once or twice at intervals of two hours. The failure of Dr. Frisch, of Vienna, in experiments of this kind is due to the slow process of vaccination adopted by him. Success can be secured only by the rapid method here described. The immunity conferred under such conditions is the best proof of the excellence of this method.

REPORT ON THE CHARLESTON EARTHQUAKE[1]

THE earthquake of August 31, which, from the locality in which its greatest power was displayed, will generally be known as the "Charleston Earthquake," was, perhaps, the most notable disturbance occurring within the limits of the United States of which we have any knowledge. It is entitled to this rank both on account of the wide area over which it was distinctly felt, and of the magnitude of the disaster which it caused in the immediate vicinity of the point of maximum intensity.

The earthquake consisted of a series of seismic disturbances which began in slight but distinctly noticeable tremors occurring on August 27 and 28, at the town of Summerville, about twenty-five miles north-west of Charleston, South Carolina.

The shock of greatest violence occurred a little before ten o'clock on the night of Tuesday, August 31. It was followed by several of lesser magnitude on that night, and during the succeeding three or four weeks. The great shock began in the city of Charleston within a few seconds of 9.51 p.m., 75th meridian time. The duration of the vibratory motion of the earth at that point was probably about forty seconds; the motion at first being moderate, but increasing with great rapidity during the last ten or fifteen seconds.

All of the loss of life and property during the whole series of disturbances is to be attributed to this first shock. Five minutes later another occurred, and ten minutes later still another; the latter being of considerable violence, but neither alone would have done any damage. The same may be affirmed of the succeeding series of disturbances, which, with greatly diminished intensity and at increasing intervals of time, continued to maintain the conditions of alarm and terror into which the people of the afflicted locality were naturally thrown by the first disturbance. Although some injury to buildings resulted from these after shocks, it is tolerably certain that in all such cases displacement and fracture had taken place in the great shock; the lesser disturbances simply finishing what had then been nearly completed.

The origin of the disturbances, appears to have been somewhere below a point fifteen or twenty miles north-west of Charleston; that is, in the neighbourhood of the town of Summerville. A chart of provisional co-seismal lines drawn by Mr. Hayden of the Geological Survey, and published in *Science* for September 10, seems to locate this centre somewhat further north than the point indicated above. At the time of its construction, however, information from many points was lacking, and that which was at hand was admittedly doubtful in some degree.

Reference is made later to the iso-seismal chart which accompanies this Report, and which indicates that the origin was near the point referred to above. Strong proof of this is also furnished in the intensity and character of the disturbance as shown by the effects which were still visible when an examination was made a few days after the principal shock. The appearance of the brick piers upon which many houses in Summerville rest was such as to justify the conclusion that the principal component of the motion at that point was vertical, and it was evident that the destruction of buildings was much less than would have resulted from a horizontal movement equal to that which had taken place in Charleston and elsewhere in the neighbourhood.

Another fact of importance is that in the vicinity of Summerville the disturbances preceding that of August 31 took place, and here they have been most numerous and most persistent. Indeed, at the present writing, nearly a month after the first perceptible shock, they still occur at irregular intervals varying from a few hours to a few days. Only the most violent of these have been felt as far as Charleston.

Nearly all the movements in Summerville and vicinity have been accompanied by, and, indeed, generally preceded by, a low rumbling sound, lasting one or two seconds, and not unfrequently this sound, always unmistakable in its character, was neither accompanied nor followed by a perceptible movement. This was a common occurrence at Summerville and in the immediate vicinity, and it was found that among several observers there would be no agreement upon the direction from which the sound appeared to come.

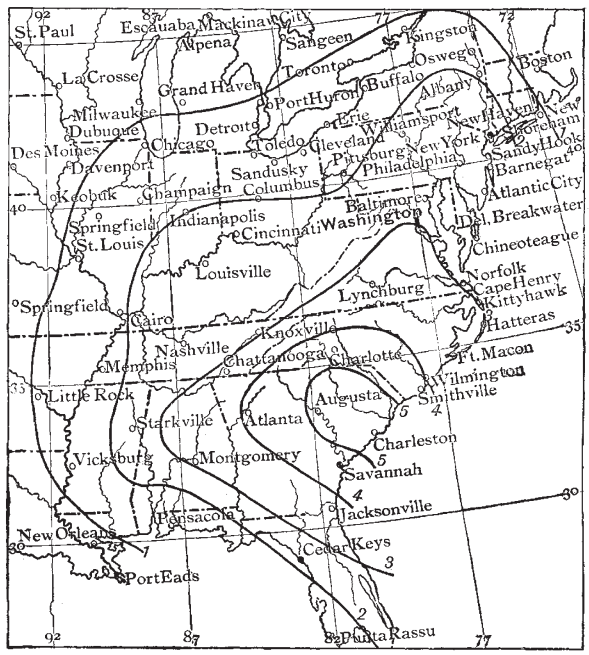

Chart of iso-seismal lines.

At a distance from ten to fifteen miles from Charleston in the direction of Summerville some of the most curious and interesting effects of the disturbance were to be seen. These were the "sand craters" and crevices, out of which extensive eruptions of sand and water had taken place on the night of August 31. The craters thus formed varied in size from an irregular oval, twenty-five feet long by fifteen feet wide, to shallow cones not over an inch in diameter and beautifully symmetrical in form. The area surrounding these openings was generally flooded with sand, often acres in extent, to a depth varying from a fraction of an inch to fifteen and eighteen inches. About the larger cavities the average depth was probably not less than six inches, and the area covered often an acre or more. The flow of sand was unquestionably only an incident to the outflowing of vast quantities of water, the greater part of which disappeared within a few hours after its appearance. The few crevices or "cracks" in the earth which were found were in character and origin similar to the "craters," being long and narrow openings, through which water with sand had been ejected.

It was difficult, in fact quite impossible, to obtain reli-

[1] By Prof. T. C. Mendenhall, Assistant. From the *Monthly Weather Review*, U.S. Signal Service, August 1886.

able information concerning the nature of this phenomenon at the moment of its occurrence. The locality in which it was principally exhibited is near a station on the South Carolina Railway, between Charleston and Summerville, known as "Ten-mile Hill." It is thinly populated, and almost entirely by negroes. Several persons who pretended to have been eye-witnesses of the outburst gave widely different testimony as to its character. According to one account, the water and sand from one of the "geysers" spouted to a height greater than that of a telegraph pole and continued to flow for four or five hours. Another, and apparently an equally credible witness, declared that the stream reached a height of six or eight feet, and that the flow continued four or five minutes. The latter statement is probably nearer the truth than the former.

A few instances of sand eruptions were found in the city of Charleston, and a few also at Summerville, and at the latter place water continued to flow from one of the openings for several days after the first shock.

It is important to observe that in no case was it found that the water thus issuing from the earth was hot or noticeably above the temperature of water in shallow wells in the neighbourhood. Reports of boiling water having been thrown up were very numerous, but no evidence that the water was really hot appeared. The use of the word "boiling" doubtless grew out of the appearance of the water as it issued from the openings, and was probably used by eye-witnesses to describe this appearance with no reference whatever to temperature.

There were also reports of the appearance of blue flames in the neighbourhood of these eruptions, but no reliable testimony to their existence could be obtained. There was also a report that was circulated extensively through the medium of the press of the country that two or three showers of hot stones had fallen upon and near the office of the *Charleston News and Courier*. An examination of some of these shortly after they had fallen forced the conviction that the public was being made the victim of a practical joke.

In the city of Charleston about forty lives were lost. The greater number of casualties resulted from injuries sustained by persons who were either in the street at the time of the shock or who rushed out and were caught by the falling debris. No adequate description of the injury to property can be given in this place, and, indeed, the results of this earthquke have been so thoroughly considered in the public press that note is unnecessary.

While there was probably not a single house in the city which was not in some degree affected by the shock of August 31, there was naturally great diversity as to the extent of the damage in different localities. Some parts of the city are built upon what is called "made land," resulting in many cases from the filling up of old creek bottoms and from other extensive levelling and grading. A more careful study of these peculiarities and their distribution may lead to the discovery of some relation between local differences in structure and the areas of greatest destruction.

Unquestionably much is to be attributed to the difference in the character of the buildings themselves, and to the relation of their lines of greatest or least strength to the direction of the wave front. As was to be expected, buildings constructed of wood suffered much less than those of brick. The interior of wooden buildings, however, would often exhibit a scene of total destruction, furniture, book-cases, &c., having evidently been moved with great violence. A very brief examination of injured buildings sufficed to establish, in a general way, the principal direction of the movement, which was probably in a north-west and south-east line.

The probability of the destruction of a building depends so largely on conditions other than the amplitude or direction of the vibration of the earth particle that the study of destroyed or damaged structures can yield little exact information concerning these elements. The displacement of bodies of simple form and structure, lying near to or upon the surface of the earth itself, is a vastly more reliable index of the direction and intensity of the disturbance. In the churchyards of Charleston many instances of displacement and overturned monuments, columns, urns, &c., were found. These were examined with some care, and a careful study of the results may bring out some information concerning the dynamics of the earthquake. A cemetery containing many pyramidal or cylindrical shafts resting upon flat stone bases is tolerably certain, when disturbed by an earthquake, to exhibit not only displacement but also instances of twisting about a vertical axis; cases of this kind were numerous at Charleston. Such rotations by no means imply a similar gyratory motion of the earth, as it is well known that they may result, and doubtless always do, from vibratory motions in a single plane. It was not at all uncommon to find two columns, very near to each other, twisted in opposite directions.

A table was given containing a *résumé* of information received at the office of the Chief Signal Officer from regular observers of the Service and from a number of voluntary observers. The place, time, supposed direction, duration, and estimated intensity were given. Much discrepancy is observable in the records of time. Confusion is especially great in a few portions of the country in which so-called "local time" is still adhered to. Whenever "standard time" is known to have been used reduction has been made to that of the 75th meridian. In a few cases, however, no reasonable supposition can explain the discrepancies. Such records must be erroneous.

A study of this column will show the great importance, in making such observations, of determining the error of the clock or watch at the earliest possible moment by comparison with the time of some known meridian. It must be said, however, that the extended use of standard time has rendered these results vastly more accurate than they otherwise would have been. Telegraphic time-signals are now within the reach of most people, and during the past two or three years a great improvement in the accuracy of time-keeping among the people has taken place.

The direction of the movement recorded against each station is that given by the observer. As it is based in many instances on the motions of swinging objects, or easily movable objects, it is of necessity often erroneous. In the absence of correct instrumental records, however, such observations are of value. The numbers expressing the intensity of the disturbance were applied at this office, from descriptions furnished by observers, according to a scale adopted by the Director of the Geological Survey.

This scale is as follows :—

No. 1. Very light. Noticed by a few persons; not generally felt.

No. 2. Light. Felt by the majority of persons; rattling windows and crockery.

No. 3. Moderate. Sufficient to set suspended objects, chandeliers, &c., swinging, or to overthrow light objects.

No. 4. Strong. Sufficient to crack the plaster in houses, or to throw down some bricks from chimneys.

No. 5. Severe. Overthrowing chimneys and injuring the walls of houses.

With these intensity numbers an attempt has been made to plot a chart of iso-seismal lines, or lines of equal intensity. The result is shown in the chart. Nothing short of the use of well-constructed seismographs can furnish satisfactory measures of the amplitude of vibrations of the earth particle or the maximum velocity of the same, but in the absence of records of such instruments, this chart, or a more perfect one constructed upon the same plan, will afford opportunity for study.

In conclusion, it ought to be stated that this brief review of the Charleston earthquake must be regarded only as an attempt to place some of the leading facts upon record, for the benefit of the readers of the *Monthly Weather Review*. It is in no way intended to anticipate the investigations now in progress by the United States Geological Survey, a full report from which, based upon all attainable information, will be looked for with great interest.

THE SIMILARITIES IN THE PHYSICAL GEOGRAPHY OF THE GREAT OCEANS[1]

AT the outset Mr. Buchanan reminded the audience of the similarities observed in the eastern and western continents, especially in their southern extremities. Such similarities in corresponding localities had been called homologous geographical features, in imitation of the homologies of comparative anatomy, and they had received much attention from students of geography. A remarkable group of similarities of this kind is to be found in the arrangement of inclosed seas lying to the northward of the three southern continents. To the northward of South America there are the Gulf of Mexico and the different basins of the Caribbean Sea; to the northward of Africa there are the Mediterranean with its different basins, and on the north-east the Red Sea; and to the northward of Australia there are the well-known seas of the Eastern Archipelago. These seas are bounded on all sides by islands and insular groups, and they are in continuous connection with two oceans, the Pacific and the Indian. The African seas are bounded entirely by continental land and communicate directly with two oceans; but in the limited sense that one sea, the Red Sea, communicates with the Indian Ocean by a single channel, and the Mediterranean Sea with the Atlantic, likewise by a single channel. Finally, the American seas are all in continuous communication with only one ocean, the Atlantic, the continental barrier towards the Pacific being continuous.

It is not unworthy of remark that the great depths (over 4000 fathoms) of the Atlantic and the Pacific Oceans occur immediately to the northward of these groups of seas, and in the western sinus of the northern portions of both oceans; while the greatest depression of the continental land, the region of the Dead Sea, is found similarly situated with regard to Africa. The analogy here, however, does not hold good all through, because it is a mere accident of climate that this area does not form a large and not excessively deep fresh-water lake.

The seas of the Malay Archipelago and those of the West Indies have important functions in the physical geography of the oceans, as they receive the warm dense water of the westerly-running equatorial currents of the Pacific and the Atlantic Oceans. The Pacific current finds no obstacle in the chains of islands which bound the Malayan seas, and is able to pass freely through into the Indian Ocean; while the Atlantic current is stopped by the continuous continental barrier of South America, and the head of water thus produced is relieved by the overflow of the Gulf Stream all the year round. Although there is no static barrier, in the shape of continuous land, to the westerly Pacific current, there is, during one season of the year, a kinetic one, furnished by the prevalence of the south-west winds during the monsoon season. These furnish the intermittent *kuro siwo*. The main cause of the westerly equatorial current is the propulsive action of the trade winds.

These winds have also great evaporating power; and, by making the surface water salter, they furnish the mechanical means of propagating the surface heat into the deeper layers of the ocean. Hence the leading characteristic of the westward or leeward regions of the intertropical oceans is water of considerable density and of high average temperature in the sub-surface layers. This characteristic is seen most clearly in the Atlantic, where there is no communication with another ocean. In the Pacific the non-continuous boundary neutralises to some extent this effect, and gives to the eastern parts of the Indian Ocean a borrowed leeward character, independent of its own climate. A secondary consequence of a leeward position in the ocean, and due to the above-mentioned characteristics of the temperature and density of such water, is the prevalence of coral formations in the western regions of the Atlantic and Pacific, and, owing to the mixture of conditions, in both eastern and western regions of the Indian Ocean.

Continental homologies, or similar features in corresponding localities, are found on the western as well as on the eastern sides of the continents. One of the most striking is the resemblance of the Gulf of Guinea on the African coast with the great Central American bight stretching from Cape St. Lucas at the extremity of the Californian Peninsula, by Panama, to the mouth of the Guayaquil River, and with the unnamed bight in the Indian ocean bounded continentally by the north-west coast of Australia and insularly by the chain of islands stretching from the Peninsula of Malacca to Australia. Oceanically these bights are homologous. It is in them that the beginnings of the westerly-running equatorial currents are to be found, and perhaps more important still, it is in them that the easterly-running counter equatorial currents end. They are to be found in each of the three oceans, and generally on the northward side of the axis of the westerly-running current. In the Atlantic it is best known by its eastern portion, the Guinea current.

The observations here recorded of the Guinea current, a hitherto unexplored region of the ocean, were made on board the steamship *Buccaneer*, at the invitation of the owners, the India-rubber, Gutta-percha, and Telegraph Works Company, of Silvertown, and were carried out during a survey for a telegraph cable from Sierra Leone to St. Paul de Loanda. From a diagram showing the variation of salinity of the surface water of the Guinea current, with distance from the coast, it appeared that for a considerable distance along the Guinea coast the salinity of the surface water was an almost accurate test of the proximity of the land. The Guinea current starts in mid-ocean, but it is most constant near the African coast. The density of the water is low, its temperature high, and its velocity, especially in-shore, is sometimes as great as three miles an hour. It varies somewhat with the season.

Bottle experiments showed an average rate of fifteen miles per day in the months of January and February, for a thousand miles along the coast. In March, the *Buccaneer* experienced no easterly current, and in connection with this absence of easterly currents off the coast may be taken the very remarkable under-current which is found setting in a south-easterly direction with a velocity of over a mile per hour at three stations almost on the equator, and to the northward of the Island of Ascension. For the double purpose of examining the currents and of obtaining a large specimen of the bottom, the *Buccaneer* was anchored in 1800 fathoms of water by means of an ordinary light anchor fitted with a canvas bag to receive the mud which would otherwise fall off the flukes on its being weighed. While the ship was lying thus at anchor, the surface water was found to have a very slight westerly set. At a depth of 15 fathoms there was a difference, and at 30 fathoms the water was running so strongly to the south-east, that it was impossible to make observations of temperature, as the lines, heavily loaded, drifted straight out, and could not be sunk by any weight the strain of which they could bear. In the Pacific the counter equatorial current in the open ocean was well observed by the

[1] Abstract, by the Author, of a Paper read at the meeting of the Royal Geographical Society on Monday, November 8, by Mr. J. Y. Buchanan.