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INTERPRETATION OF THE CALIFORNIAN EARTHQUAKE OF 1906.

[Quart. Journ. Geol. Soc., vol. lxv, 1909, pp. 1–16.]

[*From the* QUARTERLY JOURNAL *of the* GEOLOGICAL SOCIETY *for February* 1909, Vol. lxv.]

The GEOLOGICAL INTERPRETATION *of the* EARTH - MOVEMENTS *associated with the* CALIFORNIAN EARTHQUAKE *of April 18th, 1906.* By RICHARD DIXON OLDHAM, F.G.S.

THE Californian earthquake of 1906 was accompanied by very considerable displacements of the ground along a great fault-line, which has been traced for a distance of about 200 miles from its southern extremity to the point where it finally passes out under the sea. As several stations of the principal triangulation lay within the disturbed area, the Government of the United States decided to repeat the observations over this area, and determine with accuracy the present positions of the points previously fixed. The result of this work has been issued, with most commendable promptness, as an Appendix [1] to the Report of the Coast & Geodetic Survey for 1907, and the results seem of such importance, from the light thrown on the nature of the earth-movements which gave rise to this earthquake, that I have thought it desirable to make a detailed study of them from the geological point of view.

The area covered by the observations is not co-extensive with, but covers the most important part of, the seismic area; it extends from near Monterey, in the south, to Point Arena, in the north, and within this area all the points fixed by the triangulation which was carried out at various times between 1851 and 1899 were again fixed after the earthquake of 1906.

When the results came to be worked out, it was found that wherever triangulation of earlier date than about 1868 was connected up with triangulation of later date, the positions of the

[1] 'The Earth-Movements in the Californian Earthquake of 1906' by John F. Hayford, Inspector of Geodetic Work, & A. L. Baldwin, Computer, Coast & Geodetic Survey. Washington, 1908. [Reprinted in the Report of the State Earthquake Investigation Commission. Carnegie Institution, Washington, 1908.]

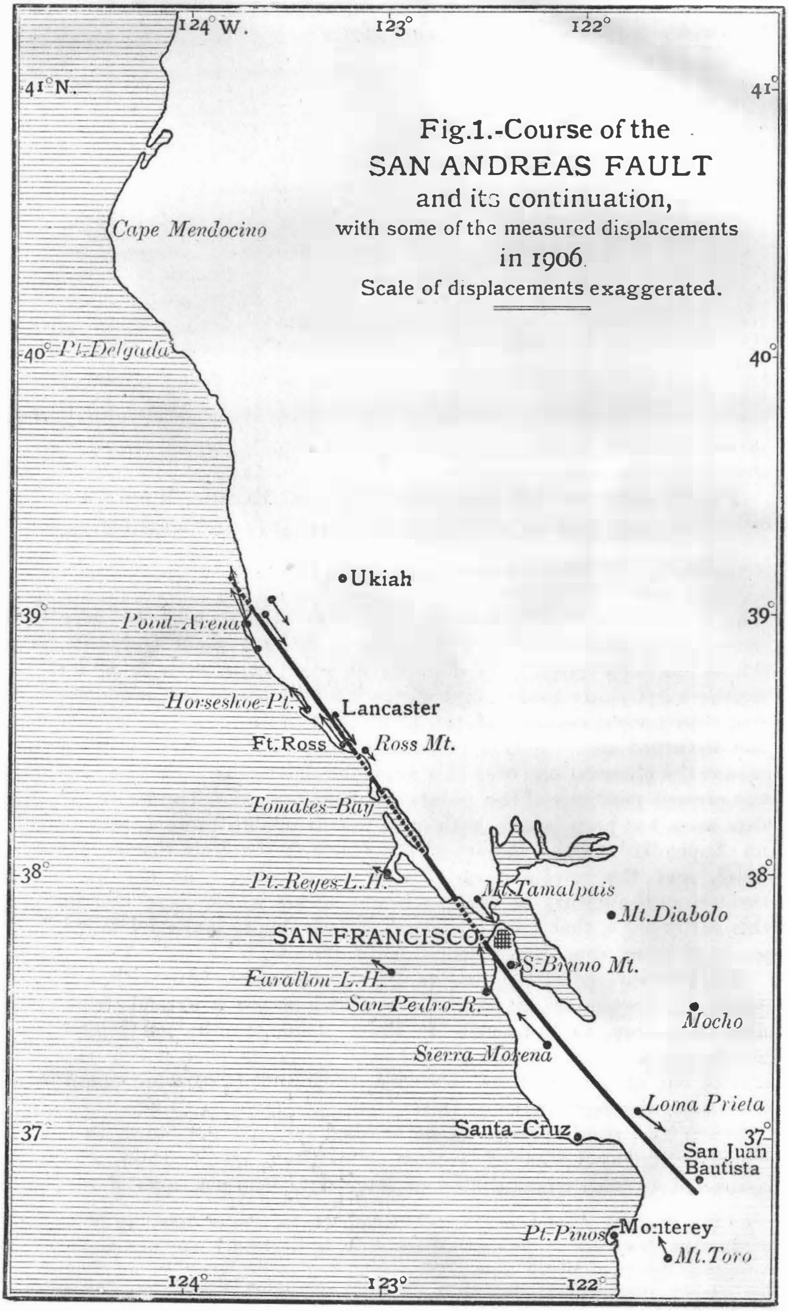


Fig.1.-Course of the
SAN ANDREAS FAULT
and its continuation,
with some of the measured displacements
in 1906.
Scale of displacements exaggerated.
124° W.
123°
122°
41° N.
41°
40°
39°
38°
37°
124°
123°
122°
Cape Mendocino
Pt. Delgada
Ukiah
Point Arena
Horseshoe Pt.
Lancaster
Ft. Ross
Ross Mt.
Tomales Bay
Pt. Reyes L.H.
Mt. Tamalpais
Mt. Diabolo
SAN FRANCISCO
S. Bruno Mt.
Farallon L.H.
San Pedro R.
Mocho
Sierra Morena
Loma Prieta
Santa Cruz
San Juan
Bautista
Pt. Pinos
Monterey
Mt. Toro

connecting points did not agree. Originally the differences were adjusted as errors of observations, but in Messrs. Hayford & Baldwin's report the more reasonable conclusion is adopted that the discrepancies are to be attributed to displacements connected with[1] the earthquake of 1868.

As a consequence of this latest elaborate discussion of the data, the numerous stations dealt with fall into three classes: first, those of which the shiftings in 1868 and in 1906 are both known and can be separated from each other; secondly, those in which the latter but not the former are determinable; and thirdly, those in which the total displacement connected with the earthquakes of 1868 and 1906 is known, but not how much was due to each separately.

In the Report the displacement of several stations in the third class is split up, that produced in 1868 being inferred from the known displacements of other stations in the same region; the method is of doubtful validity, and I have thought it safer to exclude the inferred displacements from consideration.[2] With this omission, the data available for discussion are given in the tabular statement appended to this paper (p. 15), in which the stations are re-arranged, from the original list, in their order of occurrence along the fault-line from south to north. The displacements attributed to 1868, and the total displacements, where those of 1906 were not separately determined by direct observation, are also given, but will only be referred to incidentally, attention being devoted primarily to the movements of 1906.

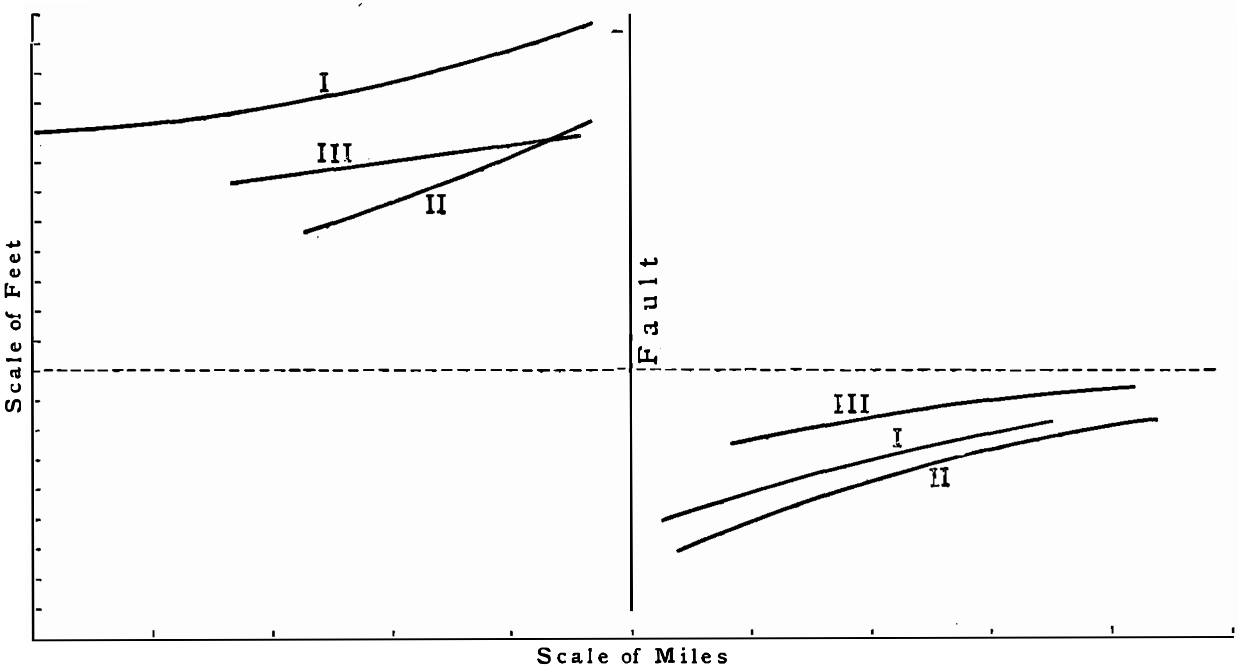
One more explanation is necessary. In the original report many of the displacements are classed as doubtful; generally, this means that the calculated displacement is so small, that it may fall within the limits of errors of observation, but in a few cases the doubt arises from the fact that either the number or the character of the observations is not such as affords a satisfactory check. I have included and used all those falling within the former category, as the fact that one station moved very little, if at all, may be as important as that another was displaced a considerable distance; but have excluded from the discussion all those of the second category, which are distinguished by a mark of interrogation in the tabular statement.

§ 2. Turning now to the discussion of the data, we may deal with the displacements in two distinct ways: either considering the calculated absolute displacements, or looking merely to the relative displacements as between neighbouring stations. The determination of the former of these depends on the assumption

[1] I use the words *connected with*, as it is by no means certain that they took place at the time of the earthquake, although they may reasonably be regarded as the result of the same cause as that which gave rise to the earthquake. In 1906, movements near the fault-line certainly occurred at the time of the earthquake; but the measured displacements of the trigonometrical stations may partly have preceded and partly have followed the earthquake.

[2] The inclusion of these data would not in any way invalidate, but rather support, the conclusions arrived at farther on; the support, nevertheless, would be more apparent than real.

Fig. 2.—*Diagram of displacements along the San Andreas fault.*



[A straight line, represented by the broken line, crossing the fault-line at right angles before the earthquake, was displaced to the positions marked by the heavy curved lines in the neighbourhood of Point Arena (I), Fort Ross (II), and south of San Francisco (III).]

that the base from which the triangulation started was unaltered by the earthquake; the latter is independent of it, for no conceivably permissible alteration in the length of the base would make any material change in the apparent relative movement of neighbouring stations. I shall therefore deal first with this, and especially with the movement of points near the fault-line.

At the extreme south, a number of stations lying west of the fault have been displaced south-eastwards by the combined effects of the movements of 1868 and 1906, and it is probable that part of this movement took place in connexion with the 1906 disturbance. The conditions in this region are, however, somewhat different from those farther north: for here the fault-line trends eastwards from its general course, and movement dies out as a surface-phenomenon. If, for the present, we exclude these stations from consideration, three facts stand out: (1) that all stations to the east have moved south-eastwards, and all to the west have moved north-westwards; (2) that the south-easterly shifting was less than the north-westerly; and (3) that stations near the fault-line have moved farther than those more remote.

These facts are noticed in Messrs. Hayford & Baldwin's report: according to their figures, the average displacement at 0·9 mile from the fault-line on the eastern side was 5·1 feet, at 2·6 miles 2·8 feet, and at 4 miles 1·9 feet; on the west side the figures are, at 1·2 miles 9·7 feet, at 3·6 miles 7·8 feet. As a number of stations were utilized in obtaining these averages, at which the displacement attributed to the 1906 earthquake was deduced by inference, it will be desirable to examine the evidence yielded by those stations at which the 1906 displacements were directly determined. These form three natural groups: the first consists of 7 stations near and to the south of San Francisco, the second of 13 stations near Fort Ross, and the third of 9 stations in the Point Arena neighbourhood. Subdividing each of these groups according to direction from the fault and again according to distance, we get the following result for stations at a distance of 5 miles or less from the fault-line:—

TABULAR STATEMENT *showing the average displacements of stations within 5 miles of the fault.*

	Under 2·1 miles.			2·1 to 5 miles.		
	No. of Stations.	Mean Distance.	Mean Shift.	No. of Stations.	Mean Distance.	Mean Shift.
W. side of fault:		miles	feet		miles	feet
San Francisco group.	2	0·9	7·9	2	3·5	7·5
Fort Ross group	7	1·3	6·9			
Point Arena group ...	1	0·9	10·7	5	4·1	8·5
E. side of fault:						
San Francisco group.	1	1·6	1·3	2	3·7	0·7
Fort Ross group	5	1·1	4·7	1	4·3	1·8
Point Arena group ...	2	0·2	5·0	1	2·4	2·6

From these figures it will be seen that the statements in Messrs. Hayford & Baldwin's report as to the greater movement near the fault are borne out, although the figures are slightly different; excluding the stations on the west side of the fault in the San Francisco group, the displacement in the outer zone is from 20 to 60 per cent. less than in the inner, and the decrease is more rapid on the eastern than on the western side. Moreover, these displacements are positive; that is to say, the stations near the fault have not lagged behind, but have moved forward in opposite directions to a greater distance than those farther away.

The increase of displacement was not, apparently, carried right up to the fault-line, and the shifting along this seems to have been less than the relative displacement of points at a little distance from the fault. The published data do not admit of any direct comparison, as we do not possess a series of measurements at points situated along or near to a straight line at right-angles to the run of the fault; but the displacements at the fault-line, as measured by the offset of interrupted fences and roads, seem to have been no greater, and sometimes less, than those at a distance of a mile or so away.[1]

The diminished displacement at the fault-line is not difficult to explain, and may reasonably be ascribed to a frictional drag or resistance to movement along this plane. The increase in displacement as the fault is neared, and until it is actually reached, is not so easy to explain; but, before dealing with this point, it will be well to see how far from the fault-line permanent displacements can be recognized, and to determine the area which has suffered permanent distortion in connexion with the earthquake.

In the Report it is assumed that the stations Mocho and Mount Diabolo had suffered no displacements, and that the line joining them could be accepted as a base-line of the triangulation in 1906–07, being unaltered in length or direction. The observations show that there has been no appreciable change in the azimuth of the line joining these two stations, and the authors have most conclusively shown that the apparent displacement of other stations cannot be explained by any alteration in its length; but they have not shown that there was no change in the length of the accepted base-line, and it is necessary to consider whether the displacement of stations, which certainly took place in connexion with this earthquake, may not have affected the assumed unaltered base.

In 1897, after the great earthquake in Assam, a part of the primary triangulation in the disturbed area was reobserved, and the result, as published by the Great Trigonometrical Survey, indicated an apparent enlargement of the area resurveyed. In this case, it was possible to show that the line which was taken as an unaltered

[1] [The Report of the State Earthquake Investigation Commission, received since this paper was read, shows that this was confined to the immediate neighbourhood of the fault-line. Fig. 15 on p. 64, fig. 21 on p. 71, and fig. 38 on p. 101 are plans of dislocated fences which show clearly a drag or diminished displacement within 120 feet or less of the dislocation.]

base-line, because it reduced the apparent displacements to a minimum, had very probably been shortened[1]; aud as this shortening would have the effect of increasing the scale of the survey, and of making the more distant stations appear to be farther removed from each other and from the base-line, it became evident that the calculated displacements were in all probability made up of two elements, (1) the real shift due to the earthquake, and (2) an apparent shift due to an alteration in length of the base-line. It was not, however, possible to determine the separate amounts due to each of these causes.

On examining the chart of displacements in California, the same feature is evident as that which was observed in Assam; that is to say, there is, in spite of irregularities and exceptions, a general tendency to displacement outwards, or away from the base-line, which suggests that this had been shortened. For instance, Point Pinos, at the southern limit of the area, has been shifted about 16 or 19 feet to south-east by east; Bodega Head, near the northern limit, has been shifted about 17 feet to north by west, as the combined result of the earth-movements in 1868 and 1906. A large part of these apparent displacements could be explained, on the supposition that the base-line has been shortened by about 8 feet; but it is not suggested that shortening to this extent has taken place, for a consideration of the apparent displacements of other stations shows that the alteration, if any, must have been considerably less than this.

For the 1906 earthquake the data are, unfortunately, scanty near the limits of the area, and the only real check which can be applied is the displacement of Farallon lighthouse by 5·8 feet to north 62° west, or at an angle of about 27° with the general direction of the fault-line. A shortening of the assumed unaltered base-line would give rise to an apparent westerly displacement of Farallon by about double as much as the shortening of the base-line: if, then, the whole of the westerly displacement of Farallon is apparent, it involves a shorteuing of the base-line by about 1·3 feet; and, if the real displacement of Farallon was parallel to the fault-line, it leaves an apparent westerly displacement of 1·8 feet to be explained by a contraction of ·9 foot in the length of the base-line. We may, therefore, conclude that any alteration which took place in the distance between Mocho and Mount Diabolo must have been of the

[1] Obsessed by the knowledge that the earth is losing heat by radiation into space, and the deduction, by no means inevitable, that it is therefore contracting, geologists have been too prone to regard all strains in the crust of the earth as necessarily compressional, and to ignore the possibility that large areas may possibly be subject to tensile strains. In the case of the Assam earthquake the hypothesis of origin, which seemed most probable to me, almost necessitated a shortening of the line taken by the Trigonometrical Survey as an unaltered base; but, if Col. Harboe's suggestion ('Beiträge z. Geophysik' vol. v, 1903, pp. 206–36) be accepted, this necessity disappears, and the expansion of the area resurveyed may be real. In California, there seems no escape from the conclusion that there has been a lengthening of the coast-line; the width of the opening of Monterey Bay has increased 10 feet and the length of the Bay of San Francisco by about the same amount, as the combined result of the movements connected with the earthquakes of 1868 and 1906.

nature of compression, and could not have exceeded 1 foot at most. This measure must be accepted as a maximum value; and although we may be certain that the base-line was not shortened by more than a foot or so, it is by no means certain that it was altered to this extent, and it is evident that the base-line was either outside, or not far from, the eastern limit of the permanently distorted area.[1]

To the westwards, it is impossible to say how far this extended under the bed of the sea; Farallon lighthouse, at 23 miles from the fault, was certainly included, for the northerly displacement cannot be explained by any shortening of the base-line, and the fact that the displacements near tho fault-line were greater on the west than on the east suggests that the permanently distorted area extended farther to the west than to the east of the fault-line. The width of the area over which displacement of the ground took place to a greater or less extent may be put, roughly, as not far from 30 miles to the east and 50 miles to the west, or a total width of about 80 miles, near the parallel of San Francisco.

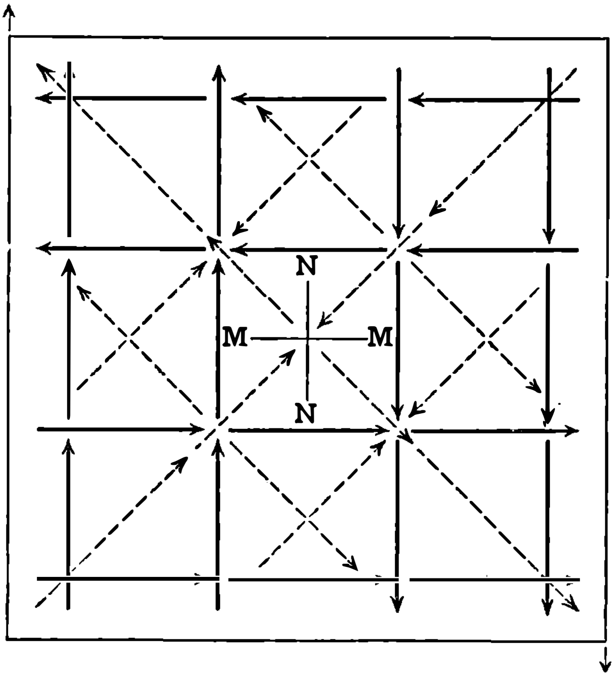
§ 2. We may now turn to the interpretation of the displacements, and are met at the outset by the apparently inexplicable nature of the movements near the fault-line, movements which appear to involve thrusts in opposite directions at the same time and the same place. An explanation has been suggested to me by Prof. Perry, which accounts for most of the facts. If a block of coherent material is subjected to a lateral distortion as indicated by the arrows outside the square in fig. 3 (p. 9), it will experience a series of stresses and strains represented by the arrows inside the square; here we have a right-handed couple, indicated by the vertical unbroken arrows, balanced by a left-hand couple, indicated by the horizontal arrows, and as the resultant of these two couples the system of compressional and tensile stresses indicated by the broken arrows. These compressional and tensile stresses, in combination with each other, produce a shear in the directions MM and NN; and, if there be weakness in either of these directions, a sliding fracture may arise, accompanied by movements on opposite sides in the directions of the unbroken arrows, while elsewhere, if there is not weakness, or the stresses are not great enough to cause fracture, there will be a strain but no movement, and so we have an effect produced which resembles the shifting at the San Andreas fault.[2]

[1] [The distribution of isoseismals, as determined by the Californian Earthquake Investigation Commission, shows that this, and the statements in the subsequent paragraph, are only true so far as they apply to displacements directly connected with the movement along the San Andreas fault. There was evidently another centre of disturbance in the San Joaquin Valley, about 40 miles east by south of Mocho and about 20 miles beyond the continuation of the Mocho-Mount Diabolo line.]

[2] To prevent misunderstanding, it may be well to state that I use the words strain, stress, and shear in their physical sense. Strain was defined by Rankine as the change of volume and figure, constituting the deviation of a molecule of a solid from that condition which it preserves when free from the action

Now, it must be borne in mind that the apparently complicated series of stresses just described is in reality a complete system of which no member can exist alone, and the production of any one of the four, by application of an external force, brings the other three

Fig. 3.—*Diagram showing couples and shearing stresses.*



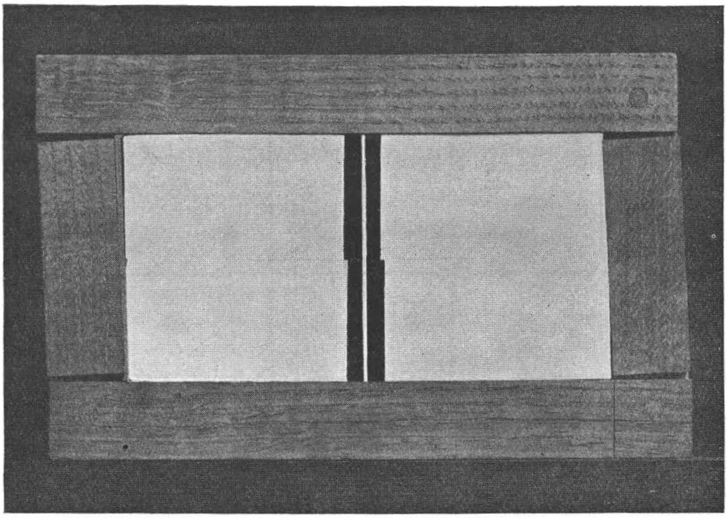
into play; consequently, it is easy to construct a model which will illustrate the effect. The form that I have adopted consists of a block of indiarubber 8 inches long by 4 inches broad, with a slit 4 inches in length cut longitudinally in its centre; this, as represented in figs. 4 & 5 (p. 10), is enclosed in a loose-jointed wooden

of external forces, and stress as the force or combination of forces which such a molecule exerts in tending to recover its free condition. Lord Kelvin introduced the use of the term stress for the external forces or system of forces by which the deformation is produced; this is equal, but opposite in direction, to the force involved in Rankine's definition, and, being usually more convenient in practice, has come to supersede it. Shear is a strain consisting of a compression in one direction, and an elongation, in the same ratio, in a direction perpendicular to the first. Strain in its popular sense involves a partial rupture of continuity, and results when the strain, in its physical sense, overcomes the molecular cohesion of the substance strained. It is somewhat unfortunate that there should be these two meanings for the same word, as they are in reality contradictory; the production of a strain in the popular sense is in fact a relief of strain in the physical sense of the word.

Figs. 4 & 5.—-*Two views of a model constructed to illustrate the displacements caused by the Californian earthquake of April 18th, 1906.*

Fig. 4.

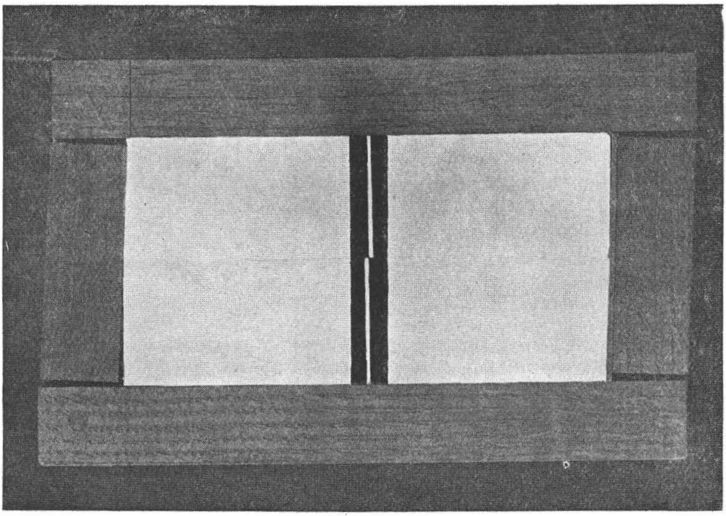
N E



W S

Fig. 5.

N E



W S

frame, fitting closely but without adhesion, and capable of distortion out of the square for the purpose of causing compression along one diagonal, while the concomitant lengthening of the other diagonal allows room for expansion of the indiarubber block. In the position represented by fig. 4 the frame is slightly distorted so as to produce compression along the diagonal E–W, the block being free to expand along the diagonal N–S, as shown by the gaps at these corners between the block and the frame; and in this view may be seen a narrow white band, extending in a straight line across the block between the centres of the two longer sides of the block. On either side of the narrow white band is a broader black band, the purpose of which will become apparent in fig. 5; in fig. 4 it is broken at the slit, the upper half being shifted to the left and the lower to the right. Fig. 5 represents the block in another condition, compressed along the diagonal N–S, and free to expand along E–W. The black band, which was broken at the slit in fig. 4, now forms a continuous band across the block, while the white line in the middle of it has become broken. There was no appreciable movement of the outer ends of these bands as between the two extreme positions, so that the edges of the black and white bands, when continuous, represent straight lines joining two stationary points, on either side of and at a distance from the slit, and a comparison of the two views illustrates the manner in which the application of shearing stresses to the block as a whole can produce positive displacements in opposite directions along a line of weakness. A comparison of the two figures shows that, as a result of the alteration of shape from that represented in fig. 4 to fig. 5, the upper half has moved to the right and the lower to the left, the amount of displacement increasing progressively as the slit is approached, and this is just what took place along the San Andreas fault-line in California.

We have, then, an explanation and an illustration of the displacements connected with the earthquake of 1906. Neither explanation nor illustration is complete in every respect, but they indicate the kind of strain which preceded and gave rise to the earthquake; they explain the occurrence of detached areas of increased violence of shock by the formation or movement of independent fissures; and finally they show that this fault was not, as has been generally thought, the cause, but a consequence, of the earthquake, if the word be used in its fullest sense as covering the whole of the disturbance.[1]

[1] [In 'Nature,' May 28th, 1908 (vol. lxxviii. p. 78), I pointed out that two distinct forms of disturbance are covered by the ordinary use of the word earthquake, namely—(1) the vibratory movement, of the nature of an elastic wave, which is due to molecular disturbance, and leaves the ground as it was before the earthquake, apart from damage to buildings or disturbance of the surface-layers which may be produced as a secondary result of the molecular displacements involved in the propagation of the wave-motion; and (2) molar displacements of solid rock, which are not the result of the wave-motion, and are permanent in the sense that the masses affected do not return to their original position after the earthquake has passed. I proposed that the word earthquake should be limited to the first sense, and that the word earthshake should be

§ 4. This conclusion, so much at variance with ideas prevalent at the present time, necessitates a brief examination of the history of our knowledge of the connexion between faults and earthquakes.

The earliest published description of the appearance of faulting at the surface of the earth at the time of an earthquake, contemporaneously recognized as such, appears to be in the account, compiled by Sir Charles Lyell from the narratives of eye-witnesses, of the New Zealand earthquake of January 23rd, 1855 [1]; but in this, and for some time subsequently, the fault-movement was regarded as a consequence, not the cause, of the earthquake. The nature of an earthquake was inaccurately appreciated—it might almost be said, was wholly misunderstood—before the publication of that remarkable series of researches by which Robert Mallet established seismology as a science; to him, an earthquake was a wave or series of waves of elastic compression, propagated outwards from a focus or origin of small size relative to the area over which the shock was felt. A disturbance of this character could not produce fissures in solid rock, but the connexion of earthquakes with faults and fractures was recognized and regarded as that of effect to cause; and when the Mino-Owari earthquake of October 28th, 1891, was found to have been accompanied by the production at the surface of a fault more than 60 miles long, with a throw of 20 feet in places, it seemed obvious that here was a sufficient cause for the phenomena which accompanied it. Moreover, the knowledge that regions where earthquakes are most frequent are also regions of great and recent tectonic changes, gave rise to a habit of connecting earthquakes with the production of the great structural features, more especially with the great faults or flexures which can be recognized by surface-observations. The Assam earthquake of 1897 was associated by Mr. La Touche [2] with the great monoclinal flexure along the southern edge of the Assam range; and in 1906 the San Francisco earthquake was immediately ascribed, by more than one authority, to fresh movement along the San Andreas fault.[3] In the former case, the prophecy was not borne out by subsequent investigation; in the latter case, it received an apparent fulfilment, which loses value with a fuller consideration of the facts known in regard to this and other earthquakes.

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used for the second. Exception has been taken to this proposal; and, on consideration, I admit the inconvenience which might arise from an attempt to limit the meaning of the word earthquake, which I use in its ordinary sense and take to include all the phenomena concerned. There seems to be, however, a real need for special terms to be used when it is necessary to distinguish between these two forms of earthquake-disturbance: for the molar displacements I propose to adapt the verb μοχλέυω, I heave or displace, which, being only used for the displacement of heavy weights or masses, appears appropriate in this connexion, and from it we obtain mochleusis for the result, and, less legitimately but conveniently, mochleuseism for the disturbance by which it is produced. Similarly, for the vibratory movement I suggest orchesis and orcheseism, from the verb ὀρχέομαι, I dance or tremble.]

[1] Bull. Soc. Géol. France, ser. 2, vol. xiii (1856) p. 661, and 'Principles' 10th ed. vol. ii (1868) Chap. xxviii.

[2] 'Nature,' vol. lvi (1897) p. 444.

[3] 'Popular Science Monthly' August 1906, p. 104.

The growth of our knowledge of earthquakes is making it continuously more and more evident that, whether great or small, they have little or no connexion with the faults which reach the surface of the earth. Leaving out of account minor earthquakes, the origin of which can seldom be determined with sufficient accuracy to connect them, even by position, with—though they can frequently be shown to be independent of—any known surface-faults, and considering only great earthquakes, we have Col. Harboe's demonstration that the origin of the Mino-Owari earthquake was probably much more extensive and complicated than the fault to which it is commonly ascribed, and the certainty that the Assam earthquake was neither solely nor mainly the result of movement along the great structural flexure which separates the elevated area of the Assam Hills from the depressed area of the Barak Valley. The Kangra earthquake of 1905 was unaccompanied by any surface-faulting, or conspicuous changes of surface-level, nor does its origin seem to have been due to movement along the great boundary-fault of the Himalayas. The Californian earthquake of 1868 was unaccompanied by any surface-faulting, and, so far as can be judged from the displacements of trigonometrical stations, was the result of a set of strains very different from that of 1906, and this again was evidently far from being localized in its origin to the displacements along the San Andreas fault. The local centre of great violence at Santa Rosa points to movement along an independent fracture or fault, and the same may be said of the earthquake at Cape Mendocino, which can only be attributed to a submarine extension of the San Andreas fault by postulating an improbable change in the direction of the course of that fault.

Not only are the irregularities in distribution, both of the violence of the shock and of the permanent displacements, inexplicable if the origin of the earthquake is assumed to have been localized to a single fissure; but they are also difficult, if not impossible, to account for if we suppose the earth's crust to have been involved as a unity in the strains which caused the earthquake. This difficulty very largely disappears if we adopt the not improbable hypothesis that the outer 30 miles or so of rocks (which we are in the habit of designating the crust of the earth) includes an outer skin of a few—probably very few—miles in thickness of more discontinuous and fractured rock.

It is not to be supposed that there is a hard and fast boundary between the rocks constituting what I have called the outer skin, and those forming the greater part of the thickness of the crust. To some extent there must be a difference of composition, for the former consists largely of clastic rocks, composed of the products of weathering and denudation, while the latter is mainly composed of matter which has not been exposed to the action of air and water at the surface of the earth. A more material difference, however, is to be looked for in the fact that the surface-rocks, being exposed to a smaller pressure, still preserve in the main the characteristics that we attach to solidity; while at a greater depth the increase of pressure causes matter, which must still be called solid, to take on the power of changing its form without breach of continuity, which we speak of as flow and regard as the most conspicuous characteristic of a fluid.

It is to the outer skin that we must look for the origin of the greater part of the disturbances which we call earthquakes, and usually to a sudden yielding, ordinarily of the nature of fracture, to strains set up in it. Probably all local earthquakes originate in the outer skin; the strains may owe their origin to slow movements of the underlying crust, but the abrupt yielding and sudden displacements do not descend into it, and such earthquakes, though occasionally of great violence near their origin, are characterized by their localization and produce no impression on the most delicate instruments at small distances outside the seismic area.

In the case of great earthquakes, like the Californian one of 1906, the surface-disturbance is still the immediate result of fracture and yielding of the outer skin, but these are the result and accompaniment of an abrupt yielding of the underlying crust. It is difficult to believe that this yielding can be precisely similar to the fractures which may be and are produced in the surface-rocks; but it is probably analogous in the sense that the ultimate result is the same, and that there is a sudden yielding and displacement of adjoining masses of matter relative to each other. On this hypothesis we have, in great earthquakes, two closely connected and yet distinct disturbances: there is first the dislocation of the outer skin, which gives rise to the surface-shock, and secondly the deep-seated displacement, or bathyseism, which gives rise to the wave-motion, which, propagated to great distances, impresses itself on suitable instruments all over the world and constitutes the teleseism, or world-shaking earthquake.

It is possible that the downward continuation of the San Andreas fault may pass deep into or even right through the crust of the earth, and have given rise to the deficiency in power of resistance which resulted in a sudden yielding under strain and so produced the Californian earthquake of 1906, but this is by no means necessary. The distribution and variation in amount and direction of the surface-displacements suggest that the yielding of the inner crust followed more or less closely the run of the coast-line, and that the strains in the outer skin were, consequently, greater along this zone than elsewhere; but there is no necessity, either in this zone or farther away, for an exact coincidence between the surface-displacements (which must have been influenced, to a large extent, in direction and amount by local irregularities in the power of resistance of the superficial rocks) and the movements which affected the crust as a whole.[1]

[1] [In the description of the surface-displacements, contained in the Report of the State Earthquake Investigation Commission, it is shown that where the outcrop of the San Andreas fault is covered by alluvium, it frequently manifests itself as a series of fractures arranged in échelon and each individually running obliquely to the general direction of the main fault. According to the view developed in the paper, the relation of the displacements in the bathyseism to the San Andreas fault is very similar to that of the displacements along the fault to the obliquely disposed surface-fractures.]

The San Francisco earthquake of 1906 is being subjected to an investigation more complete and exhaustive than any great earthquake has yet received; the report, when completed, will be a document of the greatest importance, and, until it lays all the details before us, any attempt to follow up the subject would be futile: yet this much is evident, that the great fault was not the sole, nor even the principal, cause of the earthquake, and that the movement along it was merely an incident in the final rupture, consequent on the growth of a widespread strain, distributed over an area of the earth's crust comparable in magnitude with, and possibly equalling or exceeding in size, the seismic area. This strain was of the nature of a shear, such as might be produced by a shifting more or less parallel with the coast-line, with compression in a direction about north and south and extension in a direction about east and west. How it was produced cannot be established, and more than one hypothesis is tenable; but, however produced, one thing is clear, that the forces concerned must have been very different from those which led to the formation of the San Andreas fault. The earthquake, therefore, cannot be regarded as an incident in the growth of the fault, nor the fault as the cause of the earthquake.

Appendix.

List of Displacements *associated with the Californian earthquakes of* 1868 *and* 1906, *as determined by the U.S. Coast & Geodetic Survey in* 1906–07.

Station.	Position relative to Fault.		Displacements.						
			1868.		1906.		Combined.		
	mi.	dir.	ft.	dir.	ft.	dir.	ft.	dir.	
Mount Toro	20	W.	...	......	3·1	N. 12° W.			
Gavilan	4·0	W.	...	......	...	......	17·1	S. 51° E.	
Point Pinos Station	24	W.	...	......	...	......	16·1	S. 33° E.	
Point Pinos Lighthouse.	24	W.	...	......	...	......	19·3	S. 37° E.	
Santa Cruz Lighthouse ..	12	W.	...	......	2·0	N. 37° W.	...	......	?
Santa Cruz Az. Station. .	12	W.	...	......	...	......	8·3	S. 15° E.	
Loma Prieta	3·0	E.	9·9	S. 53° E.	3·2	S. 57° E.	13·1	S. 54° E.	
Lick Observatory	22	E.	...	......	0·4	E.			
Black Mountain	0 9	E.	...	......	...	......	6·9	S. 44° E.	
Pulgas E. Base	7·0	E.	...	......	...	......	1·3	S. 58° E.	
Sierra Morena	2·7	W.	...	......	5·5	N. 44° W.			
Red Hill	12	E.	2·1	N. 52° E.	1·0	N. 35° E.	3·1	N. 47° E.	
Pulgas W. Base	2·2	E.	...	......	...	......	2·4	S. 16° E.	
Guano Island	6·0	E.	...	......	...	......	0·7	S. 28° W.	
Montara Mountain Peak	3·8	W.	...	......	5·2	N. 34° E.	...	......	?
Flat	0·9	W.	...	......	7·7	N. 24° W.			
San Pedro rock............	4·6	W.	...	......	8·3	N. 11° W.			
False Cattle Hill	2·5	W.	...	......	6·8	N. 29° W.			
Road	0·9	W.	...	......	8·0	N. 28° W.			
San Bruno Mountain ...	3·2	E.	...	......	0·8	E. 7° S.			

LIST OF DISPLACEMENTS (*continued*).

Station.	Position relative to Fault.		Displacements.					
			1868.		1906.		Combined.	
	mi.	dir.	ft.	dir.	ft.	dir.	ft.	dir.
Black Bluff	1·6	E.	...	......	1·3	S. 47° E.		
Black Ridge No. 2	4·3	E.	...	......	0·7	S. 19° W.		
Rocky Mound	20	E.	1·6	N. 8° E.	1·1	N. 35° W.	2·6	N. 9° W. ?
Bonita Point Lighthouse	3·7	E.	...	......	0·7	S. 19° W.	...	.....
Farallon Lighthouse	23	W.	4·6	N. 27° W.	5·8	N. 62° W.	9·9	N. 47° W.
Mount Tamalpais	4·0	E.	5·4	N. 12° W.	1·9	S. 36° E.	3·7	N.
Hammond	0·7	E.	...	......	...	......	5·7	W. 9° S.
Point Reyes Lighthouse	12	W	...	......	3·6	N. 67° W.		
Point Reyes Hill	1·7	W.	...	......	...	......	16·9	N. 30° W.
Hans	0·3	E.	...	......	...	......	2·1	S. 52° W.
Foster	1·2	W.	...	......	...	......	19·7	N. 31° W.
Sonoma Mountain	21	E.	...	......	...	......	4·0	N. 3° E.
Mershon	0·7	E.	...	......	...	......	1·3	S. 30° E.
Tomales Bay	1·3	W	...	......	...	......	17·5	N. 30° W.
Tomales Point	1·2	W.	...	......	...	......	16·4	N. 29° W.
Smith	1·0	E.	...	......	...	......	2·1	E. 11° N.
Bodega	1·2	E.	...	......	...	......	3·0	N. 59° E.
Bodega Head	1·4	W	...	......	...	......	17·1	N. 7° W.
Peaked Hill	1·2	E.	...	......	4·2	S. 59° E.		
Ross Mountain	4·3	E.	5·6	N. 2° E.	1·8	S. 51° E.	4·7	N. 19° E.
Chaparral	1·1	E.	...	......	4·4	S. 32° E.		
Dixon	1·1	E.	...	......	4·5	S. 44° E.		
Pinnacle Rock	1·0	W.	...	......	8·1	N. 22° W.		
Fort Ross	1·2	W.	...	......	8·2	N. 33° W.		
Henry Hill	0·9	E.	...	......	4·8	S. 40° E.		
Timber Cove	1·2	W.	...	......	7·3	N. 36° W.		
Stockhoff	1·6	W.	...	......	5·9	N. 36° W.		
Funcke	0·2	W.	...	......	7·6	N. 41° W.		
Salt Point	2·0	W.	...	......	6·6	N. 42° W.		
Lancaster	1·2	E.	6·0	N. 7° W.	5·8	S. 33° E.	2·7	N. 36° E.
Horseshoe Point	1·8	W.	...	......	4·9	N. 43° W.		
High Bluff	4·2	W.	...	......	9·1	N. 21° W.		
Pt. Arena Catholic Ch.	3·5	W.	...	......	8·8	N. 17° W.		
Sinclair	4·2	W.	...	......	8·4	N. 19° W.		
Arena	4·7	W.	...	......	8·3	N. 19° W.		
Shoemake	0·9	W.	...	......	10·7	N. 16° W.		
Clarke	2·4	E.	...	......	2·7	S. 31° E.		
Pt. Arena Lighthouse	4·0	W.	...	......	8·0	N. 19° W.		
Spur	0·3	E.	...	......	5·0	S. 36° E.		
Dunn	2·4	E.	...	......	2·6	S. 31° E.		
Lane	0·1	E.	...	......	5·0	S. 20° E.		