deeper, the thermal manifestations change from boiling springs to warm springs, the seisms become fewer but perhaps stronger, the area over which these are perceived becomes larger, probably geodetic level and creep change becomes smaller and more widespread, and in large-scale sequences across continents the geologic formations and deformations become older.

Examples of such gradation are the change cited from seismic north to volcanic south in western South America; from seismic south to volcanic north in California; from volcanic Aleutian Islands to seismic Mount McKinley; from volcanic Java to seismic Sumatra; from volcanic Tertiary to seismic modern in most of the volcano districts of the world; and across the United States from east to west from deep volcanic and deep seismic at the east to shallow or active volcanic and seismic at the Pacific coast, with much higher thermal gradients. Across the United States also we pass in general from older to younger deformations.

It is precisely because of such gradations and because of isostatic adjustment as conditioning process that it seems reasonable to consider heat and magma as conditioning the causes of big earthquakes. This would be through intrusive flow, gas expansion, change of volume by water acquisition or crystallization, deep-seated engulfment accompanying "stoping," thermal effects on the environing rocks and every other possible magmatic motion conditioning pressure, *except* volcanic eruption, subterranean explosion or "collapsing steam." No volcanologist would seriously consider any of these last as having any bearing on the earthquake problem whatever.

T. A. JAGGAR

HAWAIIAN VOLCANO OBSERVATORY

NEW YORK CITY AS A FIELD FOR EARTHQUAKE STUDY[1]

THE modern seismograph has been developed during the last thirty-five years. Within this period, the study of earthquakes has passed from a more or less speculative phase to a quantitative study of the phenomenon. In 1912, two 450 kilogram components of a Mainka seismograph were installed in the American Museum of Natural History, New York. Numerous earthquakes have been recorded on these instruments during the past thirteen years, but the greater number of the disturbances have been distant quakes which originated thousands of miles from New York. Nearby quakes have also been recorded, but most of them have been so faint that they were not felt by citizens of the city. Those of February 10, 1914, and February 28, 1925, which originated in eastern Canada, were felt, however, by a large number of the inhabitants of New York City and the northeastern United States. Although the metropolis is considered to be immune from earthquakes by a large number of scientists and laymen, the above brief résumé indicates that it is advantageous to have seismograph stations in New York City. There are two stations at present, one at Fordham University, and the other at the American Museum of Natural History.

In an earthquake record, or seismogram, we are concerned with the mechanical effects propagated from the region in which the earthquake occurred. Astronomical and seismological theory demand a solid earth with more or less uniform physical properties for the propagation of the earth waves. The wave effects on a seismogram of a distant earthquake may persist for several hours, although at the point of origin they may last for only a few seconds. On such a record three principal phases of types of waves, corresponding to the longitudinal, transverse and long waves, may be noted. The first two types travel by the shorter way, through the earth, and the third type around the earth's surface. The initial portion of the record will be recognized as the longitudinal waves or first preliminary tremors. These waves are of short period, small amplitude and tend to die down preceding the arrival of the transverse waves of second preliminary tremors, which are of longer period, quite irregular and of greater amplitude. The relative duration of these first two types of waves on the record is dependent upon the distance, the greater the distance the longer the time involved. The third type, or long waves, have a much greater amplitude and assume a strongly periodic and sinusoidal character. For distances greater than two thousand kilometers the first phase is indicated by a few waves with a period of about twenty seconds which gradually increase in amplitude. This phase is followed by a rapid development of extremely smooth waves of rather shorter period which reach a maximum amplitude, subside and pass through a succession of maxima before merging into the tail portion of the earthquake.

In nearby earthquakes where the distance is less than one thousand kilometers the preliminary waves are very much abbreviated and not well resolved into the two distinct phases.

The curved surface of the earth introduces many diffraction effects into the seismogram. These features start immediately after the P and S waves or first preliminary and second preliminary tremors begin, and are referred to as PR_1, SR_1, etc. With a whole series of diffraction effects in addition to the P and S features the earthquake record becomes com-

[1] Paper presented at Kansas City, December 29, 1925, as part of a symposium on earthquakes.

plex and difficult to read. Seismograms are not alike since no two earthquakes of like intensity originate in the same place.

Greatly improved time curves and tables giving the time of arrival of the first preliminary and second preliminary waves as functions of the epicentral distance were developed by Zeissig and later modified by Klotz. The Klotz tables, which were published by the Dominion Observatory at Ottawa, 1916, give the epicentral distance for the time interval between the arrival of the P and S, PR_1 and SR_1 waves. They are extensively used at the seismological stations in the United States and Canada for determining the distance from a station to the point of origin of an earthquake.

The location and the distribution of earthquakes reveal the present zones of maximum change in the strained lithosphere or solid part of the earth. Reeds' seismic map of the world, published in *Natural History,* New York, Vol. XXIII, p. 466, 1923, which gives the location of 276 major earthquakes for the period 1899 to 1911, shows the close association of recent earthquakes to the belts of sedimentation, dominant folding and mountain uplift during the Cenozoic era. The earth's crust trembles predominantly along two narrow zones which lie along two great circles of the earth known as the Alpine-Caucasian-Himalayan circle and the circum-Pacific circle. Modern seismographs now record the sudden major movements of the earth's crust quite independently of whether they occur on land or at sea.

A thousand earthquakes have been noted in eastern North America since the settlement of the country by Europeans. Most of these quakes were slight, but a few were violent, such as those of February 5, 1663, and February 28, 1925, in eastern Quebec Province, Canada. They occurred singly and in groups, the more prominent aggregates being 1730–1740 and 1860–1870. From July, 1924, to July, 1925, sixteen earthquakes were noted in the United States and southern Canada. Of this number, twelve were developed east of the Great Lakes. The St. Lawrence, the Montana and the Santa Barbara quakes were the most violent. The Alberta and Montana temblors were interesting in that they were the first recorded for those areas. All except the very smallest of these disturbances were recorded on the seismograph at the American Museum of Natural History.

In a local study of earthquakes it is well to note the character of the rocks, their periods of deformation, whether past or present, and whether the structure is homogeneous or broken by numerous faults. In regions which are being uplifted, faults are important in that most earthquakes are produced by sudden displacements along them.

In the metropolitan district of New York the rocks belong to five distinct geologic ages and are disposed in belts which trend in a northeast-southwest direction. The oldest constitute the crystalline basal complex and extend to unknown depths. They are regarded by local geologists to be of pre-Cambrian age. Old fault lines with different periods of development have been observed in these rocks where detailed geological studies have been made.

In northeastern New Jersey a younger series of rocks of Triassic age, which are referred to as the Newark series, occupy the downfaulted earth block between the Reading prong of crystalline rocks on the northwest and the Manhattan Island prong on the southeast. They consist of reddish conglomerates, sandstones and shales and some four flows of intruded black basaltic rocks—altogether they are about three and one half miles in thickness. The northwestern margin of the Newark basin is bounded by a great fault, as noted by the sheer face of the Ramapo Mountains in the vicinity of Suffern, New York; the structure of the region suggests that the southeastern margin of this basin is marked in the same way, but it is not definitely known, for it is concealed by the bed of the Hudson River. Numerous smaller faults also occur within the northwesternly dipping beds of the Newark series.

Faulted and tilted Triassic rocks also occur in two areas to the northeast of New York City. One of these extends northward from New Haven, Connecticut, to Hartford, and up the Connecticut River valley to the northern boundary of the state of Massachusetts. The graben structure of this district, with its faulted margins, and its dislocated blocks of "red beds" and volcanic rocks, constitute features that are not only well known from a geologic point of view, but according to historical accounts the region has been frequented by numerous small earthquakes.

The other area extends southwestward from Nova Scotia and the Bay of Fundy across the floor of the Gulf of Maine towards Boston, Massachusetts. The Triassic rocks of Nova Scotia have been known for some time, but it is only recently that the probability of the floor of the Gulf of Maine as a faulted area has been brought to our attention by Professor D. W. Johnson. These supposed faults afford a possible source for the rather frequent minor earthquakes that have occurred recently, and in historical times, at Boston, Lowell, Newburyport and other points along the New England coast.

Rocks younger in age than the Triassic occur on the seaward side of the crystalline belt in New Jersey and Long Island. They consist primarily of an alternating series of sand and clay strata. They conceal the older rocks and, so far as known, are not broken by lines of dislocation, although they have been tilted seaward by repeated uplifts of the land in Cenozoic times.

The last and one of the most interesting groups of rocks with which we have to deal are the glacial drift deposits which were left on the surface of the ground throughout New England, New York and to the westward, as the ice of the successive Pleistocene glaciations retreated northward from Staten Island and Long Island. These deposits consist of unsorted sands, gravels, boulders and in certain basins of beds of clay. They vary in thickness from zero to two hundred feet.

Following the retreat of the ice of the last glaciation northward the entire landscape of eastern North America, including the old rocks and the early postglacial lacustrine and fluvatile sediments were differentially uplifted. As noted by Leverett, Taylor, Goldthwait, Fairchild and others, the uplift varies from zero elevation, in the vicinity of Asbury Park, New Jersey, to one thousand feet about one hundred miles north of Quebec, Canada. Recent studies by the writer on the varve clays and the glacial lakes in the vicinity of New York City have confirmed this upwarping of the land surface in Postglacial time, and determined the average rate of uplift to be approximately two and one quarter feet per mile.

This differential uplift of the land, following the melting of the Quebec ice cap, suggests very strongly that the ice mass during its maximum extent was not only very thick, but that it was of great weight, and that it affected the isostatic balance of eastern North America during its advance and following its retreat. The thickness of the ice near its margin could not have been more than a few thousand feet, perhaps half a mile, which would mean a weight of two billion tons per square mile. The ice must have reached its greatest thickness in the region where the post-glacial elevation has been greatest, namely: to the north of Quebec. There the ice must have been two miles thick with a weight of eight and a half billion tons resting on each square mile. It is reasonable to suppose that post-glacial changes in elevation could not have taken place without developing stresses and strains in the rock mass, and it is natural to infer, from our present knowledge of seismology, that periodic relief from these causes was found by sudden adjustments along fault lines producing earthquakes.

Professor J. B. Woodworth, in discussing the "Post-Glacial Faults of Eastern New York" in 1907, calls attention to twelve districts in eastern North America where glaciated surfaces on crystalline rocks show numerous small step faults with individual displacements of from one to seven inches. The areas noted are Troy, Defreestville, Rensselaer, Pumpkin Hollow, Copake, Long Pond and Hyde Park, New York; Attleboro, Massachusetts; Kilburn Crag, New Hampshire; and St. Johns, New Brunswick; and two areas in southern Quebec Province, Canada. In Troy, New York, instances are cited by Woodworth where buildings situated over these faults have cracked and displaced walls.

The retreat of the ice of the last glaciation has been so recent, geologically speaking, that the writer is of the opinion that the post-glacial uplift of the land has not yet ended, and that the numerous slight earthquakes which have been recorded in eastern North America during the last four centuries, together with those which are now being recorded on seismographs, are indications that the isostatic balance of this region has not yet been reached, and that New York and other cities in eastern United States and Canada are still subject to these local quakes. The more prominent of these recent earthquakes occurred as follows:

On February 10, 1914, an earthquake was felt in numerous places along the St. Lawrence River, throughout eastern New York state and as far south as Philadelphia. According to the late Otto Klotz, of the Dominion Observatory, the epicenter of this earthquake was 120 kilometers or seventy-five miles northeast of Ottawa, Canada, and the estimated depth of its hypocenter eighty-three kilometers or fifty-three miles below the surface of the earth. This earthquake was recorded on the seismograph at the American Museum of Natural History.

On September 30, 1924, a slight earthquake which was felt in the Aroostook Valley, Maine, was recorded on the seismograph at the American Museum from 3:57 A. M. to 4:00 A. M. eastern standard time. This was followed by other quakes in New England and Quebec on January 7, February 28, March 7, March 20, April 24 and 27, and May 12, 1925. Of these the St. Lawrence earthquake of February 28, 1925, at 9h 19m 20s P. M. eastern standard time, was the most severe. It was felt over eastern Canada and the New England states, and as far south as Virginia, and as far west as the Mississippi River. According to Professor E. A. Hodgson, in an article published in the *Bulletin* of the Seismological Society of America, Vol. 15, 1925, the damage done by this quake was confined to a narrow belt covering both sides of the St. Lawrence River. The epicenter was located in latitude 47° 45′ N. and longitude 70° 30′ W., that is, about half way between Murray Bay and Chicoutimi, Quebec Province, Canada.

In conclusion, it may be stated that the seismographs indicate that no perceptible earth movements have taken place along the old fault lines in the crystalline rocks underlying New York City within the past decade nor in the faulted Triassic area to the west in New Jersey. There are some indications that slight disturbances have arisen in the Triassic belts of the Connecticut Valley and the Gulf of Maine, but these may be associated with the post-glacial uplift of eastern North America which is evidently still in force, if we may judge from the fact that the larger of the nearby earthquakes have occurred in those areas where this uplift has been greatest, namely, in Quebec Province, Canada. As New York City is situated near the southern margin of the territory covered by the last ice sheet and as the post-glacial changes in elevation have been comparatively slight there, no earthquakes have arisen within the city limits, nor are they likely to occur. Tremors, generated by quakes arising in New England and to the northward may be felt, however, within the city, particularly in those portions built on made land or unconsolidated sediments. It may be said, therefore, that the New York City district is for the most part an aseismic area and offers an excellent field for the instrumental study of distant and nearby earthquakes.

CHESTER A. REEDS

AMERICAN MUSEUM OF NATURAL HISTORY

WILLIAM E. SAFFORD

DEATH has recently taken from the United States Department of Agriculture one of its most brilliant men, whose place in the agricultural world will be extremely hard to fill.

Dr. William E. Safford, for many years an expert botanist in the Bureau of Plant Industry, died in Washington, D. C., in the latter part of January after an illness of over a year, which kept him confined closely to his room.

During all the months he was ill Dr. Safford worked regularly on two books which he wanted to finish and leave as an appropriate ending to his life labors. I understand the MSS was practically completed before he passed away.

Dr. Safford was one of the most genial, wide-awake men it has ever been my good fortune to know. He was interested in everything. A musician; an artist; a world-known writer on plants and agricultural topics of every kind; a wonderful linguist; frank and boyish in his manner; a friend of every one and every one his friend; a loving husband and parent: this is the man we all knew and loved. He was born in Chillicothe, Ohio, in 1859 and graduated from Annapolis Naval Academy in 1880 with high honors. The education given a naval officer at Annapolis is conceded to be the most thorough of any educational establishment in this country, along with West Point, but Safford was not satisfied. In 1883 he took post-graduate studies in botany and zoology at Yale and later in 1885 marine zoology at Harvard. In 1920 he was given his degree of Ph.D. at George Washington University at Washington.

While in the navy he was always deeply interested in scientific botany and marine zoology. He was probably the foremost expert on the seed foods and food plants of early pre-Columbian inhabitants of this continent and contributed many important bulletins and papers on these subjects. Mr. Safford was a prolific writer and has left a large list of publications on many scientific subjects as a record of his tremendous industry.

While still in the navy he was for two years naval governor of the Island of Guam and wrote several interesting books on the people and plants of the little known island.

He had a remarkable command of languages, being frequently called upon by the state and other government departments at Washington to help entertain distinguished foreign guests. He spoke with great fluency several of the tongues of South American countries.

In his home life Dr. Safford was most happy. He idolized his wife and two fine children, a boy and a girl, whom he left to mourn his loss.

He will be sadly missed in social and scientific circles of the National Capital.

At the time of his death Dr. Safford was economic botanist in the Bureau of Plant Industry in the United States Department of Agriculture—a position which he had held for almost twenty years with distinguished success.

It is a most unfortunate fact that the farmers and stockmen of this country know so little of the important work done by such scientists as Mr. Safford and his fellow worker in the department, Charles V. Piper, recently deceased. These two men devoted almost their whole lives to the study and development of pasturage and range plants and general agricultural forage crops in the United States. It is a great pity that the scientfiic work of this kind which has been done by men such as Safford and Piper is generally carried on so quietly and with so little blowing of trumpets as to be almost unnoticed by the everyday world.

This, however, seems to be the fate of the scientific investigator and student. The agricultural and pastoral interests of this country owe much to Mr. Safford for his work in their behalf. May his memory ever be kept green by those who like myself have profited greatly through knowing him.

WILL C. BARNES

FOREST SERVICE,
WASHINGTON, D. C.