STRAIN ACCUMULATION IN THE SANTA BARBARA CHANNEL: 1971-1987

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Geophysical evidence suggests a significant amount of north-south convergence occurs across the Santa Barbara Channel. Tectonic studies [Weldon and Humphreys, 1986] indicate a discrepancy between observed fault slip in California and the North American-Pacific plate motion (56 mm/yr-RM2) [Minster and Jordan, 1978]. 23 mm/yr of north-south shortening across the Santa Barbara Channel would account for this discrepancy (Figure 1), although some of this missing movement could occur elsewhere. Newer plate motion models (NUVEL-1) [Demets et. al., 1987], yield a lower rate of convergence. Examination of seismicity in coastal southern California indicates the Santa Barbara Channel is a region of high activity (Figures 2 and 3). Although earthquake size for those events before 1930 is not well determined, several historic events in and near this region are estimated to have magnitudes greater than 7 [Lee et. al., 1979; Yerkes and Lee, 1979], included the 1812 earthquake which may have generated a tsunami in the channel [Richter, 1958] (Figure 4). Earthquake focal mechanisms (Figure 5) suggest a north to northeast axis of compression, with a small component of left-lateral slip [Yerkes et. al., 1980]. This is true for the background seismicity as well as for moderate to large events ($M_L > 5$). Extensive study of the 1978 Santa Barbara earthquake [Corbett, 1982] suggests it occurred on a shallow north dip-

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ping thrust fault, indicative of active compression in the western Transverse Ranges. The rapid closer of the Santa Barbara Channel inferred from geophysical evidence is in line with geologic studies in the western Transverse Ranges which indicate up to 23 mm/yr north-south shortening [Yeats, 1983]. The rate for the channel may be somewhat less, perhaps 7.5 mm/yr averaged over the last 1,000,000 yrs, although the exact figure is uncertain. GPS data collected in the Santa Barbara Channel in 1987, when combined with 1971 trilateration measurements, should be sufficient to resolve the present-day convergence rate.

In late 1970 and early 1971 EDM baseline measurements were made between the California coast near Santa Barbara and the offshore islands, Santa Cruz and Santa Rosa (Figure 2). This survey (made by Greenwood and Associates) used an AGA Model 8 laser Geodimeter. Corrections for refraction were made using end-point measurements of pressure, temperature, and humidity, together with records of temperature along the line of sight taken from an airplane.

In early 1987, from January 3 to January 7, GPS data were collected at 14 sites in California and at 5 additional stations throughout North America (Experiment 3) (Figures 7 and 8). Included in the California sites were 5 of the original 6 trilateration stations (Figure 9). LACU, DEVL, and SNRI were occupied for 5 days, GAVI for 3 days, and CHAF for 1 day. Because of weather conditions, stations SOLI and MILL were used as backups for CHAF and GAVI, respectively. A GPS tie between GAVI and MILL was made shortly after this experiment and a tie between CHAF and SOLI was made in early October, 1987. Station HIMT, the trilateration site not observed in the January, 1987 survey, was occupied for 3 days in May, 1988, in a GPS network which included LUCU and an additional site (HIGH) on Santa Cruz Island (Figure 10). Thus, the entire 1971 trilateration network has been reoccupied with GPS surveys in 1987 and 1988. These data can be used to estimate the rate of crustal deformation (convergence) occurring across the Santa Barbara Channel.

GPS baselines for Experiment 3 (January, 1987) have been computed with the Bernese 2nd generation software (no ambiguity resolution). Solutions were obtained using OVRO, FTOR, and PVER as regional fiducial sites (SV3 coordinates [Murray and King, 1988]), and separately with the broadcast orbits. Surface meteorological data were used to model the atmospheric delay although the troposphere was not a free parameter in the final solution. 3 to 5 day repeatabilities for the baseline components have been determined (Figures 11 and 12). When orbits are solved, the day to day scatter is generally less than 1 cm for the length and north-south components, about 1 cm for the east-west component, and 10 cm for the vertical. The scatter does not show any significant correlation with baseline length. When broadcast orbits are used (no stations held fixed), day to day repeatabilities are larger, on the order of 1×10^{-7} for the horizontal and 7×10^{-7} for the vertical components. The RMS repeatabilities should improve when the data are reduced with the Bernese 3rd generation software and ambiguity resolution is preformed.

A comparison is made between baseline lengths obtained with the Bernese (2nd generation) and MIT softwares (Figure 13). The MIT values are from Murray et. al. [1987]. When orbits are solved in the Bernese solution (PVER, OVRO, FTOR fiducials; SV3 coordinates) the agreement is on the order of 2×10^{-7}. When broadcast orbits are used for the Bernese solution, the MIT-Bernese agreement is on the order of 8×10^{-8}. When station BRUS is excluded from the data set, the MIT-Bernese agreement improves to 4×10^{-8}. These results will change when a comparison is made between the new MIT Experiment 3 baselines, which incorporate ambiguity resolution, and values obtained with the Bernese 3rd generation software. Both data sets will employ SV4 coordinates for the fiducial locations.

Baseline changes from 1971 (trilateration) to January, 1987 (GPS-Bernese) across the Santa Barbara Channel have been computed (Figure 14). Some of the trilateration data have not been completely reduced to a form suitable to integrate with the GPS measurements. Baseline measurements for all GPS lines have been determined.

A uniform strain model is calculated from the baseline changes (Figure 15). When all lines are considered (GAVI-SNRI included), errors for the computed strain components are large (ϵ_{11} = -0.40 ± 0.51, ϵ_{22} = -1.46 ± 0.42, ϵ_{12} = -1.25 ± 0.49; all in μstrain), as are baseline residuals (up to 9 cm differences). In the 1971 trilateration survey, significant effort was employed to determine the GAVI-DEVL baseline at the expense of the GAVI-SNRI baseline. In fact, only 3 measurements were obtained for GAVI-SNRI. Additionally, temperature recordings for that baseline show large scatter. When the GAVI-SNRI baseline is excluded from the strain calculation, the associated errors for the strain components are significantly reduced (ϵ_{11} = -0.26 ± 0.17, ϵ_{22} = -2.32 ± 0.17, ϵ_{12} = -0.94 ± 0.16). Baseline residuals in this case are on the order of 1 to 2 cm. Thus, we believe the GAVI-SNRI trilateration baseline to be in error, and it is excluded in the calculation of convergence rate.

The above strain model (GAVI-SNRI excluded) yields nearly uniaxial compression of -2.68$\mu\epsilon$ oriented N21E across the Santa Barbara Channel, at a 16 year rate of -0.17$\mu\epsilon$/yr (Figure 16). This corresponds to 8 mm/yr convergence across the 50 km wide Santa Barbara Channel and 10 mm/yr shortening across the 60 km wide GPS/trilateration network. The rate calculated using the new MIT GPS baselines is nearly identical, although the axis of compression (convergence) is directed N20W as opposed to the Bernese obtained orientation of N21E.

We have determined the present-day rate of convergence across the Santa Barbara Channel to be 8 to 10 mm/yr. This conclusion is obtained from changes in baseline length measured with a 1971 trilateration survey and a January, 1987, GPS survey. The convergence rate applies to the western channel; a higher rate may be observed to the east, which would be in line with some geologic evidence. This theory can be tested when data reduction for those trilateration lines in the eastern Santa Barbara Channel is complete. These results indicate that some (or all) of the hypothesized San Andreas discrepancy may occur in this region. The rapid convergence rate, in addition to the history of large seismic events, suggests this region is a prime target for future geodetic and geophysical studies.

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Bernese (2nd generation) solution for Experiment 3 Baselines
PVER, FTOR, OVRO fiducials (SV3 coordinates)

station		#days	length	rms	vert	rms	ns	rms	ew	rms
1- 2	chaf-devl	1	51533.811	.000	397.364	.000	30116.527	.000	41744.077	.000
1- 3	chaf-gavi	1	82865.159	.000	406.013	.000	22318.080	.000	79700.267	.000
1- 4	chaf-lacu	1	41268.932	.000	857.584	.000	21497.046	.000	35171.312	.000
1- 5	chaf-snri	1	81322.401	.000	136.099	.000	38797.059	.000	71318.924	.000
1- 6	chaf-ftor	1	343761.208	.000	283.530	.000	262857.940	.000	218325.209	.000
1- 7	chaf-ovro	1	338556.373	.000	870.778	.000	325312.891	.000	92037.184	.000
1- 8	chaf-pver	1	105605.288	.000	237.763	.000	61768.069	.000	85374.712	.000
1- 9	chaf-vndn	1	121493.833	.000	318.935	.000	28358.759	.000	117956.401	.000
1-10	chaf-brus	1	131036.932	.000	141.277	.000	99118.376	.000	85254.777	.000
1-11	chaf-fibr	1	121934.523	.000	252.587	.000	121796.167	.000	5728.631	.000
2- 3	devl-gavi	3	64859.118	.007	8.741	.080	52434.604	.003	38056.173	.011
2- 4	devl-lacu	5	52030.125	.003	460.216	.040	51613.568	.003	6476.656	.011
2- 5	devl-snri	5	30930.505	.006	261.162	.060	8680.535	.003	29669.814	.006
2- 6	devl-ftor	5	344218.794	.005	680.897	.089	292974.456	.006	177791.347	.005
2- 7	devl-ovro	5	380195.893	.007	473.411	.089	355429.407	.006	132275.722	.005
2- 8	devl-pver	5	131608.681	.004	635.130	.089	31651.553	.006	127525.751	.005
2- 9	devl-vndn	5	96359.054	.008	716.104	.116	58475.282	.004	76339.780	.012
2-10	devl-brus	5	145307.293	.010	256.210	.086	69001.855	.008	127405.447	.013
2-11	devl-fibr	5	156071.638	.003	649.891	.052	151912.690	.002	35464.654	.004
3- 4	gavi-lacu	3	44550.544	.004	451.449	.108	821.035	.001	44532.247	.004
3- 5	gavi-snri	3	61720.440	.002	269.921	.016	61115.138	.002	8551.908	.013
3- 6	gavi-ftor	3	279665.736	.003	689.682	.140	240539.853	.006	140749.045	.005
3- 7	gavi-ovro	3	348421.525	.005	464.626	.140	302994.804	.006	169046.613	.005
3- 8	gavi-pver	3	185739.229	.008	643.915	.140	84086.156	.006	164869.257	.005
3- 9	gavi-vndn	3	38803.044	.006	724.882	.059	6040.680	.003	38308.529	.007
3-10	gavi-brus	3	205535.724	.012	264.956	.195	121436.458	.003	164749.625	.011
3-11	gavi-fibr	3	123698.397	.009	658.668	.060	99478.087	.002	73108.528	.013
4- 5	lacu-snri	5	70287.112	.006	721.377	.076	60294.104	.002	35983.533	.012
4- 6	lacu-ftor	5	305097.546	.006	1141.113	.073	241360.888	.004	184094.817	.008
4- 7	lacu-ovro	5	329791.714	.005	13.195	.073	303815.839	.004	126018.293	.008
4- 8	lacu-pver	5	146800.352	.007	1095.346	.073	83265.121	.004	120348.930	.008
4- 9	lacu-vndn	5	83141.171	.010	1176.320	.123	6861.714	.005	82811.590	.010
4-10	lacu-brus	5	170866.162	.008	716.425	.080	120615.425	.006	120229.286	.012
4-11	lacu-fibr	5	104483.327	.003	1110.107	.042	100299.122	.001	29058.717	.010
5- 6	snri-ftor	5	337587.716	.004	419.735	.101	301654.991	.005	149073.176	.006
5- 7	snri-ovro	5	399384.972	.002	734.573	.101	364109.943	.005	160783.601	.006
5- 8	snri-pver	5	159197.790	.006	373.968	.101	22971.017	.005	157338.905	.006
5- 9	snri-vndn	5	81985.835	.006	454.943	.066	67155.817	.006	46854.852	.010
5-10	snri-brus	5	168864.283	.016	4.952	.134	60321.320	.005	157218.492	.017
5-11	snri-fibr	5	173332.609	.004	388.729	.046	160593.226	.002	64649.298	.007
6- 7	ftor-ovro	5	316122.096	.000	1154.308	.000	62454.951	.000	308751.022	.000
6- 8	ftor-pver	5	446535.441	.000	45.767	.000	324626.043	.000	301220.982	.000
6- 9	ftor-vndn	5	256842.005	.005	35.207	.153	234499.183	.006	103436.166	.007
6-10	ftor-brus	5	474692.616	.003	424.687	.076	361976.364	.008	301104.547	.014
6-11	ftor-fibr	5	256638.686	.007	31.006	.065	141061.767	.005	212688.358	.007
7- 8	ovro-pver	5	387188.809	.000	1108.541	.000	387081.029	.000	9739.970	.000
7- 9	ovro-vndn	5	363473.038	.007	1189.515	.153	296954.149	.005	206084.623	.007
7-10	ovro-brus	5	424527.440	.008	729.621	.076	424431.363	.008	9855.570	.013
7-11	ovro-fibr	5	226240.378	.005	1123.302	.065	203516.722	.005	97633.070	.007
8- 9	pver-vndn	5	223054.502	.010	80.974	.153	90126.835	.006	203068.635	.007
8-10	pver-brus	5	37353.901	.008	378.920	.076	37350.303	.007	120.708	.014

station		#days	length	rms	vert	rms	ns	rms	ew	rms
8-11	pver-fibr	5	204821.921	.004	14.761	.065	183564.243	.005	89976.755	.007
9-10	vndn-brus	5	240825.638	.015	459.895	.192	127477.138	.010	202949.084	.019
9-11	vndn-fibr	5	145547.062	.013	66.213	.094	93437.408	.004	111026.371	.014
10-11	brus-fibr	5	238895.480	.005	393.681	.105	220914.545	.007	89858.417	.012

stations MILL, SOLI, MOJA not included

FIG 1

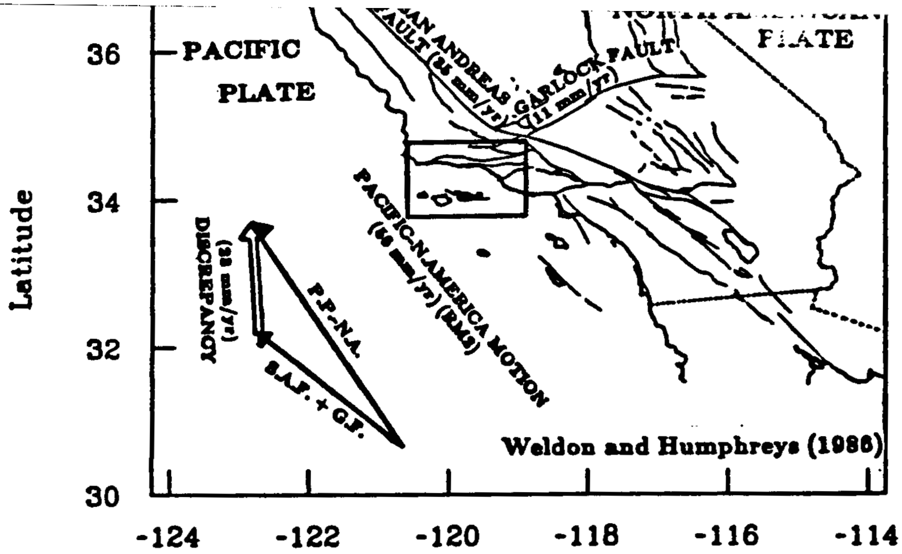


FIG 2

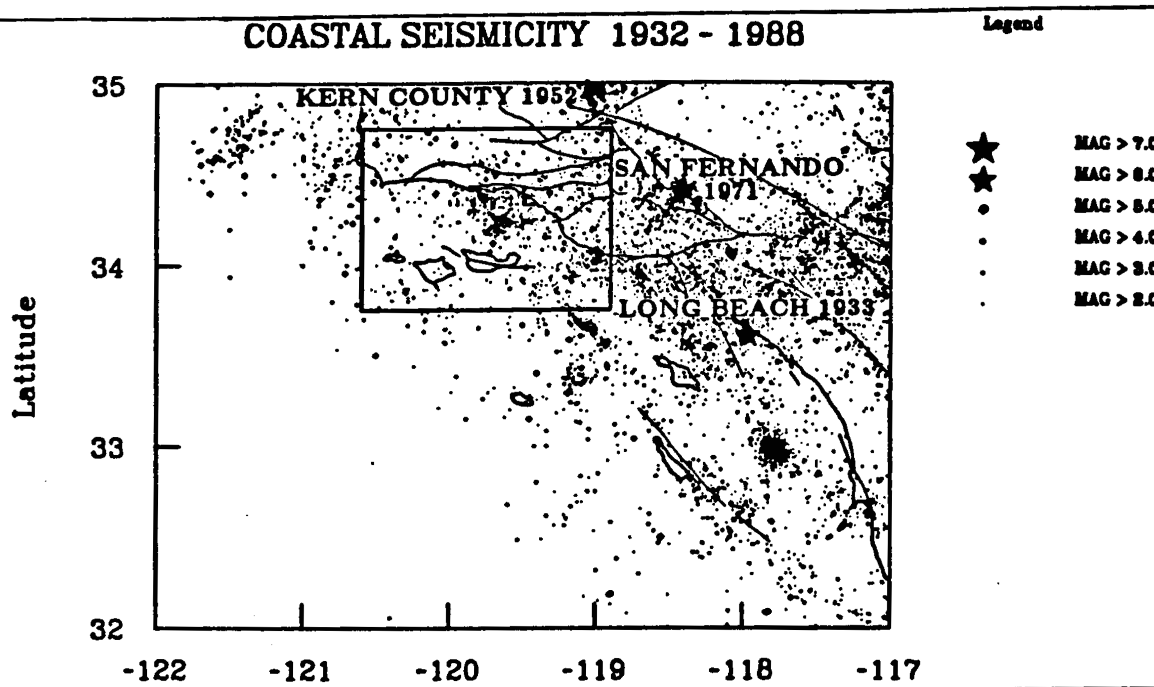


FIG 3

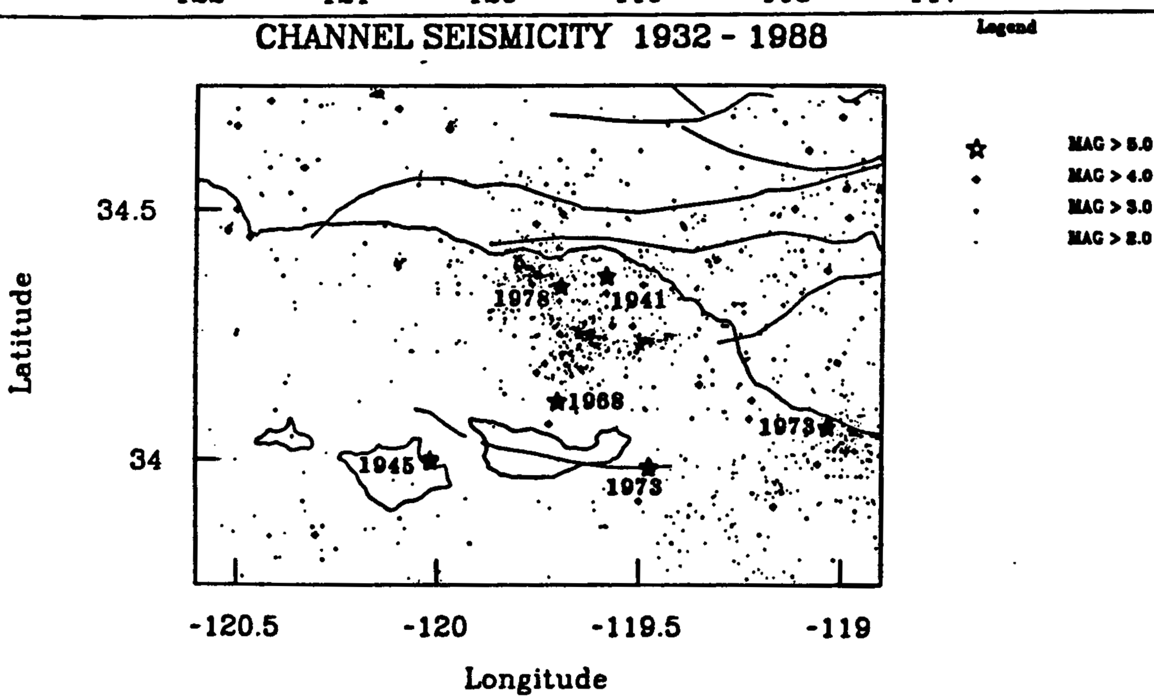


FIG 4

HISTORIC EARTHQUAKES AND MAGNITUDES

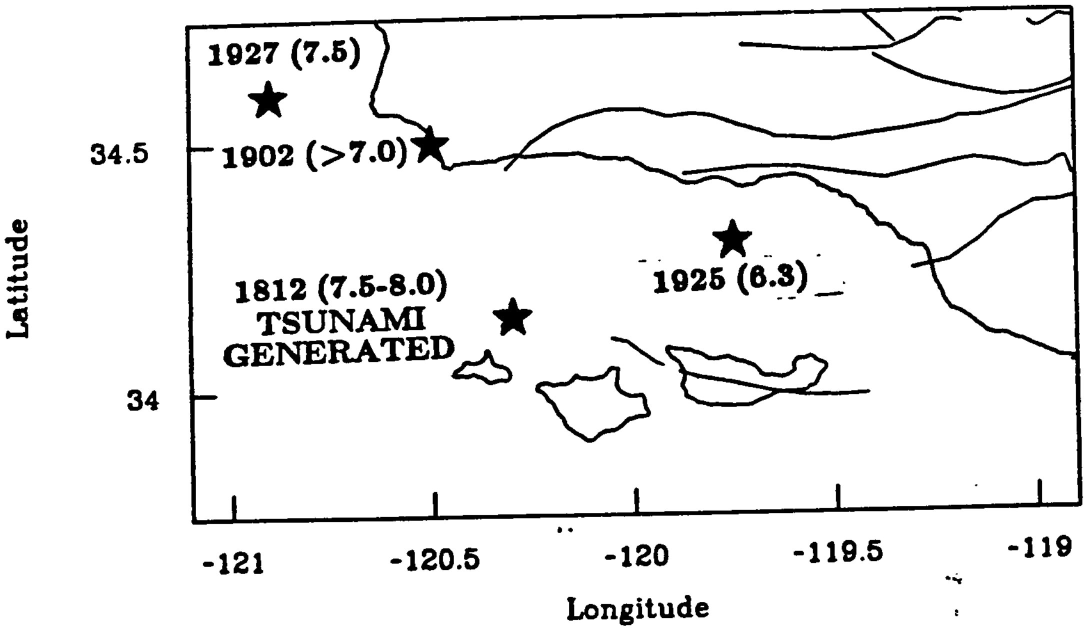


FIG 5

FOCAL MECHANISMS 1970-1978

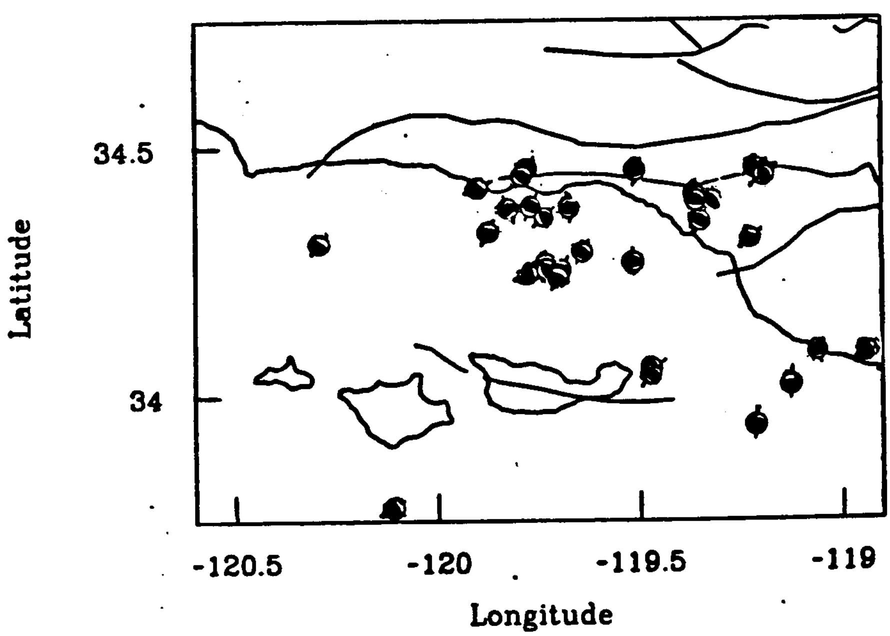


FIG 6

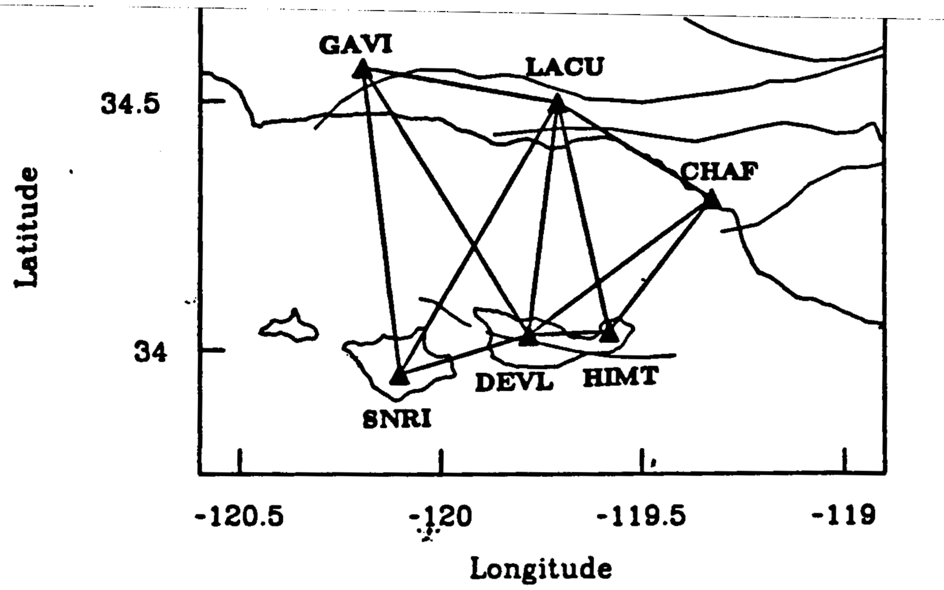


FIG 7

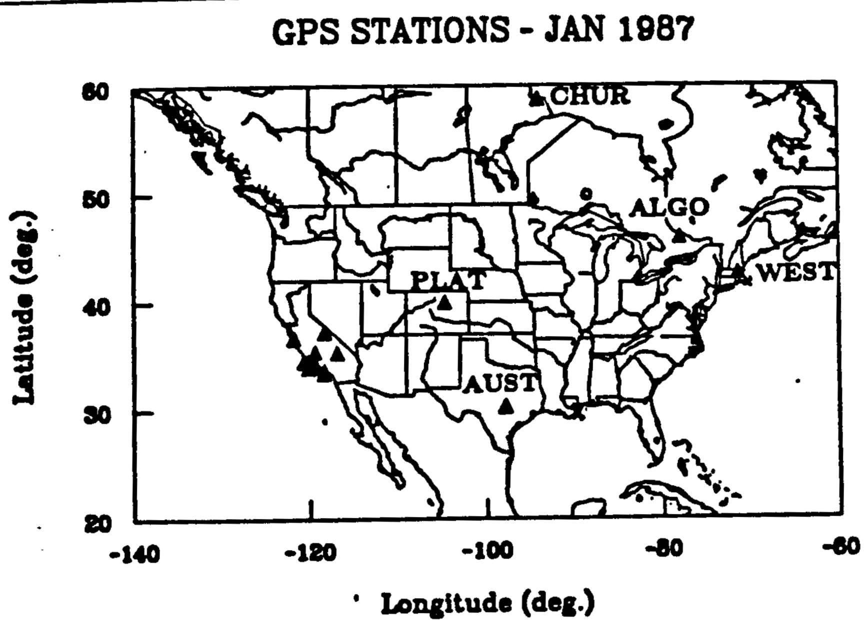


FIG 8

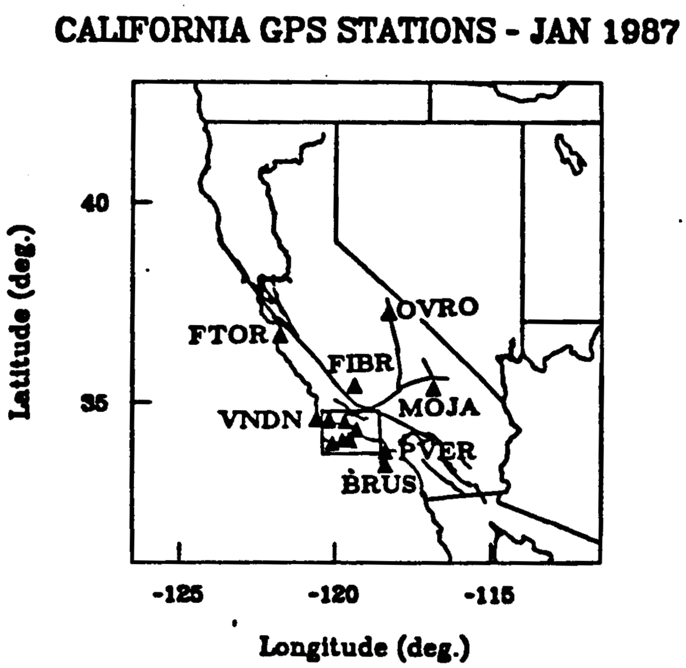
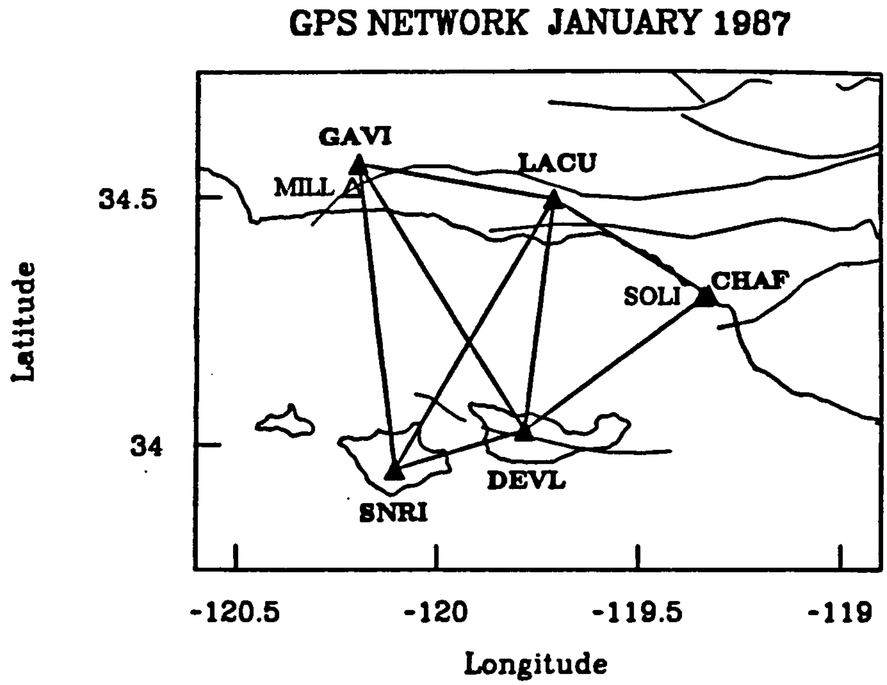
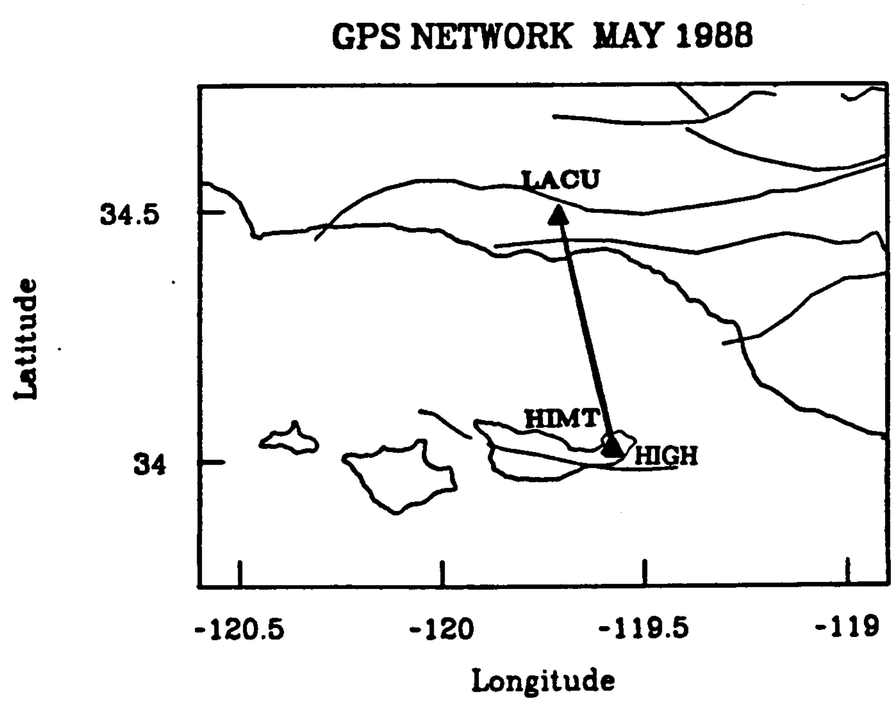


FIG 9



GPS NETWORK JANUARY 1987
GAVI
LACU
MILL
SOLI
CHAF
DEVL
SNRI
34.5
34
Latitude
-120.5
-120
-119.5
-119
Longitude

FIG 10



GPS NETWORK MAY 1988
LACU
HIMT
HIGH
34.5
34
Latitude
-120.5
-120
-119.5
-119
Longitude

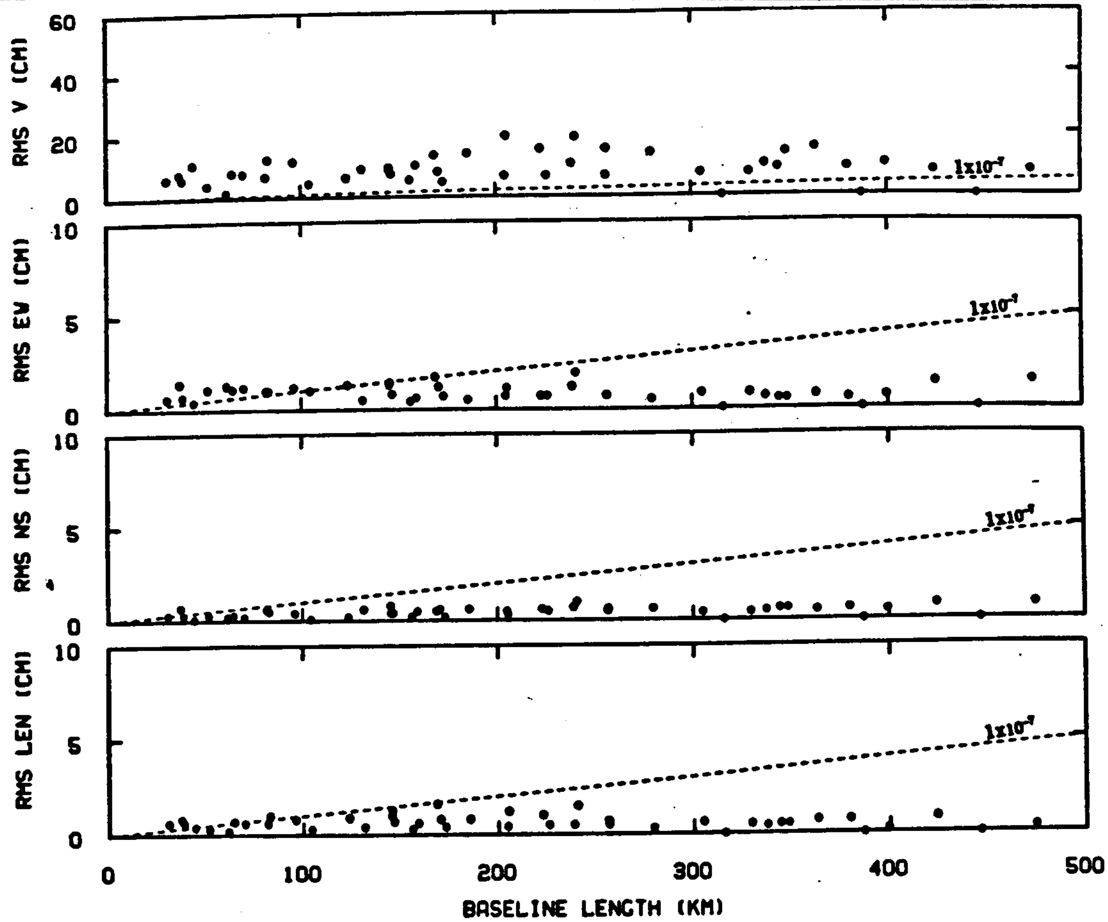


FIG 11

BASELINE SCATTER (BROADCAST ORBITS)

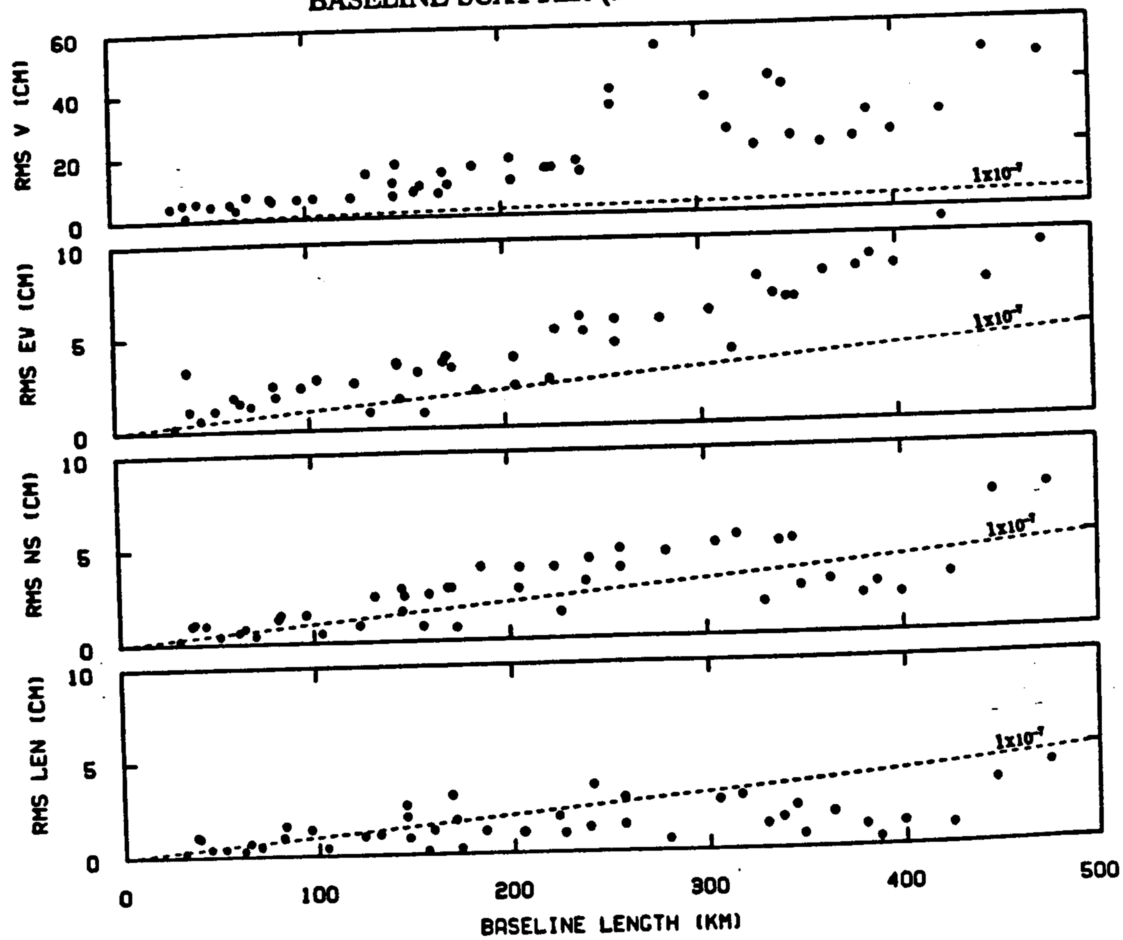


FIG 12

FIG 13

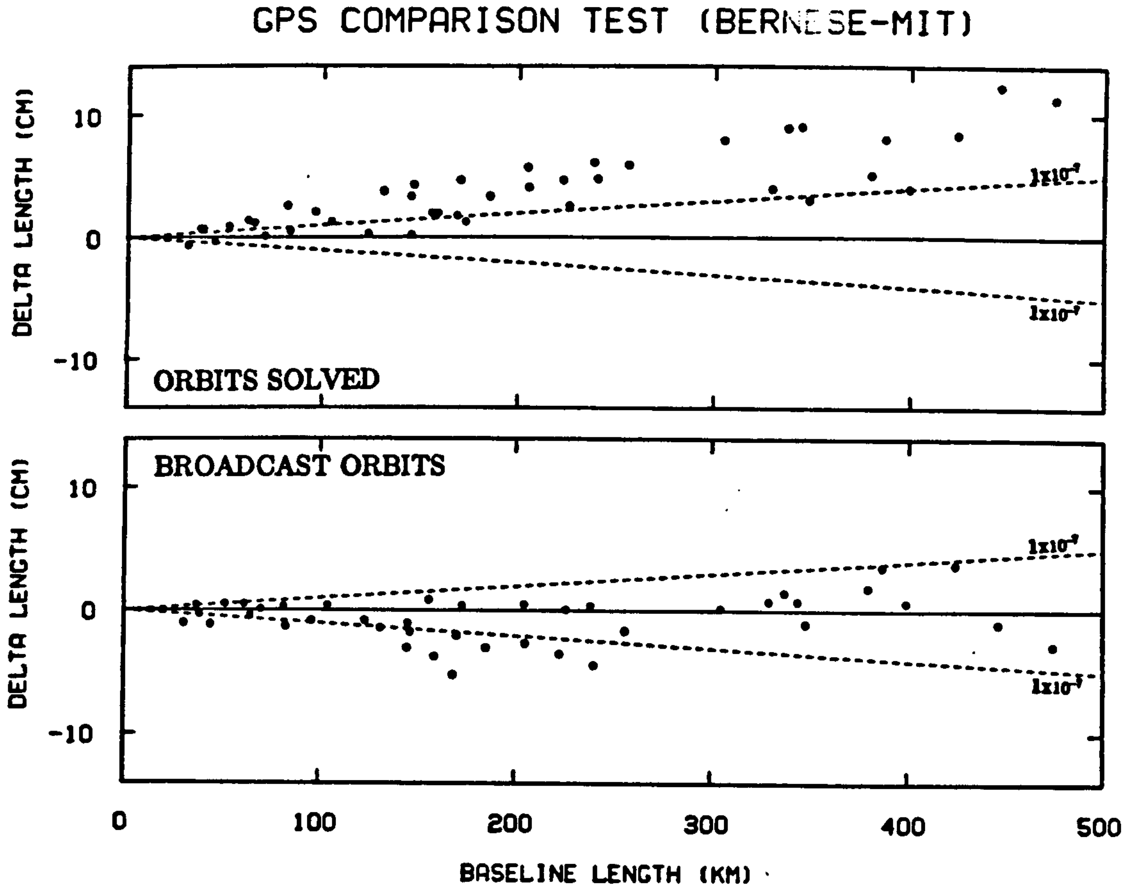

GPS COMPARISON TEST (BERNESE-MIT)
DELTA LENGTH (CM)
10
0
-10
1x10^-7
1x10^-7
ORBITS SOLVED
BROADCAST ORBITS
DELTA LENGTH (CM)
10
0
-10
1x10^-7
1x10^-7
0
100
200
300
400
500
BASELINE LENGTH (KM)

FIG 14

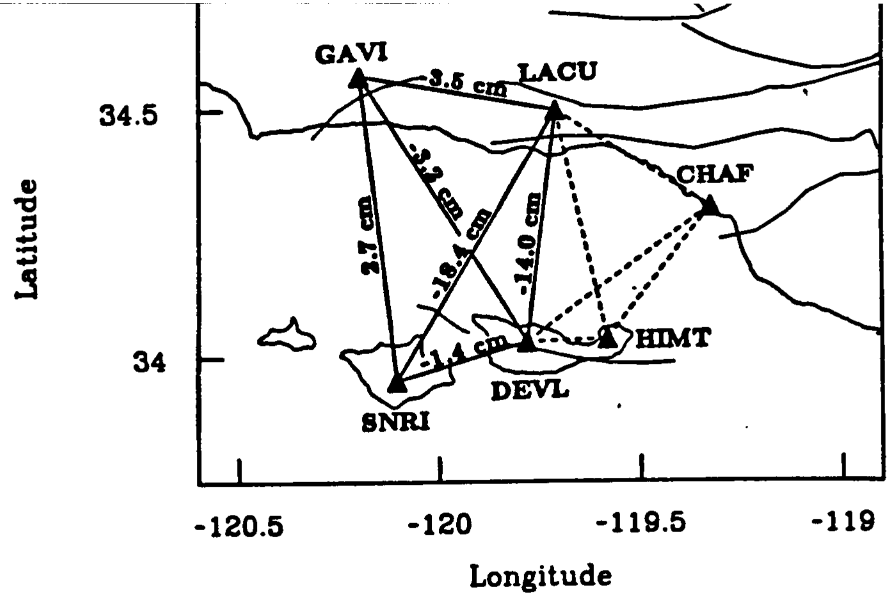


FIG 15

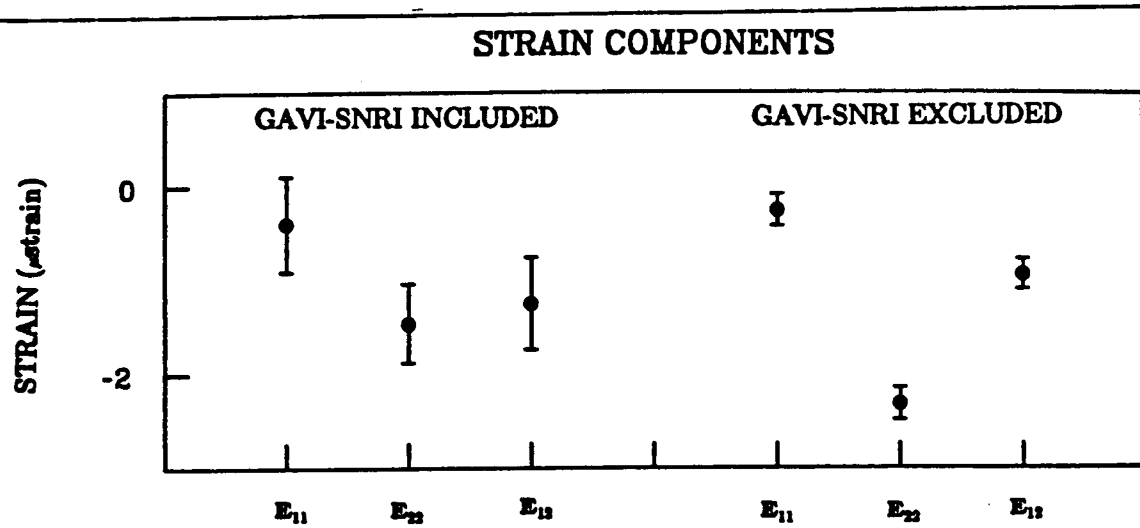


FIG 16