

ART. II.—*The California Earthquake of 1906*; * by G. K. GILBERT.

THREE days after the California earthquake of April 18, 1906, Governor Pardee appointed a commission for its scientific investigation. No funds were at his disposal to defray the expenses, but provision was made later by the Carnegie Institution, and the Institution is publishing the reports. Volume I, in two parts with atlas, has recently appeared, and a second volume is to follow.

Volume I is by Andrew C. Lawson, chairman of the commission, and includes contributions from a large number of collaborators. After an introductory account of the geology and morphology of the Coast Ranges, it treats at length of the physiographic features and physical changes associated with the earthquake, of the distribution of intensity, and of the directions of vibratory motion. The marine phenomena, the composition of the main shock, the sequence of after shocks, and various minor topics are presented, and account is given of earlier severe earthquakes in the same region.

The earthquake was of the tectonic class, and was occasioned by a slipping on the plane of an old fault. The fault outcrops at the surface, and there was a visible displacement of considerable amount. The line of outcrop trends NW.-SE., and the fault plane is vertical. There was, however, very little vertical displacement, the differential movement being almost wholly horizontal. The country adjacent to the fault on the SW. side moved bodily toward the NW., and the country on the NE. side moved toward the SE. The changes did not tend to increase the height of a mountain or the depth of a valley but merely to distort the land horizontally. The amount of displacement was measured in two ways, (1) by observation of the dislocation of roads, fences, etc., traversed by the fault, (2) by the remeasurement of a net of triangulation previously made by the Coast Survey. Fences and roads were usually offset from 8 to 15 feet, and the results from triangulation showed relative dislocation of about the same amount for

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points near the fault line. For points at greater distance the changes were less. The discussion of the data, by J. F. Hayford and A. L. Baldwin, led to the conclusion that the absolute movement was greater west of the fault than east of it, and in both directions diminished with distance from the fault, the diminution being most rapid in the immediate vicinity of the fault.

This earthquake is practically unique, among the small group that have been broadly studied, in that the stress couple to which the fault may be referred lay in the horizontal plane. The main associated distortions were distortions in ground plan, with little vertical complication. They were, therefore, exceptionally adapted for measurement by the method of triangulation, and the results actually obtained are more systematic than any previous results of the same character. It is, therefore, peculiarly unfortunate that they were qualified by a lack of chronologic unity in the trigonometric surveys preceding the fault, which were strung along through several decades. This fact made it impossible to discriminate between deformation at the time of rupture and progressive deformation during accumulation of strain before rupture; and if progressive deformation took place before rupture, the precision of the adjusted triangulation was thereby impaired. Nevertheless the results invite the careful attention of geophysicists. To the reviewer the distribution of dislocation, and especially the existence close to the fault, on each side, of a belt of maximum distortion, seems clearly not that which would obtain if the fault passed completely through a solid crust to a liquid substratum. And it appears also that, on the assumption of continuous solidity from the surface downward, the geodetic results might yield to adequate analytic treatment a conception of the order of magnitude of the vertical distance to which the fault penetrated.

The surface outcrop of the fault was definitely traced from San Juan to Point Arena, a distance of 190 miles. At Point Arena it passes under the sea, and there is doubt as to its further course. A fault made at the same time on a more northerly part of the coast may be its continuation, after inflection, or may be on an independent line; but in either case the total length of dislocation was about 270 miles.

At all points the fault follows a peculiar topographic feature to which the name *San Andreas rift* was given; but the rift is more extensive than the fault of 1906, having been traced to the Salton basin, several hundred miles southeast of San Juan. In its larger expression the rift is a trough, a trough coinciding in general trend with the Coast Ranges, but crossing various mountain ridges obliquely, or even following their crests.

In detail it comprises many small ridges and hollows, approximately parallel but otherwise irregularly disposed, and evidently caused by splintery dislocation. Streams zigzag more or less about the ridges, and the hollows contain many small ponds and marshes. There are reports of long cracks which appeared in different parts of the rift in connection with various earthquakes of the last century, and it is inferred that each of these cracks was the surface expression of a fault-slip similar to that of 1906. It is further inferred that the rift as a whole marks the outcrop of a long fault or fault zone, separating two crustal tracts which are slowly moving past one another, with gradual accumulation of strain and stress, and occasional relief by local slipping when the stress at some point overpowers the adhesion on the fault plane. The physiography of the rift is illustrated by numerous excellent photographs, and by a local contour map by F. E. Matthes. Although the rift has been mentioned in various writings of earlier date, its description in this volume practically adds a type of surface configuration to physiographic science.

In the discussion of the intensity of the shock, a distinction is recognized between the elastic wave propagated from the origin through the crust, with gradually diminishing magnitude, and the phenomena of emergence, conditioned by the nature of the surface formation. The intensity observed at the surface, and expressed chiefly by damage to buildings and other structures, is called "apparent intensity," and this only is mapped. The general map shows a long narrow belt of high intensity, following the fault, with peninsulas and outlying islands where destructive effect was enhanced by the presence of incoherent formations; but this elongation is less characteristic of the lines limiting the areas of low intensity. The outer line, touching the most remote points of sensible tremor, traverses southern Oregon, central Nevada and southern California. In view of the ideas recently advanced by W. H. Hobbs, there is a careful review of the relation of local intensity to the known major faults of the region, about forty in number. In three cases it was thought possible that some portion of the movement of dislocation was diverted from the main (San Andreas) fault to the planes of intersecting faults. A special intensity map of San Francisco, by H. O. Wood, shows with great detail the grades of violence; and its comparison with a geologic map brings out forcibly the intimate relation between effective intensity and the underlying formation.

The subject is further elucidated by the report of an experimental study by F. J. Rogers. By mechanical arrangements similar to those employed by the Japanese commission in investigating the principles of earthquake-proof construction, har-

monic horizontal motion was given to an open box containing some loose material such as sand. A block resting on and anchored to the upper part of the sand, so as to share its motion, was found not to have harmonic motion, but motion of a distinct type which varied with the conditions of the experiment. Under certain conditions the amplitude of its motion was greater than that of the motion of the box, and its maximum acceleration—the factor corresponding to earthquake intensity—very much greater. These novel experiments are not only valuable in their immediate results, but of signal importance as indicating a line of study which should develop a complete theory of the phenomena of the emergence of earthquake waves.

The marine phenomena were in accord with the terrestrial in that they indicated no bodily movements of the ground except in a horizontal sense. Vessels at sea experienced a shock; there were boilings of water near the shore; a small seiche was started in San Francisco bay; a wave several feet high washed the east shore of Tomales bay, a narrow sheet of water traversed by the fault; but there was no great sea wave such as accompany vertical dislocations of the ocean bed.

The main shock, which was of about one minute duration, was reported by many observers as consisting of two parts, or having two maxima, but by others as continuous. Considering the improbability that movement was synchronous and similar over the entire plane of rupture, it is to be assumed that the vibration had different characters at different places, but the observations are not discussed with reference to geographic distribution. There are many records of preceding or accompanying sounds, all of low pitch. The after shocks were of normal character, diminishing with time in frequency and average strength, and continuing for at least ten months. The report enumerates more than 100 in the first 24 hours; about 300 in the first month; and for succeeding months, 71, 24, 44, 28, 14, 11, 13, 15, 21, 2, 3, 1, 2. The record is recognized as fragmentary, and the actual number of sensible shocks was probably much larger. There was somewhat voluminous testimony to the occurrence of visible undulations of the surface of the ground, the speed of which was much slower than that of the elastic waves in rock.

Cracks opened in many places near the fault; from several of these were large temporary discharges of water or of water and sand; the circulation of underground water was seriously and permanently deranged, springs being destroyed, created or changed in volume; landslides and earthflows were precipitated in great number. Alluvial lands slumped toward stream channels, and soft ground was in some localities left with a wavy surface.

The volume closes without discussing the subject of future earthquakes in the San Francisco region, but furnishes material pertinent to that discussion by publishing accounts of the earthquakes of 1868, 1865 and 1857. The fault in 1857 was on the southern part of the San Andreas rift, and the fault in 1865 may have been on the same rift near the southern end of the fault of 1906. The fault in 1868 was on a parallel rift east of the southern arm of San Francisco bay. In each case the distribution of intensity in San Francisco was substantially the same as in 1906, the character of the ground having more influence than the direction of the origin.

The second and closing volume of the report will be by H. F. Reid, and will treat of the theory of the seismogram.