10. *The* EARTHQUAKE *of 7th* AUGUST, 1895, *in* NORTHERN ITALY.

By RICHARD DIXON OLDHAM, F.R.S., F.G.S.

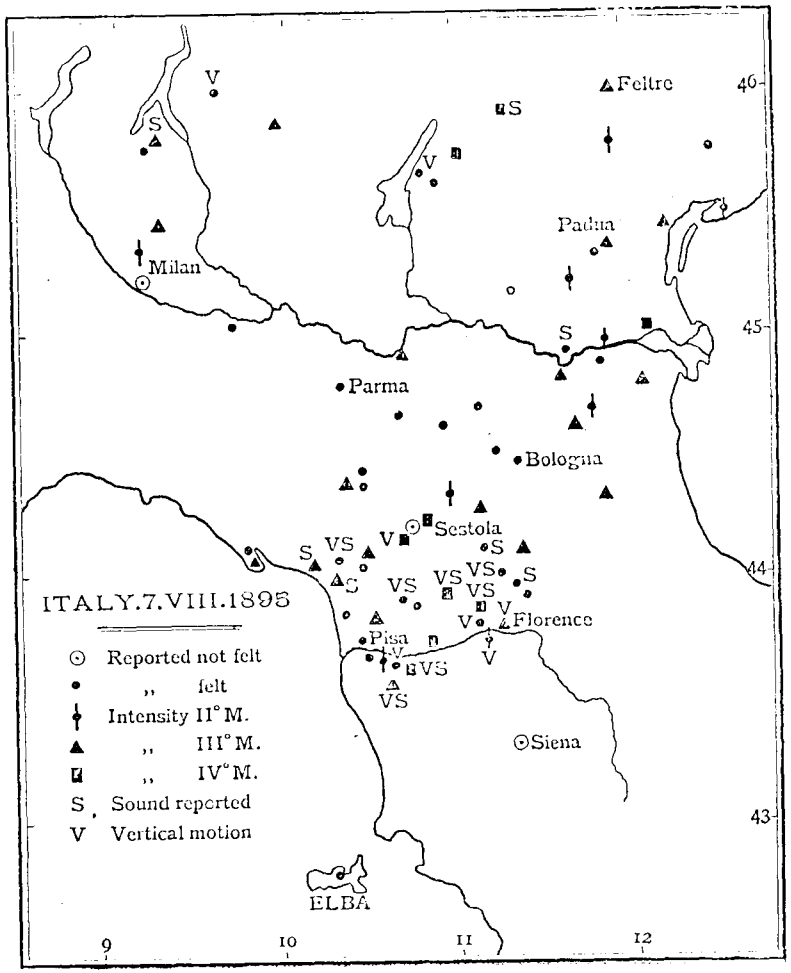
(Read November 8th, 1922.)

ON the 7th of August, 1895, an earthquake was felt over the greater part of Lombardy and Tuscany, and in the Alpine districts of Northern Italy. Although only a feeble shock, nowhere exceeding an intensity of IV° Mercalli, it is worthy of attention as being of unusual type, and affording an illustration of some general principles which have been deduced from the comparative study of a large number of earthquakes. The details of observations recorded are published in vol. i. of the 'Bollettino della Società Sismologica Italiana'; on pp. 162–67 reports from 81 distinct localities are given, mostly with little more information than a mere record of an earthquake, but a certain number contain fuller details. These localities are plotted on the map accompanying this paper (p. 232), which also gives an epitome of the pertinent facts recorded.

The time, as shown by continuous-record seismographs, was about 20h. 50m., mid-European time; the area, over which there is a practically continuous series of records, is approximately triangular, the sides being about 160 miles in length, making the seismic area about 15,000 square miles, and possibly about 20,000, if the shock is included, which was felt, at about the same time, at several places in the Island of Elba. The report, from Portoferraio, is attributed without question to the same earthquake, but it may have been an independent shock, approximately coincident in time with the larger one. In favour of this supposition may be placed the fact that the nearest locality on the mainland from which record was received is over 50 miles from Portoferraio, and that the shock was apparently not sensible, but only instrumentally recorded, at Siena, which is considerably nearer the boundary of the region covered by fairly continuous records. Against the supposition may be placed the fact that the authorities concerned in the preparation of the published accounts, who had the original reports before them, had no hesitation in regarding the reports from Elba as referring to the same earthquake as those from Tuscany. In presence of this doubt, the Elban reports will be left out of consideration: if included, they would only strengthen, and if excluded, would not invalidate, the conclusions illustrated by the other records.

An attempt was made to determine the degree of intensity, according to the Mercalli scale used in Italy, at each locality; but in the greater proportion of cases the information was too scanty to allow of this being done. In those cases where a degree could be assigned with some certainty, it is indicated on the map (p. 232), and a consideration of these shows that there was no

Sketch-map illustrating observations of the earthquake in Northern Italy of 7th August, 1895.



defined centre of maximum intensity, round which [illegible] can be drawn at regular distances. Such a centre might possibly be represented at Sestola (44° 11' lat. N., 10° 45' long. E.), where the fall of small fragments of plaster is recorded, thus might bring it into the V. Mercalli, but only very doubtfully. Against the recognition of a centre of maximum intensity, where the shock would be severe enough to attract general attention, must be put the fact that it is especially recorded that the shock was not felt at the observatory on Monte Cimone. This observatory lies about 5 miles from Sestola and in a straight line between that place and Fiumalbo (44° 11' lat. N., 10° 39' long. E.), which lies about 2 miles farther on, and at which the intensity was about the same as at Sestola. Taking the other localities, it is found that at nearly all a distinctly lower intensity is indicated; but scattered among them are places where the reports would indicate at least IV°, and some of these are on the extreme limits of the area covered by the reports. At Ala (45° 41' lat. N., 11° 0' long. E.) and Valli di Signori (45° 44' lat. N., 11° 15' long. E.) on the north, at Rettinella (45° 3' lat. N., 12° 9' long. E.) on the east, and at Pontedera (43° 40' lat. N., 10° 38' long. E.) on the south, all localities from beyond which no reports were received, an intensity of not less than IV° is indicated, though to other places nearer the centre of the seismic area a greater intensity than II° or III° M. cannot be assigned.

The sound phenomenon gives no better indication of a distinct epicentral area, for, although reports are more numerous in the region between Florence, Bologna, and Carrara, the sound was recorded at scattered places up to the extreme limits of the seismic area, as at Erba (45° 48' lat. N., 9° 13' long. E.), Valli di Signori, Argenta (44° 36' lat. N., 11° 50' long. E.), Rotta (43° 39' lat. N., 10° 41' long. E.), and Lari (43° 34' lat. N., 10° 35' long. E.).

The presence of a noticeable vertical component of the motion (sussultorio) is generally confined to the central area, but the attempt to make use of this proved as little conclusive as the distribution of intensity and sound, for the vertical movement was reported from localities at the extreme limits of the seismic area, as at Erba, Castelletto di Brenzona (45° 41' lat. N., 10° 45' long. E.), Argenta, and Lari.

The close clustering of reports from the southern portion of this area, lying in the region west of Florence and Bologna, is suggestive of an epicentral area of greater intensity of shocks; but this might well be attributed to the fact that this is a region of comparative wealth and ancient culture, where earthquakes have long been a subject of study, and where the number of potential observers and recorders would be greater than in the region on the north, from which no reports were received, until we come to the southern edge of the Alps. It may be that the peculiar distribution of the reports, and the absence of any records from

considerable areas, on either side of which the shock was recorded, is real, and directly connected with the origin of the shock: this point will be referred to later on, but, meanwhile, it must be noted that the distribution of the reports is so much in accord with the probable distribution of potential recorders, that no great importance can be attached to the absence of records from certain regions within the boundary drawn through the extreme localities at which the shock was recorded.

It is, consequently, apparent that none of the methods ordinarily employed allows of the fixing of a definite epicentre, or the drawing of successive isoseismals of decreasing intensity. To a great extent this is due to the peculiar nature of the shock, quite different in character from that usually noticed in moderate earthquakes, for which the customary scales of intensity are framed; it was much more akin to the movement which is noticed on the borders of the seismic area of a great earthquake, when the movement, as it is propagated, dies out in comparatively slow undulations, often more noticeable through the effect produced by tilting than by actual sensation. At all the places where this earthquake was recorded, an undulatory character was noticed, suspended objects were set swinging, doors and windows were shaken or moved. At Sestola it was especially recorded that there was a sensible inclination of walls, giving to persons standing at a window the impression of danger of falling out, and at some of the localities the earthquake was only recognized by a vibration of doors or windows. These are all features characteristic of the marginal portion of the seismic area of a great earthquake, and to these the ordinary scales of intensity are not applicable, for some of the results are such as would only be produced by a considerable earthquake of the more common type, where the rattling and swinging are set up by inertia, instead of by inclination of the surface, due to the passage of the long waves propagated outwards from a great disturbance. It is not unnatural to attribute the similarity of the movement, noticed in this earthquake, to a similar cause, and, if this be so, the only direction in which distance can be attained is downwards into the interior of the earth —in other words, we are not dealing with a small disturbance of shallow depth, but with the marginal area of a greater disturbance, diminished in intensity by propagation before it reached the outer surface.

In attempting to estimate the depth at which this origin lay, recourse was first made to the instrumental records, but no help was found in that quarter. The records from within or just outside the areas over which the shock was sensible, agree in fixing the time at about 20h. 49·7m. M.E.T., but there is no regularity or evident connexion between distance from the centre of the shocks and the time of record, and the variations extend from 49m. 20s. to 50m. 20s. omitting those which merely give the time to the nearest minute. Outside the seismic area the shock was recorded

only at Rome, where the time (20h. 51m. 10s.) is in accord with the supposition that the record was due to the arrival of the surface-waves. In 1895 the number of instruments capable of recording distant earthquakes was few, and none of them recorded this earthquake, which may be accounted for by the fact that at Rome, about 100 miles from the outer edge of the seismic area, there was only a slight thickening of the record on the two most sensitive of the instruments in action. Had this earthquake occurred some years later it is probable that more records, and possibly more distant records, would have been obtained from the more numerous, and more sensitive, instruments then installed; but the Rome record is of interest, as showing that the disturbance was one of the type which gives rise to long-distance records.

There remain, then, the descriptive records, on which to base an estimate of depth of origin, and, in making use of these, the first difficulty encountered is the explanation of the peculiar distribution of the records. One possible hypothesis is, as has been stated, that there was in reality a large area of tolerably uniform intensity of shock, and that the irregular distribution of the records is due to the presence or absence of potential observers. In this case we are dealing with a shock due to the propagation of wave-motion directly from the bathyseism, and this wave-motion, as revealed by the records, was of twofold character: there was first the undulatory movement, only noticed through the effect of the inclination of the surface produced by it, and also a vibratory movement of greater rapidity, giving rise to the sound phenomenon and to tremors which were everywhere of feeble intensity. The actual amount of the acceleration was everywhere small, but the reports do not admit of the formulation of any precise estimate of the variation: at the outside it may have been twice as great in the central part of the seismic area as in the marginal regions. The rate of variation of acceleration of the wave-particle with distance from the origin has not been investigated; but, if it be taken as inversely proportional to the distance from the origin, the depth would come out as something near 50 miles; while, if the variation is inversely proportional to the square of the distance, the depth might reach double this figure.

This is not, however, the only possible interpretation of the records, for it may be that the intervening gaps, from which the earthquake was not reported, represent a real absence of noticeable shocks, that the immediate origin of the earthquake was a series of fractures, of comparatively shallow depth, and that the distribution of the records represents, at least approximately, the extent of the sensible shock. In some ways, this interpretation is in accord with the peculiar distribution of the records and the absence of any defined area of maximum intensity. The records lie mostly along a line running about north-eastwards from Pisa, and along another running eastwards from Como, the two lines meeting in the district north-west of Venice; there is also indication, less

well marked, of another line joining the extremities of these two, and running from near Como towards Pisa. If the origin of the earthquake really was of the nature of two, possibly three, fractures or series of fractures, it is not conceivable that they could have been due to any cause directly connected with the tectonics of the surface-rocks: for, with the exception of the east-to-west northern line, they run across the structural features as seen on the surface. But it is conceivable that, if any general change of bulk had taken place in the material underlying that portion of the crust over which the earthquake was felt, it might be the determining factor in producing fractures in the crust, which would be unconnected with the surface tectonics, and in this way the isolated area in Elba, where an earthquake was noticed in various parts of the island, could be brought into relation with the main area in a manner not otherwise easy to explain. This change of bulk might be of equal area with the earthquake, in which case it need not lie at a great depth from the surface, but so large an area of almost uniform change is not easy to understand; it becomes more intelligible if we consider the original change of bulk to be of more restricted dimensions, and the effect, immediately below the solid crust, to be the transmitted effect of such change. This transmission would not be merely vertically upwards, but would spread outwards at a certain angle which might be as much as 45°, and in this case the ultimate origin would lie at a depth of the order of 120 miles if the dimensions were inconsiderable; but, if considerable, the depth would be proportionately diminished, and thus for an origin having one-quarter of the dimensions of the earthquake it would become about 90 miles, and 60 miles for one-half the dimensions. On the other hand, the angle of spreading of the effect would probably not be as much as 45°, and, if only 30° (corresponding to an apical angle of 60°), the depths would be nearly one and three-quarters as great as those mentioned.

From these facts and considerations it will be seen that no very positive conclusions can be drawn, nor any precise estimate made, of the depth of origin; this much, however, is clear, that the earthquake was more akin to those which give good distant records, than to the ordinary type of local earthquake; and that the depth of the ultimate origin of the shocks was great, probably of the order of about 100 miles or so, below the outer surface of the earth. This conclusion is of interest in its accordance with the deductions, recently announced by Prof. H. H. Turner, that the origins of many of the disturbances, which give rise to good long-distance records, lie at a depth of about 200 kilometres (125 miles).

II. *The* Pamir Earthquake *of 18th* February, 1911. By Richard Dixon Oldham, F.R.S., F.G.S. (Read November 8th, 1922.)

The Pamir earthquake of the 18th of February 1911, though of destructive violence in the central region and giving rise to long-distance records, would probably have passed without special notice had it not been for two circumstances: one, that it was accompanied by a landslip of exceptional dimensions, which dammed one of the principal drainage-valleys of the region, and gave rise to a permanent lake over 15 miles in length and 900 feet in depth; the other, that the late Prince Boris Galitzin formulated the conclusion that this landslip was the originating cause of the earthquake, and that this was an interesting and unique instance of coincidence of epicentre and hypocentre. Attention has been recently drawn[1] once more to this earthquake, and, although mistakes in Prince Galitzin's mathematical methods have been pointed out, the justice of his conclusion has been maintained; but this conclusion is so contrary to all other present knowledge of the character and behaviour of earthquakes, that a fuller examination of the evidence seemed desirable, and as this is not generally available, being published almost exclusively in the Russian language, it has seemed desirable to record the facts, so far as they are available.

Before dealing with the local observations and records of the earthquake, it will be well to refer briefly to Prince Galitzin's paper.[2] His conclusions were based primarily on the survey conducted in 1913 by Col. Spilko, from which it was computed that the mass of the landslip amounted to between 7 and 10 milliards of metric tons, and the height of fall was somewhere between 300 and 600 metres, from which it results that the amount of work done in falling, and set free by arrest of fall, lay between the limits of $2{\cdot}1 \times 10^{23}$ and $6{\cdot}0 \times 10^{23}$ ergs.

The next step was to estimate, from the seismographic records at Pulkovo, the amount of work transmitted past that station, and from this to compute what should have been the amount set free at the origin. The result of his computation gave $4{\cdot}3 \times 10^{23}$ ergs, a figure almost identical with the mean probable value obtained from the survey of the landslip, and hence it was concluded that the landslip gave rise to the earthquake.

The whole calculation, however, is vitiated by the fact that, in

[1] At a geophysical discussion held in the rooms of the Royal Astronomical Society on March 3rd, 1922. [See also H. Jeffreys, 'The Pamir Earthquake of 1911, February 18, in relation to the Depths of Earthquake Foci' Monthly Notices, Roy. Astronom. Soc. Geophys. Suppl. vol. i (1923) pp. 22–31.]

[2] 'Sur le Tremblement de Terre du 18 février 1911' C. R. Acad. Sci. Paris, vol. clx (1915) pp. 810–14.