°14′ W	71°22′ N	178°23′ E	54°28′ N	170° 7′ W	37°34′ N	160°40′ W
7,000......	78°22′ N	89°46′ E	68° 0′ N	154°43′ E	50°50′ N	176°15′ E	33°22′ N	170°28′ W
8,000......	69°22′ N	89°46′ E	61° 8′ N	139°36′ E	45°46′ N	164°55′ E	28°34′ N	179°19′ E
9,000......	60°22′ N	89°46′ E	54° 6′ N	129°57′ E	40° 0′ N	155°34′ E	23° 4′ N	172°40′ E
10,000......	51°22′ N	89°46′ E	46°34′ N	123°19′ E	33°24′ N	147°48′ E	17°22′ N	165°16′ E
11,000......	42°22′ N	89°46′ E	37°54′ N	118°25′ E	26°44′ N	141° 8′ E	11°20′ N	158°20′ E
12,000......	33°22′ N	89°46′ E	29°32′ N	114°30′ E	19°24′ N	125°15′ E	5°22′ N	151°41′ E
13,000......	24°22′ N	89°46′ E	20° 0′ N	111°12′ E	11°42′ N	130°53′ E	0°48′ S	145°11′ E
14,000......	15°22′ N	89°46′ E	10°48′ N	108°16′ E	5° 0′ N	124°46′ E	6°38′ S	138°39′ E
15,000......	6°32′ N	89°46′ E	3°50′ N	105°30′ E	3°10′ S	119°49′ E	13°18′ S	131°56′ E
16,000......	2°38′ S	89°46′ E	4°24′ S	102°49′ E	10°22′ S	114°46′ E	19°12′ S	124°53′ E
17,000......	11°38′ S	89°46′ E	13°12′ S	100° 3′ E	17°52′ S	109°28′ E	24°52′ S	117°18′ E
18,000......	20°38′ S	89°46′ E	21°48′ S	97° 5′ E	25° 0′ S	103°43′ E	30° 6′ S	109° 2′ E
19,000......	29°38′ S	89°46′ E	30°14′ S	93°45′ E	32° 2′ S	97°16′ E	34°44′ S	99°54′ E
20,000......	38°38′ S	89°46′ E	38°38′ S	89°46′ E	38°38′ S	89°46′ E	38°38′ S	89°46′ E

Distance from St. Louis	W		WSW		SW		SSW	
	Latitude	Longitude	Latitude	Longitude	Latitude	Longitude	Latitude	Longitude
1,000......	38° 4′ N	101°42′ W	34°44′ N	100°22′ W	32° 2′ N	97°43′ W	30° 4′ N	94°12′ W
2,000......	36°24′ N	112°49′ W	30° 6′ N	109°30′ W	25° 2′ N	104°12′ W	21°46′ N	79°33′ W
3,000......	33°48′ N	123°21′ W	24°52′ N	117°46′ W	17°48′ N	109°56′ W	13°14′ N	100°31′ W
4,000......	30°20′ N	133°10′ W	19°14′ N	125°21′ W	10°24′ N	115°14′ W	4° 38′ N	103°17′ W
5,000......	26°12′ N	142°14′ W	13°18′ N	132°24′ W	2°56′ N	120°17′ W	3°56′ S	105°58′ W
6,000......	21°32′ N	150°39′ W	7°12′ N	139° 7′ W	4°36′ S	125°15′ W	12°32′ S	108°44′ W
7,000......	16°26′ N	158°32′ W	1° 0′ N	145°39′ W	12° 2′ S	130°21′ W	21° 4′ S	111°40′ W
8,000......	11°10′ N	166° 0′ W	5°16′ S	152° 9′ W	19°24′ S	135°43′ W	29°34′ S	114°58′ W
9,000......	5°38′ N	173°11′ W	11°24′ S	158°48′ W	26°36′ S	141°36′ W	37°58′ S	118°53′ W
10,000......	0° 0′	179°46′ E	17°24′ S	165°44′ W	33°32′ S	148°16′ W	46°12′ S	123°47′ W
11,000......	5°36′ S	172°43′ E	23° 8′ S	173° 8′ W	40° 2′ S	156° 2′ W	54° 8′ S	130°25′ W
12,000......	11° 8′ S	165°32′ E	28°30′ S	178°51′ E	45°54′ S	165°23′ W	61°34′ S	143° 0′ W
13,000......	16°34′ S	158° 4′ E	33°22′ S	170° 0′ E	50°52′ S	176°43′ W	67°54′ S	155°11′ W
14,000......	21°18′ S	150°11′ E	37°40′ S	160°12′ E	54°24′ S	169°39′ E	71°58′ S	178°51′ W
15,000......	26°18′ S	141°46′ E	40°48′ S	149°21′ E	56°20′ S	154° 6′ E	72° 8′ S	151°40′ E
16,000......	30°38′ S	132°42′ E	42°54′ S	137°37′ E	56° 4′ S	137°54′ E	68°20′ S	127°17′ E
17,000......	33°48′ S	122°53′ E	43°48′ S	125°17′ E	53°48′ S	122°42′ E	62°16′ S	111° 3′ E
18,000......	36°26′ S	112°21′ E	36°20′ S	112°53′ E	49°52′ S	109°34′ E	54°46′ S	101°36′ E
19,000......	38° 4′ S	101°14′ E	41°34′ S	100°54′ E	44°40′ S	98°43′ E	46°50′ S	94°47′ E
20,000......	38°38′ S	89°46′ E	38°38′ S	89°46′ E	38°38′ S	89°46′ E	38°38′ S	89°46′ E

Distance from St. Louis	S		SSE		SE		ESE	
	Latitude	Longitude	Latitude	Longitude	Latitude	Longitude	Latitude	Longitude
1,000......	29°38′ N	90°14′ W	30° 4′ N	86°16′ W	32° 2′ N	82°45′ W	34°44′ N	80° 6′ W
2,000......	20°38′ N	90°14′ W	21°46′ N	82°55′ W	25° 2′ N	76°16′ W	30° 6′ N	70°58′ W
3,000......	11°38′ N	90°14′ W	13°14′ N	79°57′ W	17°48′ N	70°32′ W	24°52′ N	62°42′ W
4,000......	2°38′ N	90°14′ W	4°38′ N	77°11′ W	10°24′ N	65°14′ W	19°14′ N	55° 7′ W
5,000......	6°22′ S	90°14′ W	3°56′ S	74°30′ W	2°56′ N	60°11′ W	13°18′ N	48° 4′ W
6,000......	15°22′ S	90°14′ W	12°32′ S	71°44′ W	4°36′ S	55°13′ W	7°12′ N	41°21′ W
7,000......	24°22′ S	90°14′ W	21° 4′ S	68°48′ W	12° 2′ S	50° 7′ W	1° 0′ N	34°49′ W
8,000......	33°22′ S	90°14′ W	29°34′ S	65°30′ W	19°24′ S	44°45′ W	5°16′ S	28°19′ W
9,000......	42°22′ S	90°14′ W	37°58′ S	61°35′ W	26°36′ S	38°52′ W	11°24′ S	21°40′ W
10,000......	51°22′ S	90°14′ W	46°12′ S	56°41′ W	33°32′ S	32°12′ W	17°24′ S	14°44′ W
11,000......	60°22′ S	90°14′ W	54° 8′ S	50° 3′ W	40° 2′ S	24°26′ W	23° 8′ S	7°20′ W
12,000......	69°22′ S	90°14′ W	61°34′ S	40°25′ W	45°54′ S	15° 5′ W	28°30′ S	0°41′ E
13,000......	78°22′ S	90°14′ W	67°54′ S	25°17′ W	50°52′ S	3°45′ W	33°22′ S	9°32′ E
14,000......	87°22′ S	90°14′ W	71°58′ S	1°37′ W	54°24′ S	9°53′ E	37°40′ S	19°21′ E
15,000......	83°38′ S	89°46′ E	72° 8′ S	27°52′ E	56°20′ S	25°26′ E	40°48′ S	30°11′ E
16,000......	74°38′ S	89°46′ E	68°20′ S	52°15′ E	56° 4′ S	41°38′ E	42°54′ S	41°55′ E
17,000......	65°38′ S	89°46′ E	62°16′ S	68°29′ E	53°48′ S	56°50′ E	43°48′ S	54°15′ E
18,000......	58°38′ S	89°46′ E	54°46′ S	77°56′ E	49°52′ S	69°58′ E	43°20′ S	66°39′ E
19,000......	47°38′ S	89°46′ E	46°50′ S	84°45′ E	44°40′ S	80°49′ E	41°34′ S	78°38′ E
20,000......	38°38′ S	89°46′ E	38°38′ S	89°46′ E	38°38′ S	89°46′ E	38°38′ S	89°46′ E

Distance from St. Louis	E		ENE		NE		NNE	
	Latitude	Longitude	Latitude	Longitude	Latitude	Longitude	Latitude	Longitude
1,000......	38° 4′ N	78°46′ W	41°30′ N	79° 6′ W	44°46′ N	81°17′ W	46°48′ N	85°13′ W
2,000......	36°24′ N	67°39′ W	43°22′ N	67° 7′ W	49°58′ N	70°25′ W	55° 0′ N	78°24′ W
3,000......	33°48′ N	57° 7′ W	43°48′ N	54°42′ W	53°48′ N	57°18′ W	61°58′ N	68°26′ W
4,000......	30°20′ N	47°18′ W	42°50′ N	42°23′ W	56° 6′ N	42° 6′ W	67°46′ N	52°43′ W
5,000......	26°12′ N	38°14′ W	40°44′ N	30°39′ W	56°12′ N	25°54′ W	72° 6′ N	28°20′ W
6,000......	21°32′ N	29°49′ W	37°34′ N	19°48′ W	54°28′ N	10°21′ W	71°22′ N	1° 9′ E
7,000......	16°26′ N	21°56′ W	33°22′ N	10° 0′ W	50°50′ N	3°17′ E	68° 0′ N	24°49′ E
8,000......	11°10′ N	14°28′ W	28°34′ N	1° 9′ W	45°46′ N	14°37′ E	61° 8′ N	39°56′ E
9,000......	5°38′ N	7°17′ W	23° 4′ N	6°52′ E	40° 0′ N	23°58′ E	54° 6′ N	49°35′ E
10,000......	0° 0′	0°14′ W	17°22′ N	14°16′ E	33°24′ N	31°44′ E	46°34′ N	56°13′ E
11,000......	5°36′ S	6°49′ E	11°20′ N	21°12′ E	26°44′ N	38°25′ E	37°54′ N	61° 7′ E
12,000......	11° 8′ S	14° 0′ E	5°22′ N	27°51′ E	19°24′ N	44°17′ E	29°32′ N	65° 2′ E
13,000......	16°34′ S	21°28′ E	0°48′ N	34°21′ E	11°42′ N	49°39′ E	20° 0′ N	68°20′ E
14,000......	21°18′ S	29°21′ E	6°38′ S	40°53′ E	5° 0′ N	54°45′ E	10°48′ N	71°16′ E
15,000......	26°18′ S	37°46′ E	13°18′ S	47°36′ E	3°10′ S	59°43′ E	3°50′ N	74° 2′ E
16,000......	30°38′ S	46°50′ E	19°12′ S	54°39′ E	10°22′ S	64°46′ E	4°24′ S	76°43′ E
17,000......	33°48′ S	56°39′ E	24°52′ S	62°14′ E	17°52′ S	70° 4′ E	13°12′ S	79°29′ E
18,000......	36°26′ S	67°11′ E	30° 6′ S	70°30′ E	25° 0′ S	75°49′ E	21°48′ S	82°27′ E
19,000......	38° 4′ S	78°18′ E	34°44′ S	79°38′ E	32° 2′ S	82°16′ E	30°14′ S	85°47′ E
20,000......	38°38′ S	89°46′ E	38°38′ S	89°46′ E	38°38′ S	89°46′ E	38°38′ S	89°46′ E

The calculation was done with 6-place logarithms without interpolation for seconds, which gives a possible error of $\pm$ 1′, sufficiently near for any ordinary map. Since this calculation involves considerable labor, a less satisfactory substitute, may be found in a globe, on which a few guide points have been plotted by the above method, and the curves carefully drawn through them. Some such device is practically indispensable for estimating the position of an epicenter from the observations of one station.

If, however, the observations of at least three stations, a considerable distance apart, are available, then the position of the epicenter can be found by any one of several methods. The method of least squares, no matter how applied, requires considerable time. That of stereographic projection, however, is rapid and the calculations are extremely simple[9]. Take an accurate circle of unit radius, whose circumference is graduated in both directions from a point 0°, to an opposite point, 180°. Take the longitude of one of the stations, find the point corresponding to the same number of degrees E. or W., on the circle, and draw a radius to that point. On this radius lay off from the center a distance $d = \dfrac{\cos\phi}{\sin\phi + \cos\Delta}$. With the point thus found as center, and a radius $r = \dfrac{\sin\Delta}{\sin\phi + \cos\Delta}$, draw an arc. Do the same for each of the other stations. Through the center of gravity of the resulting polygon of intersection (which should be very small if the data are correct), draw another radius. Then the longitude of the epicenter can be read off at once at the end of this radius, and the distance from the center of gravity of the polygon to the center of the circle, expressed as above in terms of the radius $= \tan(45° - \tfrac{1}{2}\phi)$. To assist those who may wish to make use of our data, we have added to Table I, a table of St. Louis "*d*" and "*r*," for successive hundreds of km. The accuracy of the stereographic method depends on the size and exactness of the circle used.

[9] Dr. Otto Klotz — *Earthquake Epicenters.* — Journal of Astron. Soc. of Canada, May-June, 1910.

THE KINETIC AND DYNAMIC ANALYSIS.

The kinetic analysis of earthquake records is carried out in the St. Louis University Observatory according to approved methods. The periods and diagram amplitudes are read with a filar micrometer microscope. For the reduction of record amplitudes to earth particle amplitudes, it is necessary to work out a new table of magnifications, $\mathfrak{V}$, or better, $\frac{1000}{\mathfrak{V}}$, to obtain unit amplitude directly in microns (1 micron = 1 μ = .001 mm.) for all common values of $\frac{T_e}{T_0}$ after each change in the constants of the instrument. To do this for each component independently by solution of the equation:

$$\mathfrak{V} = \frac{V}{\sqrt{\left(1-\left(\frac{T_e}{T_0}\right)^2\right)^2 + 4\,\frac{(\log\ \mathrm{nat}\ \epsilon)^2}{\pi^2+(\log\ \mathrm{nat}\ \epsilon)^2}\left(\frac{T_e}{T_0}\right)^2}} = \frac{V}{\sqrt{S}}$$

for all values of $\frac{T_e}{T_0}$ that may be needed, is no child's task, and any assistance that tends to lessen this drain on an observer's time is most welcome. To this end Dr. Geiger's tabulated ratios of $\frac{T_e}{T_0}$ and his logarithmic curves for corresponding values of $\sqrt{S}$ are invaluable, and reduce the work of hours to that of a few minutes.[10]

The determination of the maximum motion in the main phase sometimes requires several preliminary trials. For one wave may have a slightly greater diagram amplitude, another a longer period; hence, which of the two has the greater earth amplitude can only be seen from the reduction of both. However, in such cases, both the waves will generally be inserted in the report as M_1 and M_2. These amplitudes, however, are no safe measure of the violence of a shock. The true criterion of earthquake intensities is the earth-particle acceleration, and this is very readily obtained by the handy formula $\frac{4A}{T_e^2}$. For if the earth-particle amplitude (A) is expressed in microns, the period in seconds, and the acceleration in milligals (1 milligal = .001 gal = $10\mu/\text{sec.}^2$ = .000001 g approximately), then the harmonic acceleration formula $\frac{4\pi^2 A}{T^2}$ reduces approximately to the above simple form. This deduction of the earth acceleration from the earth particle amplitude

[10] Dr. L. Geiger—*Seismische Registrierungen in Göttingen in Jahre* 1908. Nach d. K. Gessellsch. d. Wiss. zu Göttingen, Math.-Phys. Kl. 1909.

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and period, we may call the dynamic analysis of the seismogram. It is published regularly by several seismic observatories.

EARTHQUAKES REGISTERED IN ST. LOUIS UNIVERSITY OBSERVATORY DURING 1910.

The following is a list of the earthquakes recorded by our 80 kg. Wiechert astatic, horizontal pendulum during the past year 1910. We are sorry to say that, with the exception of the month of December, when we began to determine the instrument constants more accurately, the magnification was too uncertain to admit of the calculation of earth particle amplitudes from the amplitudes recorded on the seismogram. Hence for the first eleven months we have simply given the diagram "double" amplitudes ($2a$), expressed in mm. Beginning with December we substitute the earth-particle amplitude (A) in μ. The nomenclature used in characterizing the phases, etc., is that originated by Drs. Weichert and Geiger of the University of Göttingen[11]. This form, with its Latin symbols, which has been aptly styled "The International" by Rev. F. L. Odenbach, S. J., is so simple, so concise and so adaptable, that it bids fair to come into universal use. It has been adopted by most of the great Seismological Observatories of Germany, all those of Austria, some of Italy, Servia, by the U. S. Weather Bureau, the Dominion Observatory of Canada, the National Geological Institute of Mexico, and the Tsingtau Observatory in China, and by most of the observatories conducted by the Jesuit Fathers in Syria, Australia, Spain, Canada and the United States. The symbols are as follows:

SYMBOLS.

(GOETTINGEN NOMENCLATURE.)

CHARACTER OF THE EARTHQUAKE.

I = noticeable, II = striking, III = violent.

d = (terrae motus domesticus) = local earthquake (felt at station).

v = (terrae motus vicinus) = nearby earthquake (less than 1000 km.).

r = (terrae motus remotus) = distant earthquake (1000-5000 km.).

u = (terrae motus ultimus) = very distant earthquake (more than 5000 km.).

[11] Dr. L. Geiger — *Seismische Registrierungen in Göttingen in Jahre* 1907. Nachr. d. K. Gesellsch. d. Wiss. zu Göttingen, Math.-Phys. Kl.

PHASES:

P = (undae primae) = first preliminary tremors (longitudinal waves through the earth's interior).

PRn = P waves reflected n times at the earth's surface.

S = (undae secundae) = second preliminary tremors (transverse waves through the earth's interior).

SRn = S waves reflected n times at the earth's surface.

PS = transformed waves, i. e., waves which, in their reflection at the earth's surface, have been changed from longitudinal to transverse, or vice versa.

L = (undae longae) = long or "Rayleigh" waves (first phase of main or principal portion—surface waves).

M = (undae maximae) = greatest motion in the main or principal portion (complicated surface waves).

C = (cauda) after-shocks or trailers.

F = (finis) = end of visible motion.

NATURE OF THE MOTION:

i = (impetus) = sudden impulse.

e = (emersio) = gradual development (beginning uncertain).

T = period = time of complete vibration to and fro.

A = amplitude of earth motion—reckoned from the line of rest and measured in microns ($\mu = \frac{1}{1000}$ mm).

E or N attached to a symbol refers it to the E-W or N-S component.

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Jesuit Seismological Service Record of the Earthquake Station, St. Louis University

ST. LOUIS, MO., U. S. A.

LATITUDE: 38° 38′ 17″ N.
LONGITUDE: 90° 13′ 58″.5 or 6^h 0^m 55^s.9 W. Gr.

TIME: Mean Greenwich, midnight to midnight.
INSTRUMENT: Wiechert 80 kg., astatic, horizontal pendulum.

NOMENCLATURE: Goettingen.

FROM JANUARY 1st TO DECEMBER 31st.

DATE 1910	CHAR.	PHASE	TIME	PERIOD T.	AMPLITUDE $2A_E$	AMPLITUDE $2A_N$	REMARKS
			h. m.	s.	*mm*	*mm*	
Jan. 1	IIIr	P_N	11 06.3	7			$\triangle$=2440 km.
		P_E	11 06.6	6			Earthquake reported from Swan Island. Caribbean Sea.
		S_E	11 10.3				
		S_N	11 10.3				
		i_E	11 10.7	21	21		
		i_N	11 10.9	12		8	
		C_N	11 21.8	10		5.5	
		C_E	11 27	12	3.7		
		C_{2N}	11 29	12		1	
		F_N	11 54.2				
		F_E	12 02.2				
Jan. 22	IIr	e_E	9 03.5				North of Iceland.
		e_N	9 03.5				

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DATE 1910	CHAR.	PHASE	TIME	PERIOD T.	AMPLITUDE $2A_E$	AMPLITUDE $2A_N$	REMARKS
			h. m.	s.	*mm*	*mm*	
		eL_E	9 13	19	2.4		
		eL_N	13.1	13		.8	
		i_E	15	10	3.2		
		iM_{1E}	15.6	12	5		
		M_N	15.6	18		3.4	
		iM_{2E}	17	13	4.5		
		C_N	21.3	10		.6	
		C_E	21.4	11	.4		
		F_N	54				
		F_E	10 02				
Jan. 24	IIu	e_E	18 42.1	9	.6		
		e_N	42.3	6		.5	
		L_E	43.6				
		L_N	43.6				
		iM_E	43.7	10	10	4	
		iM_N	43.8	7			
		F_E	52				
		F_N	57				
Feb 4	I	e_E	15 04	15			No disturbance on N.-S.
		F	19				Continuous Waves on N.-S.
Feb. 7	I	e	3				
		F	6				

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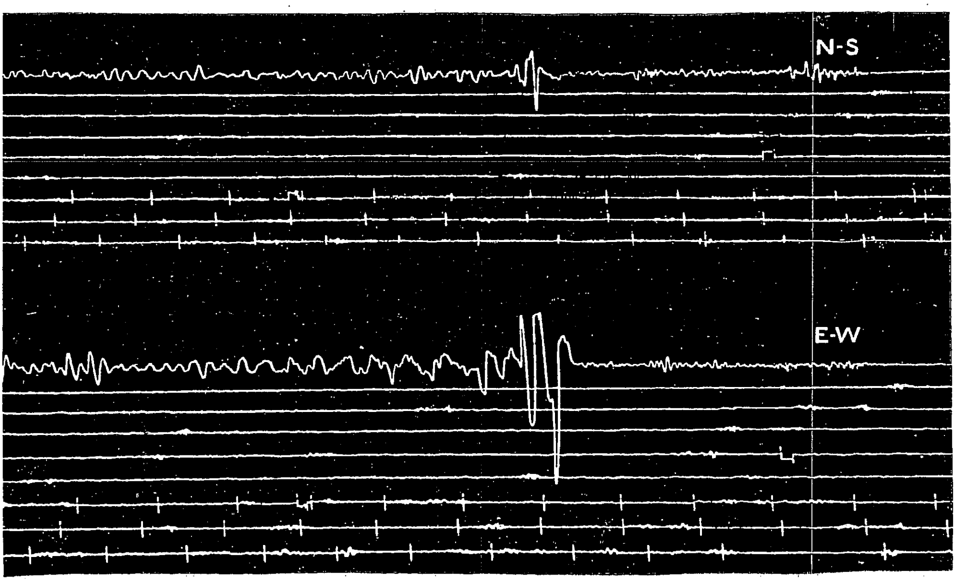

Seismogram of Jan. 1, 1910.

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DATE 1910	CHAR.	PHASE	TIME	PERIOD T.	AMPLITUDE		REMARKS
					$2A_N$	$2A_N$	
			h. m.	s.	mm	mm	
Feb. 28	II	eP_E	21 14.5				
		P_N	15.3				
		iS_E	22.3	10	.4		
		S_N	22.5	12		.4	
		L_N	24.8				
		L_E	25.1				
		M_{1E}	33.	12	.9		
		M_N	33.1	12			
		M_{2E}	37.1	10	.2		
		C_E	59.1				
		F_E	22 01.3				
Mar. 4	I	e_N	9 48				
		e_E	51				
		F	10 00				
Mar. 9	I	e_E	22 00				No disturbance on N-S.
		F_E	06				
Mar. 11		e	21 00				
		F	23 00				No record on E-W.
Mar. 30	II	P_N	17 45.1				
		eP_E	48.2				
		S_N	50.5	18		.6	
		S_E	51.2	21	.3		

DATE 1910	CHAR.	PHASE	TIME	PERIOD T.	AMPLITUDE $2A_N$	AMPLITUDE $2A_N$	REMARKS
			h. m.	s.	*mm*	*mm*	
		eL_E	18 00.5				
		M_{1E}	01.8	15	1.1		
		M_{2E}	05	13	1.1		
		M_{3E}	08.8	18	1.2		
		L_N	10.3				
		M_N	11.5	18		.8	
		C_E	13.5				
		C_E	17.5				
		F_E	20.2				
		F_N	25.7				
Mar. 31	I	e	19 00				S and L very indistinct.
		F	29				
Apr. 26	I	e	23 32				
		F	40				
Apr. 27	I	e	0 57				
		F	1 00				
May 13	II	e_N	8 12.2				Costa Rica
		e_E	21.9				
		eL_N	28.2	10		.3	
		eL_E	28.8				
		M_{1N}	34.5	12		1.2	
		M_E	34.5	9	1		

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DATE 1910	CHAR.	PHASE	TIME	PERIOD T.	AMPLITUDE		REMARKS
					$2A_E$	$2A_N$	
			h. m.	s.	*mm*	*mm*	
		M_{2N}	8 42	12	1.3	1.1	
		F_N	9 05.5				
		F_E	06.2				
May 19	I	e	6 18				
		F	21				
May 31	II	e_E	5 00.8				
		i_N	00.8	6		3.5	Very sudden shocks.
		i_E	04.9	6	3.5		
		eS	05				
		i_N	05.2	3		3	
		eL_E	09.6				
		eL_N	09.8				
		M_E	11.3	6	2		
		M_N	11.3	5		1.6	
		F	28.9				
June 1	I	e	7				
		L	01.5				
		M_E	02	18	.5		
		M_N	03	20		1	
		F_E	12				
		F_N	14				
June 16	II	P	18 56				L begins with M.

DATE 1910	CHAR.	PHASE	TIME	PERIOD T.	AMPLITUDE		REMARKS
					$2A_E$	$2A_N$	
			h. m.	s.	*mm*	*mm*	
		S_E	18 58				
		S_N	59				
		iM_E	59.7	18	5		
		iM_N	59.7	12		2.5	
June 29	I	e_E	11 39				
		S_E	40.2				Traces of six shocks on N-S Component but indistinct.
		L_E	41				
		M_{1E}	41.2	15	1.5		
		M_{2E}	53.9	15	1		
		M_{3E}	58.5	18	.9		
		F_E	12 30.1				
July 7	II	e_E	4 57.8				
		e_N	57.9				
		M_{1E}	58.5	9	8		M and L begin at the same time.
		M_{1N}	58.5	5		4	
		M_{2E}	04.3	7	1.9		
		M_{2N}	04.5	8		1.2	
		F_E	11				
		F_N	14				
Aug. 5	II	e	1 44.4				
		L_E	47.9				
		L_N	48.3				

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DATE 1910	CHAR.	PHASE	TIME	PERIOD T.	AMPLITUDE		REMARKS
					$2A_E$	$2A_N$	
			h. m.	s.	*mm*	*mm*	
		M_E	1 49.1	12	3		
		M_N	49.6	12		7.5	
		F	2 27				
Aug. 11	IIr	P	16 33.5				
		iS_E	39.6	12	1.5		
		iS_N	39.6	5		1.6	
		L_E	43.7				
		L_N	44				
		M_E	44	15	2		Amplitude interfered with by local motion.
		M_N	44.2	14			
		F_E	17 02				
		F_N	03				
Sept. 7	I	e_N	8 09	18			
		e_E	12	24	.3		
		F	20				
Sept. 7	I	e_N	10 49	15		.3	
		e_E	11 01				
		F_E	12				
		F_N	22				
Sept. 9	I	iP_E	1 30.5				
		P_N	31.6				
		L	40.2				

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DATE 1910	CHAR.	PHASE	TIME	PERIOD T.	AMPLITUDE		REMARKS
					$2A_E$	$2A_N$	
			h. m.	s	mm	mm	
		M_{1E}	1 45.3	14	1.7		
		M_N	45.8	20		.9	
		M_{2E}	47.8	15	1.1		
		M_{3E}	49.8	12	1		
		F_N	2 13				
		F_E	14.7				
Sept. 16	I	e_N	19 03				
		e_E	08				
		F_N	24				
		F_E	25				
Sept. 24	II	P_N	3 35.5				P_E could not be determined.
		S	37.5				
		L	37.7				
		M_N	37.8	8		7	
		M_E	37.8	9	7.5		
		F_N	4 09				Overlapped by the following.
Sept. 24	I	P_N	15				
		S_E	16.5				
		S_N	17.3				
		L_E	17.3				
		iM_E	17.4	9	3		
		L_N	17.7				

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DATE 1910	CHAR.	PHASE	TIME	PERIOD T.	AMPLITUDE $2A_E$	AMPLITUDE $2A_N$	REMARKS
			h. m.	s.	*mm*	*mm*	
		iM_N	4 17.9	9		1.7	
		F_N	25				
		F_E	29				
Oct. 4	II	eP	23 11				△ = 6900 km. At Antofogasta, Chile.
		iS	19.4				
		PS	20	6	2.7	1.7	
		i_{1E}	21.7	7	1.1		
		i_{2E}	22.5	6	.7		
		F_E	57				
		F_N	58				
Nov. 6	II	e	20 44				
		eS_N	47	4			
		eS_E	47	6			
		L_N	49	8		2.1	
		iL_E	49	8.5	2.9		
		M_E	51	11	3.2		
		M_N	52	9		2.3	
		iC_{1E}	54	7.5	3		
		iC_{1N}	55	7		1.2	
		C_{2E}	56	6	2.9		
		C_{3E}	58	7	1.1		
		C_{2N}	21 10	6		.7	

DATE 1910	CHAR.	PHASE	TIME	PERIOD T.	AMPLITUDE		REMARKS
					$2A_E$	$2A_N$	
			h. m.	s.	mm	mm	
		F_N	21 22				
		F_E	29				
Nov. 9	I	L_N	6 53	16		.3	
		L_E	56.5	16	.8		
		F_N	7 38				
		F_E	40				
Nov. 10	I	eL_N	3 18	22		.4	
		L_E	18	9	.3		
		F_E	4 08				
		F_N	20				
Nov. 10	I	e_N	12 47	18		.4	
		e_E	13 13	8	.3		
		eL_E	16	20	.6		
		L_N	18	15		.4	
		F_N	31				
		F_E	38				
Nov. 26	IIμ	e_E	5 10.5	18	.6		
		i_E	15.5	20	.8		
		eL_E	35	21	.5		
		M_{1E}	38	21	.7		
		M_{2E}	40	21	1.3		
		e_N	42				

DATE 1910	CHAR.	PHASE	TIME	PERIOD T.	AMPLITUDE		REMARKS
					$2A_E$	$2A_N$	
			h. m.	s.	*mm*	*mm*	
Nov. 26	IIμ	M_{3E}	5 49	15	.8		
		M_{4E}	51	15	.7		
		M_N	52	16		.5	
		C_N	59			.3	
		F_E	6 06				
		F_N	19				

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DATE 1910	CHAR.	PHASE	TIME	PERIOD T.	AMPLITUDE A_E	AMPLITUDE A_N	REMARKS
			h. m.	s.	μ	μ	
Dec. 7							Microseisms during the greater part of the day.
Dec. 10	I	e	10 00				
		L_N	20				
		eL_E	21	24			
		M_E	23	10	.6		
		M_N	24	10		6	
		F_N	11 41				
		F_E	42				
Dec. 13	II	e_E	12 20				
		e_N	21				
		eL_N	30	30		16	
		M_N	35.8	21		95	
		iL_E	39	18			
		L_N	41	24		99	
		M_{1E}	42.9	16	46		
		M_{2E}	45	19	69		
		M_{3E}	45.5	19	69		
		M_{4E}	46.7	17	42		
		C_{1E}	50				
		C_{2E}	05				
		F_E	57				
		F_N	58				

DATE 1910	CHAR.	PHASE	TIME	PERIOD T.	AMPLITUDE		REMARKS
					A_E	A_N	
			h. m.	s.	μ	μ	
Dec. 16	IIμ	e_N	15 12	12		21	
		i_{1E}	24	14	18		
		i_{2E}	26	10	6		
		iL_{1E}	16 03.1	17	47		
		iL_{2E}	05	18	34		
		eM_E	07.7	16	41		
		L_N	10	18			
		L_E	12	14	19		
		M_N	14	21		91	
		C_{1E}	21	15	18		
		C_{2E}	30	15	15		
		C_{3E}	35	18	18		
		F_N	55				
		F_E	17 11				
Dec. 23	I	e_E	1 05.5	8			Traces on N-S.
		F_E	30.7				

ACKNOWLEDGMENTS.

In conclusion, we wish to express our gratitude to those who assisted in the preparation of these pages, especially to the Rev. Henry DeLaak, S. J., Professor of Advanced Physics in St. Louis University. We take this opportunity also to thank those kind friends whose generous support has made the work of the Observatory possible. Our acknowledgments are also due to the following who, by their contributions and exchanges, have added much valuable material to the Observatory Library:

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