twenty-six plates obtained between November 9, 1901, and March 23, 1905, with the No. iv. spectrograph and the 32·5 cm. refractor of the Potsdam Observatory.

The values obtained for the velocity, referred to the sun, vary between +5·3 km. (on November 9, 1901) and −16·9 km. (on December 11, 1902).

EARLY OBSERVATIONS OF EROS.—No. 10, vol. liii., of the Harvard College Observatory Annals contains the details of a number of observations of Eros made at Harvard from twenty-one photographs obtained during the period 1893 (October) to 1896 (June).

The measurements of these plates were published in Circular No. 51 of the observatory, but in the present publication the whole of the data relating to the plates, the original measurements of the photographs, the positions of the standard stars employed, reproductions of the photographs, and many other important matters are dealt with in great detail.

As this number forms the concluding part of vol. liii. of the Annals, several reproductions previously given in the text are now reproduced on plates in a much more satisfactory manner, and published as an appendix.

OBSERVATIONS OF SATELLITES IN 1904 AND 1905.—In No. 94 of the Lick Observatory Bulletins Prof. R. G. Aitken publishes the results of the observations of satellites made at Lick during 1904 and 1905.

Forty-seven observations of the satellites of Uranus were made, the position angle and distance of each object being referred to those of another satellite.

The second part of the publication refers to the observations of Saturn's satellites during 1905, which were, in some measure, a continuation of Prof. Hussey's work in previous years. Only those combinations most likely to improve our knowledge of the orbits of the inner satellites, *i.e.* Rhea with Dione, Tethys with Enceladus, and, as a check, Tethys with Rhea, were, however, measured. Four eclipses of Saturn's satellites were also observed.

Observations of Jupiter's fifth satellite, made during 1904 and 1905, referring this object to the three inner satellites, form the subject of the concluding section of the Bulletin.

NEW VARIABLE STARS IN ORION.—From a study of the Heidelberg 6-inch plates, Prof. Max Wolf has discovered seven new variables in Orion.

Photomicrographic reproductions, through a microscope, of the regions containing the stars on the 6-inch plates are given, together with the positions and observed variations of the seven objects, in No. 4085 of the *Astronomische Nachrichten.*

RECENT ADVANCES IN SEISMOLOGY.[1]

THE most remarkable development in modern seismology is not the seismic survey of a city, or even of a country, but of the whole world. This branch of inquiry is now in active progress. Since the time of the great earthquake of Lisbon in 1755 it has been known that disturbances of the magnitude of that event, although not directly recognisable as earthquakes in regions distant from the origin, have nevertheless given evidence of commotion by causing the water in lakes and ponds to oscillate. By observing and timing the movements of the bubbles of sensitive levels, astronomers have recorded unfelt pulsatory movements of the ground which they showed to be the result of seismic disturbances in far distant countries. In Japan these unfelt movements have been automatically recorded since 1884 (Seis. Soc. Trans., vol. x., p. 6). They were recognised to have originated at a great distance, but the centres from which they sprang were not determined. Some years later, while seeking for a gravitational influence of the moon, the late Dr. E. von Rebeur-Paschwitz found on his records abnormal movements, several of which he traced to definite but very distant seismic centres. Before this, indeed, it had been predicted that a large earthquake occurring in any one part of the world would produce movements which, with proper instruments, would be recorded in any other part,[2] but it was not until after von Rebeur's announcement that serious attention was directed to what has proved to be a line of research open to workers in all countries. Many instruments have been designed to record these unfelt breathings of our earth, but there is still much uncertainty in the interpretation of all their records.

Observations also show that large earth-waves are from time to time propagated over the whole surface of the globe. These far-reaching commotions lead to the inference that their originating impulse must have been delivered over a large region. Harboe has shown that within a meizoseismic area blows of varying intensity have been struck in quick succession at points long distances apart. A district appears to have given way, not simply along the line of one large fault, but along many minor faults. Oldham estimated that the Assam earthquake of 1897 had been accompanied by the bodily displacement of 10,000 square miles of country along a thrust plane. If we interpret the time observations made in connection with this disturbance in the light of the suggestion made by Harboe, then this relief of seismic strain originated over an area of 500,000 square miles.

Although a large block of the earth's crust may thus be fractured, our knowledge of the depth to which the effects of fracturing descend is largely one of inference. From the observations hitherto published, which are now in progress at Przibram, it would seem that a seismogram obtained at a depth of 1150 metres differs but little from one obtained on the surface. This is contrary to observations on small earthquakes, which, although they may alarm the inhabitants of a town and shatter chimneys, may pass unnoticed in shallow mines.

The fact that the large earth-waves have what is practically a constant arcual velocity of approximately 3 km. per second, whether the path be across continents, over ocean floors, or over districts which vary greatly in their geological structure, suggests the idea that the crust of the earth is moved as a whole, and that under the influence of its own elasticity and gravity it behaves in a manner similar to a sheet of ice upon an ocean swell. An alternative view is to assume that the wave motion is due to energy retained within the crust itself, the heterogeneity of which is superficial. Whichever be the case, we may picture a crust yielding irregularly, and possibly through its total thickness, until it gives up its energy to a medium which transmits undulatory movements with uniform velocity.

Many hypotheses have been adduced which suggest thicknesses for the superficial covering of our globe. To these as an outcome of recent seismological research we may add one more. Preceding the large waves of a teleseismic disturbance we find preliminary tremors. These are apparently propagated through the body of the globe with an average speed along paths which are assumed to be chords at about 10 km. per second. This high and nearly constant rate of transmission, however, only obtains for paths which represent arcs greater than 30°. For chords which lie within a depth of thirty miles the recorded speeds do not exceed those which we should expect for waves of compression in rocky material. This, therefore, is a maximum depth at which we should look for materials having similar physical properties to those we see on the earth's surface. Beneath this limit the materials of the outer part of this planet appear rapidly to merge into a fairly homogeneous nucleus with a high rigidity. Following closely on the heels of the preliminary tremors, but in advance of the large undulations, a second phase of motion appears, the chordal velocity of which up to distances of 120° is approximately 6 km. per second. These are tentatively regarded as the outcrop of distortional waves. When these are better understood it may be expected that they also will play their part in shedding fresh light upon the physics of the earth.

I will now turn to a consideration of the regions in which these sudden accelerations of geological change are in operation. They may be grouped as follows:—

Regions which lie on the western suboceanic frontier of the American and the eastern frontier of the Asiatic continents, and regions which lie on a band passing from the West Indies through the Mediterranean to the Himalayas.

In addition to these there are two minor regions, one following the eastern suboceanic frontier of the African continent, which I have called the Malagasy region, and

[1] Abridged from the Bakerian Lecture delivered by Prof. John Milne, F.R.S., at the Royal Society on March 22.
[2] See "Earthquakes," p. 226, International Scientific Series, 1883.

an Antarctic region which lies to the south-west of New Zealand.

Generally it would appear that regions of instability are to be found along the margins of continents or tablelands which rise suddenly to considerable heights above oceanic or other plains.

At the present time we may, therefore, say that mega-seismic disturbances do not occur anywhere, but only in districts with similar contours. Are we dealing with primitive troughs and ridges which are simply altering their dimensions under the continued influence of secular contraction, or do these reliefs of seismic strain represent isostatic adjustments which denudation and sedimentation demand?

These and other activities may be looked to as primal causes leading up to displays of pronounced seismic activity. Their frequency, however, may be dominated by influences which at certain seasons or times cause an increase or decrease in seismic strain.

In the wide variations in position and rapidity of flow of ocean currents and in measured oscillations of sea-level which appear to be seasonal in their recurrence, we see influences which may give rise to seismic frequency in districts that possess a high degree of seismic sensibility. Other causes affecting large areas, and also possibly the frequency of small or after-shocks in different seismic districts, have by Knott and others been sought for in the loads due to the accumulation of snow, and in the seasonal fluctuations in the direction of barometric gradients. It does not seem likely, however, that stresses due to such influences have any marked effect upon the frequency of those reliefs of seismic strain which shake the world.

The data which we possess bearing upon this question are as yet far too meagre to admit of satisfactory analysis. It is, nevertheless, interesting to note the direction in which they point. In the six years ending in 1904 we find that off the west coast of North America fifty-one large earthquakes originated during the winter months (October to May) and thirty-five during the summer months. Off the east coast of Asia, north of the equator, the numbers for these seasons were forty-nine and forty-three. These numbers added together show that for the North Pacific, as a whole, 100 disturbances took place in winter and seventy-eight in summer, while in the Central Asian or Himalayan region the corresponding numbers are twenty-five and twenty-seven. Beneath an ocean, therefore, some indication has been obtained of seasonal seismic frequency, while on a continental surface no such frequency has yet been indicated.

If we take a chart showing the varying position of our earth's North Pole in relation to its mean position, we see that the secular movement of the pole is by no means always uniform. Although it may at times follow a path about its mean position which is approximately circular, at other times there are comparatively sharp changes in direction of motion which may even become retrograde. If now on a chart of this description we mark the time-positions of very large earthquakes, we find that they cluster round the sharper bends of the pole path.

In a period of nearly thirteen years (1802 to 1904) I find records for at least 750 world-shaking earthquakes, which may be referred to three periods continuous with each other, and each two-tenths of a year or seventy-three days' duration. The first period occurs when the pole movement followed an approximately straight line or curve of large radius, the second equal period when it was undergoing deflection or following a path of short radius, and the third when the movement was similar to that of the first period. The numbers of earthquakes in each of these periods taken in the order named were 211, 307, and 232, that is to say, during the period when the change in direction of motion has been comparatively rapid, the relief of seismic strain has not only been marked, but it has been localised along the junctions of land blocks and land plains where we should expect to find that the stress due to change in direction of motion was at a maximum. Until the magnitude of these induced stresses has been estimated, it would be premature to assume that the frequency under consideration is directly due to change in direction of pole movement, it being quite as likely that both phenomena may result from a general cause.

A world-shaking earthquake, wherever its motion is pronounced, gives rise to movements which may extend over three or four hours. They come to a close as a series of pulsations, each lasting a few minutes, and separated from each other by approximately equal intervals of rest. The expiring efforts of an earthquake present something more akin to musical reverberation than to intermittent and irregular settlement of disjointed material.

If instead of studying the life-history of an earthquake as recorded at a given station, we compare the seismograms it has yielded at different distances from its origin, we learn something of the manner in which its energy has been radiated and dissipated. An earthquake which in the vicinity of its origin has a duration of sixty minutes may appear at its antipodes ninety or 100 minutes later as a feeble movement with a duration of only four or five minutes. From the time this movement has taken to travel the half circumference of the globe the inference may be drawn that the surviving phase of such an earthquake is that of the large waves. The compressional and distortional precursors, together with the rhythmical succession of followers, are no longer visible on seismograms. The importance of this knowledge to those who are engaged in the analysis of earthquake registers is apparent.

The paucity of available data renders it premature to make deductions respecting possible alternation in seismic frequency in various localities. But if, instead of confining our attention to a relationship between earthquakes, we consider the question of the relief of volcanic strain, many illustrations may be adduced which indicate a close connection between such activities. For example, all the known volcanic eruptions which have occurred in the Antilles, from the first which took place in 1692, have been heralded or closely accompanied by large earthquakes in that region, but more frequently by like disturbances in neighbouring rock-folds, particularly that of the Cordilleras. This was notably the case in 1902. On April 19 of that year an unusually large earthquake devastated cities in Guatemala. Small local shocks were felt in the West Indies, and on April 25 it was noticed that steam was escaping from the crater of the Mont Pelée, in Martinique. These activities continued to increase until May 8, when they terminated with terrific explosions, submarine disturbances, and the devastation of great portions of the islands of Martinique and St. Vincent.

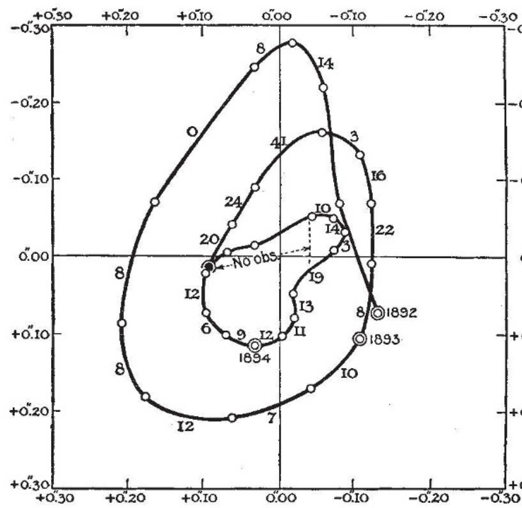

FIG. 1 shows, after Th. Albrecht, the path of the North Pole from 1892 to 1894 inclusive. Each year is divided into tenths or periods of 36·5 days. Numerals indicate the number of large earthquakes which occurred in each of these divisions, commencing with the third tenth of 1892.

The last illustration of hypogene relationship between these regions occurred on January 31 of the present year. On that date a heavy earthquake originated off the mouth of the Esmeralda River, in Colombia. Sea-waves inundated the coast, islands sank, and a volcano erupted. The newspapers of February 2 announced that cables between Jamaica and Puerto Rico had been interrupted, and on later dates it was reported that severe shocks had been felt among the West Indian islands, that six or seven submarine cables had been broken, and that Mont Pelée and La Soufrière, in St. Vincent, were again active.

In concluding this short discourse, I wish to direct attention to a class of phenomena from which the working seismologist cannot escape. At certain times horizontal pendulums may be fitfully moving continuously for hours or even days. Similar movements have often been noticed with balances and with other instruments. They are frequently referred to as microseismic disturbances. Inasmuch as they vary with varying meteorological conditions, and

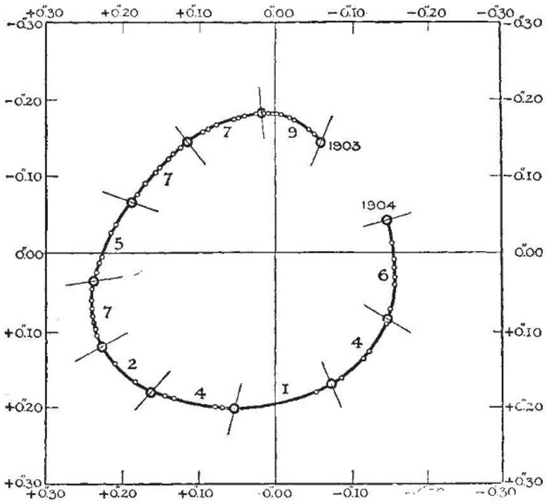

FIG. 2.—This is similar to Fig. 1, but refers to the year 1903, during which period the pole displacement was more uniform than that indicated in Fig. 1.

may be different in neighbouring rooms, I am inclined to think that it would be more accurate to describe these unwelcome visitors, with which not only seismologists, but also astronomers and others, have to contend, as air tremors. When, however, these irregular movements are replaced by movements which have definite periods very different from those of the recording instrument itself, and are at the same time regular in amplitude, it seems possible that they may be connected with actual pulsatory motion of the surface of the ground.

In addition to tremors and pulsations, the records on the films from seismographs show that nearly at all times with barometric loading. The quantity of water in wells and that flowing in drains and from springs has been observed to vary with fluctuations in atmospheric pressure. Where this takes place, subsurface operations are revealed which may be sufficient to give rise to changes in surface level. Very marked changes of level take place at certain stations during wet weather. In the Isle of Wight, at Shide, which is situated on the side of a valley cut through an anticline of chalk, when heavy rain occurs, levels and horizontal pendulums indicate a tilting towards the bed of the valley. An instrument on the opposite side of the valley behaves in a corresponding manner. In other words, if these observed movements can be regarded as extending to the bed of the valley, it may be said that with rain the steepness of each of its sides is increased. During fine weather the direction of movement is reversed. A more regular movement is, however, found in a tilting known as the diurnal wave. With the same assumption as to the extent of corresponding motion we find, but only during fine weather, that the direction of movement of the sides of the same valley during the night corresponds to that observed during wet weather. During the day it is the same as that which takes place during fine weather. For convenience we may regard the valley as opening and closing. Similar observations have been made on the two sides of a valley which has been cut through alluvium in Tokio.

Probably an important part in the production of these diurnal movements is played by the differential loading and unloading of neighbouring areas by solar influences. During wet weather, in virtue of subsurface percolation and lateral drainage generally, the sides and bottom of a valley where water-level is raised carry a greater load than the bounding ridges. Under these conditions the bottom of a valley may sag and its sides close inwards. During fine weather, in virtue of evaporation and drainage, a movement in the opposite direction may be established. The fine-weather diurnal movement corresponding to the opening of a valley may find a partial explanation in the removal of load by evaporation, but more particularly by plant-transpiration. These activities are more pronounced during the day than at night, and they tend to reduce subsurface percolation and drainage towards the bed of a valley. The comparatively small retrograde nocturnal movement may be partly attributed to an increase of valley load at night, at which time transpiration and evaporation are replaced by surface and subsurface condensation. Transpiration and evaporation being at a minimum at night, it may be assumed that lateral percolation and surface drainage towards the bed of a valley are increased, and, possibly as a consequence of this action, the volume of water in certain wells and that flowing in certain streams and drains has been found to be greater at night than during the day.

Another activity which may result in a nocturnal increase

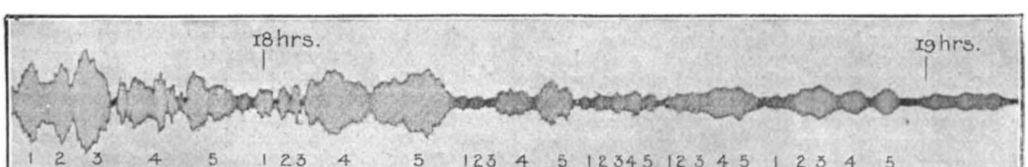

FIG. 3.—Recurrences of Wave Groups A to F in the terminal vibrations of the Colombian Earthquake of January 31, as recorded at Shide, Isle of Wight. Scale 108 mm. = 1 hour.

a slow change of level is taking place. For years a pier may be undergoing a tilt in one direction. Besides this general movement the instruments reveal the existence of waves that indicate a difference in the direction of movement in different seasons. Superimposed upon these again we find records of changes of level which may be associated with variations in the difference in loads on two sides of an observing station. When a horizontal pendulum swings towards the area of greatest atmospheric pressure it apparently indicates a change directly or indirectly connected in the subsurface flow of water is the expansion of the air in soil by the slowly descending heat of the previous day, this expansion forcing soil-water into passages of easiest escape.

The explanation offered for the phenomena under consideration may be found wanting; but the facts remain that round the face of the globe diurnal superficial distortions can be observed which vary in magnitude and direction, and that rainfall is accompanied by measurable changes in the slopes of certain valleys.