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EARTH MOVEMENTS IN CALIFORNIA

BY

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# EARTH MOVEMENTS IN CALIFORNIA

By WILLIAM BOWIE, *Chief, Division of Geodesy, U. S. Coast and Geodetic Survey*

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## INTRODUCTION

Very soon after the California earthquake in 1906 parties of the Coast and Geodetic Survey were organized to reoccupy a number of old triangulation stations in the vicinity of San Francisco Bay and to reobserve the angles of the triangles with a view to detecting movements which had taken place since the first observations were made a number of years before.

The reoccupation of these triangulation stations took place during the interval from July, 1906, to July, 1907. It extended continuously northwestward from the stations Mount Toro and Santa Ana to Ross Mountain. The area covered was about 170 miles in length and 50 miles in width.

The old triangulation had been done between the years 1851 and 1899 for the control of surveys upon which charts of the bureau were to be based.

The results of the triangulation of 1906 and 1907, as compared with the older work, are contained in Appendix 3 of the report of the Coast and Geodetic Survey for 1907, by John F. Hayford, at that time inspector of geodetic work, and A. L. Baldwin, computer. In the 1906-7 work 11 precise, 8 primary, and 41 secondary stations were occupied. The differences between the old and the 1906-7 geographic positions are shown in tables in the report of the work. Two maps show the earth movements on April 18, 1906, and in 1868.

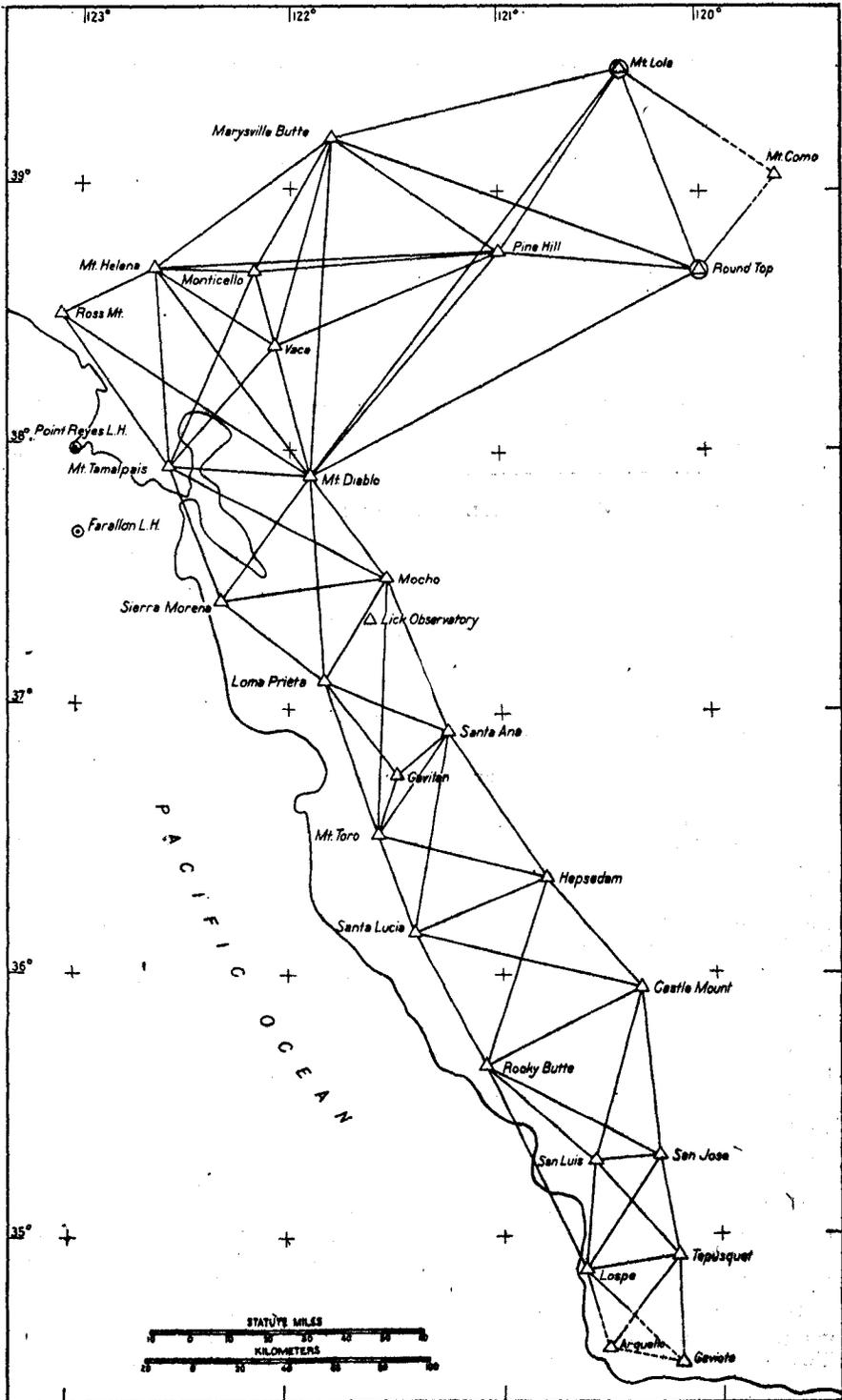


FIG. 1.—Triangulation in California reobserved in 1922-23, northern section

Observations were made at all stations indicated, except Arguello and Gaviota, in seasons of 1922 and 1923. The original observations were made prior to 1887.

Since the publication of the report by Hayford and Baldwin, it had been felt that the new triangulation should have been started from a point farther from the fault of the 1906 earthquake than the stations Mount Diablo and Mocho (see fig. 1), which were used as the base in the 1906-7 work.

At the request of Dr. Arthur L. Day, director of the geophysical laboratory of the Carnegie Institution and chairman of the committee on seismology of that institution, to the Director of the U. S. Coast and Geodetic Survey, plans were made for the re-occupation of precise triangulation stations in California, extending westward from Mount Lola and Round Top, two mountain peaks in the Sierra Nevada Mountains, in latitude approximately  $39^{\circ}$  and longitude  $120^{\circ}$ , westward to the coast and thence to the south and east to the Mexican border. The new work was begun in 1922.

This work was designed to show especially whether any movements had occurred along the coast of California with respect to the area occupied by the Sierra Nevadas in the eastern part of the State. If the whole of the area of California and that just to the eastward were moving as a geological unit, the new triangulation would show small or no changes in the geographic positions of the stations involved, but if the coast were undergoing horizontal movements while the interior remained fixed there would be noticeable changes in the geographic positions of the coast stations.

The plan adopted called for the early reoccupation of the triangulation stations shown in Figures 1 and 2. They extend from Mount Lola and Round Top, with Mount Como as a check point, to Ross Mountain and Mount Tamalpais, on or near the coast, and thence along the coast of California to the southward to a junction with the line joining San Jacinto and Cuyamaca, two stations of what has been called the Texas-California arc.

During the season of 1922, the work was extended from Mount Lola and Round Top southward to the stations Loma Prieta and Mocho. In 1923 the reoccupation of stations was begun at Loma Prieta and Mocho. The work was carried southward in that year to the line Arguello-Gaviota where the observing party encountered heavy fogs which threatened to delay operations materially. Learning that the weather was more favorable to the southward the party was moved to the vicinity of San Diego, where observing began at stations Cuyamaca and San Jacinto and was extended northward and westward to the stations Laguna and Chaffee, inclusive (see fig. 2). The work was discontinued with those stations owing to the exhaustion of the funds made available by Congress for the geodetic work to study earth movements.

Much credit is due Messrs. C. L. Garner and Floyd W. Hough, the chiefs of the field work in 1922 and 1923, respectively, for the efficiency and accuracy with which they carried on the operations, and also to the members of their parties. The office computation and adjustment were ably done under the immediate direction of Dr. O. S. Adams.

It is proposed that during the season of 1924, the remaining stations (New San Miguel, Santa Cruz West, Santa Cruz East, and Santa Barbara) will be reoccupied and thus a junction formed between the northern and southern portions of the arc.

Further plans for testing earth movements in California have not been perfected at the present time, although it is expected that the triangulation stations to the northward of Ross Mountain will be occupied and a connection made with the international latitude station at Ukiah, and that at least one quadrilateral of the Texas-California arc will be reobserved. This would extend from the line

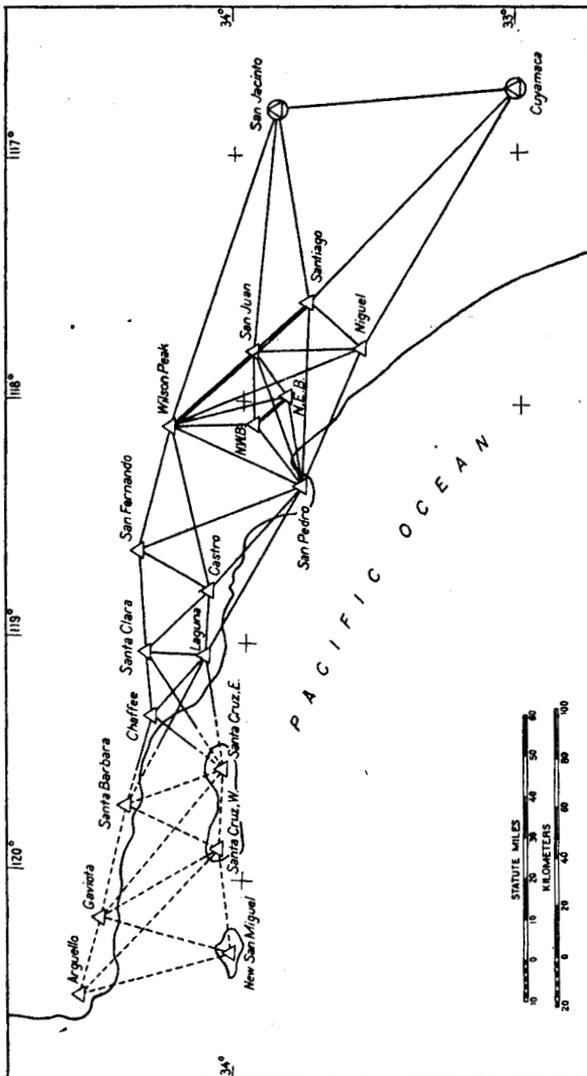


FIG. 2.—Triangulation in California reobserved in 1923, southern section

All stations except the six from which dotted lines are drawn, were occupied during the season of 1923. The stations were established and the first observations made at them prior to 1900. The triangulation shown in Figure 1 extends northward from stations Arguello and Gavito.

Cuyamaca-San Jacinto to triangulation stations near the Colorado River in the southeastern part of California. It is readily understood that, for the purpose of using triangulation in detecting horizontal earth movements, connections should be made with triangulation stations rather far removed in distance from the area which is suspected of undergoing movements.

## REOCCUPATION OF TRIANGULATION STATIONS

The old triangulation had been done for the purpose of controlling the geographic positions of charts along the coast of California and to correlate those charts with the triangulation along the Atlantic coast. All of the old triangulation had been computed and adjusted to the North American Datum a number of years before and therefore the geographic positions resulting from the observed angles of the first occupations of the stations and from the observed angles of 1922 and 1923 are in every way comparable. They are on the same datum and they are computed to the same degree of refinement.

## INSTRUCTIONS

The instructions issued to Clem L. Garner, chief of the party in 1922, read in part as follows:

You will begin observations for precise triangulation from the line Mount Lola-Round Top of the thirty-ninth parallel triangulation, with observations made on the station on Mount Como as a check on the identification of the old stations. You will extend the triangulation to the westward and southward.

This triangulation is to be executed in connection with investigations relative to movements in the earth's crust throughout the region over which you will work and it is, therefore, desirable to make the triangulation as accurate as possible, without undue expense, in order that it may provide a proper base for future comparisons. You will, therefore, take special precautions against conditions which would cause horizontal refraction and will adopt such an observing program as will secure triangle closing errors with 2.5'' as a maximum, and with not more than 1'' as a mean. It is recommended that each direction at a station be measured on at least two nights with not less than 12 acceptable directions on each night. One direction at each station may have only 16 acceptable positions observed and these may be on a single night if by so doing a day may be saved and provided further that the closures are within the above limits. It is desirable to secure as good closing errors as possible, with such a program, but if the results are not within the requirements you should increase the number of observations or the number of nights on which observations are made in order to secure results coming within the prescribed limits.

Since it is important to have the astronomic azimuths of as many lines as possible, you will observe on Polaris for azimuth at each of your main scheme stations, provided your party will not be delayed as much as a day at any one station to get the astronomic observations. An azimuth should be observed at alternate stations of the main scheme, even though the party is delayed thereby.

Prominent objects whose geographic positions have not been determined should be observed on from the stations you occupy. You should also make connections with triangulation stations of the United States Geological Survey and of the Forest Service and also with the principal marks of the General Land Office whenever this can be done without delaying the progress of your party.

The instructions issued to F. W. Hough, chief of party operating in 1923, were in all essential parts the same as those issued to Mr. Garner for the 1922 season.

## ACCURACY

On figures 1 and 2 are indicated the stations which were reoccupied in 1922 and 1923. The lengths of the lines of the old triangulation depend on the measured Yolo base, which is connected by a quadrilateral with the triangulation stations Monticello and Vaca, at the northern end of the scheme, and the measured line between Los Angeles northwest base and Los Angeles southeast base at the southern end of the arc. These two base lines are sufficient to control

the lengths, for the individual figures between the bases are strong; that is, they are well shaped to carry the lengths through the triangles.<sup>1</sup>

Triangulation necessarily is subject to many small errors, but their effect is largely eliminated by the methods employed in the field and office. The sources of errors which need to be considered are those due to the imperfections in the graduation of the horizontal circle of the theodolite, to the inaccurate pointing of the telescope on the lamp, heliograph, or pole at the distant station, to the reading of the micrometer microscopes, and to the effect of horizontal refraction on the line of sight between the observer and the object observed on. The combined effect of all the errors except the last is not great if good instruments are used and many measurements of the directions are made. The effect of the refraction, however, can not be easily eliminated. It is greatest when a line passes near a hill or mountain side and the wind is blowing from the high ground across the line. It is the custom of the engineers of the Coast and Geodetic Survey, in making the selection of stations for new triangulation, to avoid lines that pass close to slopes. A line that is barely clear of an intervening flat-topped ridge or plateau does not seem to be materially affected by lateral refraction.

The effects of the accidental and systematic errors are largely eliminated by having a quadrilateral system instead of a chain of single triangles. In the quadrilateral there are checks in the angle observations and in the derived lengths of the sides of the triangles.

The probable error of a direction in the precise triangulation done by the Coast and Geodetic Survey averages about  $\pm 0''.50$ . The probable error of the reobserved directions in 1922 and 1923 of the triangulation in California is  $\pm 0''.32$ . When it is realized that the sides of an angle of  $1''$  are 1 foot apart at a distance of 40 miles it is readily seen that when the average closing error of  $1''$  for a triangle has been obtained, the geographic positions may be carried through the triangles with considerable accuracy. It is reasonably certain that should there be no actual ground movement between the time of making the first and the second set of observations along an arc of precise triangulation the differences in geographic position should usually not be more than 2 or 3 feet in 100 miles.

#### DISCREPANCIES BETWEEN OLD AND NEW TRIANGULATION, NORTHERN SECTION

Figure 3 shows by arrows the directions and distances between the positions of the old observing and that of the years 1922 and 1923, for the triangulation stations at the northern end of the scheme. If the arrow is pointing to the north the geographic position from the latest observing is to the northward of the one derived from the earlier work.

Upon the assumption that no movement whatever has occurred for the stations Mount Lola and Round Top, which were first occupied in 1879, the arrows shown on the sketch would be actual earth movements which have occurred between the earlier and the later observing, provided there have been no errors whatsoever in the

<sup>1</sup> See specifications for triangulation in Special Publication No. 26 of the U. S. Coast and Geodetic Survey, entitled "General Instructions for Field Work of the Coast and Geodetic Survey."

triangulation. This last assumption of course can not be true and, therefore, the movements shown by the arrows are a combination of errors of triangulation and earth movements.

The differences in geographic positions for the stations Pine Hill, Marysville Butte, Monticello, Vaca, and Mount Helena could have been caused by the errors in the observations made in the seventies and those in 1922 and 1923. For these stations the maximum difference in position is at Marysville Butte, 80 miles to the westward of Mount Lola, amounting to 3 feet to the northward. The differences in position for the other four stations in question are small, being 2 feet or less. It is significant that for the five stations under consideration the arrows representing the differences in geographic positions are pointing in different directions.

It seems reasonable to suppose from a study of the differences in position to the westward of Mount Lola and Round Top to the stations Mount Helena and Vaca that the area involved has remained practically quiescent during the 40 or more years between the first and the last observations. It was found that the angles remeasured at Round Top and at Mount Lola in the triangle involving those two stations and Mount Como, agreed very closely with the observations made in 1879. This is a clear indication that no distortion of that triangle had occurred since the first observations. Apparently there has been no general movement or distortion of the central and eastern part of California between latitudes  $38^{\circ} 30'$  and  $39^{\circ} 30'$ .

When we study the changes in geographic positions as shown by the arrows for the stations along the coast, working from Ross Mountain southward we are struck by two facts. First, that the movement seems to be without any general order from Mount Ross to the line joining the stations Mount Toro and Santa Ana; and, second, that from Mount Toro and Santa Ana southward there is a progressive change in geographic positions with practically all of it taking place in a northerly direction. It would seem that these two sections of the work should be given separate consideration.

As this paper is designed to be only a preliminary report on earth movements in California no attempt will be made to incorporate in it the results of the work of 1906-7.

Some outstanding features of the new results are worthy of special remark. For instance, there seems to be a general trend to the southward of stations to the eastward of the San Andreas fault while the mean change of all of the stations, as a group, to the westward of the fault, down to station Mount Toro, is to the northward. There is some regularity in direction and amount of the differences to the northward of the line Mount Toro and Santa Ana on the east side of the fault. This is not true for the west side. At Point Reyes Lighthouse the difference is 12 feet to the northward, while at Farallon Lighthouse the difference is 6 feet to the southwestward. Those two stations are only about 23 miles apart. At Santa Cruz the change is  $2\frac{1}{2}$  feet to the southeast while at Point Pinos, about 25 miles away, it is 10 feet to the northeast.

The stations Mount Diablo and Mocho forming the basis for the 1906 and 1907 triangulation have changed their positions  $3\frac{1}{2}$  and 4 feet, respectively, to the southward. It is not certain that all of

these two differences can be attributed to the errors of triangulation owing to the very small differences which have appeared in the triangulation directly to the northward but it seems reasonably certain that the errors due to triangulation may be of the order of magnitude of 2 or 3 feet at Mount Diablo and Mocho and may, in fact, be as great as the differences in geographic positions shown for those two stations.

If it is assumed that the differences to the west and south of stations Mount Helena and Vaca to Mount Toro and Santa Ana, inclusive, are due entirely to actual earth movements, we should have to conclude that there is no general trend of the earth's surface as a whole in any one direction and that whatever movements may be taking place or may have taken place in the last 40 years or so are due to local causes and that the stresses are acting in many directions. The resultant of all the changes at stations between Mount Ross to the north and the stations Mount Toro and Santa Ana to the southward would be almost nothing as referred to the stations Round Top and Mount Lola.

It is worthy of note that observations for latitude made at the Lick Observatory by Dr. R. H. Tucker during the last 20 or more years indicate that the mountain on which the observatory is located has not had any north or south drift. Dr. Tucker's observations strengthen the results of the new triangulation in showing that Lick Observatory has not materially changed its position during the many years since triangulation observations were first made there.

The two sections to the north and south of stations Mount Toro and Santa Ana seem to show that different types of processes in the earth's crust have been at work or that the old or the new triangulation has been subjected to errors much greater than those usually present in precise triangulation.

The names of the stations to the northward of Mount Toro and Santa Ana, including Round Top and Mount Lola, together with their geographic positions from the old and the new triangulations, the change in latitude and longitude, and the resultant direction and amount of change are given in the following table. There are also given for each station the date or dates when occupied for the early triangulation and for the triangulation made during the season of 1922 and 1923.

*Changes in geographic positions if Mount Lola and Round Top are held fixed*

Station and dates of observations	Latitudes, old and new	Difference in seconds and meters, new-old	Longitudes, old and new	Difference in seconds and meters, new-old	Resultant difference in positions		Direction from old position clockwise from south
					Meters	Feet	
Pine Hill.....	1876.....	38 43 11. 112	120 59 22. 962	-0'.021	0.530	1.7	253 06
	1922.....	38 43 11. 117	120 59 22. 941	-0.507m			
Marysville Butte.....	1876.....	39 12 22. 361	121 49 11. 540	-0'.012	0.852	2.8	199 44
	1922.....	39 12 22. 387	121 49 11. 528	-0.288m			
Vaca.....	1880.....	38 22 33. 808	122 05 01. 988	-0'.008	0.621	2.0	353 15
	1922.....	38 22 33. 788	122 05 01. 985	-0.073m			

Changes in geographic positions if Mount Lola and Round Top are held fixed—Con.

Station and dates of observations	Latitudes, old and new	Difference in seconds and meters, new-old	Longitudes, old and new	Difference in seconds and meters, new-old	Resultant difference in positions		Direction from old position clockwise from south	
					Meters	Feet		
Mt. Diablo.....	1876.....	37 52 55.482	-0°084	121 54 48.355	-0°010	1.076	3.5	346 54
	1922.....	37 52 55.448	-1.048m	121 54 48.345	-0.244m			
Mt. Helena.....	1876.....	38 40 11.080	-0°015	122 37 57.817	+0°018	0.635	2.1	43 13
	1922.....	38 40 11.065	-0.463m	122 37 57.835	+0.435m			
Mt. Tamalpais.....	1882.....	37 55 27.507	-0°051	122 35 45.242	-0°007	1.581	5.2	353 48
	1922.....	37 55 27.456	-1.572m	122 35 45.235	-0.171m			
Point Reyes L. H.....	1874.....	37 59 45.412	+0°115	123 01 20.595	+0°028	3.611	11.8	169 06
	1922.....	37 59 45.527	+3.546m	123 01 20.623	+0.683m			
Monticello.....	1880.....	38 39 50.645	-0°011	122 11 22.327	+0°006	0.369	1.2	23 09
	1922.....	38 39 50.634	-0.339m	122 11 22.333	+0.145m			
Ross Mt.....	1891.....	38 30 20.583	-0°048	123 07 09.221	+0°018	1.543	5.1	16 25
	1922.....	38 30 20.535	-1.480m	123 07 09.239	+0.436m			
Sierra Morena.....	1883.....	37 24 38.266	+0°004	122 18 28.006	+0°042	1.040	3.4	96 47
	1923.....	37 24 38.270	+0.123m	122 18 28.048	+1.033m			
Mocho.....	1887.....	37 28 39.696	-0°035	121 33 18.781	-0°025	1.241	4.1	330 21
	1923.....	37 28 39.661	-1.079m	121 33 18.756	-0.614m			
Loma Prieta.....	1884.....	37 06 40.912	-0°037	121 50 36.423	-0°069	2.051	6.7	303 48
	1923.....	37 06 40.875	-1.141m	121 50 36.354	-1.704m			
Farallon L. H.....	1891.....	37 41 58.250	-0°021	123 00 03.605	+0°072	1.879	6.2	69 51
	1922.....	37 41 58.229	-0.647m	123 00 03.677	+1.764m			
Lick Observatory, small dome.....	1882-1887.....	37 20 31.511	-0°037	121 38 31.707	-0°032	1.387	4.6	325 22
	1923.....	37 20 31.474	-1.141m	121 38 31.675	-0.788m			
Santa Ana.....	1852.....	36 54 19.368	-0°015	121 13 57.738	-0°026	0.793	2.6	305 39
	1923.....	36 54 19.353	-0.462m	121 13 57.712	-0.644m			
Mount Toro.....	1885.....	36 31 34.712	+0°032	121 36 32.276	-0°023	1.140	3.7	210 07
	1923.....	36 31 34.744	+0.986m	121 36 32.253	-0.572m			
Gavilan.....	1852.....	36 45 20.910	+0°044	121 31 11.350	-0°009	1.374	4.5	189 20
	1923.....	36 45 20.954	+1.356m	121 31 11.341	-0.223m			
Santa Cruz Azimuth Station.....	1852.....	36 58 42.023	-0°015	122 03 18.094	-0°021	0.695	2.3	311 40
	1923.....	36 58 42.008	-0.462m	122 03 18.673	-0.519m			
Point Pinos Latitude Station.....	1854-1866.....	36 37 59.186	+0°014	121 55 31.632	+0°150	3.752	12.3	96 37
	1923.....	36 37 59.200	+0.432m	121 55 31.782	+3.727m			
Point Pinos L. H.....	1854-1866.....	36 38 01.551	-0°159	121 55 58.939	-0°169	6.454	21.2	319 25
	1923.....	36 38 01.392	-4.901m	121 55 58.770	-4.199m			
Hepsedam.....	1885.....	36 18 53.603	+0°027	120 49 26.362	-0°009	0.862	2.8	195 08
	1923.....	36 18 53.630	+0.832m	120 49 26.353	-0.225m			
Santa Lucia.....	1885.....	36 08 45.328	+0°067	121 25 05.937	-0°022	2.137	7.0	194 55
	1923.....	36 08 45.395	+2.065m	121 25 05.915	-0.550m			
Rocky Butte.....	1884.....	35 39 56.026	+0°116	121 03 32.063	-0°011	3.586	11.8	184 26
	1923.....	36 39 56.142	+3.575m	121 03 32.052	-0.277m			
Castle Mount.....	1885.....	35 56 21.338	+0°088	120 20 22.908	+0°038	2.875	9.4	160 38
	1923.....	35 56 21.426	+2.712m	120 20 22.946	+0.953m			
San Luis.....	1883.....	35 16 41.102	+0°149	120 33 40.087	+0°019	4.617	15.1	174 02
	1923.....	35 16 41.251	+4.592m	120 33 40.106	+0.480m			
San Jose.....	1884.....	35 18 55.652	+0°155	120 16 08.225	+0°030	4.837	15.9	170 59
	1923.....	35 18 55.807	+4.777m	120 16 08.255	+0.758m			
Lospe.....	1875.....	34 53 38.475	+0°197	120 36 19.944	-0°007	6.074	19.9	181 41
	1923.....	34 53 38.672	+6.071m	120 36 19.937	-0.178m			
Tepusquet.....	1875.....	34 54 37.432	+0°211	120 11 09.654	+0°022	6.526	21.4	175 06
	1923.....	34 54 37.643	+6.502m	120 11 09.676	+0.558m			
Arguello.....	1875.....	34 34 58.957	+0°212	120 33 39.011	-0°026	6.567	21.5	185 48
	1923.....	34 34 59.169	+6.533m	120 33 38.985	-0.663m			
Gaviota.....	1873.....	34 30 07.450	+0°240	120 11 53.426	-0°009	7.399	24.3	181 47
	1923.....	34 30 07.690	+7.395m	120 11 53.417	-0.230m			

When the sketch showing the differences in position by arrows was first studied it was thought that the changes were due to actual earth movements and that the movements had been progressively greater to the southward. It was only after careful thought and analysis of the sketch that it was realized that some of the changes to the southward of the line Mount Toro-Santa Ana might possibly have been caused by an unobserved shortening of a line of the triangulation during the old observing or during the observing of 1922 and 1923. An analysis of the evidence for and against this idea is given below.

It is evident that an undetected change in the length of a line of an arc of triangulation might occur should the observing be completed to the line and then the observing be continued from it after some lapse of time. The change in length due to earth movements would have to occur during the interval between observations. Such a change was suspected, but upon investigation it was found that no such break in the observations had occurred to the south of the line Mount Tamalpais-Mount Diablo. Except at Mount Diablo all the directions at each station were observed in a single observing period; hence if any change in position of a station had occurred during the occupation of a station or during the interval of time between the occupation of a station and the occupation of contiguous stations, the closing errors of the triangles involved would indicate the trouble.

If the theodolite, lamp, and heliotrope had not been mounted over the same spot at a station, the closing errors would have been affected.

The very small triangle closures discussed below show the absence of troubles like those mentioned in the two preceding paragraphs.

#### COMPARISON OF OLD AND NEW TRIANGLES

Data for the triangles extending from Mount Tamalpais and Mount Diablo southward to stations Arguello and Gaviota are given below. The triangles are shown in the same order as on pages 521 to 523 of Appendix 9, Coast and Geodetic Survey Report for 1904. For any one triangle the angle at a station between the lines from that station to the other two stations follows the name of the station in question. The values given are for the adjusted spherical angles. The seconds only are given for the "new" or 1922 or 1923 values. The differences in the values are given in the column headed "Difference, new - old."

Data for old and new angles

Number of triangle	Stations	Spherical angles		Difference, new-old	Closing error of triangles			
		Old	New		Old	New		
		°	'	''	''	''	''	
1.....	{Mocho.....	26	16	13.008	13.25	+00.24	} +0.275	} +0.01
	{Mount Tamalpais.....	23	47	56.387	56.93	+00.54		
	{Mount Diablo.....	129	55	57.040	56.26	-00.78		
2.....	{Sierra Morena.....	57	27	09.013	13.30	+04.29	} -0.089	} -0.74
	{Mount Tamalpais.....	61	37	29.974	33.25	+03.28		
	{Mount Diablo.....	60	55	29.410	21.85	-07.56		
3.....	{Sierra Morena.....	49	53	07.162	05.69	-01.47	} +0.338	} +1.89
	{Mount Diablo.....	69	00	27.630	34.41	+06.78		
	{Mocho.....	61	06	33.386	28.06	-05.31		
4.....	{Sierra Morena.....	107	20	16.175	18.99	+02.82	} +0.249	} +0.64
	{Mount Tamalpais.....	37	49	33.567	36.32	+02.73		
	{Mocho.....	34	50	20.378	14.83	-05.55		
5.....	{Loma Prieta.....	36	11	04.456	03.91	-00.55	} +0.287	} +1.65
	{Mount Diablo.....	31	05	54.364	51.99	-02.37		
	{Mocho.....	112	43	07.355	10.28	+02.92		
6.....	{Loma Prieta.....	46	51	45.970	45.45	-00.52	} -1.294	} +0.18
	{Sierra Morena.....	95	13	49.174	40.54	-08.63		
	{Mount Diablo.....	37	54	33.265	42.42	+09.16		
7.....	{Loma Prieta.....	83	02	50.426	49.36	-01.07	} -1.345	} +0.44
	{Sierra Morena.....	45	20	42.012	34.85	-07.16		
	{Mocho.....	51	36	33.968	42.20	+08.23		
8.....	{Santa Ana.....	42	50	14.583	14.51	-00.07	} +0.365	} +0.36
	{Loma Prieta.....	80	33	21.932	25.17	+03.24		
	{Mocho.....	56	36	30.580	27.41	-03.17		
9.....	{Mount Toro.....	20	22	10.805	09.82	-00.98	} -0.151	} +1.90
	{Loma Prieta.....	130	00	01.482	06.75	+05.27		
	{Mocho.....	29	37	54.086	49.80	-04.29		
10.....	{Mount Toro.....	56	18	32.776	35.22	+02.44	} -0.112	} +1.20
	{Loma Prieta.....	49	26	39.550	41.58	+02.03		
	{Santa Ana.....	74	14	55.436	50.96	-04.48		
11.....	{Mount Toro.....	35	56	21.971	25.40	+03.43	} +0.404	} -0.34
	{Mocho.....	26	58	36.494	37.61	+01.12		
	{Santa Ana.....	117	05	10.019	05.47	-04.55		
12.....	{Hepsedam.....	42	17	43.327	41.94	-01.39	} +0.239	} +0.11
	{Mount Toro.....	69	40	43.759	40.79	-02.97		
	{Santa Ana.....	68	01	42.432	46.79	+04.36		
13.....	{Santa Lucia.....	33	07	17.480	20.63	+03.15	} -0.179	} -0.53
	{Mount Toro.....	119	21	05.520	00.11	-05.41		
	{Santa Ana.....	27	31	42.430	44.69	+02.26		
14.....	{Santa Lucia.....	92	30	24.831	30.38	+05.55	} -1.391	} +0.66
	{Mount Toro.....	49	40	21.761	19.32	-02.44		
	{Hepsedam.....	37	49	18.953	16.84	-03.11		
15.....	{Santa Lucia.....	59	23	07.351	09.75	+02.40	} -0.973	} +1.30
	{Santa Ana.....	40	30	00.002	02.10	+02.10		
	{Hepsedam.....	80	07	03.280	58.78	+04.50		
16.....	{Rocky Butte.....	47	32	29.783	33.60	+03.82	} +2.441	} -2.12
	{Santa Lucia.....	78	04	28.396	22.70	-05.70		
	{Hepsedam.....	54	23	10.603	12.48	+01.88		
17.....	{Castle Mount.....	30	15	49.770	48.48	-01.29	} +1.383	} +0.08
	{Santa Lucia.....	32	28	00.954	56.49	+04.46		
	{Hepsedam.....	117	16	16.988	22.74	+05.75		
18.....	{Castle Mount.....	38	25	06.514	05.17	-01.34	} +1.656	} -2.02
	{Rocky Butte.....	95	58	37.355	39.93	+02.57		
	{Santa Lucia.....	45	36	27.443	26.21	-01.23		
19.....	{Castle Mount.....	68	40	56.284	53.65	-02.63	} +0.598	} +0.18
	{Rocky Butte.....	48	26	07.573	06.33	-01.24		
	{Hepsedam.....	62	53	06.385	10.26	+03.88		

## Data for old and new angles—Continued.

Number of triangle	Stations	Spherical angles				Difference new-old	Closing error of triangles	
		Old			New		Old	New
		°	'	"	"	"	"	"
20	San Luis.....	61	30	41.479	42.14	+00.66	-5.515	+1.90
	Rocky Butte.....	68	40	51.354	49.96	-01.39		
	Castle Mount.....	49	48	37.758	38.40	+00.73		
21	San Jose.....	56	02	56.990	57.18	+00.19	-1.597	-0.06
	Rocky Butte.....	53	28	15.135	13.03	-02.11		
	Castle Mount.....	70	28	59.818	61.73	+01.91		
22	San Jose.....	93	30	48.745	49.32	+00.58	+1.607	+0.85
	San Luis.....	65	48	53.935	52.18	-01.76		
	Castle Mount.....	20	40	22.061	23.24	+01.18		
23	San Jose.....	37	27	51.755	52.14	+00.38	-2.311	+2.81
	San Luis.....	127	19	35.415	34.32	-01.10		
	Rocky Butte.....	15	12	36.219	36.93	+00.71		
24	Lospe.....	58	46	49.621	51.44	+01.82	+2.311	+1.77
	Rocky Butte.....	35	55	05.998	05.22	-00.78		
	San Jose.....	85	18	15.927	14.88	-01.05		
25	Lospe.....	31	00	49.427	49.07	-00.36	+4.648	-0.40
	Rocky Butte.....	20	42	29.780	28.29	-01.49		
	San Luis.....	128	16	46.117	47.96	+01.84		
26	Lospe.....	27	46	00.193	02.37	+02.18	-0.026	+2.17
	San Luis.....	104	23	38.468	37.72	-00.75		
	San Jose.....	47	50	24.172	22.74	-01.43		
27	Tepusquet.....	30	20	49.047	52.21	+02.26	-1.568	+0.44
	San Luis.....	58	51	44.308	41.65	-02.66		
	San Jose.....	90	47	28.859	29.25	+00.39		
28	Tepusquet.....	83	03	56.706	56.97	+00.26	-2.226	-2.40
	Lospe.....	53	59	03.019	00.93	-02.09		
	San Jose.....	42	57	04.687	06.51	+01.82		
29	Tepusquet.....	52	43	06.758	04.76	-02.00	-0.684	-0.67
	Lospe.....	81	45	03.213	03.30	+00.09		
	San Luis.....	45	31	54.160	56.07	+01.91		
30	Arguello.....	50	01	59.843	59.50	-00.34	-1.139	-1.23
	Lospe.....	86	03	08.111	07.03	-01.08		
	Tepusquet.....	43	54	55.427	56.85	+01.42		
31	Gaviota.....	41	56	00.352	59.90	-00.45	-0.272	0.00
	Lospe.....	52	04	21.721	20.96	-00.76		
	Tepusquet.....	85	59	42.336	43.55	+01.21		
32	Gaviota.....	76	12	10.052	-----	-----	-0.242	-----
	Arguello.....	61	43	06.894	-----	-----		
	Tepusquet.....	42	04	46.909	-----	-----		
33	Gaviota.....	34	16	09.700	-----	-----	-1.109	-----
	Arguello.....	111	45	06.737	-----	-----		
	Lospe.....	33	58	46.390	-----	-----		

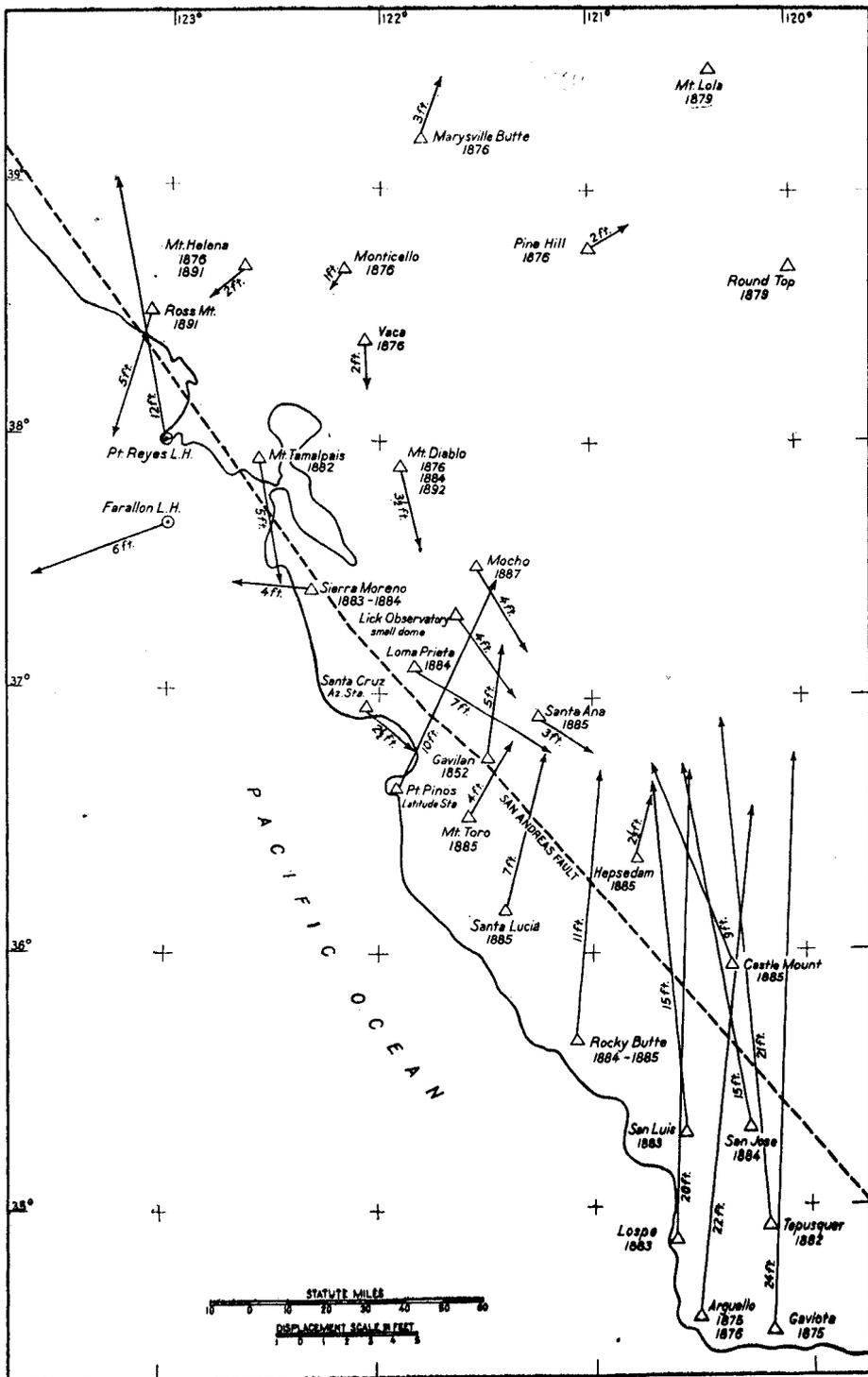


FIG. 3.—Discrepancies between old and new triangulation, northern section

The differences in geographic positions, as computed from the early observations and from the recent ones, are shown by arrows. The direction of each arrow indicates the direction of shift in geographic position during the interval between the two sets of observations. A part of the change in geographic positions is due to unavoidable accidental errors in making the angle observations, but most of the changes seem to indicate actual earth movements. In the computations it was assumed that no earth movements had occurred at stations Mount Lola and Round Top, on the Sierras. Those two stations form the base for the computation of the new geographic positions of all the other stations shown on the sketch.

The dates on which the stations to the southward of Mount Tamalpais and Mount Diablo were first occupied are given below:

Stations occupied	Date
Mount Tamalpais .....	August to October, 1882.
Mount Diablo .....	{ June to September, 1876. November to December, 1884. June to July, 1892.
Mocho .....	August to October, 1887.
Sierra Morena .....	November, 1883, to January, 1884.
Loma Prieta .....	February to March, 1884.
Santa Ana .....	November to December, 1885.
Mount Toro .....	January to February, 1885.
Hepsedam .....	December, 1885, to January, 1886.
Santa Lucia .....	October, 1885.
Rocky Butte .....	November, 1884, to January, 1885.
Castle Mount .....	October, 1885.
San Luis .....	November to December, 1883.
San Jose .....	January, 1884.
Lospe .....	February to May, 1883.
Tepusquet .....	October to November, 1882.
Arguello .....	December, 1875, to February, 1876.
Gaviota .....	May and October to December, 1875.

The recent observations at the stations listed above were made in 1922 and 1923.

A careful analysis of the sketch showing the changes in geographic positions indicates that, should the line between Mount Toro and Santa Ana have been shortened by about 5.5 feet and had the line swung about 2.4 seconds of arc to the northward around Mount Toro during the early triangulation, nearly all of the differences in position for the stations to the southward could be accounted for. The arrow at Mount Toro shows the approximate amount of shortening of the line needed, but the swing of the line around Mount Toro is to the southward.

It does not seem possible that any change occurred during the first triangulation which could have changed so much the length of the line. The evidence in the sizes of the closing errors of the triangles is against the idea.

The four triangles involved in the quadrilateral, Loma Prieta, Mocho, Santa Ana, and Mount Toro, have exceedingly small closing errors, the largest one being only 0.404 second. The largest correction to the 12 directions of that quadrilateral is only 0.372 second, while the average correction to a direction is only 0.10 second.

All of the observations at Mount Toro and at Santa Ana were made in 1885, those at Loma Prieta in 1884, and those at Mocho in 1887.

If there had been any earth movements affecting the lines to the extent that is needed to cause the change in geographic positions, certainly these movements could not have occurred in this quadrilateral between the observations of 1885 and 1887, for the closing errors of the triangles of the quadrilateral could not then have been so small as 0.404 second: The large relative movements of the positions in the quadrilateral to the north of the line Mount Toro-Santa Ana would have required changes in the angles of from two to five seconds. A foot at a distance of 40 miles subtends an angle of one second and many of the lines involved in the triangulation to the south of San Francisco are of the order of magnitude of 40 miles in length. This fact enables one to visualize the great changes in the angles which are involved in the changes in the geographic positions.

For the four triangles of the old work of the quadrilateral just to the south of the line Mount Toro-Santa Ana the maximum closing error is  $1''.391$  and the adjustment of the quadrilateral gave a maximum correction to a direction of only  $0''.728$ . The observations at the four stations of the quadrilateral were made during 1885. There surely could not have occurred any earth movement which could have affected materially the geographic positions of those four stations during the period from the first to the last observations for the group.

In the quadrilateral Santa Lucia-Hepsedam-Castle Mount-Rocky Butte, the average closing error of the triangles from the old observations is about  $1''.5$ . These errors are not large enough to have caused the relative movements in the four stations of this quadrilateral. And of course the errors are quite inadequate to cause the changes in the geographic positions, indicated by the arrows on Figure 3, for the stations under consideration.

In view of the evidence set forth above we are forced to the conclusion that no relative earth movements occurred while the first series of observations were made (1884-1887) at the stations between Mocho on the north and Rocky Butte on the south, which could have caused the great changes in geographic position between the old and the new triangulation.

It is desirable to test the results of the recent observations with a view to learning whether the progressive increase in the changes in geographic positions to the southward of the stations Mount Toro and Santa Ana may be due to errors in them.

The four triangles from recent observations in the quadrilateral to the north of Mount Toro and Santa Ana have closing errors of  $0''.36$ ,  $1''.90$ ,  $0''.34$ , and  $1''.20$ . With such small closing errors we might expect no change in position of a station greater than about 1.5 feet as a result of errors of observation alone. The relative motion between Mocho and Mount Toro is about 7 feet, between Santa Ana and each of the stations Mount Toro and Loma Prieta about 4 feet, and between Loma Prieta and Mount Toro 8 feet. There is no possibility of anything being present in the recent observations at the stations of the quadrilateral under discussion which could have changed the length of the line joining stations Mount Toro and Santa Ana sufficient to account for the changes in geographic positions of the stations to the southward.

The two recently observed quadrilaterals below the line Mount Toro-Santa Ana show small closing errors of triangles. The largest closing error in the first quadrilateral is  $1''.30$  with an average of  $0''.67$ . In the second quadrilateral to the southward the values are  $2''.12$  for the largest closing error of a triangle with a mean closure of  $1''.53$ . With closing errors of triangles as small as those indicated above, we can not find any cause in the recent observations for the changes in positions for stations between Mocho and Rocky Butte.

Relative changes in the geographic positions of the stations from Mocho to Rocky Butte seem to have been due in large part to earth movements and not to errors of the observations made either in the middle eighties or during the past two years. The parts which may be due to observational errors are small as compared with those caused by earth movements.

As the changes in position for the stations Pine Hill, Marysville Butte, Monticello, Mount Helena, and Vaca, just to the west of

Mount Lola and Round Top, are small it does not seem probable that any error in length from observations alone could have developed in the triangles formed by them, either in the old or the new observations, which could have caused the large changes in positions to the southward.

The transcontinental arc crossed California in a double quadrilateral from the lines Mount Lola-Round Top and Round Top-Mount Conness. The western stations were Mount Helena, Mount Tamalpais, Mount Diablo, and Mocho. No closing error of the 18 triangles, from the original observations, involved in the scheme was as great as  $1''.00$ . This shows the old work to have been of great accuracy and strength.

The Yolo base, which controls the lengths of the western portion of the transcontinental arc, was connected with the lines joining Mount Helena, Mount Tamalpais, and Mount Diablo through the stations Monticello and Vaca. There were only 3 of the 19 triangles of the base net whose closures were greater than  $1''.00$ . Those 3 had closures of  $2''.60$ ,  $1''.06$ , and  $1''.29$ .

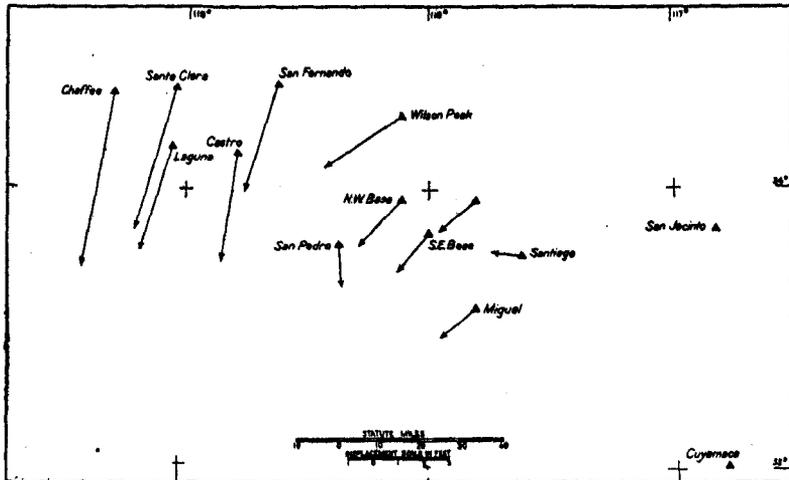


FIG. 4.—Discrepancies between old and new triangulation, southern section

The computations of the new geographic positions are based upon stations San Jacinto and Cuyamaca, which are assumed to have remained fixed. The new geographic positions were computed through a single chain of triangles without least square adjustment of the quadrilaterals involved in the scheme. Possibly the differences in geographic positions would have been smaller had the adjustment been made. Probably most of the changes in position shown by the arrows are due to incidental errors in the triangulation and in the method of computation.

There are 6 triangles from the lines joining the 3 stations Mocho, Mount Diablo, and Mount Tamalpais, at the western end of the transcontinental arc to the line Mocho-Loma Prieta. Four of the closing errors are less than  $0''.40$ , while the other two closures are only  $1''.29$  and  $1''.35$ . The triangles are well shaped and there is probably very little error in the length of the line, at the southern part of the net, due to observational errors.

There were 37 triangles forming the 1922 net, extending from Mount Lola and Round Top to the line Loma Prieta-Mocho. Only 9 of them had closing errors greater than  $1''.00$  and only 4 were greater than  $1''.50$ , and none was as large as  $2''.00$ .

With all the evidence set forth above we must reach the decision that there was no earth movement along or across a line of the triangulation during the early or recent observations which could have changed the length of the line by approximately 4 feet in 40 miles. As was stated earlier, such an undetected change in the line Mount Toro-Santa Ana could have explained practically all of the changes at the southern stations shown by arrows on Figure 3. Such a change in length could not have occurred.

There are rather large closing errors for the triangles of the figure Rocky Butte-Castle Mount to Lospe-Tepusquet from both the old and the new observations. The maximum closure for the old work is  $5''.52$  with an average of  $2''.04$ . From the new observations the maximum closure is  $2''.81$  with an average of  $1''.28$ . The large closing errors of the old and the new work seem in some way to have been caused by lateral refraction of the lines. A repetition of the observations of the directions involved in some of the large closing errors did not materially affect the results. It is rather strange that this figure should have been so much affected by large closing errors in the observations of widely separated periods while the observations to the northward had small closing errors for both the old and the new work.

To the southward of the line Lospe-Tepusquet the old closures were small and no stations to their southward, except Arguello, were occupied in 1923, though the directions from those two stations on Arguello and Gaviota were observed in that year. Those observations made it possible to compute the new geographic positions of Arguello and Gaviota from two triangles, one of which had only two observed angles. There is no evidence from the angles and triangles of the old and the new work which points definitely to changes in the lengths of the triangle sides that would make the large changes in the geographic positions. The changes, if due to the triangulation rather than to earth movements, would require a large change in length accumulated gradually from the north down to the line Mount Toro-Santa Ana or a similar change developing entirely in the region around stations Mount Toro and Santa Ana. The evidence set forth above seems to be positively against the latter view.

#### RECOMPUTATION OF SECTION OF ARC NORTH OF SANTA BARBARA CHANNEL

There has been no great distortion of the triangulation from Mount Toro and Santa Ana southward to Lospe and Tepusquet. This fact is clearly indicated by the data shown graphically on Figure 3. The changes in positions, resulting from a computation extending northward from Lospe and Tepusquet in which the old positions of the two stations were held fixed and the 1923 angles were used, are shown by arrows on Figure 5. As the area covered by the scheme of triangulation has not changed much in shape, there have been no progressive changes in the angles and derived distances southward from Mount Toro and Santa Ana.

The data used in constructing Figure 5 are given in the following table:

*Changes in geographic positions if Lospe and Tepusquet are held fixed*

Station and dates of observations	Latitudes, old and new	Difference in seconds and meters, new-old	Longitudes, old and new	Difference in seconds and meters, new-old	Resultant difference in positions		Direction from old position clockwise from south
					Meters	Feet	
Santa Ana.....	{1852. 36 54 19. 368	-0°053	121 13 57. 738	-0°081	2. 586	8. 5	309 11
	{1923. 36 54 19. 315	-1. 634m	121 13 57. 657	-2. 005m			
Mount Toro.....	{1885. 36 31 34. 712	-0°019	121 36 32. 276	-0°032	0. 968	3. 2	306 22
	{1923. 36 31 34. 693	-0. 586m	121 36 32. 244	-0. 796m			
Hepsedam.....	{1885. 36 18 53. 603	-0°066	120 49 26. 362	-0°061	2. 540	8. 3	323 12
	{1923. 36 18 53. 537	-2. 084m	120 49 26. 301	-1. 522m			
Santa Lucia.....	{1885. 36 08 45. 328	-0°017	121 25 05. 937	-0°024	0. 797	2. 6	311 08
	{1923. 36 08 45. 311	-0. 524m	121 25 05. 913	-0. 600m			
Rocky Butte.....	{1884. 35 39 56. 026	-0°014	121 03 32. 063	-0°013	0. 541	1. 8	322. 49
	{1923. 35 39 56. 012	-0. 431m	121 03 32. 050	-0. 327m			
Castle Mount.....	{1885. 35 56 21. 338	-0°047	120 20 22. 908	-0°027	1. 599	5. 2	334 57
	{1923. 35 56 21. 291	-1. 449m	120 20 22. 881	-0. 677m			
San Luis.....	{1883. 35 16 41. 102	-0°025	120 33 40. 087	+0°003	0. 774	2. 5	5 38
	{1923. 35 16 41. 077	-0. 770m	120 33 40. 090	+0. 076m			
San Jose.....	{1884. 35 18 55. 652	-0°026	120 16 08. 225	-0°007	0. 820	2. 7	347 33
	{1923. 35 18 55. 626	-0. 801m	120 16 08. 218	-0. 177m			
Lospe.....	{1875. 34 53 38. 475		120 36 19. 944				
	{1923. ....						
Tepusquet.....	{1875. 34 54 37. 432		120 11 09. 654				
	{1923. ....						
Arguello.....	{1875. 34 34 58. 957	-0°008	120 33 39. 011	-0°006	0. 291	1. 0	328 13
	{1923. 34 34 58. 949	-0. 247m	120 33 39. 005	-0. 153m			
Gaviota.....	{1873. 34 30 07. 450	+0°001	120 11 53. 426	-0°010	0. 257	0. 8	265 18
	{1923. 34 30 07. 451	+0. 031m	120 11 53. 416	-0. 255m			

Had there been no change in the distance between Lospe and Tepusquet nor in the geographic positions of those stations, we might justly conclude that stations Santa Ana, Hepsedam, and Castle Mount were the only ones, shown on Figure 5, which had surely shifted in position. There is some probability that San Luis and San Jose had moved toward Lospe and Tepusquet, but at the other five stations the changes are rather small.

The great accuracy of the old and of the new triangulations to the north of Mount Toro and Santa Ana, as shown by the small triangle closures, seems to preclude the accumulation from the northward of the great change in length of the lines of the triangles near those stations during the old or the new observations, which is needed to explain the difference in positions to the southward.

The evidence points toward actual earth movements, involving the stations from Mount Toro and Santa Ana southward, between the early and late observations. Some of the change in geographic positions is, of course, due to unavoidable errors in the triangulation, but the major part of the changes appears to have been due to horizontal shifting of the earth's surface.

When a connection has been made in the vicinity of Santa Barbara Channel, between stations Arguello and Gaviota to the northward and stations Chaffee and Laguna to the southward, it will be possible to get additional evidence as to whether the large differences in geographic position just to the northward of Santa Barbara Channel are due to errors in triangulation or to actual earth movements.

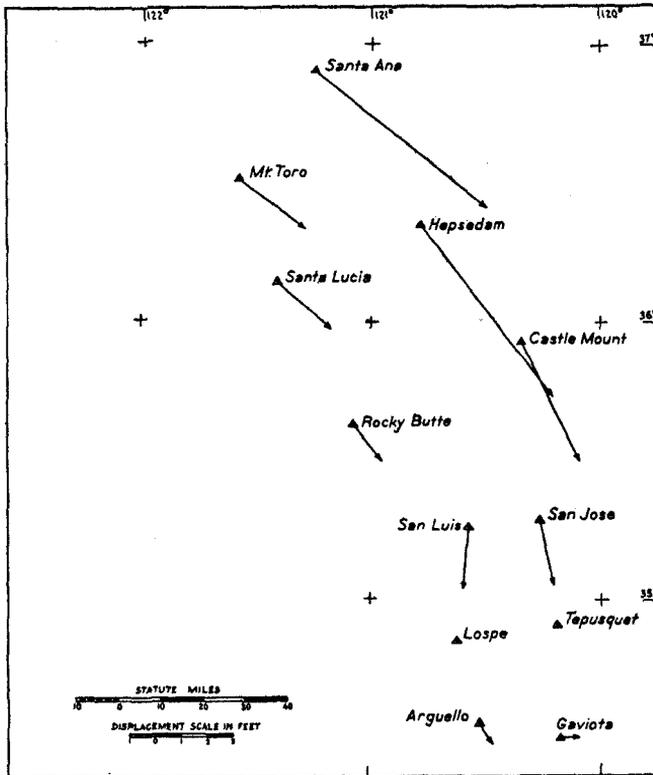


FIG. 5.—Relative discrepancies north of Santa Barbara Channel

The arrows shown on this sketch represent the differences in geographic positions of certain triangulation stations on the assumption that no changes in geographic positions, due to earth movements, had occurred at stations Lospe and Tepusquet. In Figure 3, large earth movements are indicated for most of the stations shown on this sketch, but on Figure 3 Mount Lola and Round Top were used as the base for the computation of the new geographic positions.

#### DISCREPANCIES BETWEEN OLD AND NEW TRIANGULATION, SOUTHERN SECTION

A very careful inspection of the angles of the triangles from the line Cuyamaca-San Jacinto to the line Laguna-Chaffee indicates that there has been very little change in any of the angles from the time they were observed in the nineties, when the triangulation stations were first established.

If there has been a change in the length of one of the lines of the upper triangulation, say, Mount Toro-Santa Ana, as indicated above, then there should be a proportionate increase in the changes in geographic positions with the distance from the vicinity of the line Mount Toro-Santa Ana throughout the scheme to the stations San Jacinto and Cuyamaca. The direction of change in the geographic

positions should vary with the changes in the direction of the axis of the arc of triangulation.

If on the other hand, there has been an actual movement of the earth to cause the large changes in the geographic positions of the triangulation stations just above the Santa Barbara Channel, and should no change have occurred in the positions of the triangulation stations to the southward of that channel, then when the northern and southern portions of the arc of triangulation have been joined and the computations of the geographic positions made by using the new values for the angles, there would be no uniformly progressive change in the geographic positions to the southward. It is practically certain that, if any earth movements have occurred in the region covered by the lower 200 miles of the Pacific arc of precise triangulation, the movement has all been in one direction without appreciable distortion of the block of the crust involved. As the lengths of the line between stations San Juan and Los Angeles northwest base, as computed from the Los Angeles base through the old angles, and from the Michelson base through recent angles, differ by only 0.13 meter, or only about 1 part in 200,000 of the length of the line, it seems that no expanding or contracting of the area involved has occurred.

The geographic positions of the stations at the southern end of the arc, based on the stations San Jacinto and Cuyamaca, assumed not to have been in any way affected, together with data showing the differences in geographic positions of the stations since the first triangulation was done, are shown in the following table:

*Changes in geographic positions in southern California*

Station and dates of observations	Latitudes old and new			Difference in seconds and meters, new-old	Longitudes old and new			Difference in seconds and meters, new-old	Resultant difference in positions		Direction from old position clockwise from south		
	°	'	"		°	'	"		Meters	Feet		°	'
Santiago.....	1899..	33	42	38.517	+0 <sup>o</sup> 002	117	32	01.192	+0 <sup>o</sup> 014	0.365	1.2	99	46
	1923..	33	42	38.519	+0.062m	117	32	01.206	+0.360m				
Niguel.....	1884..	33	30	45.473	-0 <sup>o</sup> 012	117	44	01.133	+0 <sup>o</sup> 017	0.574	1.9	49	53
	1923..	33	30	45.461	-0.370m	117	44	01.150	+0.439m				
San Juan.....	1886..	33	54	50.138	-0 <sup>o</sup> 012	117	44	15.277	+0 <sup>o</sup> 017	0.573	1.9	49	45
	1923..	33	54	50.126	-0.370m	117	44	15.294	+0.437m				
San Pedro.....	1853..	33	44	46.585	-0 <sup>o</sup> 016	118	20	07.404	-0 <sup>o</sup> 002	0.496	1.6	354	06
	1923..	33	44	46.569	-0.493m	118	20	07.402	-0.051m				
Wilson Peak.....	1890..	34	13	26.222	-0 <sup>o</sup> 021	118	03	39.906	+0 <sup>o</sup> 035	1.105	3.6	54	10
	1923..	34	13	26.201	-0.647m	118	03	39.941	+0.896m				
Los Angeles northwest base.....	1889..	33	55	05.648	-0 <sup>o</sup> 019	118	03	23.777	+0 <sup>o</sup> 019	0.762	2.5	39	50
	1923..	33	55	05.629	-0.585m	118	03	23.796	+0.488m				
Los Angeles southeast base.....	1889..	33	47	34.646	-0 <sup>o</sup> 016	117	56	30.319	+0 <sup>o</sup> 014	0.610	2.0	36	08
	1923..	33	47	34.630	-0.493m	117	56	30.333	+0.360m				
Castro.....	1898..	34	05	09.244	-0 <sup>o</sup> 044	118	47	06.433	+0 <sup>o</sup> 005	1.362	4.5	5	24
	1923..	34	05	09.200	-1.366m	118	47	06.438	+0.128m				
San Fernando.....	1898..	34	19	47.989	-0 <sup>o</sup> 044	118	36	01.454	+0 <sup>o</sup> 016	1.416	4.6	16	47
	1923..	34	19	47.945	-1.356m	118	36	01.470	+0.409m				
Santa Clara.....	1898..	34	19	33.234	-0 <sup>o</sup> 057	119	02	18.987	+0 <sup>o</sup> 016	1.803	5.9	13	07
	1923..	34	19	33.177	-1.756m	119	02	19.003	+0.409m				
Laguna.....	1857..	34	06	31.665	-0 <sup>o</sup> 042	119	03	51.742	+0 <sup>o</sup> 012	1.330	4.4	13	23
	1923..	34	06	31.613	-1.294m	119	03	51.754	+0.308m				
Chaffee.....	1867..	34	18	03.039	-0 <sup>o</sup> 068	119	19	49.301	+0 <sup>o</sup> 001	2.095	6.9	7	04
	1923..	34	18	02.971	-2.096m	119	19	49.302	+0.026m				

The data are too few to justify a discussion of the processes which may have been operating to cause changes in geographic positions along the San Andreas fault to the northward of the stations Mount Toro and Santa Ana. But it is apparently justifiable to conclude that whatever processes are at work are local and that there is no general trend of any large portion of the surface of California covered by the investigations to move in a single direction at an appreciable rate. It seems probable that the forces acting are within the crust just below the affected areas and that there is no force, in the upper crust at least, competent to cause changes in geographic positions of the triangulation stations operating from the ocean basins toward the continents or under the continental mass acting toward the oceans.

### GRAVITY ANOMALIES IN CALIFORNIA

Gravity stations which were established in California by the Coast and Geodetic Survey have been reduced by the isostatic method. The results for these stations are published in Special Publication No. 99 of the Coast and Geodetic Survey, but it is desirable to give in this publication some essential data for the stations in question. There are given below the names, numbers, geographic positions, and isostatic anomalies for the California gravity stations and the locations of these stations are shown graphically with isostatic anomaly contours on Figure 6. The numbers used for the stations in the table and on the illustration are the same as those used for these stations in Special Publications Nos. 40 and 99.

All of the isostatic anomalies for gravity stations in California are negative except one and that is zero. This fact might lead one to believe that the crust beneath is out of isostatic equilibrium, but this is probably not true, since the stations are on recent geological formations and there is a tendency for the anomalies at stations so located to be negative. This is caused by the presence of material lighter than normal in the form of recent unconsolidated sediments which have a smaller attractive effect on the pendulum than would material of normal density. The effect of material of light or heavy density near gravity stations is discussed at length in Special Publications Nos. 40 and 99 of the Coast and Geodetic Survey.

The gravity anomalies at stations in California, with interpolated values are shown on Figure 6. The anomalies are the differences between the observed and computed values of gravity. The computed values are based on the Bowie No. 1,<sup>2</sup> gravity formula, with corrections applied for the height of station, the effect of topography, and the isostatic compensation assumed to be uniformly distributed to a depth of 113.7 kilometers. Slight changes in the anomalies would result if the depth used were 96 kilometers, the best value now known, but the changes would not be sufficient to modify materially the results of the isostatic investigations in which gravity data are used.

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<sup>2</sup> See p. 8 of Special Publication No. 99.

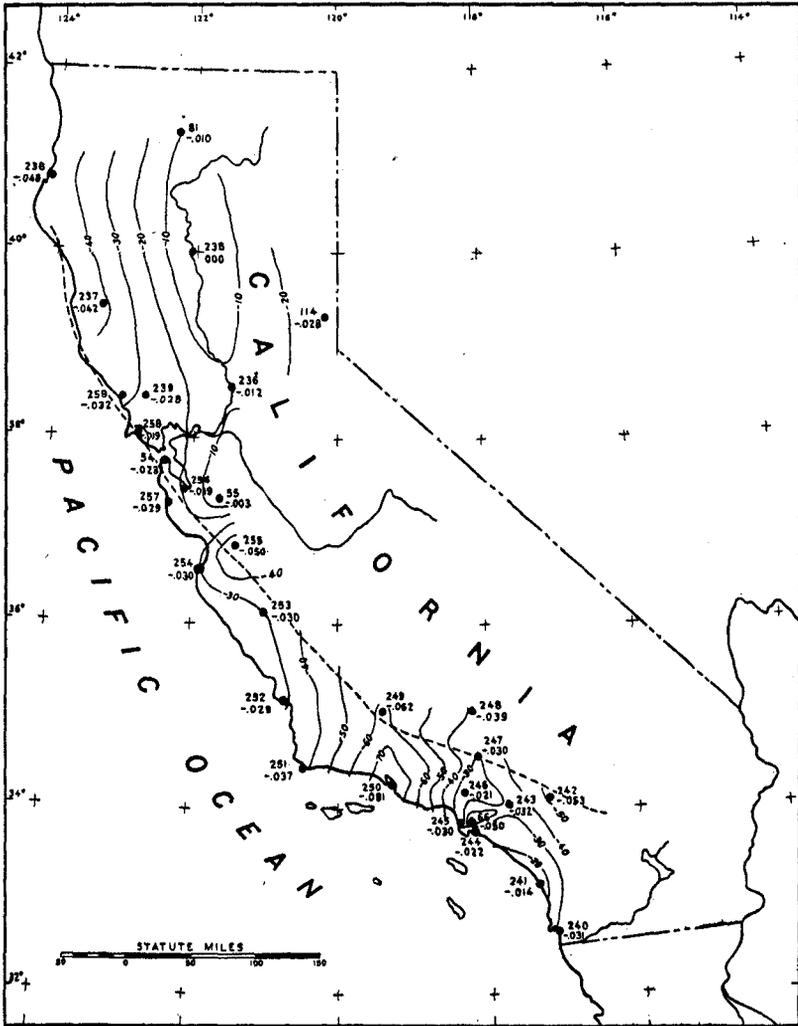


FIG. 6.—Gravity determinations in California

This illustration shows the location of the gravity stations established in California and the gravity anomalies. The anomalies are given to the third place of decimals in dynes. The contours indicate the lines of equal gravity anomalies and are constructed by interpolations between the several stations. The stations are numbered the same as in special publication No. 99 of the United States Coast and Geodetic Survey.

The following table contains data for the California gravity stations, which will be of use in connection with Figure 6.

*Data for gravity stations in California*

Station		Latitude	Longitude	Elevation	Iso- static anom- aly
Number	Name				
		° ' "	° ' "	Meters	
54.....	San Francisco.....	37 47.5	122 25.7	114	-0.023
55.....	Mount Hamilton.....	37 20.4	121 38.6	1,282	-0.003
66.....	Compton.....	33 53.4	118 13.2	20	-0.050
81.....	Sisson.....	41 18.3	122 19.6	1,048	-0.010
114.....	Truckee.....	39 19.6	120 11.4	1,805	-0.028
235.....	Tehama.....	40 01.6	122 07.2	65	-0.000
236.....	Sacramento.....	38 34.8	121 29.8	7	-0.012
237.....	Willits.....	39 24.9	123 22	420	-0.042
238.....	Eureka.....	40 48.2	124 09.7	12	-0.048
239.....	Santa Rosa.....	38 26.4	122 43.0	48	-0.028
240.....	San Diego.....	32 42.8	117 09.9	7	-0.031
241.....	Oceanside.....	33 11.6	117 22.5	39	-0.014
242.....	Highland.....	34 07.5	117 12.5	393	-0.053
243.....	Pomona.....	34 03.2	117 45.2	258	-0.032
244.....	Long Beach.....	33 46.3	118 11.6	8	-0.022
245.....	Redondo Beach.....	33 50.6	118 23.3	23	-0.030
246.....	Burbank.....	34 11.1	118 18.9	187	-0.021
247.....	Palmdale.....	34 35	118 08	808	-0.030
248.....	Mojave.....	35 03.2	118 10.4	838	-0.039
249.....	Maricopa.....	35 03.8	119 24.0	257	-0.062
250.....	Ventura.....	34 16.8	119 17.6	24	-0.031
251.....	Concepcion.....	34 26.9	120 28.3	65	-0.037
252.....	Avila.....	35 10.6	120 43.9	13	-0.029
253.....	San Lucas.....	36 07.8	121 01.2	122	-0.030
254.....	Monterey.....	36 36.0	121 53.8	6	-0.030
255.....	Hollister.....	36 51.1	121 24	88	-0.050
256.....	Palo Alto.....	37 26.6	122 09.7	15	-0.019
257.....	San Gregorio.....	37 19.4	122 23.3	16	-0.029
258.....	Point Reyes Station.....	38 04.0	122 48.7	8	-0.019
259.....	Duncans Mills.....	38 27.3	123 03.8	7	-0.032

If the crust of the earth under California, as a whole, is in isostatic equilibrium, it would seem that the earthquakes and movements of the surface are due to local causes resulting from the erosion of the highlands and the deposition of material in contiguous valleys and along the coast or to the expansion or contraction of crustal material below the affected regions.

#### CONCLUSION

After the close of the observing season of 1924 when additional data are available, another report will be made to give the changes in geographic positions for all of the precise triangulation in California to the southward of the thirty-ninth parallel.

The results so far obtained show the necessity of continuing the geodetic operations in California and their extension to other areas, if we are to learn the rates at which earth movements take place horizontally and vertically. All this may have a great influence on the prediction of the places and possibly the approximate times at which earthquakes are likely to occur.