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Data from Theodolite Measurements of Creep Rates on San Francisco Bay Region Faults, California: 1979-2007

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Introduction

Our purpose is to update with six additional years of data, our creep data archive on San Francisco Bay region active faults for use by the scientific research community. Earlier data (1979-2001) were reported in Galehouse (2002) and were analyzed and described in detail in a summary report (Galehouse and Lienkaemper, 2003). A complete analysis of our earlier results obtained on the Hayward fault was presented in Lienkaemper, Galehouse and Simpson (2001). Jon Galehouse of San Francisco State University (SFSU) and many student research assistants measured creep (aseismic slip) rates on these faults from 1979 until his retirement from the project in 2001. The creep measurement project, which was initiated by Galehouse, has continued through the Geosciences Department at SFSU from 2001-2006 under the direction of Co-P.I.'s Karen Grove and John Caskey (Grove and Caskey, 2005), and by Caskey since 2006. Forrest McFarland has managed most of the technical and logistical project operations as well as data processing and compilation since 2001. We plan to publish detailed analyses of these updated creep data in future publications.

We maintain a project web site (http://funnel.sfsu.edu/creep/) that includes the following information: project description, project personnel, creep characteristics and measurement, map of creep measurement sites, creep measurement site information, and data plots for each measurement site. Our most current, annually updated results are therefore accessible to the scientific community and to the general public. Information about the project can currently be requested by the public by an email link (fltcreep@sfsu.edu) found on our project website

Methods

The amount of creep is determined by noting changes in angles between sets of measurements taken across a fault at different times. This triangulation method uses a theodolite to measure the angle formed by three fixed points to the nearest tenth of a second of arc (Galehouse and Lienkaemper, 2003). For the first 14 years of measurements, the angle was measured 12 times on each measurement day. Since then, we have been measuring it eight times each day. The amount of slip between measurement days can be calculated trigonometrically using the change in average angle. The precision of the measurement method is such that we can detect with confidence any movement greater than 1-2 mm between successive measurement days. A discussion of errors, uncertainties and seasonal variations can be found in Galehouse and Lienkaemper (2003).

We have regular measurement sites at 34 localities on active faults, and we include data from one site that had to be abandoned (SACR). These site locations are shown as triangles and site codes on the accompanying map (Figure 1) and identified by name in Table 1 and in the data sheets. In addition to the sites in the San Francisco Bay region, we have one measurement site on the San Andreas fault in the Point Arena area, one on the Bartlett Springs fault near Lake Pilsbury and two on the Maacama fault in Willits and east of Ukiah. In the past, we typically measured sites with a history of creep every two months and sites without a creep history about every three months. We expect to reduce frequency of measurements at several less active sites in order to establish and monitor new arrays on additional fault segments that may exhibit creep.

In addition to our ten regular sites on the Hayward fault, we have established 22 additional Hayward fault annual survey sites (shown by dots in Figure 2 and by name in the data sheets and in Table 2) with J. Lienkaemper of the USGS. We began measuring each of these additional sites annually in July - August 1994.

Data

Table 1 shows the least squares average rate of movement at each site determined using linear regression and the simple average rate determined by dividing the total net right-lateral

displacement by the total time measured. All measurement sites span a fault width of 57-267 m, except Sites GVRT and SGPR that span a greater width because of site considerations. The fault width spanned is noted in Table 1 and represents the distance from the theodolite on one side of a fault (IS, instrument station) to a target on the other side (ES, end station). Data sheets for each site follow Table 2. Each data sheet is identified in the upper left by site code and name. Hayward fault sites are ordered from northwest to southeast using kilometer distances along the fault measured from Point Pinole (P, in Figure 2) using the grid in Lienkaemper (2006). These data are also available for downloading in the Excel format to facilitate analysis of the data at http://pubs.usgs.gov/of/2007/1367data/ (SFBayRegion07.xls and HaywardFault07.xls). They are also available as tab delimited raw data. The data include all 34 regular measurement sites and the 22 SFSU/USGS annual survey sites on the Hayward fault. We show summary plots of the creep data by fault zone for: the Calaveras fault (Fig. 3a and 3b), Concord-Green Valley and Bartlett Springs faults (Fig. 4), Rodgers Creek and Maacama faults (Fig. 5), San Andreas and San Gregorio (Fig. 6) and Hayward fault (Figs. 7a and 7b).

Acknowledgments

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References Cited

Galehouse, J.S., 2002, Data from Theodolite Measurements of Creep Rates on San Francisco Bay Region Faults, California: 1979–2001: U.S. Geological Survey Open-File Report 02-225, 94 p. http://geopubs.wr.usgs.gov/open-file/of02-225/

Galehouse, J. S. and Lienkaemper, J. J., 2003, Inferences drawn from two decades of alinement array measurements of creep on faults in the San Francisco Bay region: Bulletin Seismological Society America v. 93, p. 2415-2433.

Grove, K., and Caskey, S. J., 2005, Theodolite and total station measurements of creep rates on San Francisco Bay Region faults: National Earthquake Hazards Reduction Program, Annual Project Summaries, Volume 46, U. S. Geological Survey, Reston, VA. (On-line report) http://earthquake.usgs.gov/research/external/reports/03HQGR0080.pdf

Lienkaemper, J.J., 2006, Digital database of recently active traces along the Hayward fault, California: U.S. Geological Survey Data Series DS-177, 20 p. http://pubs.usgs.gov/ds/2006/177/

Lienkaemper, J. J., Galehouse, J. S., and Simpson, R. W., 2001, Long-term monitoring of creep rate along the Hayward fault and evidence for a lasting creep response to 1989 Loma Prieta earthquake: Geophysical Research Letters, v. 28, p. 2265-2268.

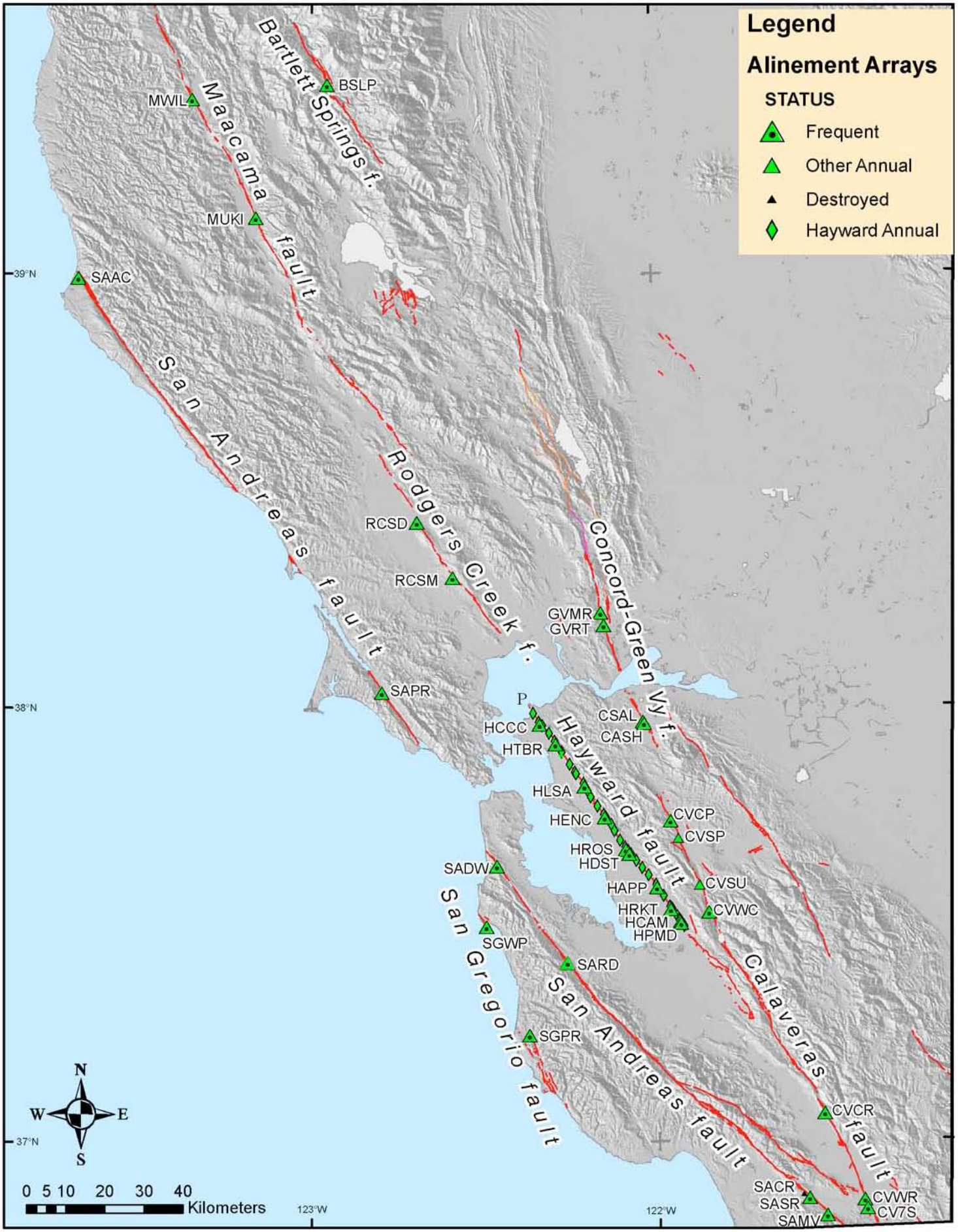

Figure 1. Locations of alinement arrays. Regular arrays shown as triangles, annual arrays on Hayward fault shown as diamonds. P, Point Pinole. For names of regular arrays, see Table 1.

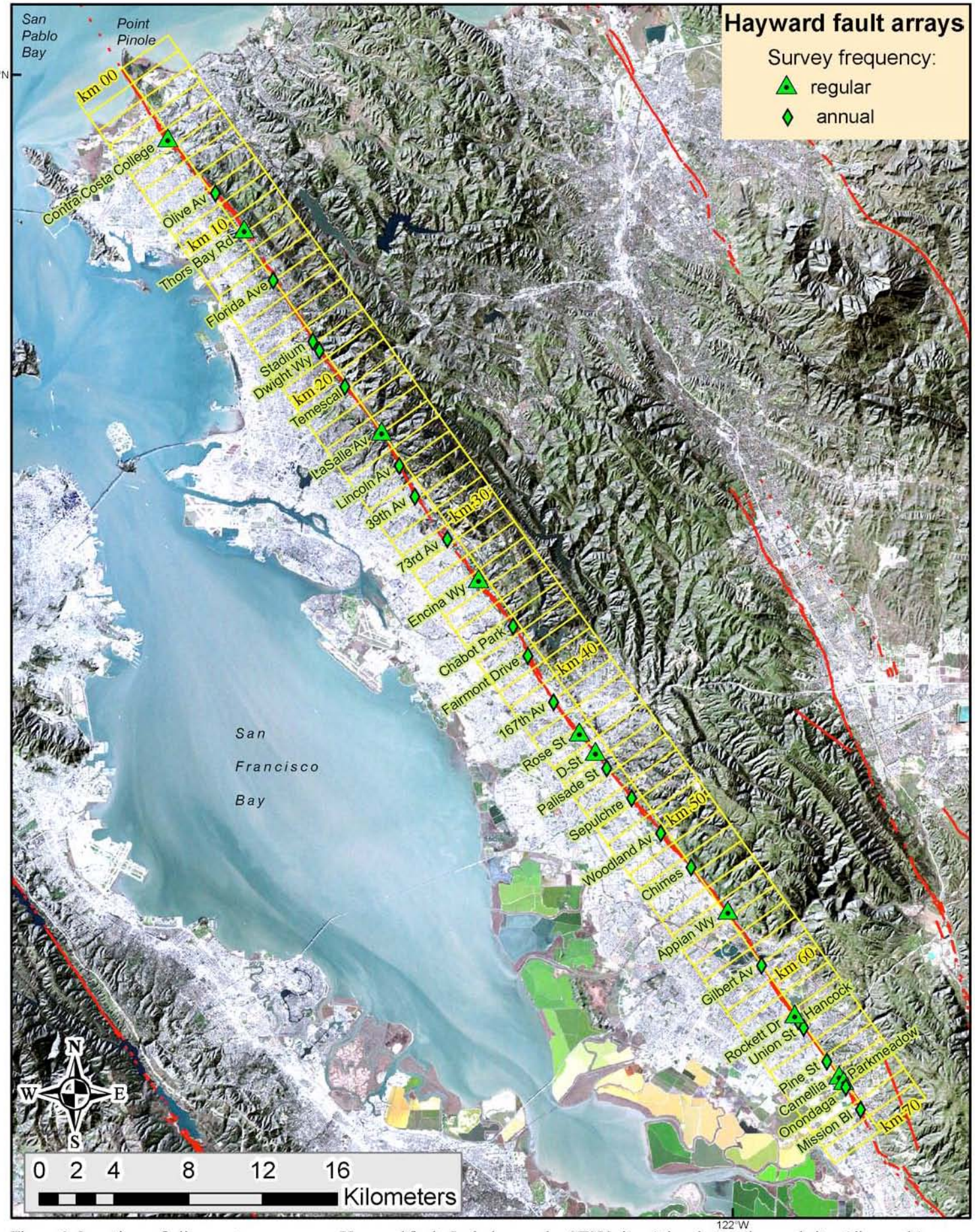

Figure 2. Locations of alinement arrays across Hayward fault. Includes regular SFSU sites (triangles) and annual sites (diamonds), see Tables 1 and 2 for additional information. Yellow grid shows distance in kilometers from San Pablo Bay after Lienkaemper (2006).

Calaveras Fault

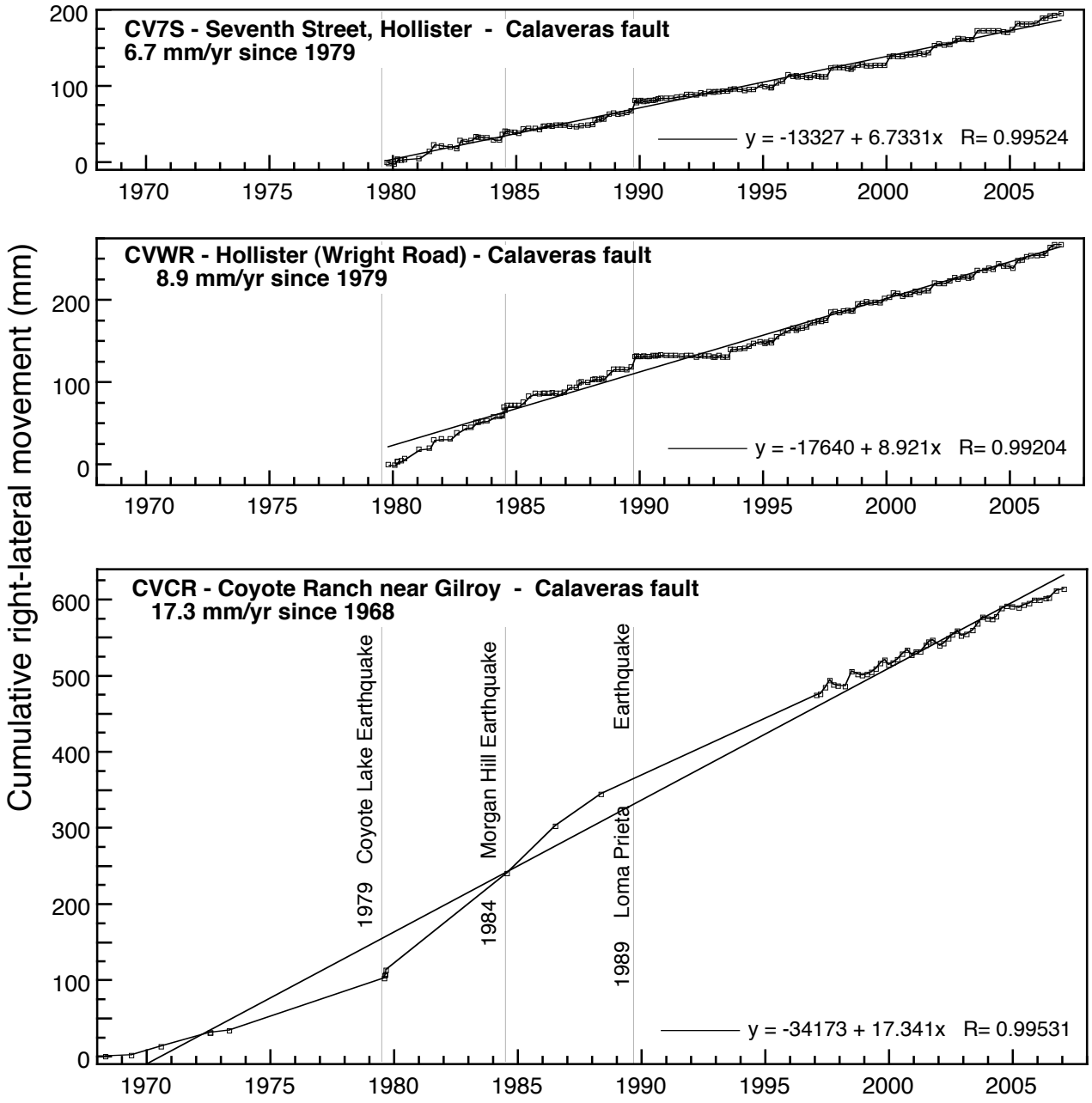

Figure 3a. Alinement array measurements, Calaveras fault.

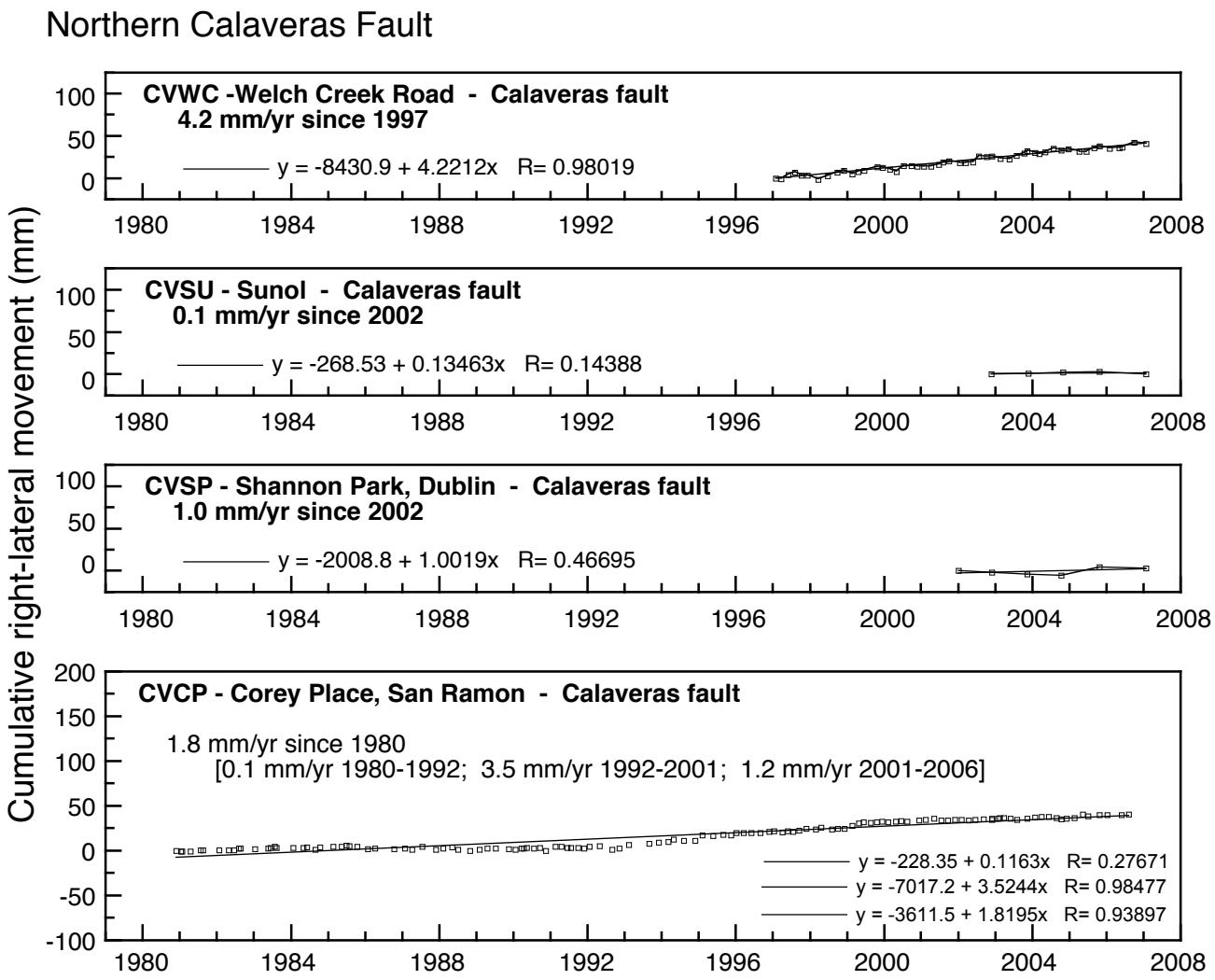

Figure 3b. Alinement array measurements, Northern Calaveras fault.

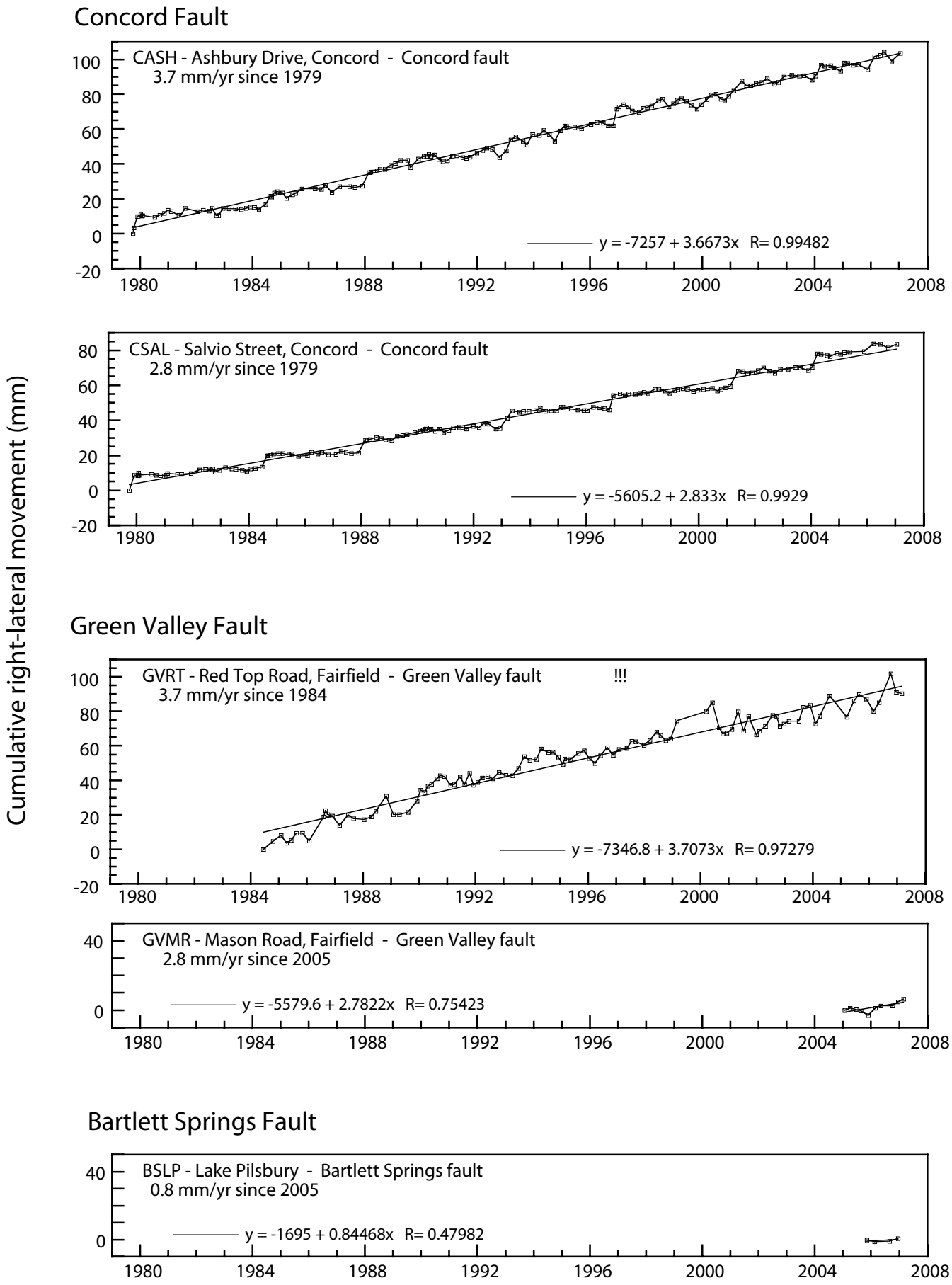

Figure 4. Alinement array measurements, Concord-Green Valley and Bartlett Springs faults.

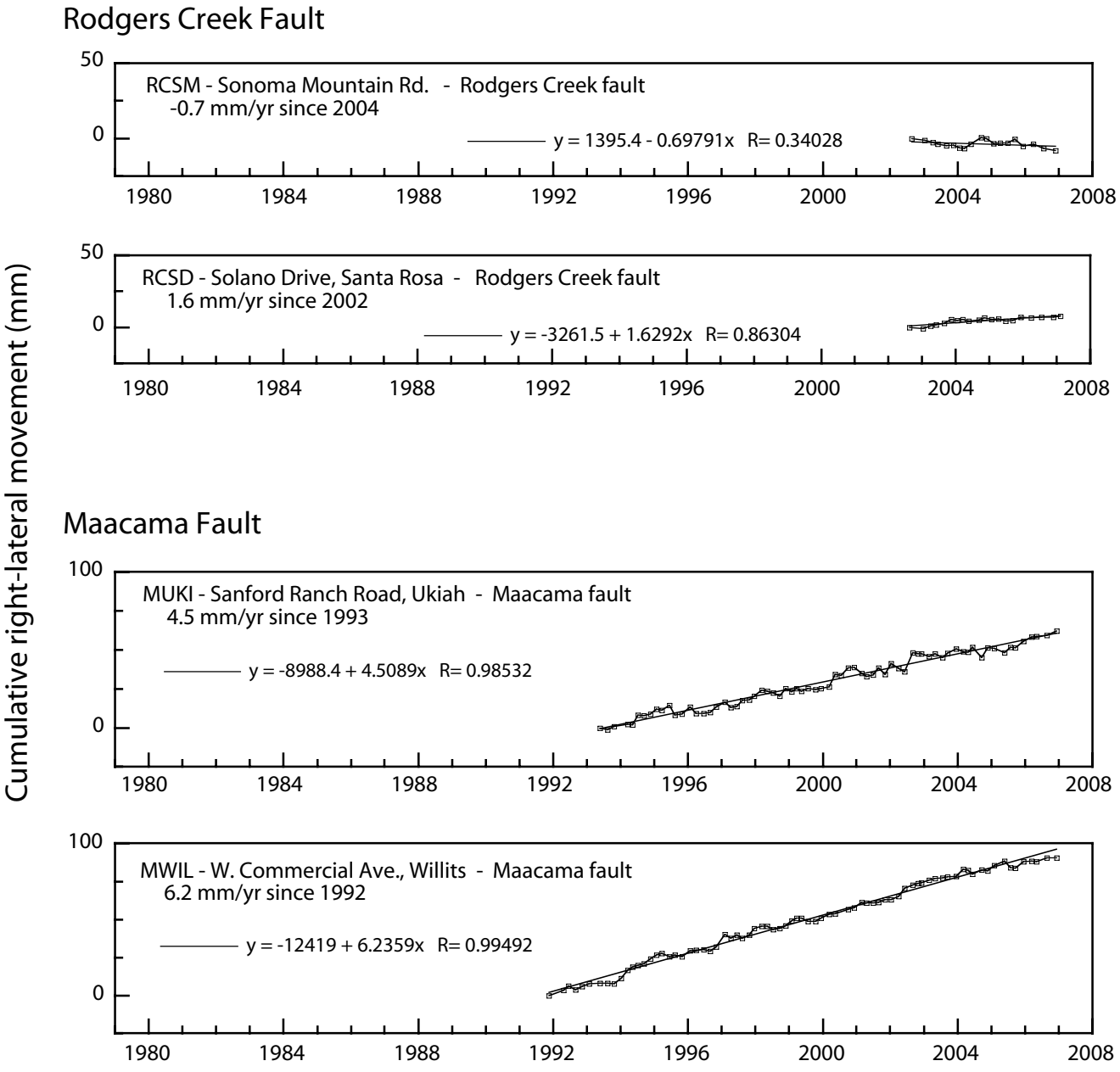

Figure 5. Alinement array measurements, Rodgers Creek and Maacama faults.

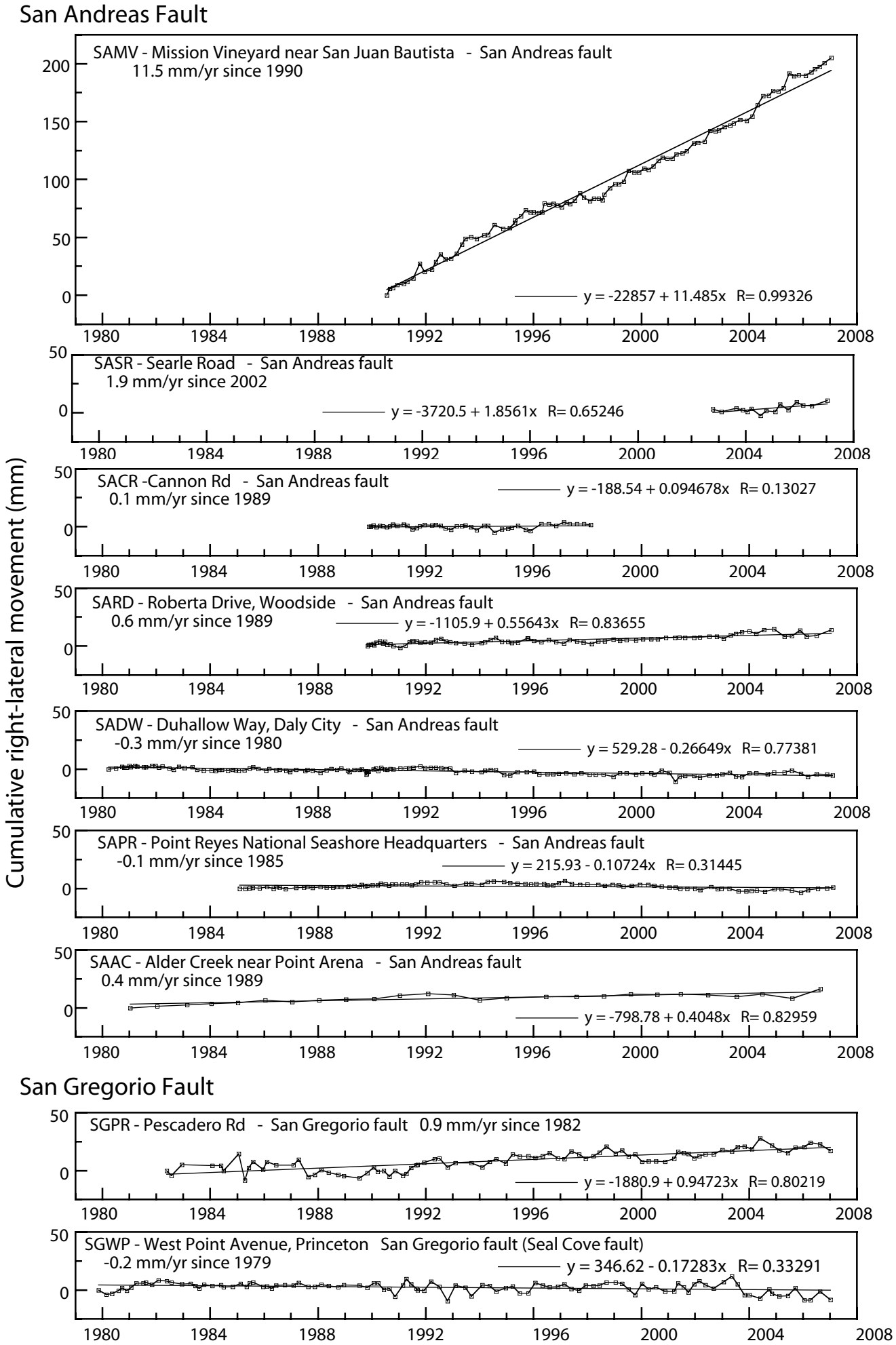

Figure 6. Alinement array measurements, San Andreas and San Gregorio faults.

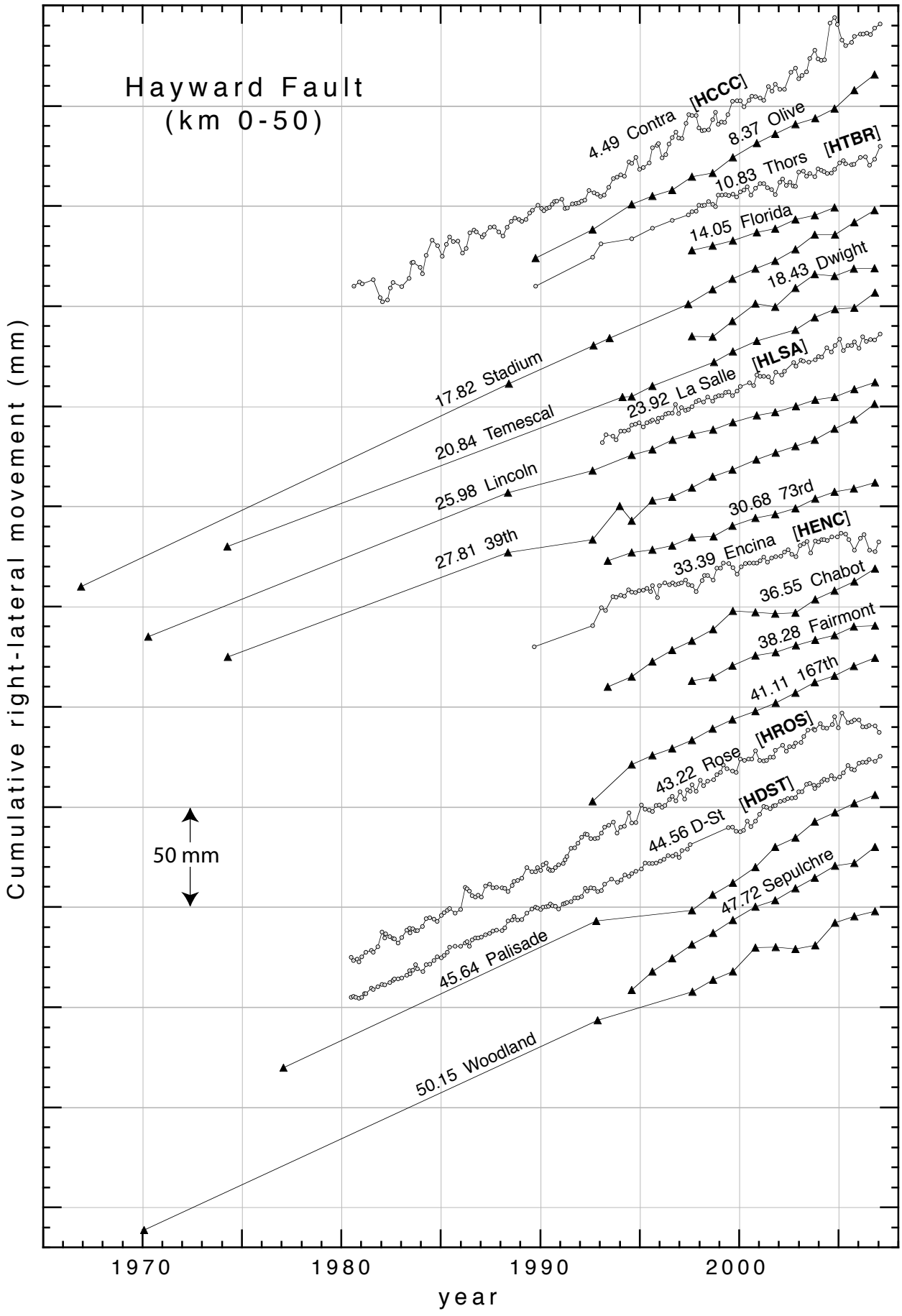

Figure 7a. Alinement array measurements, Hayward fault, sites from km 0 to 50.

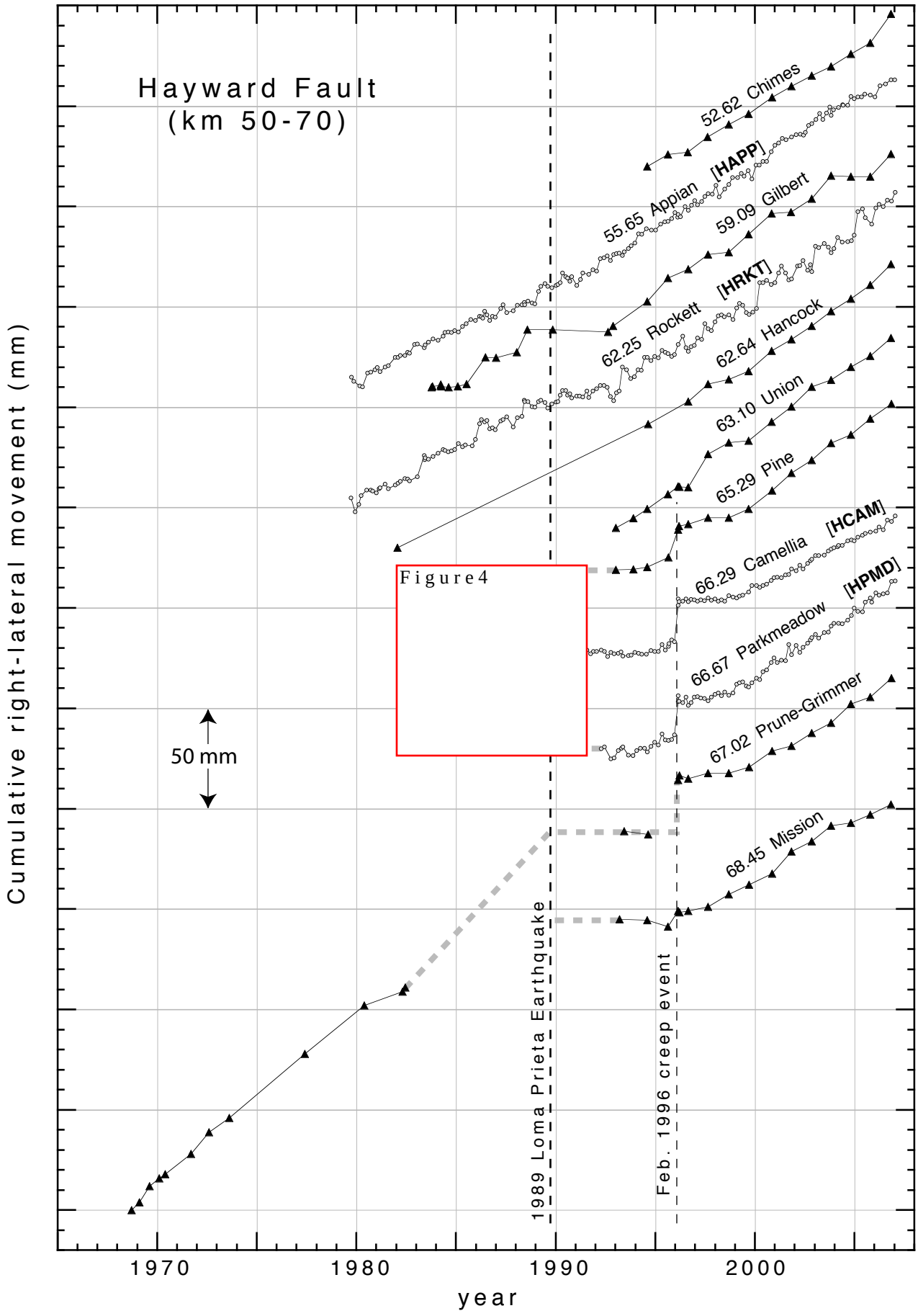

Figure 7b. Alinement array measurements, Hayward fault, sites from km 50 to 70

Table 1. Average Rates of Right-Lateral Movement, San Francisco Bay Region

Site:	Fault	Site Name	Longitude (WGS84)	Latitude (WGS84)	Length (m)	Linear regression average creep rate (mm/yr)	± (mm/yr)	Average* creep rate (mm/yr)	yr
BSLP	Bartlett Springs	Lake Pilsbury	-122.95726	39.44560	102.186	—	—	—	1.1
CASH	Concord	Ashbury Drive	-122.03524	37.97189	133.206	3.7	0.03	3.8	27.3
CSAL	Concord	Salvio Street	-122.03824	37.97569	57.110	2.8	0.03	3.1	27.3
CV7S	Calaveras	Seventh Street	-121.40631	36.84952	89.656	6.7	0.05	7.1	27.3
CVCP	Calaveras, Northern	Corey Place	-121.96083	37.74569	111.066	1.8	0.06	1.6	25.7
CVCR	Calaveras	Coyote Ranch	-121.52521	37.06981	99.280	17.3	0.21	15.9	38.7
CVSP	Calaveras, Northern	Shannon Park	-121.93713	37.70649	150.000	1.0	0.95	0.6	5.1
CVSU	Calaveras, Northern	Sunol	-121.87693	37.59850	243.000	0.1	0.53	0.0	4.2
CVWC	Calaveras, Northern	Welch Creek Road	-121.85183	37.53570	158.534	4.2	0.12	4.1	10.0
CVWR	Calaveras	Wright Road	-121.41381	36.86982	109.048	8.9	0.09	9.8	27.3
GVMR	Green Valley	Mason Road	-122.16186	38.23603	143.137	2.8	0.86	3.2	2.1
GVRT	Green Valley	Red Top Road	-122.15054	38.19848	343.750	3.7	0.09	4.0	22.7
HAPP	Hayward	Appian Way	-122.00193	37.59240	124.892	5.6	0.04	5.4	27.3
HCAM	Hayward	Camellia Drive	-121.93528	37.51235	88.352	4.3	0.11	3.9	16.9
HCCC	Hayward	Contra Costa College	-122.33902	37.96918	146.036	5.2	0.06	5.0	26.5
HDST	Hayward	D Street	-122.08162	37.67021	112.322	4.5	0.02	4.5	26.6
HENC	Hayward	Encina Way	-122.15148	37.75453	123.801	2.7	0.10	3.0	17.3
HLSA	Hayward	LaSalle Ave	-122.21005	37.82638	182.842	3.8	0.05	3.9	14.0
HPMD	Hayward	Parkmeadow Drive	-121.93262	37.50960	156.911	6.0	0.11	5.7	14.8
HRKT	Hayward	Rockett Drive	-121.96187	37.54210	179.751	5.3	0.06	5.6	27.3
HROS	Hayward	Rose Street	-122.09121	37.67983	153.769	4.8	0.04	4.2	26.6
HTBR	Hayward	Thors Bay Road	-122.29294	37.92449	119.540	3.3	0.10	4.0	17.3
MUKI	Maacama	Sanford Ranch Road	-123.16748	39.13906	288.744	4.5	0.09	4.6	13.6
MWIL	Maacama	W. Commercial Ave	-123.35699	39.41235	125.864	6.2	0.07	6.0	15.1
RCSD	Rodgers Creek	Solano Drive	-122.69446	38.43687	90.502	1.6	0.22	1.7	4.5
RCSM	Rodgers Creek	Sonoma Mtn. Rd	-122.59046	38.30928	137.926	-0.7	0.45	-1.9	4.3
SAAC	San Andreas	Alder Creek	-123.69059	38.99986	265.982	0.4	0.06	0.6	25.6
SACR	San Andreas	Cannon Road	-121.58611	36.88261	88.0	0.1	0.11	0.2	8.2
SADW	San Andreas	Duhallow Way	-122.46564	37.64419	205.637	-0.3	0.02	-0.2	26.9
SAMV	San Andreas	Mission Vineyard Rd	-121.52171	36.83502	134.663	11.5	0.14	12.4	16.5
SAPR	San Andreas	Point Reyes	-122.79796	38.04398	76.491	-0.1	0.03	0.0	22.0
SARD	San Andreas	Roberta Drive	-122.26154	37.41700	91.176	0.6	0.04	0.8	17.2
SASR	San Andreas	Searle Road	-121.57280	36.87453	262.687	1.9	0.60	1.8	4.3
SGPR	San Gregorio	Pescadero Road	-122.37294	37.25450	454.793	0.9	0.08	0.7	24.6
SGWP	San Gregorio, Seal Cove	West Point Ave	-122.49664	37.50369	262.033	-0.2	0.05	-0.3	27.2

*average = total slip/total time

Table 2. Average Rates of Right-Lateral Movement, Hayward Fault, Sites Surveyed Annually

Distance from Pt. Pinole (km)	Site Name	C ity	Longitude (WGS84)	Latitude (WGS84)	Length (m)	Linear regression average creep rate (mm/yr)	± (mm/ yr)	Average* creep rate (mm/yr)	yr	Note
8.37	Olive Drive	Richmond	-122.30959	37.94252	150	5.2	0.10	5.4	17.1	
14.05	Florida Avenue	Berkeley	-122.27340	37.89980	127	3.0	0.10	3.0	7.2	1
17.82	Memorial Stadium	Berkeley	-122.25061	37.87066	166	4.7	0.03	4.7	39.9	
18.43	Dwight Way	Berkeley	-122.24107	37.86447	105	4.2	0.36	3.7	9.2	
20.84	Temescal	Oakland	-122.23137	37.84853	154	3.9	0.06	3.9	32.6	
25.98	Lincoln	Oakland	-122.19863	37.80999	110	3.4	0.08	3.5	36.5	
27.81	39th	Oakland	-122.18931	37.79504	139	3.8	0.11	3.9	32.5	
30.68	73rd	Oakland	-122.16977	37.77426	90	3.0	0.07	2.9	13.4	1
36.55	Chabot Park	San Leandro	-122.12993	37.73184	231	4.0	0.24	4.4	13.4	
38.28	Fairmont	San Leandro	-122.12131	37.71749	167	3.1	0.14	3.0	9.2	1
41.11	167th	Castro Valley	-122.10578	37.69495	91	4.7	0.14	5.0	14.2	
45.64	Palisade	Hayward	-122.07397	37.66270	179	4.6	0.24	4.6	29.8	
47.72	Sepulchre	Hayward	-122.05902	37.64798	107	5.6	0.15	5.8	12.2	
50.15	Woodland	Hayward	-122.04140	37.63097	73	4.3	0.10	4.3	36.8	1
52.60	Chimes	Union City	-122.02325	37.61422	120	5.9	0.19	6.2	12.2	
59.09	Gilbert	Fremont	-121.98094	37.56645	89	5.1	0.14	5.0	23.1	2
62.64	Hancock	Fremont	-121.95914	37.53942	89	5.7	0.18	5.7	24.8	2
63.10	Union	Fremont	-121.95584	37.53614	168	6.9	0.13	6.8	13.8	2
65.29	Pine	Fremont	-121.94181	37.51973	98	5.9	0.21	5.8	17.6	2
67.02	S. Grimmer	Fremont	-121.93046	37.50720	130	5.9	0.31	6.3	24.4	2
67.21	Onondaga	Fremont	-121.92894	37.50516	73	2.4	0.20	2.8	24.4	2,3
68.45	Mission	Fremont	-121.92182	37.49629	169	4.9	0.27	4.2	13.7	2

Notes:

1) array may miss significant fault traces

2) slip rate includes considerable slow-down following 1989 Loma Prieta Earthquake

3) array misses a major creeping fault trace

*average = total slip/total time