

Bulletin of the Seismological Society of America

VOL. 31

OCTOBER, 1941

No. 4

MECHANISM OF FAULTING IN SOUTHERN CALIFORNIA INDICATED BY SEISMOGRAMS*

By B. GUTENBERG

INTRODUCTION

FOR ABOUT twenty years it has been known that the first impulse due to the direct longitudinal waves of an earthquake produces a compression of the particles in certain areas of the earth's surface, whereas in other extended regions a rarefaction (dilatation) is observed. The pattern depends on the movements at the source. A summary of the earlier literature has been given by Kawasumi (1937). The purpose of the present paper is to investigate such patterns of compressions and dilatations in local shocks in southern and central California and to draw conclusions respecting the mechanism of faulting.

THEORY

A theoretical study of the problem must start with assumptions regarding the mechanism of the movement at the origin of an earthquake. The simplest suppositions are that:

- 1) The earthquake originates at a point at some depth.
- 2) The fault is vertical.
- 3) The movement is either purely horizontal or purely vertical.

The first assumption does not affect the present investigation significantly, as in local earthquakes the first recorded impulse (due to longitudinal waves) theoretically starts at a single point, wherever it is recorded, at the beginning of the faulting. The fracture proceeds over a certain part of the fault surface with a speed which, according to the theory, does not exceed that of longitudinal waves. This is confirmed by experiments. The speed with which a break is propagated in glass has been investigated by Schardin, Elle, and Struth (1940). The velocity of the longitudinal waves in the glass was 5.4 km/sec., that of the transverse waves 3.2 km/sec. These are about the same velocities as those in granite. The main breaking started from the affected point and radiated in all directions with a velocity of about 1.5 km/sec., or

* Manuscript received for publication April 19, 1941.

about one-half that of the transverse waves. (See also Barstow and Edgerton, 1939, 1941.) However, this type of breaking hardly corresponds to the break along a fault in nature. On the other hand, after a detonation, or after applying other extreme means to produce extraordinary strains, secondary centers of breaking occurred shortly after the passage of the longitudinal waves. In some instances, for example after scoring the glass with a diamond, or where the breaking strength of the glass was weakened by the introduction of wires, secondary centers of breaking appeared along the line of weakness with the velocity of the transverse waves or a slightly smaller velocity. Although there is no doubt about the importance of these experiments for the problem of fracture along faults in general, the experimental conditions differ so much from those in faulting, especially with respect to the dimensions, that a close agreement between the fracture velocities observed in the experiments and those occurring in faulting is not to be expected.

The only conclusion which pertains to the velocity of faulting in an earthquake seems to have been drawn by Benioff (1938). From the time of arrival of longitudinal and transverse waves in the Long Beach earthquake of March 10, 1933, he concluded that the first transverse waves recorded at Pasadena did not start at the point of the first fault movement, but from a point closer to Pasadena in the region where the faulting during the main shock ended. This is possible, if the velocity of faulting was between the velocities of longitudinal and transverse waves (about 5.6 and 3.2 km/sec., respectively). Benioff found that the faulting speed required to explain the observed travel times is about 4.2 km/sec. The relatively early arrival of transverse waves which has been noticed in many other local earthquakes might be explained in a similar way. On the other hand, the longitudinal waves theoretically must arrive everywhere in the same order in which they have left the fault, as their velocity is higher than that of the faulting. Consequently, the first impulse leaving the focus must arrive everywhere earlier than any wave starting from a different point of the fault. However, in practical research some confusion is not unusual, as the first impulse visible on the record does not necessarily correspond to the first impulse arriving at the station. Frequently the first impulse is recorded only at nearer stations, while at greater distances it is too small to be detectable; another phase or a later, stronger impulse then may mark the beginning of the record.

If the movement along the fault is purely vertical, the fault itself must be vertical, so that in this case the second assumption mentioned at the beginning of this section is included in the third. If there is a purely horizontal displacement along a dipping fault, the epicenter of the earthquake will not be on the fault trace at the surface. The general pattern of compressions and dilatations will be the same but displaced perpendicular to the fault trace by an amount which depends on the dip angle of the fault and on the depth of focus. The

observations indicate that in southern California, at least in the larger shocks, the calculated epicenters are usually on a major fault within the limits of error.

More complicated models concerning the mechanism of earthquakes have been investigated, for example by Ishimoto (1932), Kawasumi (1932, 1933), Minakami (1934), and Byerly (1938).

The foregoing remarks refer to the physical processes. On the other hand, assumptions must be made with respect to the tectonic process involved in order to get a complete picture. Two types of hypothesis have been discussed in the literature more than others: first, that the initial movement at the focus is the result of two opposing forces, either compression from opposite sides,

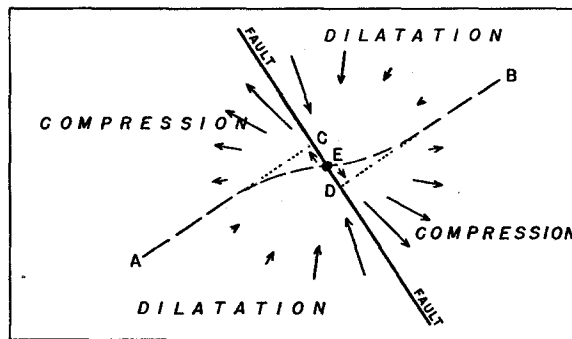


Fig. 1. Theoretical distribution of compressions and dilatations from an earthquake originating at a point of the vertical fault along which the movement is a purely horizontal shear and follows the rebound theory.

resulting in an overthrust, or a pull in opposite directions, or a combination of both; and second, that the region of the source is subjected to a shear which results in faulting. The mechanism of the faulting process has been worked out by Reid (1910a; 1910b; see also 1933), and is known as the "elastic rebound theory." It may be summarized as follows. An unknown cause acting in the same direction during a relatively long time produces gradually increasing relative displacements of neighboring portions of the earth's crust. As soon as the elastic strains surpass the breaking strength of the material, the rock fractures, starting at a point ("focus" of the earthquake). "The only mass movements that occur at the time of the earthquake are the sudden elastic rebounds of the sides of the fracture to positions of no elastic strain" (Reid, 1910b, p. 338).

Figure 1 gives a sketch of the conditions if there is a purely horizontal shearing. AEB, which is supposed to be a horizontal plane many miles below the surface of the earth, was originally a straight line. At the moment when it was bent into the form indicated in the figure, the breaking strength of the material was reached at the point E and a break started there. The part AE

of the line snapped back to the supposedly unstrained position AC , and simultaneously the part EB to DB . How far the points A and B are to be taken from the fault is still not known; Reid supposes a few miles.

In seismograms of shocks large enough to furnish a complete record, the first movement is due to a longitudinal wave starting at E , as we have seen. However, in the nonhomogeneous crust, longitudinal waves may travel along

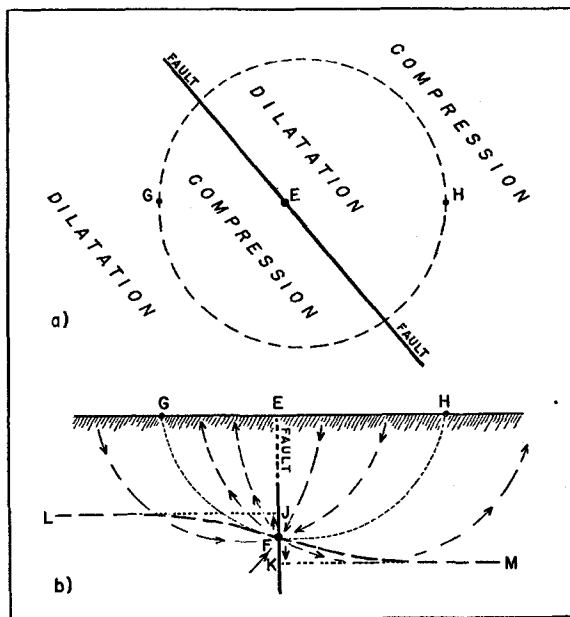


Fig. 2. Theoretical distribution of compressions and dilatations from an earthquake originating at a point of a vertical fault along which the movement is a purely vertical shear and follows the rebound theory. *a.* Plan. *b.* Cross section: E indicates the epicenter and F the focus.

various paths to a given point, each reaching a different maximum depth. Which of them arrives first depends on the change of velocity with depth and on the depth of focus.

The direction and amplitude of the first longitudinal wave near the source is indicated in figure 1 by the arrows. Except for the relatively small section of the fault where the faulting begins, the transition from the relatively large compressions in the advancing wave front on one side of the fault and the dilatation which is propagated on the opposite side of the fault takes place rather rapidly, but is not there discontinuous; the boundary conditions there do not permit movement in opposite directions of adjoining points on opposite sides of the fault as long as no break occurs. This, however, does not modify the result, indicated in the figure, that in the neighborhood of the focus two

quadrants are to be expected with initial compressions, and two with dilatations. No change with distance is to be expected, and so all stations located in quadrants marked "compression" should record an initial impulse directed upward by a vertical seismograph and away from the epicenter on any horizontal instrument. In the other two quadrants the direction of the first movement should be reversed.

Figure 2 gives a similar sketch for a purely vertical displacement. Part *b* gives a cross section. *F* indicates the focus, *E* the epicenter. The resulting pattern is complicated by the curvature of the rays. The fault plane marks one boundary between compressions and dilatations; the rays leaving the focus about horizontally, another one. The distances *GE* and *EH* depend on the change of velocity with depth and on the depth of focus; their difference is small (exaggerated in the figure). For an average continental area, the order of magnitude of this radius *R* of the circle for a given depth of focus *h* equals *EF* is approximately:

$\frac{h}{R}$	5	10	30	km.
	75	160	300	km.

However, it must be considered that the data just given refer to the "direct" longitudinal wave \bar{P} , and that the waves refracted through the deeper layers may arrive earlier. Again, the limiting distance depends on the velocities and the depth of focus. In California, the wave passing through the whole continental layer and having its deepest point in the "sima" forms the first impulse on the seismograms at distances beginning at about 110 km. from the epicenter; in the Alps and southern Germany the limiting distance is larger, about 150 km. As this wave starts downward at the focus, its initial impulse has always the same direction as the beginning of \bar{P} beyond *G* or *H*. Thus, for the first impulse recorded in California shocks, the radius *R* of the circle in figure 2 is usually about 110 km. It should also be pointed out that a compression may change into a rarefaction, and vice versa, at any reflection. (Refracted waves, in general, arrive at the station with the same type of initial movement with which they have left the focus.)

If many data are available for a single shock, the pattern of the resulting areas with initial compressions and initial dilatations can be studied. If records at a few stations only are available, and the faults in the region under consideration are parallel, a figure may be useful which covers this area and shows with one symbol those epicenters which were the source of initial compressions at a given station, and with a different symbol the locations of shocks giving an initial rarefaction. If in figure 1 or figure 2, *a*, the station is to be southeast of the epicenter *E* and this station is plotted as the center of a new figure, then the epicenter *E* will be to the northwest; in general: the figure giving the theoretical areas of epicenters causing an initial compression at a given station under the assumptions of figure 1 or figure 2 will be found by rotating figure 1

or figure 2, *a*, by 180° . For horizontal movements the resulting figure will be exactly the same as figure 1; that is, the northwest sector of compression is replaced by the southeast sector, and the two quadrants with dilatations are exchanged in a similar way, leaving the whole pattern unchanged. However, in figure 2, *a*, all areas with compressions will be replaced by areas with dilatations, and vice versa. Of course, if the faults are not exactly parallel, irregularities in the pattern must result.

MATERIALS USED

In the investigation of the pattern of compressions and dilatations in southern California, at first seismograms of a few large shocks were tried. The results were much more consistent than had been anticipated, and the study was

TABLE 1
COÖRDINATES OF STATIONS

Station	Symbol	North latitude	West longitude
Pasadena.....	Pa	$34^\circ 08.9'$	$118^\circ 10.3'$
Mount Wilson.....	MW	$34^\circ 13.5'$	$118^\circ 03.4'$
Riverside.....	R	$33^\circ 59.6'$	$117^\circ 22.5'$
Santa Barbara.....	SB	$34^\circ 26.5'$	$119^\circ 42.9'$
La Jolla.....	LJ	$32^\circ 51.8'$	$117^\circ 15.2'$
Tinemaha.....	T	$37^\circ 05.7'$	$118^\circ 15.5'$
Haiwee.....	H	$36^\circ 08.2'$	$117^\circ 57.9'$
Palomar.....	Pr	$33^\circ 21.0'$	$116^\circ 51.5'$
Berkeley.....	B	$37^\circ 52.3'$	$122^\circ 15.6'$

gradually expanded until it finally covered the records of all local earthquakes from January, 1934, to December, 1940. For this period, epicenters have been determined as well as possible in routine practice by Dr. C. F. Richter and Mr. R. E. Rogers. Data for a few earlier shocks which had been well located in special research were also used. Since 1933, at all routine stations of the network (Pasadena, Mount Wilson, Riverside, Santa Barbara, Tinemaha, Haiwee, La Jolla) one short-period Benioff vertical seismograph and two Wood-Anderson torsion seismographs recording the east-west and north-south components have been in operation. At Pasadena, several other instruments were in use, in particular one or two short-period Benioff horizontal seismographs for most of the time. Further, since the end of 1939, a short-period Benioff vertical instrument has been in operation at Palomar. Finally, Dr. Perry Byerly kindly permitted the author to use records available at Berkeley, especially those of the short-period Benioff vertical installed there. The coördinates of the stations are given in table 1. The locations of the stations are indicated on the inset map in figure 5.

If the first motion in a seismogram under investigation seemed to be due to a direct or a refracted longitudinal wave, and the direction seemed to be beyond doubt, it was listed. However, at least once in a while the true first movement would be lost in microseisms, and the direction listed would be opposite to the actual direction. If the first impulse was clear but small, this was noted. In other instances, there was some doubt about the initial direction, owing either to microseisms or to minute marks or other reasons. For these the direction was listed with a question mark. Really doubtful cases were omitted.

Most data depend on the Benioff verticals, which have a much higher sensitivity than the torsion instruments. When all components were available, they usually agreed very well in respect to the direction. In relatively few cases they did not agree; possibly, the first motion was not recognizable on one or both of the horizontal components. Such discrepancies are not due to a systematic mistake concerning the significance of the direction on the record. The Wood-Anderson torsion seismographs have a definite directional response as long as the installation of the instruments and the drum remains unchanged. The response of an electromagnetic instrument is changed if either at the seismograph or at the galvanometer the connection of the wires is reversed. This has happened repeatedly at the stations of the Pasadena group in servicing the instruments. At Pasadena such changes are found within a very few days and are corrected immediately; at the auxiliary station they are corrected at the time of some later visit. The directional response of all instruments during the period covered by the investigation has been checked independently by Dr. Richter and the author.

The first movement has sometimes been observed to arrive systematically from a direction which differs slightly but definitely from the direction toward the source. For example, Dr. Richter and others, working on earthquakes originating in the region of the San Bernardino Mountains slightly south of east from Pasadena, have found independently that the longitudinal waves of these shocks arrive at Pasadena from the north of east. The northerly component is indicated by three independent instruments (two short-period, one long-period). In the present investigation this was found, without exception, to be correct. Possibly there is a body of rock with higher velocity than usual to the north of the direct path. This hypothesis would be supported by the finding of Wood and Richter (1933) that quarry blasts near Victorville, just north of the San Bernardino Mountains, were recorded at Pasadena with several phases "which appear to correspond to successive arrivals of waves traveling, apparently, along direct paths with different apparent velocities." One of these, about 6.0 km/sec., is decidedly higher than the velocity usual in granite (about 5.55 km/sec.) and may be characteristic of a body of high-velocity rock to the north of the direct path from the San Bernardino Mountains to Pasadena. Such a body of material with higher velocity would cause refracted longi-

tudinal waves which could arrive earlier than the direct wave at Pasadena and in a somewhat different azimuth. At Mount Wilson, with a latitude only about $4\frac{1}{2}'$ (8 km.) to the north, the longitudinal waves produced by the same shocks in the San Bernardino Mountains arrive regularly from south of east, as they should. This indicates how small are the quantities which are involved.

The results found for different shocks from a given epicenter, or from epicenters only a few minutes of arc apart, were combined. Limitations of space make it impossible to list separately the findings for the 1960 shocks which gave a useful record at one, at least, of the stations. In table 2 the findings for each of the 464 distinctly different epicenters are listed. The first column gives the coördinates of the epicenter. Usually they were given by Dr. Richter and Mr. Rogers to the nearest minute of arc (about 2 km. in distance). However, some of them are marked as accurate only within a degree. Such epicenters were used only in a few instances in outlying sections, especially Lower California and Nevada. The position of most epicenters in the area about Pasadena, Mount Wilson, and Riverside is probably good to within 5 kilometers (3 miles). The coördinates of most of the epicenters in the remaining regions probably are not in error by more than 15 km.

Each epicenter used has been denoted by a letter followed by a number (third column in table 2). The letter usually refers to an area bounded by one degree in latitude and longitude. Thus, the area marked "H" is bounded to the south by 33° (inclusive), to the north by 34° (exclusive), to the east by 117° (inclusive), and to the west by 118° (exclusive). In several instances, such areas affected by a few shocks only are combined. The numbers are given from south to north in each "square." Table 3 gives the sums of all data for each separately lettered area.

Of the total of 4207 independent determinations of initial motions, many of which are based on the reading of several records, 1103, or more than one-quarter, are based on records at Mount Wilson. This is due to the fact that the unrest of the ground (microseisms) there is very small so that the vertical instrument can be operated with a higher sensitivity than at the other stations, and that small beginnings of earthquake records can be trusted more than at the other stations. At Riverside, 954 shocks proved to be useful, and at Pasadena, 918. The difference in the microseisms at Pasadena and at Riverside or Mount Wilson is larger than would be expected from the figures; for a maladjustment in the Benioff vertical seismograph (usually resting of the mass against the stop after considerable changes in temperature) ordinarily is discovered and repaired at Pasadena within twenty-four hours, while the records for the auxiliary stations are mailed to Pasadena and developed there only once a week, and repairs are not usually made immediately, so that often the instrument remains out of order for two weeks or more.

(Continued on p. 285)

TABLE 2

NUMBER OF COMPRESSIONS AND DILATATIONS OBSERVED FOR EACH EPICENTER

(No. equals number of epicenter, N equals number of shocks used from this epicenter. For symbols of the stations see table 1. For each epicenter and in each column, first the number of compressions is given, and, following the bar, the number of dilatations. An asterisk indicates that at least half of the number refers to beginnings marked as either "small" or "direction somewhat doubtful.")

Epicenter		No.	N	Pa	MW	R	SB	T	H	LJ	Pr	B
N. Lat.	W. Long.											
		A										
30	117	1	2							0-2		
31	115	2	7		0-1	1*-0				7-0		
31.40	115 05	3	2	0-1	0-1	0-1		0-1	0-1*	2-0		
31.7	115.1	4	11	1-1*	1-1*	1*-1				4-3	0-3	
31.5	116.0	5	1							1*-0		
31.40	116.30	6	8	2-0		1-1				6-1	0-1	
31.7	117.2	7	2	0-1	0-2					0-2		
		B										
32.1	114.3	1	1			0-1						
32.0	115.2	2	14	2-0	1*-1*	0-1*				14-0		
32.15	115.10	3	2		0-1*	0-2						
32.20	115.20	4	1							0-1		
32.20	115.45	5	1							1*-0		
32.26	115.36	6	11	2-0	2*-2*	0-2*				8-0		
32.30	115.00	7	1			0-1						
32.30	115.20	8	1			0-1						
32.5	115.6	9	2		1*-0					1*-0		
32.44	115.27	10	12	1-0 0-1	1-0 1-3*	1-0 2-1*	1-0	0-1*		1-0 2-1	7-1	
32.53	115.36	11	6		2-0	1-0				4*-0		
32.54	115.13	12	15	3-0	0-2*	3-1*				14-0	0-1	
32.55	115.25	13	5	0-1*	0-1	1*-0				4-0		
		C										
32	116	1	2							0-2		
32.00	116.40	2	9	2-1	1-2	3-0				4-4	1-0	
32.06	116.30	3	1	0-1								
32.3	116.6	4	2							0-2		
32.20	116.30	5	2	1-0		1*-0				1-1		

TABLE 2—Continued

Epicenter		No.	N	Pa	MW	R	SB	T	H	LJ	Pr	B
N. Lat.	W. Long.											
° /	° /	C										
32 32	116 11	6	15		1*-1	3-1*				11-4		
32 35	116 38	7	1			0-1				0-1		
32 36	116.0	8	2	2-0	1-1*					2-0		
32 40	116 30	9	1	1-0	1-0	0-1						
32 45	116 00	10	1		1-0							
32 45	116 25	11	1		1*-0	0-1*				1-0		
32 47	116 08	12	1		0-1					0-1*		
32 47	116 17	13	1		1-0	1-0				0-1*		
32 50	116 50	14	1							0-1		
32 52	116 00	15	1		1-0							
32 52	116 12	16	1	1-0		1-0						
32 55	116 25	17	3	0-2	0-2	2-1				2-0	0-1	
32 56	116 15	18	1							1-0		
32 57	116 54	19	2	0-1		0-2				1-1		
		D										
32 00	117 04	1	1							0-1		
32 00	117 30	2	6	1-1*	0-1	0-3			0-2	0-6		
32 05	117 50	3	1		0-1	0-1				0-1	0-1	
32 10	117 40	4	1			0-1				0-1		
32 30	117 15	5	1			0-1				0-1		
32 30	117 30	6	1							0-1		
32 33	117 49	7	2	0-1	0-2	0-2	0-1*			0-1		
32 45	117 50	8	1	0-1	0-1	0-1						
32 52	117 30	9	5	0-1	0-2	0-4				0-4		
		E										
32 30	118 05	1	1			0-1				0-1		
32 37	118 02	2	2	0-1	0-1	0-1						
32 37	118 12	3	1	0-1	0-1	0-1				1-0		
32 45	118 12	4	1	0-1	0-1	0-1				1-0		
32 50	118 45	5	1	0-1	0-1	1-0	0-1*			1*-0		
32 53	118 15	6	5	0-1	1-3*	0-2				1-0		
32 54	118 22	7	1	0-1								
32 37	119 20	8	1		0-1	0-1				1-0		

TABLE 2—Continued

Epicenter		No.	N	Pa	MW	R	SB	T	H	LJ	Pr	B
N. Lat.	W. Long.											
° /	° /											
33 05	115 59	1	12	2-4*	3*-2	4-2*				11-0	3*-0	
33 10	115 30	2	4	0-1*		2*-0				3-0		
33 20	115 30	3	1			0-1						
33 23	115 36	4	4		0-1	3-0				1-2*	1-0	
		G										
33 00	116 15	1	9	0-3	1-4	1*-2*				4-1*	2-0	
33 00	116 40	2	1	1-0		0-1*				1-0		
33 00	116 51	3	4	1-0	2-0	1*-0				3-0		
33 00	116 55	4	1							0-1		
33 01	116 20	5	2			1*-0				1-1*		
33 03	116 30	6	3	0-2	1-0	1-1				3-0		
33 05	116 10	7	2		0-1	0-1				2-0		
33 05	116 40	8	4	0-1	1-1*	0-2				3-0		
33 06	116 16	9	2		0-1*					1-0		
33 07	116 26	10	10	3*-0	1-4*	1*-4*				10-0	2-0	
33 09	116 05	11	14	3*-4	4*-4	2-4				7-0		
33 09	116 35	12	11	3-0	2-1*	5-1*				10-0		
33 11	116 09	13	8	2-3	3-0	1-4*				5-1		
33 11	116 26	14	18	1*-4*	8-5	4-7				9-1	1*-0	
33 14	116 12	15	3	1-1	0-1	1*-1*				2-1*		
33 15	116 30	16	9	1-3	1*-3	0-1				6-1		
33 16	116 19	17	8	2-1	3*-2*	3-1				6-0	1-0	
33 17	116 23	18	2	1-0	1*-1	1-0				1*-0	1-0	
33 20	116 20	19	4	0-4	1-1*	1*-2*				0-1*		
33 20	116 25	20	1	1*-0	1*-0	1*-0						
33 21	116 56	21	5	0-2	1-1	1-2				3-0		
33 23	116 36	22	5			0-4				1-0		
33 25	116 21	23	2		1-2	0-1						
33 25	116 25	24	1	1-0	1-0	1-0						
33 25	116 48	25	2	1*-0		1-0						
33 29	116 36	26	1	1-0	1-0	1-0	1*-0	0-1*	0-1*	0-1		
			51	14-10	18-6	19-14				17-7		
33 29	116 57	27	82	38-5	50-3	67-3	1-0		1-0	0-33		
33 30	116 48	28	3			1-2						
33 31	116 29	29	9	4*-3	2-1*	6-2*				3-0		
33 35	116 42	30	3	1-0	2-0	2-0				0-1		

TABLE 2—Continued

Epicenter		No.	N	Pa	MW	R	SB	T	H	LJ	Pr	B
N. Lat.	W. Long.											
° ' "	° ' "											
		G										
33 36	116 16	31	3	1-0	2-0	1-0				0-1		
33 37	116 50	32	2		1-0	1-1				0-1		
33 42	116 15	33	4	2-0	0-2	2-2*				0-2		
33 42	116 59	34	3	2-0	3-0	2-0				0-1		
33 43	116 51	35	2	0-1	0-1	0-1*				0-1		
33 45	116 25	36	3	0-1*	1-1	2-0				0-1*		
33 45	116 40	37	5	0-1	1-2	2-0				0-1		
33 50	116 10	38	1		1-0							
33 50	116 58	39	1	0-1								
33 51	116 35	40	3	0-1	2-1	2-0						
33 51	116 44	41	2	1-1	2-0	1-0				0-2		
33 54	116 52	42	5	2-2	4-0	2-0						
33 55	116 35	43	1		1-0	0-1				0-1*		
33 55	116 40	44	2	1-0	0-1	2-0				1-0		
33 56	116 45	45	11	5-3	9-1	5-1				0-2		
33 57	116 27	46	3	1*-0	2-0	3-0				0-1*		
33 58	116 58	47	1	1*-0		1-0				1-0		
		H										
33 05	117 50	1	1			0-1						
33 08	117 58	2	1	0-1	0-1	0-1						
33 11	117 30	3	1	0-1	0-1*	0-1				0-1		
33 16	117 03	4	5		1-0	0-2				1-4		
33 21	117 53	5	1			0-1						
33 22	117 05	6	4	1-0	1-2	1-1				1-3*	2-0	
33 23	117 18	7	5		1-2	2-1				0-2		
33 24	117 50	8	1	1-0	0-1*							
33 25	117 10	9	3	1-1	1*-0	0-2				0-2		
33 25	117 30	10	1			0-1						
33 30	117 38	11	1			0-1*						
33 33	117 11	12	4	0-1*	3-0	3-0				0-1		
33 34	117 17	13	1			1-0						
33 34	117 49	14	1			0-1						
33 34	117 59	15	1	0-1	0-1	0-1	1-0	0-1	0-1	0-1*		
			49	2-15	2-30	17-19	2*-0	1-0		0-1	1-0	

TABLE 2—Continued

Epicenter		No.	N	Pa	MW	R	SB	T	H	LJ	Pr	B
N. Lat.	W. Long.											
° /	° /	H										
33 36	117 21	16	2	1-0		0-2				0-1		
33 37	117 27	17	2	0-1	0-2	0-2				0-1	0-1	
33 38	117 39	18	2	0-1*	1-1							
33 39	117 04	19	2	2-0	2-0	2-0						
33 40	117 14	20	5	2-0	4-0	4-1						
33 40	117 50	21	1	1-0		1*-0						
33 41	117 19	22	7	3-0	6-0	4-2				0-1	1-1	
33 41	117 54	23	5	1*-1	0-1	1*-3						
33 42	117 26	24	2	1-0	2-0	0-1	1-0	0-1	0-1	0-2		
33 42	117 31	25	28	9-12	1*-19	3*-22						
33 43	117 01	26	4	1*-0	1-0	3-1	1-0	0-1*	0-1*	0-8		
33 44	117 22	27	6	1-0	3-0	2-4				0-1		
33 44	117 48	28	6	2-3	1-5	5-0		0-1		0-1		
33 45	117 15	29	1	1-0	1-0	1-0				0-1*		
33 45	117 30	30	1	0-1	1-0	1-0						
33 46	117 36	31	3	0-2	1-2	2*-1						
33 46	117 56	32	9	2-3	1-8	4-2	1-0	0-1*		0-1*		
33 48	117 38	33	1	0-1	0-1	1-0						
33 50	117 10	34	2		1-0	0-2						
33 50	117 22	35	30	11-1	24-1	10-14				0-1	2-0	
33 50	117 30	36	4	2-0	3-0	0-3						
33 50	117 35	37	1	0-1	0-1	0-1						
33 50	117 40	38	4	0-2	0-1	4-0						
33 50	117 49	39	6	0-4	0-5	4-1				0-1		
33 51	117 44	40	3	0-3	0-1	2-1*						
33 52	117 03	41	2	2-0	2-0	1-0				0-1		
33 53	117 37	42	10	6-1	6-2	4-2						
33 54	117 12	43	1		1-0	1-0						
33 54	117 50	44	2		0-2	1-0						
33 55	117 32	45	16	12-0	15-0	3-8	1*-0			0-1		
33 55	117 41	46	5	0-1	3-0	3-2						
33 56	117 45	47	1		0-1	1-0						
33 57	117 37	48	8	3-1	7-0	5-2						
33 59	117 12	49	2	2-0		2-0				1-0		
33 59	117 23	50	1	1-0								

TABLE 2—Continued

Epicenter		No.	N	Pa	MW	R	SB	T	H	LJ	Pr	B
N. Lat.	W. Long.											
° /	° /	I										
33 00	118 23	1	1		0-1*					1-0		
33 05	118 18	2	1			0-1*						
33 11	118 02	3	1	0-1	0-1	0-1				1-0		
33 15	118 15	4	1	1-0	1-0							
33 18	118 08	5	3	0-2	2-0							
33 25	118 10	6	1			1*-0				1-0		
33 25	118 18	7	1		1-0	1-0						
33 25	118 44	8	2	1-0	0-1							
33 28	118 25	9	2		0-1	0-1						
33 29	118 17	10	3	1*-1	0-3	1*-1						
33 33	118 13	11	1		1*-0							
33 33	118 21	12	3	0-3	0-2	1-1	0-1*			1-0		
33 35	118 30	13	1		0-1							
33 35	118 48	14	2	0-2	0-2	1*-0						
33 36	118 01	15	30	3*-10	2*-19	5-12	1-0			1-1*		
33 36	118 24	16	7	2*-3	1-5	0-3	1*-0			1*-0		
33 37	118 09	17	3	0-3	0-3	0-1						
33 38	118 12	18	8	0-7	0-6	0-4						
33 43	118 05	19	26	3-9	2-14	7-6				1-1		
33 43	118 42	20	2		0-2		1-0					
33 43	118 48	21	1	1-0								
33 44	118 21	22	5	0-5	0-4	1*-0						
33 46	118 08	23	68	6-37	7-45	19-19	4-1	1-0	2*-0	4-1	2-0	
33 46	118 13	24	4	1*-3	2*-1	1-0				0-1		
33 47	118 00	25	3	1-1	1-2	2-0	1-0			1*-0		
33 47	118 23	26	1	0-1	0-1	1-0						
33 47	118 33	27	13	1-12	1*-11	11-0	3-0	0-1	0-2		3-0	
33 48	118 17	28	1	0-1	0-1							
33 49	118 26	29	2	0-1	0-2	1-0						
33 50	118 05	30	1			0-1						
33 50	118 09	31	6	1-4	0-4	2-1*						
33 51	118 14	32	2	1-1	0-1							
33 52	118 29	33	2	0-2	0-1	1-0	1-0			0-1		
33 54	118 19	34	5	1-4	1-3	3-0						
33 55	118 04	35	2	0-2	0-1	1-0						

TABLE 2—Continued

Epicenter		No.	N	Pa	MW	R	SB	T	H	LJ	Pr	B
N. Lat.	W. Long.											
° /	° /											
I												
33 56	118 14	36	6	1-4	0-5	1*-1						
33 56	118 20	37	1	1-0	1-0							
33 57	118 09	38	8	0-7	0-7	1-1						
33 57	118 36	39	18	11-5	10-5	8-0	2*-1*		0-2*		1-0	
33 58	118 03	40	1	0-1	0-1	1-0						
33 58	118 22	41	19	0-12	1*-17	3-1						
33 59	118 18	42	18	0-17	1-16	1*-3			0-1	1-0	0-1	
J												
33 05	119 20	1	1	0-1	0-1		0-1*					
33 09	119 27	2	3	0-2	0-3	0-1	0-1			0-1*	0-1*	
33 35	119 10	3	1	1-0	1-0							
33 40	119 30	4	1	0-1	0-1	0-1	0-1					
33 45	119 06	5	7	2*-3	3*-3	3-0	1*-1					
K												
34 00	115 45	1	3	1-1	0-1	1-1*						
34 00	116 21	2	8	0-1	2-0	7-0				0-2		
34 00	116 30	3	2	1*-0	1*-0	2-0						
34 00	116 54	4	1			1-0						
34 01	116 35	5	1	0-1		0-1				0-1		
34 03	116 17	6	39	25-1	26-0	25-0	3-0	2-0	3-1	1-21	0-20	
34 04	116 26	7	11	6-1	8-0	6-3		0-1*		0-2	0-1	
34 04	116 45	8	3	2-0	3-0	0-1						
34 06	116 48	9	2		1-0	2-0						
34 06	116 53	10	20	6-0	8-0	17-1						
34 08	116 57	11	1	1-0	1-0	1-0						
34 10	116 50	12	1	1-0	1-0							
34 11	116 14	13	3	1-0	3-0	3-0				0-2		
34 11	116 37	14	3	2-0	3-0	3-0				0-1	1*-0	
34 11	116 57	15	5	1*-2	2-0	4-0						
34 12	116 21	16	4	0-3	0-2	3-0						
34 15	116 05	17	1		1-0							
34 18	116 48	18	1	1*-0	1-0	1-0						
34 19	116 55	19	4	3-0	2-0	2-0						
34 21	116 19	20	2		1-1*	1-0						

TABLE 2—Continued

Epicenter		No.	N	Pa	MW	R	SB	T	H	LJ	Pr	B
N. Lat.	W. Long.											
° /	° /											
		K										
34 23	116 31	21	9	1*-7	4-4	3-4			0-1*			
34 25	116 51	22	1	1-0	1-0	1-0						
34 30	116 42	23	1	0-1	1-0		1-0					
34 35	116 44	24	1	0-1	0-1*							
34 36	116 54	25	1			0-1						
34 43	116 21	26	1		0-1*							
34 45	116 10	27	1	0-1		0-1			1*-0			
34 45	116 28	28	10	1-4	4*-3	3*-5				0-2*		
34 45	116 50	29	1		0-1							
34 55	116 55	30	1		0-1	0-1						
		L										
34 00	117 47	1	1		0-1	1-0						
34 01	117 27	2	5	4-1	4-0	2-3				0-2		
34 01	117 53	3	1			1-0						
34 02	117 41	4	5	2-1	3-2	1-3					1-0	
34 03	117 18	5	15	11-0	12-0	4-7	1-0	0-1	0-1	0-1	0-1	
34 03	117 34	6	6	5-0	5-0	2-4				0-1		
34 04	117 01	7	2	1-0	1-0	2-0						
34 04	117 20	8	5	2-0	4-0	1-2					1-0	
34 05	117 46	9	4	3-0	1-2	3-1						
34 06	117 31	10	4	4-0	4-0	0-3	1-0	0-1	0-1	0-1		
34 06	117 42	11	19	10-0	16-0	6-2			0-1			
34 07	117 25	12	9	8-0	5-0	0-7	1*-0	0-1*	0-2	1-0		
34 07	117 35	13	3	1-2	2-1	0-3	2-0	0-2		0-1		
34 10	117 00	14	1	0-1	0-1	0-1						
34 10	117 30	15	4	3-0	2-1	0-1						
34 10	117 46	16	1		1-0							
34 11	117 06	17	3	2-0	2-0	3-0				0-1		
34 11	117 51	18	7	5-1	5-2	2-2	1-1	0-1	0-1	0-2		
34 12	117 13	19	3	2-0	2-0	2-0						
34 12	117 21	20	6	4-1	4-0	2-2				0-1	0-1	
34 14	117 02	21	2	1-0	1-0	2-0						
34 15	117 13	22	3	1-0	1-1	3-0						
34 15	117 48	23	3	2-1	3-0	1-2						
34 17	117 18	24	1	1-0	1-0	1-0						
34 20	117 02	25	10	4-0	7-1	7-2				0-1		

TABLE 2—Continued

Epicenter		No.	N	Pa	MW	R	SB	T	H	LJ	Pr	B
N. Lat.	W. Long.											
° ' "	° ' "	M										
34 25	117 52	26	1		0-1	0-1						
34 30	117 34	27	1			1-0						
34 30	117 57	28	1	0-1	0-1							
34 31	117 18	29	2	0-1	1-1	1*-0						
34 35	117 23	30	1		0-1	0-1						
34 36	117 30	31	1	0-1*	0-1	0-1						
34 39	117 04	32	2	0-1		0-2						
34 48	117 05	33	5	2-0	1-2	0-3						
34 55	117 01	34	4	3-1	3-1	0-3					0-1	
34 58	117 10	35	1			0-1						
		M										
34 00	118 25	1	1	0-1		1*-0						
34 01	118 21	2	3	0-3	0-2							
34 01	118 33	3	2	1-0	2-0	1-0						
34 02	118 08	4	5	2-2	0-4							
34 04	118 16	5	1	0-1	0-1	1-0	0-1					
34 05	118 55	6	2	1-1	1-1	1-0	0-1					
34 08	118 44	7	10	2-1	7-2	1-0						
34 09	118 09	8	1		1-0							
34 11	118 16	9	2	1-1	1-1							
34 17	118 37	10	2	0-2	0-2							
34 18	118 08	11	5	1-2	1-4	0-1						
34 18	118 33	12	1	1*-0	1-0	1-0	1*-0					
34 18	118 52	13	5	1-3	1-3		0-2	0-2*	1-0			
34 19	118 19	14	2	1-1	1-1							
34 20	118 15	15	1	1-0	1-0	1-0						
34 20	118 30	16	1	1-0	1-0							
34 21	118 24	17	2	1-1	1-0	0-1						
34 25	118 46	18	2	1-0	2-0	1-0						
34 28	118 05	19	1	0-1	0-1							
34 28	118 13	20	3	0-3	0-2	0-2						
34 29	118 48	21	3	0-1	1-1		0-1*					
34 29	118 55	22	4	1-3	1-3	0-3						
34 30	118 35	23	10	0-10	0-2	0-3						
34 35	118 40	24	2	0-2	0-2	0-1*						
34 36	118 34	25	1	1-0	1-0							

TABLE 2—Continued

Epicenter		No.	N	Pa	MW	R	SB	T	H	LJ	Pr	B
N. Lat.	W. Long.											
° /	° /	M										
34 36	118 55	26	3	2-1*	2-1		1-1		1*-1*			
34 41	118 23	27	2	1*-0	1-1	0-1*		0-1	1-0			
34 43	118 58	28	1	1-0	0-1*	1-0	1*-0	0-1				
34 55	118 15	29	1		0-1							
34 57	118 51	30	2	1-1	1-1	0-1	0-1	0-1				
34 58	118 59	31	1	0-1	0-1							
34 59	118 35	32	3	0-1	0-3	1*-0						
		N										
34 11	119 02	1	1	0-1	1-0							
34 12	119 10	2	2	2-0	2-0		2-0					
34 15	119 24	3	1		1-0		1*-0					
34 15	119 32	4	5	1-1	2-0	1*-0	0-4					
34 15	119 45	5	2	1*-0	1-0		0-2					
34 20	119 35	6	1	0-1	0-1	0-1	0-1					
34 24	119 43	7	9	2-3	6-0		7-3*		0-1			
34 25	119 04	8	3	1-0	1-0	1*-0	1-1					
34 25	119 15	9	1	1-0			0-1					
34 26	119 51	10	3	0-1			2-1					
34 30	119 15	11	2				2-0					
34 30	119 25	12	1	1-0	1-0	0-1	1-0					
34 30	119 48	13	1				0-1*					
34 31	119 39	14	9	3-0	2-4		3-4					
34 32	119 33	15	3	1*-1	3*-0		0-1					
34 35	119 15	16	1	1-0								
34 35	119 42	17	9	3-0	2-1	1-0	4-5					
34 36	119 37	18	3	1-0	1*-0		3-0					
34 39	119 00	19	1	0-1								
34 42	119 11	20	1		0-1		0-1					
34 45	119 45	21	1	0-1			1-0					
34 49	119 00	22	12	4-4	3*-2*	9-0	1-5	0-3*	1-2			
34 52	119 10	23	3	0-3	1*-2		0-2	0-2			0-1	
34 55	119 20	24	1		1*-0		0-1					

TABLE 2—Continued

Epicenter		No.	N	Pa	MW	R	SB	T	H	LJ	Pr	B
N. Lat.	W. Long.											
° /	° /											
O												
34 23	120 23	1	2	1-0	2-0							
34 34	120 46	2	28	8-4	18-2	2-0	11-5	0-1*				
34 35	120 20	3	5	2-1	2-1*		1*-3	2*-1*				
34 35	120 25	4	1				0-1*					
34 42	120 15	5	1	0-1	0-1		0-1					
34 45	120 20	6	1	1-0	1*-0							
34 50	120 35	7	3	1-0	1-0		3-0					
P												
35 00	116 13	1	1	1-0	1-0	0-1			1-0			
35 05	116 14	2	4	0-1		0-1		1*-0				
35 15	116 57	3	1	0-1	0-1	0-1						
35 28	116 42	4	1	1*-0	1*-0	1*-0						
35 33	116 59	5	1		0-1*			1*-0	0-1*			
35 36	116 24	6	1		0-1							
35 48	116 40	7	1		0-1*	0-1*			1-0			
35 50	116 32	8	2	0-1	0-1			0-1	2-0			
35 56	116 52	9	1		0-1	0-1			1-0			
Q												
35 00	117 00	1	7		0-3	0-6						
35 15	117 53	2	2		0-1	0-1			0-1			
35 23	117 52	3	2	0-1	0-2	1-0			1-1		1-0	
35 23	117 58	4	1			0-1						
35 25	117 36	5	1					0-1	0-1			
35 35	117 05	6	2	0-1	0-1	0-1*			0-1*			
35 36	117 39	7	2	0-2	0-1	0-1	1-0	0-1	0-1	0-1		
35 36	117 49	8	1						1-0			
35 37	117 17	9	2		0-1	0-1*		0-1*	0-1*			
35 44	117 55	10	5		1*-1			0-2*	3-1			
35 50	117 00	11	2	1-0		1-0		0-1*	1-0			
35 50	117 39	12	4		0-1*	1-0		0-1*	3-1			
35 50	117 52	13	3	0-1				1*-1*	3-1			
35 58	117 55	14	3	0-1		0-3*			3-0			
35 59	117 17	15	1					0-1*				

TABLE 2—Continued

Epicenter		No.	N	Pa	MW	R	SB	T	H	LJ	Pr	B
N. Lat.	W. Long.											
° /	° /	R										
35 00	118 53	1	6	1-3	2-2	1*-0	1*-0	1-2*				
35 01	118 23	2	1	1-0	0-1	1*-0						
35 05	118 40	3	1	0-1	0-1	1*-0			1*-0			
35 06	118 20	4	1		1-0				1-0			
35 10	118 10	5	1		0-1							
35 11	118 59	6	1	0-1	0-1		1*-0	0-1				
35 17	118 52	7	3	0-2	0-3	0-1	0-1*	0-1*	0-1*			
35 22	118 50	8	2	0-2	0-1*	0-1*	0-1	0-2	0-1			
35 37	118 12	9	1	0-1	0-1			0-1	0-1			
35 42	118 22	10	20	1-4	4-2	6-2	1-4	6-7	13-7			
35 48	118 31	11	1			0-1*		1-0	0-1			
35 50	118 00	12	2	0-1	0-1	0-1		0-2	0-2			
35 53	118 17	13	1	0-1	0-1	0-1*		1-0	1-0			
35 59	118 29	14	4	0-1*	0-1*			4-0				
		S										
35 00	119 30	1	1	1-0	0-1		0-1					
35 02	119 16	2	2	2-0		2-0	0-1*					
35 05	119 07	3	3	1-2	1-1		2-0	2-1	2-0			
35 15	119 09	4	1	0-1	0-1*	1*-0	0-2					
35 20	119 26	5	1		0-1							
35 20	119 50	6	1				0-1					
35 27	119 15	7	1	0-1		0-1*	0-1*	0-1	1-0			
35 40	119 18	8	1	0-1	0-1	0-1	0-1	0-1	1*-0			
		T										
35 07	120 05	1	2	0-1	2-0		1-1		0-1*			
35 17	120 29	2	1	0-1*	0-1		1*-0		1*-0			
35 22	120 58	3	1				1-0					
35 46	120 28	4	1					1-0	1-0			
35 48	120 20	5	24	12-0	13-1	4-1	0-16	13-4	16-1		1-0	0-6
35 50	120 45	6	1				1*-0	0-1*	1*-0			
35 56	120 29	7	11	6-2	3-2	2-0	0-7	6-0	6-0			1*-0
35 58	120 35	8	1	0-1			0-1	0-1*				
35 42	121 07	9	1	1-0	1-0							
35 57	121 30	10	1		1*-0		0-1	1-0	0-1*			
35 20	124 40	11	1		1-0			0-1	0-1*			

TABLE 2—Continued

Epicenter		No.	N	Pa	MW	R	SB	T	H	LJ	Pr	B
N. Lat.	W. Long.											
° /	° /											
36 00	114 48	1	1			0-1						
36 30	115 00	2	1					1-0				
36 00	116 00	3	1					1*-0				
36 41	116 58	4	1					1-0	0-1			
36 00	117 14	5	3	0-1		0-1		0-1	3-0			
36 00	117 35	6	1	0-1				0-1*	1-0			
36 00	117 44	7	8	0-3	0-2	0-1		0-2	6-2*			
36 09	117 57	8	16	0-3	0-3	0-2		0-8	9-2			
36 10	117 50	9	1					1-0	1-0			
36 12	117 43	10	1					1*-0	1*-0			
36 38	117 51	11	1					0-1				
36 39	117 13	12	6			0-1*		6-0	0-1*			
36 40	117 25	13	1					1*-0				
36 48	117 06	14	1						1-0			
36 55	117 30	15	1					1-0	1-0			
		V										
36 00	118 24	1	1			0-1*		0-1	1-0			
36 02	118 30	2	1					1-0	1-0			
36 08	118 48	3	1*					0-1	1-0			
36 20	118 15	4	1		0-1*			1-0	1-0			
36 22	118 00	5	8	0-1		0-1		7-1	0-1			
36 25	118 10	6	1						0-1			
36 30	118 05	7	1			0-1		0-1	0-1			
36 40	118 06	8	3	0-1			0-1*	3-0	0-3			
		W										
36 00	120 33	1	1				0-1*	0-1				
36 05	120 17	2	1					1-0				
36 06	120 00	3	1						0-1			
36 10	120 55	4	2		0-1			0-1	0-1*			2-0
36 14	120 19	5	1	0-1	1*-0			0-1	0-1			
36 18	120 54	6	1	1-0	0-1		0-1	0-1	1*-0			1*-0
36 30	120 55	7	1	1*-0			0-1*	1*-0				
36 10	121 32	8	1				0-1					0-1
36 12	121 18	9	1		1*-0							
36 24	121 00	10	2	0-1			0-1	1-0	0-1			1*-0

TABLE 2—*Concluded*

Epicenter		No.	N	Pa	MW	R	SB	T	H	LJ	Pr	B
N. Lat.	W. Long.											
° /	° /	Y										
38 35	117 50	1	8			1-0		1-7	1*-1			
38 00	118 00	2	31					9-22	1-2			
38 00	118 35	3	16					1-15				
38 12	118 36	4	1					0-1				
38 18	118 18	5	1					0-1				
38 30	119 00	6	1	0-1								
38 48	120 06	7	1					1-0				
		Z										
39 00	117 00	1	6					0-6				
39 12	117 30	2	1					0-1				
39 00	118 00	3	2					0-2				
39 00	119 12	4	1					0-1				
39 40	122 00	5	1	1-0				0-1				

A higher sensitivity is also used at the trial station at Palomar. All other stations have relatively large microseisms which permit only a much smaller magnification of the instruments, at some even not one-tenth of that at Pasadena. Besides, the determination of epicenters is less accurate and more difficult in the regions of the stations which are more remote from the center of the group. As a consequence, records of only 201 shocks could be used at Santa Barbara, of 219 at Haiwee, and of 289 at Tinemaha. The somewhat larger figure (426) for La Jolla is due to the occurrence of larger shocks in the Imperial Valley and Lower California.

DISTRIBUTION OF COMPRESSIONS AND DILATATIONS

Table 3 shows that in certain regions, for example the area *K*, compressions prevail greatly at one station, dilatations at another. To get a clearer picture, the data of table 2 were used in two different ways. First, for each station a map was constructed indicating for each epicenter whether it was the source of shocks producing prevaillingly initial compressions or dilatations at the given station. Figure 3 shows part of these maps for Mount Wilson, Riverside, and La Jolla.¹ Second, maps were constructed using all stations simultaneously. Sections of these maps are reproduced in figures 4 to 6. Care should be taken not to misinterpret the data. For example, an arrowhead toward Pasadena at

¹ Maps and figures were drawn by Mr. J. Nordquist; the faults were indicated as given by Willis and H. O. Wood (Willis, 1923) and by Jenkins (1938).

TABLE 3
NUMBER OF COMPRESSIONS AND DILATATIONS OBSERVED FOR EACH AREA
(Arrangement and symbols as in table 2)

Area	Number of		Pa	MW	R	SB	T	H	LJ	Pr	B
	Epic.	Shocks									
A.....	7	33	3-3	1-5	3-3	1-0	0-1	0-1	20-8	0-4	
B.....	13	72	8-2	8-10	8-10		0-1		49-2	7-2	
C.....	19	49	7-5	8-7	12-7				23-19	1-1	
D.....	9	19	1-4	0-7	0-13	0-1	0-2		0-16	0-1	
E.....	8	13	0-6	1-8	1-7				5-1		
F.....	4	21	2-5	3-3	9-3				15-2	4-0	
G.....	47	332	96-57	135-51	149-66	2-0	0-1	1-1	99-64	7-0	
H.....	50	265	71-59	96-91	99-110	7-0	1-5	0-3	3-36	6-2	
I.....	42	286	37-159	35-189	75-58	14-3	1-1	2-5	13-5	6-1	
J.....	5	13	3-7	4-8	3-2	1-4			0-1	0-1	
K.....	30	142	54-24	74-15	86-19	4-0	2-1	4-2	1-31	1-21	
L.....	35	142	81-13	91-20	48-57	6-1	0-6	0-6	1-11	2-3	
M.....	32	85	22-43	28-40	10-13	3-7	0-5	3-1			
N.....	24	76	22-17	28-11	12-2	28-33	0-5	1-3		0-1	
O.....	7	41	13-6	24-4	2-0	15-10	2-2				
P.....	9	13	2-3	2-6	1-5		2-1	5-1			
Q.....	15	38	1-6	1-11	3-14	1-0	1-9	15-9	0-1	1-0	
R.....	14	45	3-17	7-16	9-7	3-6	13-16	16-13			
S.....	8	11	4-5	1-5	3-2	2-7	2-3	4-0			
T.....	11	45	19-5	21-5	6-1	4-26	21-7	25-4		1-0	1-6
U.....	15	44	0-8	0-5	0-6		13-13	23-6			
V.....	8	17	0-2	0-1	0-3	0-1	12-4	4-6			
W.....	13	16	2-2	2-3	1-0	2-6	2-4	4-6			
X.....	27	72	1-6	1-11	2-3	0-2	15-46	13-29		0-1	6-2
Y.....	7	59	0-1		1-0		12-46	2-3			1-7
Z.....	5	11	1-0				0-11				
Total.....	464	1960	453-465	571-532	543-411	93-108	101-188	120-99	229-197	36-38	8-15

a given epicenter means only that after a shock at this epicenter (within the limits of error) the first longitudinal wave recognizable on the Pasadena record indicated an initial compressional movement at Pasadena. Usually, this can be interpreted also by stating that a compression left the focus in the direction toward Pasadena. However, this may sometimes mean that the initial movement at the focus was a purely horizontal movement with a component toward Pasadena, or that the block on the side of the fault on which Pasadena is situated moved upward without horizontal displacement (if the distance to Pasadena was less than that of the critical circle in fig. 2, usually about 110 km.); if Pasadena was more distant than 110 km., it may have been a purely vertical movement downward of the same block; finally, several types of combinations of vertical and horizontal movements could give an initial compression at Pasadena in the case just mentioned. Only by knowing the direction of the fault and combining data from stations in various directions and at various distances may conclusions be drawn with confidence. The convergence of the arrows toward the stations is of course due to the arrangement of the figures.

In regions where the faults are almost parallel, figures of the type of figure 3 are preferable for the interpretation of the results. From figure 3 and similar figures for the other stations it is obvious that the pattern of compressions and dilatations within the limits of the map corresponds very closely to that found theoretically in figure 1. Whether the beginning of the seismogram from a shock in the region of figure 3 corresponds to a compression or a dilatation hardly depends upon conditions at the epicenter, but chiefly upon the direction of the epicenter relative to the station. In all three maps of figure 3 and also in those for the other stations the boundaries between epicenters supplying dilatations and those giving compressions at a given station are given approximately by two straight lines (light dotted lines in fig. 3) through the station, one in the direction of the faults, the other perpendicular to it. Some of the exceptions are certainly due to errors, either in the plotted direction of the first movement or in locating the epicenter; they increase with distance from the station, owing to the decrease in the amplitudes of the first impulse on the seismogram and, especially in the southern part of the map, to the increasing difficulty in locating the epicenters. Probably both sources of error are responsible for exceptional points plotted in the southeast area of the map for Mount Wilson. Some clerical errors certainly have been introduced in the course of the investigation. Other discrepancies will be real, owing either to the fact that contrary to our theoretical assumptions the faults are not strictly parallel, or to the fact that the vertical movement at the fault was not zero. For example, shocks from some of the epicenters between the Elsinore fault and the San Jacinto fault produced compressions at Riverside, whereas from figure 1 dilatations should be expected; the other stations do not show any discrepancy for this region. The direction toward Riverside is so close to that

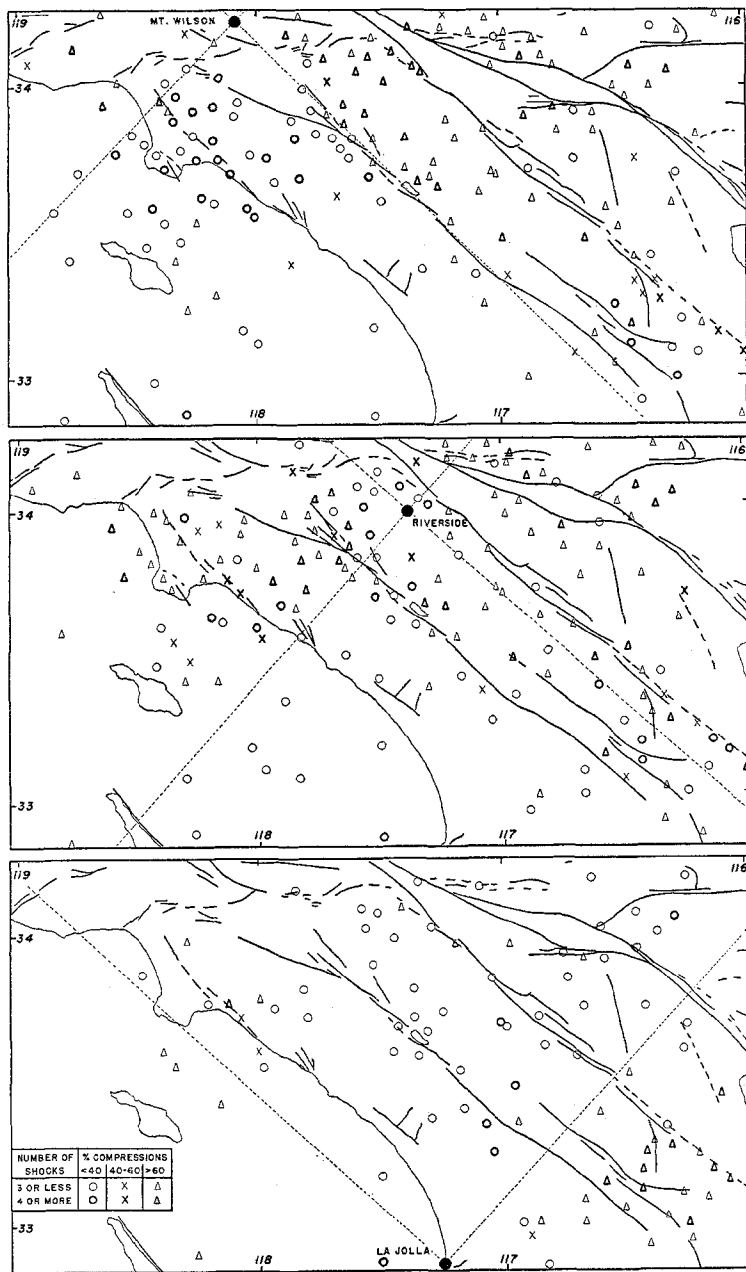


Fig. 3. Epicenters of shocks producing compressions and of shocks producing dilatations at: (top) Mount Wilson, (middle) Riverside, (bottom) La Jolla.

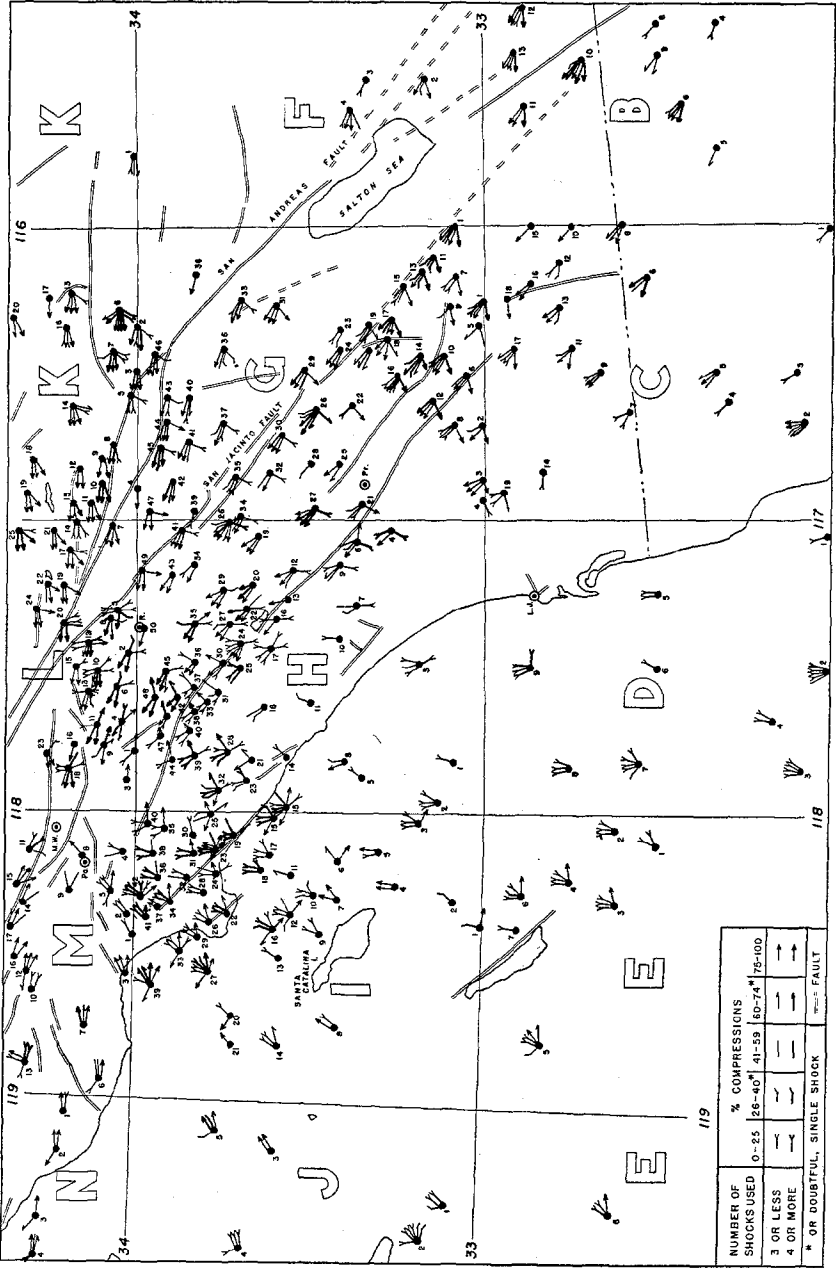


Fig. 4. Distribution of compressions and dilatations in shocks originating in southern California south of the Transverse Belt. Letters indicate the area, and numbers the epicenters as in table 2. The figure should not be used for drawing conclusions unless the accompanying text is also consulted.

of the faults in the area just mentioned that small deviations in the direction of the faults from the average, or small vertical movements, or small errors in the location of some of the epicenters, would account for the exceptional points in the pattern. An area with deviations from the rule lies to the east of Santa Catalina Island. Otherwise, the agreement between the observations and the pattern in figure 1 is surprisingly good, so that we may conclude safely that in the area mapped in figure 3 the results indicate that the suppositions made in constructing figure 1 apply to this region: movements at the source take place in excellent agreement with the rebound theory; vertical movements are relatively small; the movements are uniform over the whole region, irrespective of whether the shock occurs on a large fault or in the area between two major faults; in practically all instances the block on the northeast side of the fault starts to move toward the southeast relative to the other block.

The results found from figure 3 are supplemented by conclusions drawn from figure 4. As mentioned above, this latter figure indicates whether the first impulse from a given focus left this and arrived at the station as a compression or a dilatation; epicenters showing no clearly prevailing direction are marked by a line without arrowhead. The general distribution of the arrows is rather uniform, although the results are not quite so clear as those in figure 3, which can be interpreted more easily. The material given in table 2 covers ground extending beyond the limits of figure 4 to the west, south, and east. (For the north, see figs. 5 and 6.) To the west there are only a few additional epicenters. To the south, the unmapped data seem to agree with the conclusions; the observations, the location of the epicenters, and the information about the direction of the faults are the less reliable the farther to the south the epicenters are. This is similarly true for the unmapped epicenters to the east of figure 4. Moreover, shocks decrease in that region in number as well as in magnitude.

A few epicenters listed in table 2 and mapped in figures 3 and 4 require special notes.

B. 10.—The data given separately in table 2 refer to the Imperial Valley shock of May 18, 1940. This is the only instance in table 2 in which faulting has been found at the surface consistently and beyond doubt. According to the investigations of Buwalda and Richter (1940, 1941), the fault trace, trending about S 35° E for at least 40 miles, showed consistently a horizontal displacement of the southwest side to the northwest relative to the northeast side by a maximum amount exceeding 15 feet. The vertical dislocation, locally attaining 4 feet, was usually much less and the throw was sometimes to one side and sometimes to the other. The recorded compressions and dilatations correspond exactly to the field evidence under the assumption that the rebound theory is correct. Different data, in part, for the aftershocks may be due either to the loss of the first movement at the distant stations or to relatively small shifts

in the epicenters. Differences in the location of the sources of aftershocks and the main shocks by as much as 50 km. or even more are the rule with shocks of the magnitude of the Imperial Valley earthquake.

G. 14.—Agua Caliente fault near Verruga. Up to September, 1939, these shocks usually recorded with an initial compression at Mount Wilson and Riverside, later on with dilatations. The arrival times indicate a slight shift in the epicenter. Time intervals for beginnings at Riverside and Pasadena are:

1935, Oct. 14	1938, July 10	1939, Aug. 19	Nov. 26	Dec. 5	Dec. 14
9.5	9.3	10.7	10.5	11.3	11.3 sec.

Considering all the data available, the maximum shift in epicenter cannot have exceeded 15 km., but Mount Wilson and Riverside are close to the line dividing the areas of compressions and dilatations for these shocks. The effect may have been increased by the fact that the faults in the region of the epicenter have distinctly different directions. At Pasadena, only 5 of the 18 shocks had a beginning large enough to permit decision with respect to the direction and even then only with some doubt. This is characteristic of records of shocks from epicenters near the boundary lines between compressions and dilatations.

G. 26.—The epicenter listed separately is that of the Terwilliger Valley earthquake of March 25, 1937. (See Wood, 1937). The data for shocks from this source supply another example to indicate that in the neighborhood of the boundary lines between areas of compressions and dilatations the observed initial direction does not change at random. For this epicenter the directions toward Pasadena, Mount Wilson, and Riverside are close to the direction of the faults, and the direction toward La Jolla is almost perpendicular to it, so that all four stations are close to a boundary line between compressions and dilatations. The differences in the location of the epicenter are small, but clearly indicated by the time intervals of the first waves at Pasadena and Riverside. There is also a peculiar change in the amplitude ratio A of the seismogram maxima at La Jolla and Riverside. Table 4 gives data for larger shocks from this epicenter. As the epicenter moves in a direction toward Pasadena, keeping about equal distances from La Jolla and Riverside, La Jolla moves from the northwestern zone of compressions (figure 1) into the southwestern zone of dilatation.

H. 15.—The shock separately listed is the Long Beach earthquake of March 10, 1933. Riverside is here practically on the line separating compressions and dilatations, whereas Pasadena and Mount Wilson are definitely in the region of dilatations. Shocks 50 miles farther to the northwest produce compressions at all three stations. As a consequence, shocks near Huntington Beach rarely show a clear beginning at Riverside, whereas shocks from the neighborhood of Redondo Beach have frequently a rather poor beginning at Mount Wilson and

Pasadena. The beginnings of the records just mentioned seem to be influenced, too, by complications in the path under the Los Angeles Basin.

I. 23.—This epicenter, near Signal Hill, belongs to the earthquake of October 2, 1933. This is one of the larger aftershocks of the Long Beach earthquake, and had initial compressions at all seven permanent stations, whereas the main Long Beach earthquake started everywhere except at Santa Barbara with a dilatation. Therefore, the possibility has been discussed that the "Signal Hill shock" may have been one of the rare occasions on which the fault movement has reversed after an overshooting of the equilibrium position. However, there

TABLE 4
INITIAL BEGINNING OF SHOCKS FROM EPICENTER G. 26 (TABLE 2) AT LA JOLLA
(For details see text)

Date	Time ^a	M ^b	Time difference		A	Beginning LJ
			Pa-R	R-LJ		
	Hr. Min.		Sec.	Sec.		
1937, Mar. 26	13:24	4	12.2	0.3	3	Comp.
1937, Apr. 6	9:44	3½	12.0	0.3	4	Comp.
1937, Apr. 9	7:03	3½	12.0	0.1	2½	Comp.
1937, Mar. 25	12:04	4	11.5	0.2	2	Comp.
1937, Nov. 29	15:52	3½	11.3	0.6	1½	Comp.
1938, Jan. 10	3:52	3½	11.2	?	2½	Comp.
1937, Apr. 7	13:32	3	11.2	0.4	½	Dilat.
1937, Mar. 25	15:20	4	10.7	1.0	3	Comp.
1939, May 12	11:25	4½	10.6	0.4	1	Comp.
1937, Oct. 11	2:26	3	10.4	?	(1)	Dilat.
1937, Mar. 25	8:49	6	9.9	0.6	?	Dilat.
1937, Oct. 24	14:41	3	9.6	0.4	(4)	Dilat.
1937, Oct. 22	15:32	3	9.2	0.8	(3)	Dilat.

^a All times are given as Pacific Standard Time (8 hours slower than G.C.T.)

^b M equals magnitude.

is now doubt about this explanation. Mount Wilson and Pasadena are less than 50 km. from the line separating compressions and dilatations in case of a purely horizontal movement; Riverside is probably in the northeast sector with dilatations (fig. 1); La Jolla is in the line of the fault within the limits of error; a small vertical movement superimposed on the horizontal movement could easily account for the difference at all these stations and those in the Owens Valley. The only station far from any critical line is Santa Barbara, and the record there starts with a compression in both shocks. Although a reversed movement along the fault is not excluded, the evidence is not good enough to favor such an explanation. During this entire research no clear instance of a "reversed" movement along a fault has been found.

For the region extending to the north from the San Gabriel and Santa Monica Mountains, maps similar to those in figure 3 were constructed. Although the general distribution of compressions and dilatations still follows the pattern given in figure 1, there are many more exceptions than in figure 3. In the Transverse Belt, where there are two major groups of faults with directions intersecting each other obliquely, compressions and dilatations seem to scatter at random. Other exceptional areas are in the Sierra Nevada. However, this is just what is to be expected. Figures of the type of figure 3 should give a pattern with well-defined boundaries only where the faults are nearly parallel.

Figures 5 and 6 show the prevailing initial movements for epicenters in these regions. All remarks made in connection with figure 4 apply here; especially, no conclusions can be drawn from these figures under the assumption that the arrows represent the directions of the movements. Moreover, neither the figures nor tables 2 or 3 can serve as a basis for discussions on seismicity, for the geographical distribution of shocks useful in this investigation depends on the accuracy with which epicenters can be located and upon the distance from stations with small microseisms.

In the area south of the San Andreas fault in figure 5, the general trend of the movements seems to be in the usual sense. Exceptions may be due to faults having a different direction. Whereas in figures 3 and 4 incorrect locations of epicenters disturb the pattern only in the neighborhood of boundary lines, they must result in an inextricable mixture of compressions and dilatations in those regions of figures 5 and 6 in which the directions of the faults change from place to place.

In the region of the San Bernardino Mountains the pattern in general corresponds to that given in figure 1. This is true, too, for the Mohave Desert area; in its western part the activity is relatively low. The Garlock fault has not been very active in recent years. The locations of the stations are not favorable to the investigation of the horizontal component of the movement in the direction of this fault; if such a component exists, it is probably directed toward the east on the southern side of the fault. There are contradicting data, especially from records of the stations north of the fault. Some of the epicenters located near the Garlock fault may belong to faults running in a different direction.

The directions of the faults in the southernmost part of the San Joaquin Valley are not indicated on the maps. The majority of compressions and dilatations from shocks of this region correspond to those from shocks on the San Andreas fault, which, however, have been relatively rare since shocks have been located with higher accuracy (about 1932). An interesting epicenter is the one marked N. 22, near the bend of the San Andreas fault. As is to be expected, a relatively small shift in the epicenter changes the pattern of dilatations and compressions. Whereas Riverside is always in the southeastern sector of compressions (figure 1), Pasadena and Mount Wilson are in this same sector for

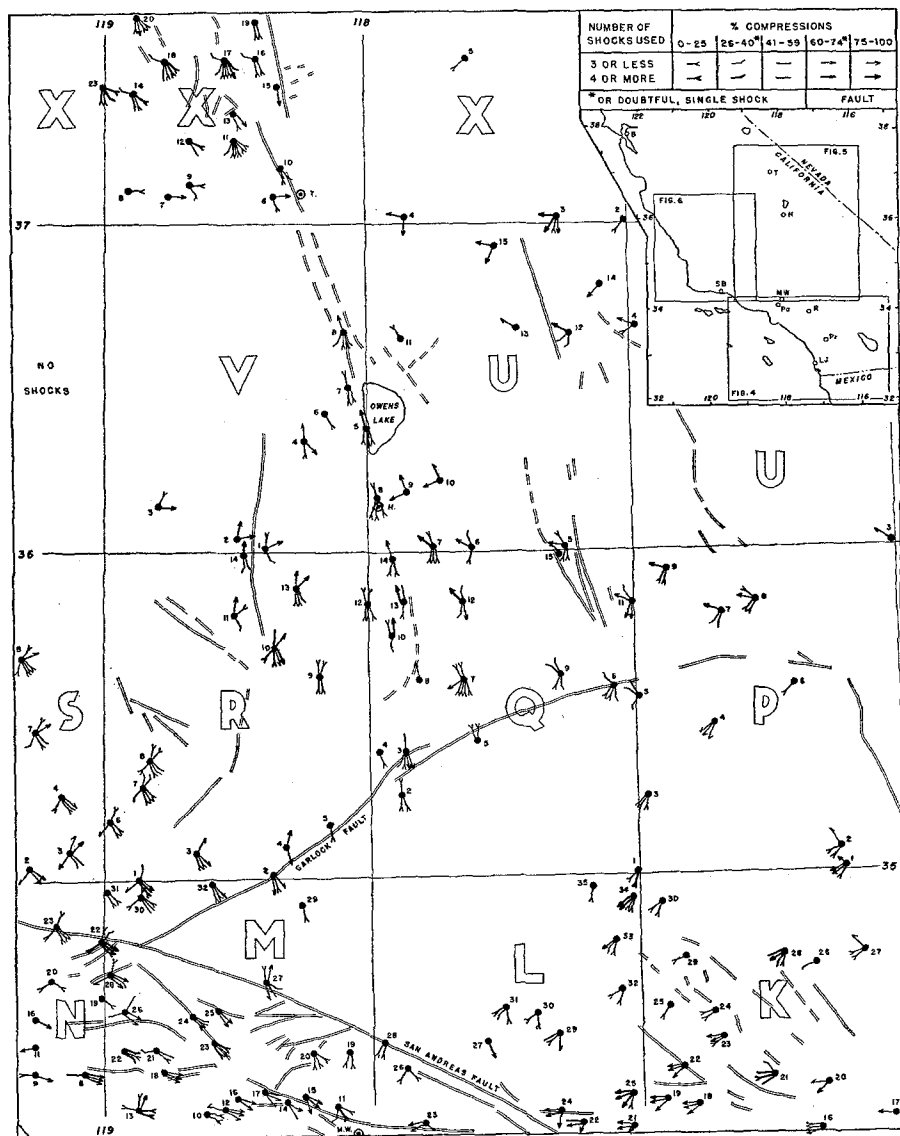


Fig. 5. Distribution of compressions and dilatations in shocks originating in central California north of the Transverse Belt, eastern section. Inset: map of southern and central California showing the location of the stations and key to figures 4, 5, 6. Symbols for stations as given in table 1. Letters indicate the area, and numbers the epicenters as in table 2. The figure should not be used for drawing conclusions unless the accompanying text is also consulted.

some shocks, in the southwestern sector of dilatations for others. The differences in travel times suggest a shift of the epicenters in a northeasterly direction rather than along the San Andreas fault. In general, the farther to the northeast the epicenters are, the smaller are the maximum amplitudes at Santa Barbara relative to those at Pasadena; the decrease from about 7 to about $\frac{1}{2}$ is much too rapid to be due to the increase in distance from Santa Barbara, but is probably connected with the position of the epicenter relative to the main branch of the fault, that is, to the southwest or northeast of it.

Several epicenters are near the Kern River fault. Again, there are differences in the pattern of compressions and dilatations, this time probably connected with the direction of the fault near the epicenter. The data are too scanty and uncertain in every respect to permit the drawing of definite conclusions. For example, the shocks referred to epicenter *R. 10* have arrival times at Pasadena between 0.6 sec. earlier and 7.7 sec. later than at Tinemaha. If this is due to differences of location of the epicenter along a line approximately in a north-south direction, the corresponding foci are spread over a distance of about 30 km. As figure 5 shows, the faults there have quite different directions, and no definite pattern can be expected from using the combined data of these shocks. In 4 out of 5 shocks for which the time interval of arrival at Pasadena minus arrival at Tinemaha is between -0.6 and $+3.1$ seconds (southern epicenters), the first impulse at Haiwee is a dilatation and the initial directions at all stations correspond to the pattern in figure 1, whereas in 6 out of 7 shocks with time intervals from 3.1 to 5.9 seconds the movement at Haiwee starts with a compression. This as well as the compressions recorded at Haiwee from epicenters farther to the north near the Kern River fault indicate a different type of movement there, whereas at the southern epicenters of this group the movements possibly occur in the "usual" way.

In the central Sierra Nevada, in and south of the Mammoth Lakes area (region *X*, west of Owens Valley), the pattern is uniform, but does not correspond to the "usual" pattern. At Tinemaha, the beginnings are regularly dilatations, while compressions would correspond to figure 1. This may be due to a somewhat different direction of the faults, or to vertical movements. If the latter is the reason, the areas east of the faults should move downward, unless the foci are very shallow.

To the south and southeast of Owens Valley, the usual pattern prevails. Along the Owens Valley fault, the direction of the arrows is so close to the direction of the faults (owing to the locations of the two stations there, both very near the fault) that no convincing conclusions can be drawn. The relatively few data there and to the northeast of Owens Lake (region *U*) agree with the general pattern. This is true, too, for the epicenters north of Owens Valley and southeast or east of Lake Tahoe (*X. 21*, *Y. 2* and *3*, all unmapped). *Y. 2* corresponds to a series of rather widely scattered foci in western Nevada

and includes the Nevada shock of December 20, 1932. This earthquake has been investigated by Gianella and Callaghan (1934). They found that a few small horizontal movements could be recognized in the field; in these, "the east side has actually moved south with respect to the west side, and this direction of movement is indicated by the pattern of the echelon fissures" (*loc. cit.*, p. 362). The shock on January 30, 1934, near 38° N, $118\frac{1}{2}^{\circ}$ W (near epicenter Y. 3), did not supply useful beginnings; at Tinemaha, the first visible wave corresponds to a dilatation, with considerable doubt. Callaghan and Gianella (1935) found that a fault running southwest-northeast was formed at the time of the earthquake with mainly vertical displacement. "The pattern of the *en échelon* fissures indicates a slight relative horizontal movement or component of movement of the north side toward the southwest with respect to the south side" (*loc. cit.*, p. 167).

Data for the Coast Ranges are plotted in figure 6. In the neighborhood of Santa Barbara, the pattern is rather regular, but the epicenters are not located well enough and the data are not sufficient to permit definite conclusions to be drawn. Shocks referred to epicenter O. 2 (off Point Arguello) probably really belong to different foci; no exact locations can be found, as Santa Barbara, Pasadena, Mount Wilson, Riverside, and the epicenters are almost on one line, and the other stations are usually too distant to record the beginning of these shocks.

Most shocks near the section of the San Andreas fault in figure 6 supply the "usual" pattern; in the northern part of figure 6, the epicenters are rather far from the stations, and the impulse considered the first movement may be a later one. The most prominent epicenter is T. 5, the source of the "Parkfield shocks." (See Byerly and Wilson, 1935.) The directions of the initial movement are very persistent. The only comment concerns Tinemaha; up to June 11, 1934, the shocks recorded there with a compression, the shocks during the following days recorded with an initial dilatation. Again, as previously, definite shift of the epicenters is indicated by the differences of the first arrival at the various stations. During the first period, the waves arrived at Pasadena between 5.7 and 3.5 sec. later than at Tinemaha; during the second period, this time interval was between 3.6 and 2.9 sec., indicating more southeasterly location of the sources. During the earlier period, Tinemaha was in the southeast sector of compressions (fig. 1); later on, it was in the northeast sector of dilatations.

No shocks are located in the region between 36° and 37° N and 119° to 120° W. Data for the more frequent earthquakes near the San Andreas fault north of 36° N are scarce. The initial movements at Berkeley were investigated (not listed) for about 30 shocks, but, in general, give no indication with respect to the movement along the fault; the direction epicenter-Berkeley is too close to the direction of the fault. However, a shock off the coast of northern California,

near $41\frac{1}{2}^{\circ}$ N, $124\frac{1}{2}^{\circ}$ W, has been investigated by Byerly (1938). He came to the conclusion (*loc. cit.*, p. 13) that "the earthquake was caused by movement on a fault bearing about $N 40^{\circ}$ W and dipping about 84° northeasterly. The

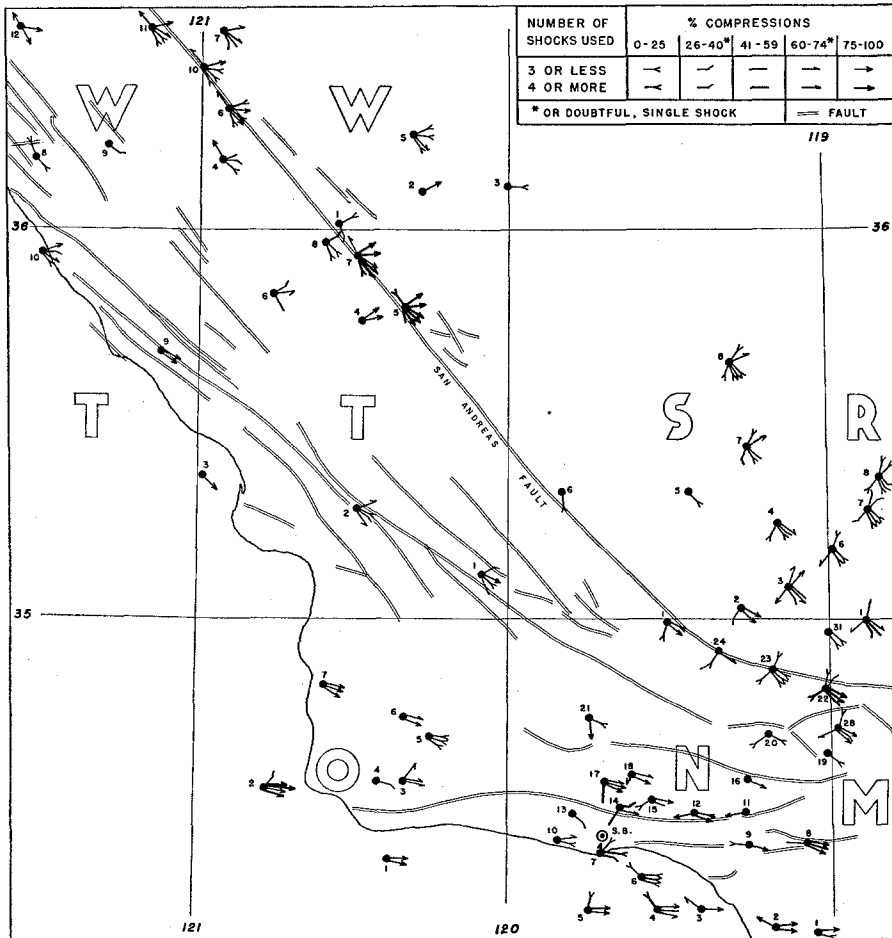


Fig. 6. Distribution of compressions and dilatations in shocks originating in central California north of the Transverse Belt, western section. Letters indicate the area, and numbers the epicenters as in table 2. The figure should not be used for drawing conclusions unless the accompanying text is also consulted.

displacement consisted of a motion of the Pacific side northerly and of the continental side southerly, as in 1906." In general, only a few data are available for the dip angle of the faults in southern and central California; however, geological as well as seismological evidence in these instances indicate that the faults are substantially vertical.

GEOLOGICAL EVIDENCE

Before the San Francisco earthquake of 1906, few details were known about the faults and the types of faulting in California. The first detailed investigation was published by Lawson (Lawson *et al.*, 1908), who discussed the horizontal movements in the vicinity of the San Andreas fault in central California. During the following decades, material was gathered in the field and discussed by Professor Lawson, other members of the staff, and students of the University of California, but in general did not find its way into print. For the Haywards fault, Buwalda (1929) published evidence to the effect that the recent horizontal movement agrees with the movement along the San Andreas fault: the northeast side has moved southeastward relative to the southwest side. At the Sixth Pacific Science Congress, Lawson (1939) stated that even as far from the California coast as the Mother Lode country, faulting indicates the same type of motion as occurs in the coastal region.

In the segment of the San Andreas fault from the region affected by the 1906 earthquake to the Mohave Desert, the recent displacements are in the same sense, as shown by stream offsets, especially in the Carrizo Plain. (See Wood and Buwalda, 1931.) Some of the many photographs from the air (which exhibit outstanding examples of such displacements) have found their way into publications. The following segment to the southeast is discussed by Noble (1926, 1932), who finds the same direction of the movements there as in the northern parts. This type of movement (eastern block moves toward the south relatively) is true, too, for the fault developed during the Imperial Valley earthquake of 1940, already discussed, which extends beyond the Mexican border.

Statements in print concerning the direction of movements along other faults are still more rare, although the general facts are well known and have been discussed verbally for many years. For the Los Angeles Basin, Eaton (1924) stated that the movement of the basin is toward the northwest on the coastal side relative to the landward side. In a later paper (Eaton, 1933) he indicated the direction of the fault movements on the map. For southern California see also Miller (1940).

The only paper in which detailed evidence for the movements over larger parts of California were given seems to have been presented by Buwalda (1937). His conclusions are that at a considerable number of widely separated localities "the block west of the fault has recently moved relatively northward. A long strip at least, of considerable but variable width, is being subjected throughout to vigorous shearing forces roughly similar in direction."

Evidence concerning movements in the Sierra Nevada is known, but no details seem to be available in print. The direction of the movements seems to differ considerably from the "usual" direction, and vertical movements seem

to play an important role. A segment of the Owens Valley fault along the east slope of the Sierra Nevada was the source of the great Owens Valley earthquake of 1872, for which Hobbs (1910) has collected information. There is no doubt from his account and earlier reports of others that relatively large horizontal movements occurred in this shock, but it is characteristic of the progress made in geology during the past fifty years that in the older publications there is scarcely any information about the direction of the horizontal movements. The only mention of a direction by Hobbs refers to a paper by Whitney (1872) in which, in reference to a road from Bend City to Independence, he states: "Here, according to a careful diagram of the locality, drawn by Captain Scoones, it appears that the road running east and west has been cut off by a fissure twelve feet wide, and the westerly portion of it carried 18 feet to the south. The same thing was noticed by us at Lone Pine and Big Pine, with regard to fences and ditches, the horizontal distance through which the ground had been moved varying from three to twelve feet." This direction would be opposite to the direction of movements along the San Andreas fault. Whitney considered them local phenomena. Fortunately, Hobbs included in his report two photographs, made by Mr. W. D. Johnson of the U. S. Geological Survey in 1907, which indicate a movement in the "usual" direction (Hobbs, 1910, Pls. XIX and XX, *b*, and p. 379), unless the pictures have been reversed in the process of reproduction. The first shows a row of trees perpendicular to the fault with an offset of the foreground by 9 feet to the left; if the picture is taken toward the west, the east block in front has moved southward; if it is taken toward the east, the west block in front has moved northward; the relative movement is the same, irrespective of what is assumed. The second photograph is taken toward the west, showing the Alabama Hills and the Sierra in the background, and an arroyo with a displacement by about 20 feet toward the left (south) in the foreground (eastern block). These, and other indications known to the author only by verbal report, seem to indicate that the movement along the Owens Valley fault in 1872 was in the same direction as the recent movements along the San Andreas fault.

The geological data as a whole confirm the findings from the pattern of compressions and dilatations.

CONCLUSIONS

1. The patterns formed by areas with initial dilatations in records of local earthquakes in southern California strongly support the rebound theory.

2. South of the Transverse Ranges, the directions of the movements, with few exceptions, are very uniform from the continental shelf to beyond the San Andreas fault, where the shocks become scarce and supply seismograms showing only small beginnings. In almost all earthquakes the block on the northeast side of the fault moves southeastward relative to the other block. Vertical movements are usually relatively small. There is no difference in this respect

between the larger shocks on the major faults and the many small shocks scattered between them. Reversed movements have occurred rarely, if at all.

Northward from the Santa Monica Mountains, the fault pattern complicates the picture, but there is no evidence that this area does not conform to the general results found for southern California. In the Sierra Nevada, movements of another type are indicated. Most of the shocks with foci to the east and northeast of Owens Valley begin at the two Owens Valley stations with the direction to be expected if this region is included in the general movement; however, there are indications that other types of movement have already larger importance there.

3. Southern and central California from the oceanic margin of the shelf to beyond the regions of Owens Valley and Imperial Valley are under a shearing stress such that its tendency is directed approximately toward the southeast at the bottom of the continent relative to the crust beneath the Pacific. These shearing stresses are straining continuously the whole region in a way similar to that when a sheet of paper is deformed by moving two opposite sides in opposite directions. If at a weak point (fault) the breaking strength is reached, an earthquake occurs. During the known history, a few large shocks have occurred, and on the average there is about one shock every day potentially strong enough to be generally felt near the epicenter.

The source of the stress is unknown, but it is probably connected with the difference in structure of the earth's crust under the Pacific Basin and under the continent.

LIST OF REFERENCES

- BARSTOW, F. E., and EDGERTON, H. E.
1939. "Glass-Fracture Velocity," *Jour. Am. Ceramic Soc.*, 22:302-307.
1941. "Further Studies of Glass Fracture with High-Speed Photographs," *ibid.*, 24: 131-137.
- BENIOFF, H.
1938. "The Determination of the Extent of Faulting, with Application to the Long Beach Earthquake," *Bull. Seism. Soc. Am.*, 28:77-84.
- BUWALDA, J. P.
1929. "Nature of the Late Movements on the Haywards Rift, Central California," *Bull. Seism. Soc. Am.*, 19:187-199.
1937. "Recent Horizontal Shearing in the Coastal Mountains of California," *Proc. Geol. Soc. Am. for 1936*, p. 341. (Abstract)
- BUWALDA, J. P., and RICHTER, C. F.
1940. "Seismological Notes," *Bull. Seism. Soc. Am.*, 30:305-306.
1941. "Imperial Valley Earthquake of May 18, 1940," presented to the Cordilleran Section, Geol. Soc. Am., on April 19, 1941. (Not yet printed)
- BYERLY, P.
1938. "The Earthquake of July 6, 1934: Amplitudes and First Motion," *Bull. Seism. Soc. Am.*, 28:1-13.
- BYERLY, P., and WILSON, J. T.
1935. "The Central California Earthquakes of May 16, 1933, and June 7, 1934," *Bull. Seism. Soc. Am.*, 25:223-246.
- CALLAGHAN, E., and GIANELLA, V. P.
1935. "The Earthquake of January 30, 1934, at Excelsior Mountains, Nevada," *Bull. Seism. Soc. Am.*, 25:161-168.
- EATON, J. E.
1924. "Structure of the Los Angeles Basin and Environs," *Oil Age*, 21:18, 52.
1933. "Long Beach, California, Earthquake of March 10, 1933," *Bull. Am. Assoc. Petrol. Geol.*, 17:732-738.
- GIANELLA, V. P., and CALLAGHAN, E.
1934. "The Cedar Mountain, Nevada, Earthquake of December 20, 1932," *Bull. Seism. Soc. Am.*, 24:345-384.
- HOBBS, W. H.
1910. "The Earthquake of 1872 in the Owens Valley, California," *Gerlands Beitr. z. Geophys.*, 10:352-385.
- ISHIMOTO, M.
1932. "Existence d'une source quadruple au foyer sismique d'après l'étude de la distribution des mouvements initiaux des secousses sismiques," *Bull. Earthq. Res. Inst. (Tokyo)*, 10:449-471.
- JENKINS, O. P.
1938. Geological map of California, Division of Mines, Sacramento.
- KAWASUMI, H.
1933, 1934. "Study on the Propagation of Seismic Waves" (second paper), *Bull. Earthq. Res. Inst. (Tokyo)*, 11:403-453 and 12:660-705.
1937. "An Historical Sketch of the Development of Knowledge Concerning the Initial Movement of an Earthquake," *Publ. Bur. Centr. Séismol. Internat.*, Ser. A, fasc. 15, pt. 2, pp. 258-330.
- LAWSON, A. C.
1939. Sixth Pacific Sci. Cong., Sect. 1-A, Discussion on Aug. 3, A.M., 1939. (Not printed)
- LAWSON, A. C. *et al.*
1908. "The California Earthquake of April 18, 1906," Carnegie Inst. of Washington, 2 vols. and atlas.
- MILLER, W. J.
1940. "Some Features of Faulting in Southern California," *Jour. Geol.*, 48:385-420.

MINAKAMI, T.

1935. "Distribution des mouvements initiaux d'un séisme dont le foyer se trouve dans la couche superficielle et détermination de l'épaisseur de cette couche," *Bull. Earthq. Res. Inst.* (Tokyo), 13:114-129.

NOBLE, L. F.

1926. "The San Andreas Rift and Some Other Active Faults in the Desert Region of Southeastern California," *Carnegie Inst. Year Book* 25, 1925-26, pp. 415-428.
1932. "Excursion to the San Andreas Fault and Cajon Pass," 16th Internat. Geol. Cong. *Guidebook* 15, pp. 10-21.

REID, H. F.

- 1910a. "The Mechanics of the Earthquake," *The California Earthquake of April 18, 1906*, Vol. II, Carnegie Inst. of Washington.
1910b. "On Mass Movements in Tectonic Earthquakes and the Depth of the Focus," *Gerlands Beitr. z. Geophys.*, 10:318-350.
1933. "The Mechanics of Earthquakes. The Elastic Rebound Theory. Regional Strain," in *Physics of the Earth*, VI, Seismology, *Bull. Nat. Res. Council*, No. 90.

SCHARDIN, H., ELLE, D., and STRUTH, W.

1940. "Ueber den zeitlichen Ablauf des Bruchvorganges in Glas und Kunstglas," *Zeitschr. f. Techn. Physik*, 21:393-400.

WHITNEY, J. D.

1872. "The Owens Valley Earthquake," *Overland Monthly*, 9:130-140, 266-278.

WILLIS, B.

1923. "A Fault Map of California," *Bull. Seism. Soc. Am.*, 13:1-12 and map.

WOOD, H. O.

1937. "The Terwilliger Valley Earthquake of March 25, 1937," *Bull. Seism. Soc. Am.*, 27:305-312.

WOOD, H. O., and BUWALDA, J. P.

1931. "Horizontal Displacement along the San Andreas Fault in the Carrizo Plain, California," *Bull. Geol. Soc. Am.*, 42:298-299. (Abstract)

WOOD, H. O., and RICHTER, C. F.

1933. "A Second Study of Blasting Recorded in Southern California," *Bull. Seism. Soc. Am.*, 23:95-110.

CALIFORNIA INSTITUTE OF TECHNOLOGY

PASADENA, CALIFORNIA

(Balch Graduate School of the Geological Sciences, contribution no. 311)