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1907.

ORDINARY GENERAL MEETING.*

DAVID HOWARD, ESQ., D.L., V.P., IN THE CHAIR.

The Minutes of the previous meeting were read and confirmed and the following candidates were elected :—

ASSOCIATES.—Lieut.-Col. W. W. Baker, R.E., Bombay. Malcolm W. Searle, Esq., K.C., LL.D.

The following paper was then read by Col. Hendley, in the absence of the author :—

THE SAN FRANCISCO AND VALPARAISO EARTHQUAKES AND THEIR CAUSES. By WARREN UPHAM, M.A., D.Sc., F.G.S.A. (Hon. Corresponding Member). (With map.)

FOUR months after the terrible earthquake and resulting conflagration which destroyed more than half of San Francisco, the largest city on the Pacific coast of North America, a similar appalling disaster, with much greater loss of life but less of property, has stricken Valparaiso, the largest South American Pacific seaport.

THE SAN FRANCISCO EARTHQUAKE.

Briefly noted, the Californian earthquake, most disastrous in San Francisco, but also dealing much destruction throughout a large area both north and south of that city, occurring in the early morning of Wednesday, April 18th, 1906, at 12 minutes and 6 seconds past 5 o'clock, killed probably in all the stricken region nearly 1,000 people ; and the shock and ensuing fires inflicted a total property loss, according to the lowest careful estimates, of about $300,000,000.

The sudden horror of the first and most violent earthquake shocks, as told by witnesses, and the harrowing experiences of

* Monday, January 7th, 1907.

many during the next three days in escaping from the wide devastation of fire, are so fresh in the memories of those who were there, and of all who have read the accounts given in newspapers, magazines, and books already published, narrating and portraying the awful events and scenes, that they need not be again recited. In this paper attention will be directed mainly to geological description and explanation, so far as can be determined, of the causes of these two earthquakes, which came so near together, bringing ruin temporarily to the fairest and most prosperous cities on the Pacific coast of both the northern and southern American continents.

The first and greatest shock in San Francisco and the contiguous country had a duration of one minute and five seconds, as recorded at the observatory of the State University in Berkeley. It was followed within an hour by twelve minor shocks. During the same day the number of the secondary shocks was thirty-one ; and they continued for many days, generally diminishing in frequency and intensity, as is the usual history of great earthquakes. The ensuing minor shocks are due to secondary adjustments of the faulted rocks after the principal fractures and slips have relieved, almost instantaneously, the greater part of the stress which was pent up and growing through many years.

An area about 400 miles long from north to south and averaging fifty miles in width displayed in more or less degree the destructive effects of this earthquake. Its tremors were slightly felt much farther, from Coos bay in Oregon south to Los Angeles, and eastward across California into Nevada, being especially notable along the eastern flank of the Sierra Nevada.

To much greater distances, and indeed all the way around the world, the rock waves or vibrations ran rapidly and were recorded by the seismographs of observatories. Particularly important records of this paroxysm were thus obtained at Tokyo in Japan and at Potsdam in Germany.

Marvellous speed of transmission of the earth tremors or waves, similar to that ascertained in the case of the Charleston earthquake in 1886, was shown by the time of observations in Washington, D.C., and in Sitka, Alaska. Professor C. F. Marvin, of the United States Weather Bureau, writes of the transmission of the earth vibrations to the city of Washington :

"The great circle distance from San Francisco to Washington is about 2,435 miles, whereas the distance through the crust is about 40 miles shorter, and the straight-line path cuts below the surface

of the earth about 186 miles at its deepest point . . . . Because of its greater density and the enormous superincumbent pressure, the elastic properties of the deep-lying substance of the earth seem to propagate vibrations with higher and higher velocities the deeper the path. These considerations lead to the conclusion that if earthquake vibrations follow the path of the chord the speed of propagation should not be constant for all distances from the origin, but should be greater as the distance from the origin becomes greater. This has generally been found to be true in the case of the preliminary tremors, and will doubtless be shown in this earthquake when accurate reports from numerous stations are examined. From San Francisco to Washington the speed along the chord is found to be 5·4 miles (8·7 kilometres) per second. This is based on Professor Davidson's time at San Francisco, viz., 5.12 a.m. This result is perhaps a trifle faster than we might expect.

"The strong waves do not seem to follow the path of the chord, but rather travel along the surface at a slower rate, which is nearly constant for all distances. In the present case the velocity is 3·1 miles per second for the first strong waves, or as low as 2·2 miles per second for the maximum waves. Both of these speeds, however, are a little high, perhaps."

From records of an observatory of the United States Coast and Geodetic Survey at Sitka, 1,455 miles distant by the great circle from San Francisco, and about 1,447 miles by the chord, the velocity of the fisrt tremors from this earthquake, supposed to have come along the chord, was 5·6 miles, or 9·0 kilometres, per second, the whole distance being traversed in four minutes and eighteen seconds.

Origin of this Earthquake from Rock Faulting.

Three days after the San Francisco shock, Governor Pardee of California appointed a commission of geologists to investigate its results and causes. Of this commission Professors Andrew C. Lawson and A. O. Leuschner, both of the State University, are respectively chairman and secretary; and the other members are Professors G. K. Gilbert of the United States Geological Survey, H. F. Reid of Johns Hopkins University, J. C. Branner of Stanford University, George Davidson of the State University, Charles Burkhalter of the Chabot Observatory, and William W. Campbell, director of the Lick Observatory. The commission have issued a preliminary report, noting chiefly the evidence of a prolonged new fracture and dislocation of the earth crust on an old fault plane, called the San Andreas fault, which cuts north-north-westward diagonally across the Coast

Ranges and passes into the sea at Mussel Rock, about seven miles south-west of San Francisco.

Other researches of the commission are in progress, to be published later, concerning the intensity of the shock at varying distances from the fault line, and the speed of passage of the shock and tremors around and also through the earth. When so thorough a study shall be completed as was given by Dutton and others to the Charleston earthquake, it may be hoped that important inferences will be obtained relative to the constitution of the earth's interior and its fluidity or solidity, a question of profound interest to geologists and physicists.

North of the Golden Gate, the San Andreas fault crosses outlying parts of the coast in several places; and south of Mussel Rock it passes by San Andreas and Crystal Springs lakes, and is traced to the vicinity of Mt. Pinos in Ventura county. Its known extent is about 375 miles. South-eastward from San Francisco, its course is remarkably straight, running obliquely across the mountainous belt that lies between the coast and the San Joaquin valley. This great fault plane, nearly vertically cutting the earth crust to great depths, is paralleled by several other ancient faults of similar character, a few miles apart, traversing the San Francisco peninsula, but movements of this earthquake appear to have affected only the San Andreas fault. (See map.)

The published report of the Earthquake Investigation Commission says:

"The cause of these movements in general terms is that stresses are generated in the earth's crust which accumulate till they exceed the strength of the rocks composing the crust and they find a relief in a sudden rupture. This establishes the plane of dislocation in the first instance, and in future movements the stresses have only to accumulate to the point of overcoming the friction on that plane and any cementation that may have been effected in the intervals between movements.

"The earthquake of the 18th April, 1906, was due to one of these movements. The extent of the rift upon which the movement of that date took place is at the time of writing not fully known. It is, however, known from direct field observations that it extends certainly from the mouth of Alder Creek near Point Arena to the vicinity of San Juan in San Benito County, a distance of about 185 miles. The destruction of Petrolia and Ferndale in Humboldt County indicates that the movement on the rift extended at least as far as Cape Mendocino, though whether the line of rift lies inland or off shore in that region is still a matter of inquiry. Adding the inferred extension of the movement to its observed extent gives us

a total length of about 300 miles. The general trend of this line is about N. 35° W., but in Sonoma and Mendocino counties it appears to have a slight concavity to the north-east, and if this curvature be maintained in its path beneath the waters of the Pacific it would pass very close to and possibly inside of Capes Gordo and Mendocino. Along the 185 miles of this rift where movement has actually been observed the displacement has been chiefly horizontal on a nearly vertical plane, and the country to the south-west of the rift has moved north-westerly relatively to the country on the north-east of the rift. By this it is not intended to imply that the north-east side was passive and the south-west side active in the movement. Most probably the two sides moved in opposite directions. The evidence of the rupture and of the differential movement along the line of rift is very clear and unequivocal. The surface soil presents a continuous furrow, generally several feet wide, with transverse cracks, which show very plainly the effort of torsion within the zone of the movement. All fences, roads, stream courses, pipe-lines, dams, conduits, and property lines which cross the rift are dislocated. The amount of dislocation varies. In several instances observed it does not exceed 6 feet. A more common measurement is 8 to 10 feet. In some cases as much as 15 or 16 feet of horizontal displacement has been observed, while in one case a roadway was found to have been differentially moved 20 feet. Probably the mean value for the amount of horizontal displacement along the rift line is about 10 feet, and the variations from this are due to local causes, such as drag of the mantle of soil upon the rocks or the excessive movement of soft, incoherent deposits. Besides this general horizontal displacement of about 10 feet there is observable in Sonoma and Mendocino Counties a differential vertical movement not exceeding 4 feet, so far as at present known, whereby the south-west side of the rift was raised relatively to the north-east side, so as to present a low scarp facing the north-east. This vertical movement diminishes to the south-east along the rift line, and in San Mateo county is scarcely if at all observable. Still farther south there are suggestions that this movement may have been in the reverse direction; but this needs further field study.

"As a consequence of the movement it is probable that the latitudes and longitudes of all points in the Coast Ranges have been permanently changed a few feet, and that the stations occupied by the Coast and Geodetic Survey in their triangulation work have been changed in position. It is hoped that a re-occupation of some of the stations by the Coast and Geodetic Survey may contribute data to the final estimate of the amount of movement.

"The great length of the rift upon which movement has occurred makes this earthquake unique. Such length implies great depth of rupture, and the study of the question of depth will, it is believed, contribute much to current geophysical conceptions.

* * * *

"Within the area of destructive effects approximately 400 miles in length by 50 miles in extent the intensity varied greatly. There was a maximum immediately on the rift line. Water pipes, conduits, and bridges crossing this line were rent asunder. Trees were uprooted and thrown to the ground in large numbers. Some trees were snapped off, leaving their stumps standing, and others were split from the roots up. Buildings and other structures were in general violently thrown and otherwise wrecked, though some escaped with but slight damage. Fissures opened in the earth and closed again, and in one place reported a cow was engulfed. A second line of maximum destruction lies along the floor of the valley system of which the Bay of San Francisco is the most notable feature, and particularly in the Santa Rosa and Santa Clara valleys. Santa Rosa, situated 20 miles from the rift, was the most severely shaken town in the State, and suffered the greatest disaster relatively to its population and extent. Healdsburg suffered to a nearly similar degree. San José, situated 13 miles, and Agnews, about 12 miles from the rift, are next in the order of severity. Stanford University, 7 miles from the rift, is probably to be placed in the same category. All these places are situated on the valley floor and are underlain to a considerable depth by loose or but slightly coherent geological formations, and their position strongly suggests that the earth waves as propagated by such formations are much more destructive than the waves which are propagated by the firmer and highly elastic rocks of the adjoining hill lands. This suggestion is supported by a consideration of the destructive effects exhibited by towns and single buildings along the same valley line which are situated wholly or partly on rock. Petaluma and San Rafael, though nearer the rift than Santa Rosa, suffered notably less, and they are for the most part on, or close to, the rocky surface. The portions of Berkeley and Oakland which are situated on the alluvial slope suffered more than the foothills, where the buildings are founded on rocks. The same suggestion is further supported from a consideration of the zone of maximum destructive effect on the south-west side of the rift. This zone lies in the Salinas Valley. The intensity of destructive action at Salinas was about the same as at San José, and the town is situated on the flood-plain deposits of the Salinas River. Along the banks of the Salinas River and extending from Salinas to the vicinity of Gonzales, so far as our reports at present show, the bottom lands were more severely ruptured, fissured, and otherwise deformed than in any other portion of the State . . .

"The Commission, in presenting this brief report, has had in mind the demand on the part of the people of the State and of the world at large for reliable information as to the essential facts of the earthquake. It has, therefore, not presumed to engage in any discussion of the more abstruse geological questions which the event

naturally raises. It leaves such discussion for a more exhaustive report, which can only be prepared after the campaign of data collection is complete, and that may be some months hence."*

Previous Earthquakes of California.

During all the Pleistocene and recent periods of geologic history the area of California, and indeed of all our Pacific coast, has been frequently shaken by less or more severe earthquakes. Professor Edward S. Holden has catalogued them from 1769 to 1896, recording at least ten shocks of as great intensity as the last in the region of San Francisco.

The most severe shock in all this list was that of Owen's Valley or Inyo, about 275 miles east-south-east of San Francisco, on March 26th, 1872. Its fault line was near the steep east border of the Sierra Nevada, and the surface rocks and soil were broken along a distance of forty miles from north to south, with displacement of the side adjoining the mountain range, as compared with the other side, from 5 or 10 to 25 feet of vertical uplift.

In the thirty-seven years from 1850 to 1886 inclusive, Holden's catalogue shows 254 noticeable earthquakes in San Francisco, or an average of seven yearly. During the same time no less than 514 other earthquakes, not noticed in San Francisco, were felt in other parts of the State.

Summing up the characteristics of the California earthquakes, Dutton writes:

"High intensities are not common. The lighter intensities are felt over considerable areas, which suggest great depth of focus. The seismographic traces show considerable length of period and well-marked separation between the short preliminary tremors and longer waves, which is indicative of considerable distance travelled by the vibrations between the centrum and the recording station. The deep foci, the long periods, the absence of small tremors, the considerable areas over which light vibrations are felt, are indicative of tectonic rather than volcanic origin."

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* A very interesting and detailed account of the Californian earthquake of 1906 is given by Professor T. W. E. David, of Sydney University, in the Sydney *Daily Telegraph* of December, who visited San Francisco shortly after the conflagration. His account closely agrees with that of the author.—Editor.

Two Principal Seismic Belts of the World.

About nine-tenths of all earthquakes occur along the two greatest and longest mountain belts of the world, one mainly encircling the Pacific Ocean, and the other stretching past the Mediterranean sea and far east through Asia.

From Cape Horn northwards through the western hemisphere towers the grand mountain belt of the Andes and the North American Cordilleras, the latter having their newest ranges on their west border, and both adjoining closely the Pacific coast. In Alaska this belt passes westerly, and its outermost south-western range forms the Alaska peninsula and Aleutian Islands. Continuing westerly and in general taking nearly the course of a great circle, the same broad and far prolonged belt of mountain systems comprises Kamtchatka, the Kurile Islands, Japan, Formosa, the Philippines, Borneo, and Celebes, on the north-western and western side of the Pacific Ocean. In total, this Pacific coastal orographic belt extends over an arc of about 240 degrees, or some 16,000 miles.

The second great series of mountain chains is a very complex belt passing from east to north-west and west, comprising New Guinea, the Sunda Islands and the Malay peninsula, Anam and Siam, the colossal Himalayan ranges, the Caucasus, Carpathians, Balkans, Alps, Apennines, Pyrenees, and Atlas mountains, extending quite across the eastern hemisphere.

Along these two lines, transverse to each other, one having an extent of two-thirds and the other of half of the earth's circumference, the great lateral pressures of the earth's crust, primarily due probably to the cooling and contraction of its interior, have been relieved during the latest geologic ages by plication, faults, and uplifts, producing these most massive and prolonged series of mountains.

Many earthquakes occur in connection with the eruptions of volcanoes, which are found in many parts of these complex mountainous belts; but other earthquakes, much exceeding the former in respect to numbers, energy, and immense extent of the areas shaken, are independent of volcanic action, being instead due to fracture and faulting of the rock-formations far from any active or recently extinct volcanoes. Shocks of the latter class are called tectonic, meaning that they are associated with processes of mountain-building and upheaval of continents. To this class the shocks (or *temblors*, if we use the Spanish word) of San Francisco and Valparaiso belong, and also nearly

all the great destructive earthquakes of which we have historical records.

The Valparaiso Earthquake.

About eight o'clock on Thursday evening, August 16th, not quite four months after the Californian outburst, an equally or more terrible earthquake killed probably 2,000 people in Valparaiso and an adjoining large area of Chile, and wrought a destruction of property, with the great fires following, that is conservatively estimated at some $200,000.000.

The first and most violent shock was followed by many less severe shocks during the subsequent days and weeks, showing conclusively that this was a great tectonic earthquake. The earth-waves or tremors and vibrations travelled with similar amazing speed as in the case of the Charleston and San Francisco shocks, and were recorded 5,000 miles away by the seismographs of the United States Weather Bureau in Washington, D.C., where the earth disturbance lasted several hours, ceasing about midnight.

Probably the Valparaiso shock originated in rock fracture and displacement on some principal fault plane cutting the land area in parallelism with the mountain ranges and the coast, but inside the shore line. That it was not, as with many earthquakes, beneath the sea, whether somewhat near to or remote from the shore, is indicated by the absence of any great sea wave, such as is raised by submarine shocks, sometimes rolling over the coast far above the highest tide level. This occasional accompaniment of violent earthquakes, most dreadful in its destruction of human lives, was absent from both these recent Californian and Chilian disasters.

Previous Seismic Records of Chile.

The west coast of South America has abounded with earthquakes, mostly of slight effects but rarely very destructive, ever since the earliest coming and settlements of Europeans; and geologists recognise evidences of the same history through long preceding periods.

In the tabulation by De Montessus de Ballore, comprising very extensive records of earthquakes throughout the world, and giving a grand total of 131,292 observed shocks, mostly belonging to the last fifty years, Central Chile, from Illapel to Concepcion, including the region of Valparaiso and Santiago, had in forty-four years, from 1836 to 1841 and from 1849 to

1886, a recorded number of 1,512 shocks, or an average of about thirty-five yearly. "It is the Chilian coast and Andes," remarks Dutton, "in which the seismicity of South America reaches its highest development."

Secular Movements of the Earth's Crust.

Darwin, in his *Geological Observations on South America*, noted proofs, in raised shore lines with recent marine shells, that a vast area of this Pacific coast, extending from Southern Patagonia to Lima, a distance of about 2,500 miles, had been lately much uplifted, the vertical measure of the movement varying from 85 to 1,300 feet. The maximum uplift observed was in the vicinity of Valparaiso, where, however, in the 220 years preceding 1834 the vertical upward movement had not exceeded nineteen feet; but during the relatively short time of seventeen years, from 1817 to 1834, it had amounted to ten feet and seemed still in progress. Only a part of that average uprise of more than half a foot yearly could be attributed to a violent earthquake which occurred in 1822, and the remainder had taken place at a very slow and imperceptible rate.

It may be thought that the whole uplift of the Chile coast was accompanied by faulting and slight earthquakes, as more than thirty perceptible shocks have been observed on an average yearly in that district. But it seems more probable that in some other regions, and therefore even to some degree in Chile, extensive secular uplifts or depressions of large areas, continuing through several or many centuries, have taken place by gentle and moderate flexure of the rock crust, without faulting, or at least without any large displacement, and perhaps without energetic earthquakes.

Such a gradual crustal movement appears to have elevated the area of the Glacial Lake Agassiz, during the recession of the ice-sheet at the end of the Glacial period, where now is the basin of the Red River and Lake Winnipeg. This area, 500 miles long or more from south to north, and measuring 50 to 150 miles or more in width, was differentially uplifted to a maximum vertical amount of probably about 500 feet in the geologically short time, estimated about 1,000 years, while the glacial lake existed; and the uplift was nearly or quite finished before the latest remnant of the ice-sheet on Central Canada was melted away, thereby reducing Lake Agassiz to its present representatives, lakes Winnipeg and Manitoba. The continuousness and the gradual and unbroken northward

ascent of the old beach ridges of Lake Agassiz show decisively that no faults having much displacement occur in the large part of the glacial lake area surveyed by the present writer in Minnesota, North Dakota, and Manitoba, amounting to more than 30,000 square miles.

Courage for Rebuilding.

After powerful faulting and earthquakes have brought rest from the long accumulating stress of the earth crust, it may be expected that many years will elapse before so great pressure or strain will be again developed as to repeat and continue the rock displacement and oscillation. So it is with well-founded perseverance that the people of these stricken cities, possessing the best harbours of the west side of the two continents of this western hemisphere, have set themselves to rebuild their fallen homes, factories, and marts of commerce. The scene gives us an increased appreciation of the grand capabilities of man's mind and heart and hand. What does it tell of a higher, overruling and creating Power?

Quick, generous, and large aid from their fellow men far and near came to the maimed and hungry sufferers of earthquake and fire. We are inspired with better hope and confidence for the development of all the noble and kindly qualities which exalt mankind. Have the shaking and fiery trials also any teaching of the highest values of life and death in their relation to the Supreme Giver?

When a destroying plague or tornado or earthquake comes, we may be tempted for a time to distrust the grand truth of the goodness and universal fatherhood of God; but the correlative ennobling truth of the universal brotherhood of men then shines forth most clearly. The mighty affliction awakens in every heart sympathy, a brotherly spirit, and sweet charity, the greatest of virtues. Yet I will not doubt the divine goodness. Soon or late, in the ordinary course of nature, not less than in its wildest catastrophe, everyone is called to say, with old Job, in highest faith of God's ultimate kind providence and care, "Though He slay me, yet will I trust in Him." Is death more to be dreaded, and less to be welcomed, knowing that "He giveth His beloved sleep," if the summons be sudden, to a multitude together, after the momentary pang of a great convulsion of Nature, than if it be slow and gentle, with long warning and more suffering, to each one alone?

There are good reasons for the rebuilding of these cities, and

they are being rebuilt on better foundations and with greater foresight and effort for durability and safety than before. Then if the terrifying tremor comes again, the brave citizens will be conscious that they have done their best and are in the path and place of duty. The earthquake is more likely to try the quality of these people again than if they should remove to many other parts of the world; but no region on all its surface, though long remaining unshaken, can be assured of complete immunity from this danger.

The thanks of the meeting were then moved by the Chairman for this interesting communication, and he invited discussion thereon.

Discussion.

Rev. A. Irving, D.Sc., congratulated the Institute on the valuable paper by Dr. Warren Upham, and thanked the author for putting forward so clearly the causal relation of earthquakes of the San Francisco and Valparaiso type to those tectonic forces which are operative as mountain-building agents, which of necessity continue more active in such comparatively young mountain ranges as those which mark the features of the Pacific seaboard of the dual American continent. The speaker confessed, however, to some feeling of regret that more recognition had not been given to previous literature bearing upon the subject. He referred more especially to the writings of his friend, Dr. Andrew C. Lawson, the Chairman of the Commission appointed by the Californian State authorities, after the San Francisco earthquakes in April last, to investigate the causes of that disaster. He held in his hand, and read quotations from, a most able paper by Professor Lawson, on "the Geomorphogeny of the Coast of North California," in which it was clearly shown, some twelve years ago, that the basin of the harbour of San Francisco was formed by a subsidence—a "sag-down," as engineers would say—of the crust in Quaternary and recent geological time, letting in the waters of the Pacific to fill the shallow basin (nowhere more than 250 feet in depth), submerging the lower portion of the valley of the Sacramento, and converting

the former river gorge into the present magnificent "Golden Gate." So clearly had the geotectonic structure of the region been worked out by Lawson, that the speaker had ventured in a public address (within a fortnight of the occurrence of the earthquake) to offer with some confidence what seemed to him—as a deduction from Dr. Lawson's paper—to be the true explanation of the earthquake, in the sudden relief of strain in the bed-rocks of the region, along a plane or planes of slip-faulting, which are generally found in the synclinal portions of all great flexures of the earth's crust.

In the interim "Report" of the Commission, which reached him three or four weeks later from Dr. Lawson, he had the satisfaction to find that the explanation he had suggested agreed with that put forward by the Commission as given in Dr. Upham's paper.

The speaker regretted that Dr. Upham had not been able to give more detailed information, at present, as to the nature of the crustal movements, which had operated with such disastrous results in the Valparaiso region; but he strongly suspected that further investigations might result in interpreting those upward movements mentioned by the author, as indicating "over-thrust" fault-planes due to the fact that the region in question is situated on the ridge of an anti-clinal fold. If that should turn out to be the case, the fact would probably account for the wider extension of the disastrous results there than in the San Francisco region.

Dr. Irving ventured to put before the Meeting an interesting problem, which had presented itself to his mind, as to a possible connection in time between the occurrence of the San Francisco earthquake and the great eruption of Vesuvius about a week before, with the abnormally extensive extrusion of lava from the depths at which molten or potentially-liquid rock-material exists.* The latitude of Vesuvius and of San Francisco being nearly the same, and approximately 40° N., a simple calculation gives us a rapidity of rotational movement from west to east along that zone of latitude of something like 700 miles per hour (about ten times greater than the velocity of the fastest express train) to represent the 1,000 miles per hour velocity of rotation of the outer rind of the earth in equatorial regions. The extrusion of lava at Vesuvius

* On this point reference may be made to the speaker's letters to *Nature* in May, 1905, vol. lxxii, pp. 8 and 79.

and the escape of vast quantities of super-heated water would tend to create a vacuum below the mountain; but that result would be prevented by the inflow of the surrounding molten or potentially-liquid material. Taking into account the vast eastward momentum (here pointed out) of the whole mass, dynamical considerations led us to believe that the inflow would be chiefly from the west of the Neapolitan area; and therefore the power of buoying up the crust would be diminished along a zone of latitude extending a good way in that direction round the globe. Such a disturbance of equilibrium would make itself especially manifest where the conditions of the crust caused local weakness and a tendency to subsidence, such as Dr. Lawson had shown to exist in the San Francisco region. He put this forward as a thesis for discussion, and would be glad if any better mathematician than himself could find a flaw in the argument.

[It might be noted that the great San Andreas line of fault shown on the map accompanying the paper, running nearly parallel to the Coast Range, was also shown on a very valuable map, which had been constructed by Professor Branner, of Sandford University, and was published in the Supplement to *The Times* on December 17th, 1906, showing how seismic intensity was centered in and around the San Francisco region as the result of the local instability of the crust.]

Professor H. LANGHORNE ORCHARD, M.A., B.Sc.—Although tectonic earthquakes may be said to be independent of volcanic action, yet there is a connection between earthquakes and volcanoes. Volcanoes form outlets for the accumulated and pent-up energy, thus moderating the violence of the outbreak. The volcano is like the safety-valve of a steam-engine. This explains the fact (referred to by the author) that earthquakes accompanied by volcanic action are less destructive than others.

With regard to the two great seismic belts (traced out in the paper), it is a relief to note that England is not in either of these belts, though apparently perilously near to the second. Probably we owe more than is generally supposed to the friendly vicinity of Iceland.

The great depth of rupture, in the case of the San Francisco earthquake, is remarkable, and the Investigation Commission are to be thanked for directing attention to the importance, in relation to geophysical science, of studying the question of depth.

I should like to ask Professor Hull what, in his view, is the general explanation of the circumstance that earthquake waves which are propagated through loose geological formations are more disastrous than those propagated through firm ones as stated by the author.

We shall concur with the learned author that these destructive visitations afford no argument against the goodness of God and His over-ruling power; and that it is death itself, not its method or mode, that claims our serious concern. Undoubtedly, the only sure basis for a rational fortitude in presence of death is that unlimited trust in God which was possessed by Job.

Professor LOGAN LOBLEY, F.G.S.—Besides being an interesting account, Dr. Warren Upham's paper contains some points of considerable scientific and seismic value. With its main contention that the two earthquakes were of tectonic and not of volcanic origin I am in entire agreement.

Such earthquakes are the result of forces originating pressures, strains and tensions which, when resistance is overcome produce, a sudden movement of the surface rocks. The whole of the Pacific coast of America is being elevated, and it is this that causes its frequent and sometimes disastrous earthquakes, as well as the volcanic activity which is also a conspicuous characteristic of this region. Thus both the earthquakes and the volcanic eruptions have the same ultimate cause and so are, in a sense, related.

I cannot, however, agree with the author that these forces are produced by the shrinkage of the globe from cooling, for I have shown, I think, conclusively, that there has been no appreciable diminution of the mean radius of the globe since Cambrian times. These great forces producing elevations and subsidences, rock foldings and earthquakes, and giving the conditions allowing volcanic action are, I believe, due to regional expansions and contractions.

Neither can I favour the suggestion that there was a connection between either of these seismic movements and an eruption of Vesuvius ejecting an insignificant amount of material 6,000 miles distant.

We certainly owe our thanks to Dr. Warren Upham for presenting us with his concise account of two memorable catastrophes.

Col. T. H. HENDLEY, C.I.E.—Previous speakers, as well as the writer of the paper, have referred to the rapidity of the transmission of the earth tremors. Under certain circumstances the

motion may be seen, as for example, when, one night in the hot season, I was reading in bed in a large room in India, of which the floor was a smooth surface of white marble cement. A smart earthquake shock occurred, and my bed was actually raised, but the solid floor, nearly six feet thick, heaved up like the sea when a wave passes over it, without being broken.

Dr. Upham observes that the intensity varied greatly over the large disturbed area. Even in small districts such variation is noticed.

In Mymensingh, in Eastern Bengal, I saw the ruins of the English church, which was represented by a pile of stones. Houses close by were also destroyed, yet within a few yards of them stood others which were intact.

The curious effects of earthquakes were peculiarly illustrated in Bengal, where I would mention the case of a temple spire near the Dacca Racecourse. The upper part of the heavy solid shaft had been separated by a horizontal fracture from the lower portion, and had been turned round, without leaving the perpendicular, so as to rest at an angle upon its base. Many other peculiar effects are often noticed, such as distortions of rails, extraordinary alterations in positions of the parts of walls, and so on.

As to the moral and mental effects glanced at by Dr. Upham, the Nawab of Murshidabad, being an invalid, was carried out of his palace by his servants when the great Bengal earthquake took place, and although he himself escaped, the severe injury and death to one of his men so affected him that at the time of my visit he would never remain long under a masonry roof, but received his friends in a small thatched building. Similar instances are very common.

As regards the great destruction attending sea waves which are raised by submarine shocks, we might instance the enormous loss of life some years ago, amounting to perhaps a quarter of a million persons, in the Bakarganj disaster in the Sundarbans in the Ganges Delta. Even an ordinary rise of a foot or two at flood times in the monsoon season is dangerous. Once when I was going in a steamer towards Barisal the capital of that district, I saw cattle on a village site standing with their heads just out of the water, and villagers on the house roofs, all waiting patiently for the flood to subside. It is easy under such conditions to realise

what a sudden upheaval and a great sea wave may do. When the great disaster of which I have spoken happened, many feeble persons escaped only because they were not strong enough to get away in boats or retreat to higher ground and were left in the tree tops.

There are many other incidental questions which are suggested in the interesting paper to which we have listened, but I would only ask one question, and that is, whether any observations had been made as to the effect of the San Francisco earthquake on the barometer? When the Krakatoa catastrophe occurred the meteorograph at Jeypore, which was under my care, indicated that a wave passed round the world two or three times.

Professor HULL, F.R.S. (Secretary)—I wish, in seconding the resolution, to be allowed to make a few remarks on the geological aspects of this valuable communication.

First—I may observe that this earthquake shock of 1906—though lamentably disastrous to life and property—if it had taken place two centuries ago, would have been passed over as a matter of indifference to the outer world.* If there were any inhabitants at all, they would have consisted of a few Indians, to whom the shock would have brought no great terror or loss. The disasters which followed the earthshock of last year were due to the existence of a great city with all the appliances of modern civilisation.

Second—The vertical displacement of the ground and rocks on either side of the St. Andreas fault, or fissure, was trifling when compared with that which has taken place in very recent geological times in other parts of the world. For instance, the great fault crossing the Grindelwald in Switzerland, which I have myself seen, along which the granitoid rocks are upheaved several thousands of feet, is as recent as the Middle Tertiary or Pliocene period. That of the Arabah Valley in Arabia Petræa, which has been traced for about 400 miles from the Gulf of Akabah into Syria, has an uplift of about 4,000 feet where it passes along the eastern margin of the Dead Sea and is of the same age; and, to come nearer home, the fault which bounds the great plain of Cheshire on the east side at the foot of Mowcop, in North Staffordshire, has a displacement of about 3,000 feet. But what is remarkable is, that the two former

* San Francisco was not occupied by Europeans till the year 1776.

dislocations are geologically of very recent date; and any displacements of the strata since the Pliocene period are comparatively insignificant, and would be little thought of were it not for the spread of civilised inhabitants and their works.

Third—The third point I would like to refer to is the wonderful accuracy, due to astronomical methods, by which the rate of transmission through the earth's crust of the shock (or "wave") has now been attained. Dr. Warren Upham's remarks on this point are of great interest, where he shows the rate as transmitted through an arc of a Great Circle,* as compared with that of its chord. In proportion to the distance from the focus of disturbance, the relative lengths increase till the diameter of the earth is reached.

The respective rates are shown on the board, as given by Professor C. F. Marvin, and seem to bear out his conclusion that the density of the interior mass increases with the depth from the surface. This is one of the physical problems on which opinions differ, as the effect of the increase of temperature due to depth is to diminish density. Which of these agents *ultimately* prevails is at present unknown. These observations have a strong bearing on the question of the state of the earth's matter below the "crust." The great uplifts of the Middle Tertiary period appear to have given place to gentle and moderate flexures of the rock "crust" in more recent times, as stated by the author. I regret very much I cannot give a satisfactory reply to Prof. Orchard's question, except that loose material gives way more readily than solid when shaken,

* *i.e.*, a circle, or arc of one, of which the centre passes through the centre of the earth.