RESULTS ALREADY OBTAINED OR SHOWN BY THE CATALOGUE AND MAP OF CENTRES.

AFTER SHOCKS.—About the time that the catalogue was commenced, Mr. F. Ōmori very kindly undertook an examination of the shocks succeeding the great earthquake of October 28th, 1891, which are now indicated upon the map in district number 7. This he did, following up the investigation by an analysis of the disturbances since 1889 in district 11, a series which recently occurred in district 10, and another series belonging to a region lying between 8 and 9, which, although now quiescent, about 40 years ago was unusually active. As an outline of Mr. Omori's investigations is published in the Seismological Journal, Vol. III., p. 71, and in greater detail in the Journal of the College of Science, Vol. VII., Pt. 2, it would be out

of place to give any detailed reference to them here. Briefly, it seems that when a large disturbance is followed by a long series of after shocks, the number of these is roughly proportional to the area first shaken, or what may provisionally be called the intensity of the initial impulse. The character of the curves which represent the frequency of the after shocks in relation to time, are remarkably similar, and having determined by observation the form of the earlier portions of a frequency curve, it seems possible to roughly calculate not only the number of shocks which will be experienced before the district settles to its normal state of seismic activity, but also the interval of time that will be involved in such an operation. For the earthquakes considered by Mr. Omori it may be concluded that the Earth's crust had been so far fractured that there was an approximate similarity in the heterogeneity of the disjointed material, which therefore, as it settled, gave rise to after shocks following a somewhat similar law. Another observation was that the larger of the after shocks travelled to greater distances than their smaller companions, and in consequence there was a marked difference in frequency at places situated at different distances from the primative origin. If there is any law in this decrease in frequency with distance, then the frequency of what are evidently after shocks observed upon a coast line, as in districts 1 and 10, might enable an observer to make a rough estimate of the distance of an inaccessible submarine origin. That satisfactory results would be obtained from such an investigation is, however, doubtful.

DISTRIBUTION OF EARTHQUAKES.—An inspection

of the map of earthquake origins or centres, shows that the central portions of Japan, which are the mountainous districts where active volcanoes are numerous, is singularly free from earthquakes. The greater number of disturbances originate along the eastern coast of the empire, and many of these have a submarine origin. That very few earthquakes are shown on the coast line between districts 1 and 2 is in a great measure due to the fact that in this region there are but few observing stations, the island of Yezo in which these districts are situated, being sparsely populated. A line drawn from N.N.W. to S.S.E., or from numbers 7 to 557, is the chief anticlinal axis of the northern island, and from the southerly prolongation of this beneath the ocean, earthquakes from time to time originate which shake not only the eastern coast of Yezo but also many of the districts on the main island, Although districts like 11, 9, 8, and then through 7, suddenly northwards up to 13 or 14, lie along the strike line of the southern portion of the empire, a greater number of earthquakes seem to originate from the face of the steep monoclinal slope which Japan presents toward the Pacific Ocean.

Lines, 120 geographical miles in length, running in an easterly or south-easterly direction from the highlands of Japan into the Pacific Ocean, like similar lines drawn from the Andes westwards into the same ocean, have a slope of 1 in 20 to 1 in 30, and in both of these districts earthquakes are frequent. On the contrary, along the face of flexures which are comparatively gentle, being less than half these amounts, which may be seen along the borders of most of the continents and islands of

the world, earthquakes are comparatively rare. The inference from this, is that, where there is the greatest bending, it is there that sudden yielding is the most frequent. In the case of many of the Japanese earthquakes, this takes place along the face of a monoclinal feature of the world's surface, and the intimate relationship between monoclines and faults is known to all geologists, the former being, in the words of Sir Archbald Geikie, an incipient stage of the latter.

EARTHQUAKES AND SECULAR MOVEMENTS.—Another feature indicated by the map or known to the writer from personal observation, is that earthquakes are frequent in those districts where there are evidences of secular elevation or depression, that is to say, in those districts where movement of the earth's crust is yet slowly taking place.

In districts 1, 2, 5, 6, and 7, the writer knows from repeated observation that there are evidences of very recent elevation, and certainly in these districts earthquakes are extremely frequent. The signs + and − in the neighbourhood of districts 8, 9, 11, 12, and 13, and along the Inland Sea, lying to the north of 8 and 9, but to the south of 12, also show a like relationship.

The only exceptions to the general rule appear to be the westerly portion of the district between 12 and 13, where there are evidences of secular movement, and earthquakes are of rare occurrence, and in 15 where these conditions are reversed. The district number 14 represents a series of earthquakes originating along the line of a valley between high mountains running from N.N.E. to S.S.W. Another good example of earthquake fracturing following a line of weakness down a

valley between high mountains until it reached the plain, was the disturbance of October 28th, 1891, which, as has been explained, resulted in the abnormal conditions shown in district 7.

In Japan, therefore, earthquakes have been frequent along the steep monoclinal face of the country, in the synclinal trough of deep valleys, possibly along the continuation of the Yezo anticlinal, and in districts where secular movement is in progress. In Italy, earthquakes originate along the anticlinal of the Appenines, and from what we know of the geological history of the country, which had its greatest growth in Tertiary times, and from the bradyseismic movements on the coast, it is not unlikely that the shakings it experiences announce the fact that secular yielding is yet in progress. The earthquakes of Switzerland and those which shake the Himalayas, and the younger mountains of the world, may also be taken as due to orogenic causes which seem to be so actively in operation in Japan.

EARTHQUAKE SOUNDS.—A map that has been prepared, but which has not been reproduced with the catalogue, shows the distribution of earthquakes accompanied by sound phenomena. To indicate that a sound was heard, a dot is used, for a sound with a shock the sign +, for a sound before a shock the sign —, while for a sound after a shock the sign |. After a volcanic explosion it might be expected that a sound wave propagated through the atmosphere might succeed a trembling of the ground.

Because this latter sign, although there are one or two cases of its occurrence in districts 6, 7, 12, and 14, generally near to active or old volcanoes, and about 2 cases

in district 8, it may be assumed that earthquake sounds, rather than representing atmospheric waves radiating from an epifocal area, represent elastic vibrations transmitted through the ground, and therefore arrive at a given station in advance of any quasi-elastic surface undulation. Inasmuch as earthquake sounds only travel a few miles from their origin, the intervals between them and an earth movement which can be felt is very small. The result of this is that it often appears that the two phenomena are simultaneous, and therefore on the map we find nearly as many signs indicating "sound with shock," as those which indicate "sound before shock." Sounds are often heard which cause people to run from their houses, expecting a shock which does not come. The dots on the map represent sounds which have been to ordinary observers simultaneous with an actual shaking of the ground. Taking the districts in order, we find the sound phenomena distributed as follows:—

1.—Sounds fairly frequent on the coast at the most easterly and most southerly portions of the district. Inland and on the northern coast they are rare. This may indicate that the majority of earthquake origins lie to the S.E. and are submarine.

2 and 3.—Sounds are rare. Many of the origins of these shocks are submarine. The coast between 2 and 3 is composed of soft materials.

4 and most easterly part of 5.—Here the coast is rocky, built up of palæozoic strata. Sounds are fairly frequent. In the southern part of 5, where there is much soft tertiary material sounds are rare.

6.—Sounds are frequent in the northern part of the district, which is mountainous, while in the plain of Musashi, constituting the southern part, they are rarely heard.

7.—Amongst the palæozoic hills of the district and extending down into the plain, sound phenomena accompany about 30 per cent. of the disturbances.

8 and 9.—Although the districts are mountainous, sounds are rarely heard. Possibly the shocks originate beneath the ocean.

10, 11, and 12.—Sounds are fairly frequent.

13.—Here, which is another mountainous region, sound phenomena are common.

14.—Sound is occasionally heard.

15.—Along a sandy coast bordering a plain, sound phenomena seem never to be heard.

Generally sound is heard in rocky mountainous districts, while on the alluvial plains it is but very rarely observed.

EARTHQUAKES WHICH HAVE BEEN PROPAGATED TO EUROPE.—The object in appending the list of Earthquakes which was kindly drawn up for me by Dr. E. von Rebeur-Paschwitz, is to show that some of the Japanese disturbances have travelled as far as Europe, where for minutes or hours, although they were unfelt by persons, they caused movements in delicately adjusted horizontal pendulums. A similar series of unfelt disturbances originating in distant countries or beneath the oceans, have been recorded in Japan. Although it would be out of place to discuss these disturbances in connection with the present catalogue, it is hardly out of place to indicate the advantages which might be derived if we had a catalogue which would show their times of arrival and the character of their movements at different points upon the earth's surface. A disturbance in passing from Japan to Europe *apparently* does so with an increasing velocity, the preliminary tremors sometimes performing the journey, as calculated Dr. E. von Rebeur-Paschwitz at a rate of 12 km. per second, while the larger motions follow

slowly afterwards at $\frac{1}{6}$ or $\frac{1}{8}$ of this rate. Among the many questions to be answered, the most important perhaps is to define the direction of the wave paths, which may have been on the surface, or through the substance of the earth in radial or by refraction through materials of varying density and elasticity, in curvilinear lines. Possibly motion may have been transmitted along all such paths. In the two latter cases, velocities determined from observation between two stations on the earth's surface are only *apparent* velocities which would be practically infinite at places in the vicinity of the antipodes of an origin.

In the preliminary tremors which yield these apparently very high velocities followed by the slower waves, Dr. Adolfo Cancani and other investigators see the realization of the normal and transverse vibrations of an isotropic solid, but, as pointed out by Dr. C. G. Knott, on account of the heterogeneity of the earth's crust and the reflections and refractions which necessarily take place, whatever elastic wave we start with, this must as it progresses from medium to medium be repeatedly broken up into condensational and distortional waves, and no clear separation of these forms of motion could be expected to be found at any distant station. Near to an origin, and even at a distance of several hundreds of miles from the same, the writer's own observations show that the ground is thrown into long undulations, which therefore, although partially elastic in their character, are greatly influenced by gravity. These waves are apparently identical with those which slowly tilt the pendulums from side to side at stations distant a quarter of the earth's

circumference. The preliminary tremors may be truly elastic disturbances not necessarily originating at the centrum, but, as Dr. Knott suggests, the result of the transformation of the quasi-elastic disturbance as it travels into truly elastic motion. In this case the phenomenon would in some of its features be analogous to the sound which precedes a trotting horse. Although such a phenomenon has undoubtedly an existence, to suppose that the preliminary tremors observed in Europe originated in this manner is apparently forbidden by the fact that it would give to them a velocity higher than the already abnormally high one which is accredited to them on the assumption that they travelled from Japan to Europe on the surface of the Earth. To determine whether these tremors are the result of vibration directly or curvilinearly transmitted though the earth from the origin, is evidently a problem of the greatest interest to the student of earth physics. To extend our knowledge in this direction, a ring of stations provided with instruments of like character is required round the world. We know what occurs in Japan and in Europe, but at present Siberia and America are regions of seismic darkness. If in these latter countries a few observatories could be established, a catalogue of their records would in all probability give us in a few years more certain information about the interior and crust of our earth than we shall ever learn by years of speculation.