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By Forrest S. McFarland, James J. Lienkaemper, and S. John Caskey

Open-File Report 2009–1119

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Suggested citation:
McFarland, F.S., Lienkaemper, J.J., and Caskey, S.J., 2009, Data from theodolite measurements of creep rates on San Francisco Bay Region faults, California, 1979-2009: U.S. Geological Survey Open-File Report 2009-1119, 17 p. [http://pubs.usgs.gov/of/2009/1119/].

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Introduction

Our purpose is to update our creep-data archive on San Francisco Bay region active faults with two additional years of data 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). From 1979 until his retirement from the project in 2001, Jon Galehouse of San Francisco State University (SFSU) and many student research assistants measured creep (aseismic slip) rates on these faults. The creep measurement project, which was initiated by Galehouse, has continued through the Geosciences Department at SFSU from 2001-2006 under the direction of Karen Grove and John Caskey (Grove and Caskey, 2005) and by Caskey since 2006 (Caskey, 2007). Forrest McFarland has managed most of the technical and logistical project operations, as well as data processing and compilation since 2001. Data from 2001-2007 are found in McFarland and others (2007). Henceforth, we plan to release these data annually and publish detailed analyses of the 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 Web site.

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 (see fig.1 inset; 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).

Until 2007 we had 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 (fig. 1) and are identified by name in table 1 and on the data sheets. In addition to the sites in the San Francisco Bay region, we had one measurement site on the San Andreas Fault in the Point Arena area, one on the Bartlett Springs Fault near Lake Pillsbury, 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. However, since the last report we have reduced the frequency of surveys at each site; which has allowed us to add nine new sites north of San Francisco Bay (fig. 1), including four sites on the Rodgers Creek and Maacama Fault system and five sites on the Green Valley–Hunting Creek–Bartlett Springs Fault system.

In addition to our ten regular sites on the Hayward Fault, we established 22 additional Hayward Fault annual survey sites (shown by diamonds in figs. 1 and 2 and by name in the data sheets and in table 2). We began measuring each of these additional sites annually in 1994. In the future, the regular Hayward Fault sites will be measured only annually, too, unless significant earthquake activity occurs.

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 57-289 m, except Sites GVRT and SGPR, which 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; fig. 1 inset) to a target on the other side (ES, end station). Angles are measured with respect to another target (OS, orientation station). All Hayward Fault sites are summarized in table 2. Data sheets for all sites are available in the data folder as a single PDF file. 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/2009/1119/ (SFBayRegion09.xls and HaywardFault09.xls). They are also available as tab-delimited raw data. Data for the previous reporting period (2007-2009) include the average angle and its 1-σ uncertainty. Also provided for each reading is the current site correction used; the sine of the angular difference between the fault azimuth and azimuth of the array (IS-ES). Each measurement of apparent slip must be divided by its site correction. The data include all 34 regular measurement sites, the 22 SFSU/USGS annual survey sites on the Hayward Fault, and the most recently installed sites for which more than one survey is now available. We show summary plots of the creep data by fault zone for the Calaveras Fault (figs. 3 and 4), Concord-Green Valley and Bartlett Springs Faults (fig. 5), Rodgers Creek and Maacama Faults (fig. 6), San Andreas and San Gregorio Faults (fig. 7) and Hayward Fault (figs. 8 and 9).

Acknowledgments

This project has been continuously funded since 1979 by various grants and contracts from the U.S. Geological Survey, National Earthquake Hazards Reduction Program (latest contract was 07HQAG0032). Special thanks go to the many student research assistants from San Francisco State University who have been instrumental in collecting these theodolite data since 1979. We are particularly grateful to Brett Baker, Beth Brown, Carolyn Domrose, Jessica Fadde, Carolyn Garrison, Oliver Graves, Theresa Hoyt, Leslie Pawlak, Jon Perkins, Jon Polly, Carl Schaefer, and Jim Thordsen, who each worked with us for more than three years. Thanks also to Bob Abrams, Chris Alger, Linda Bond, Denise Coutlakis, Lisa Garmin, Matt Harrigan, CJ Hayden, Kathleen Isaacson, Heather Lackey, Regan Long, Marina Mascorro, Dan McVanner, Barbara Menne, Nicole Peirce, Brian Pierce, Holly Prochaska, Anne Marie Scherer, Gary Schneider, Debra Smith, Leta Smith, William Hassett, and Robert Sas who have all served as theodolite operators. Additional thanks go to Theresa Hoyt for performing quality assurance on the recent data. Reviews by Dave Ponce and Bob Simpson also improved the consistency and clarity of the report.

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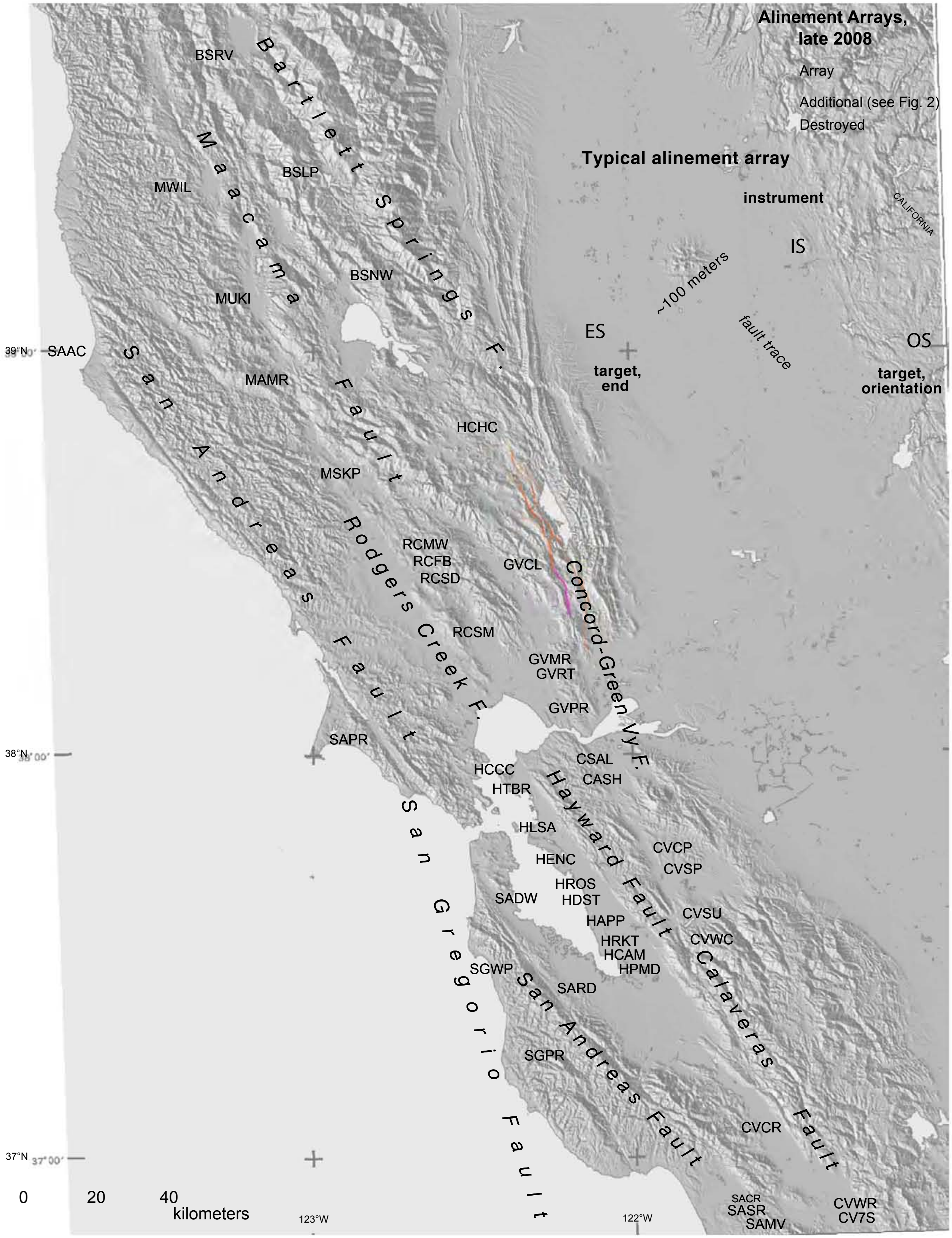

Figure 1. Locations of alinement arrays, San Francisco Bay region. Arrays shown as triangles, additional arrays on Hayward Fault shown as diamonds. P, Point Pinole. Summary information for most arrays in table 1. All Hayward Fault arrays in table 2. Inset is idealized array described in text. Faults in red zoned as active (Bryant and Hart, 2007); other traces, preliminary mapping of Green Valley-Bartlett Springs Faults (Lienkaemper, unpub'd.)

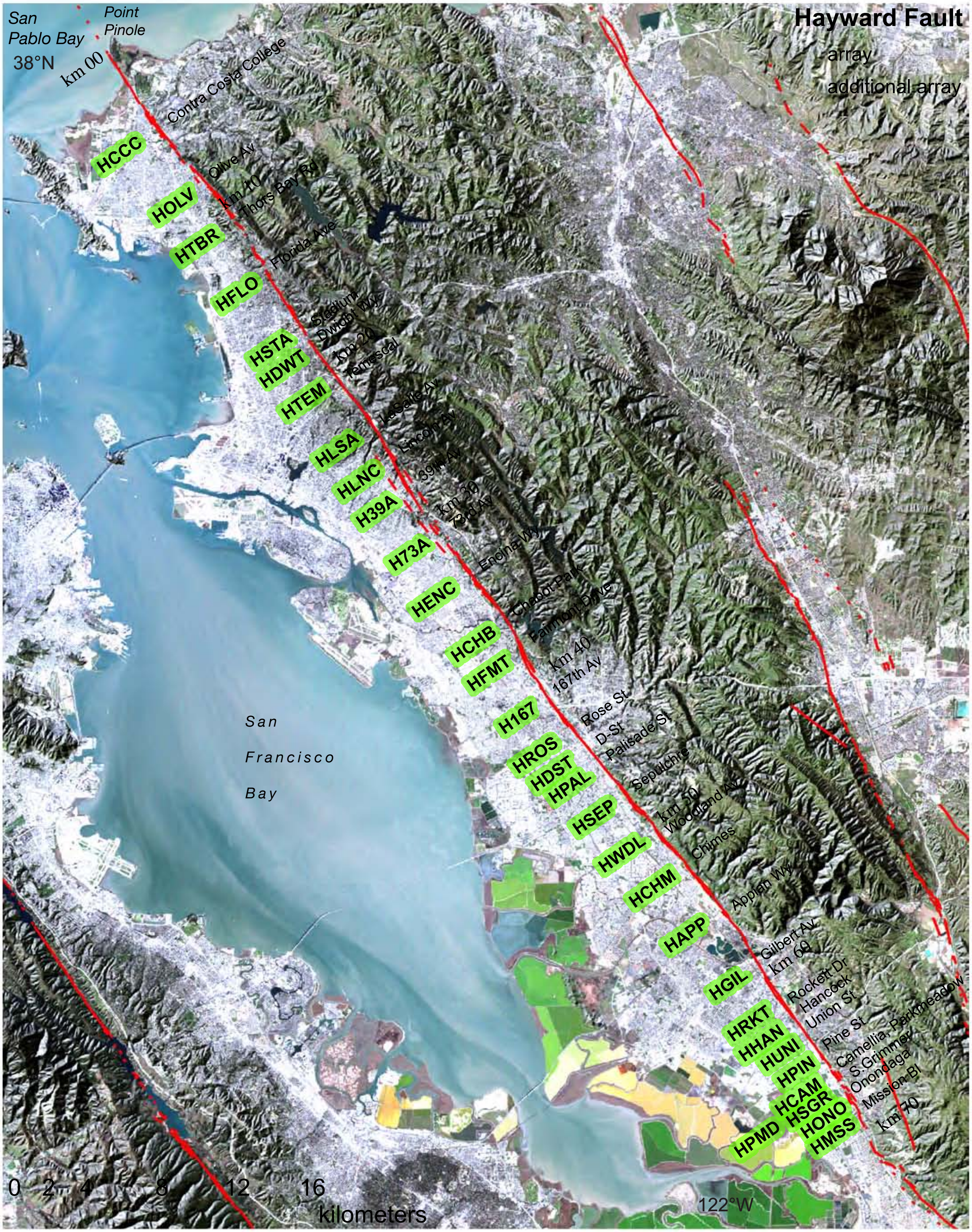

Figure 2. Locations of alinement arrays across Hayward Fault. Includes formerly frequent SFSU sites (triangles) and former annual sites (diamonds), see tables 1 and 2 for additional information. Yellow grid shows distance in kilometers from San Pablo Bay after Lienkaemper (2006). Faults in red zoned as active (Bryant and Hart, 2007).

Calaveras Fault

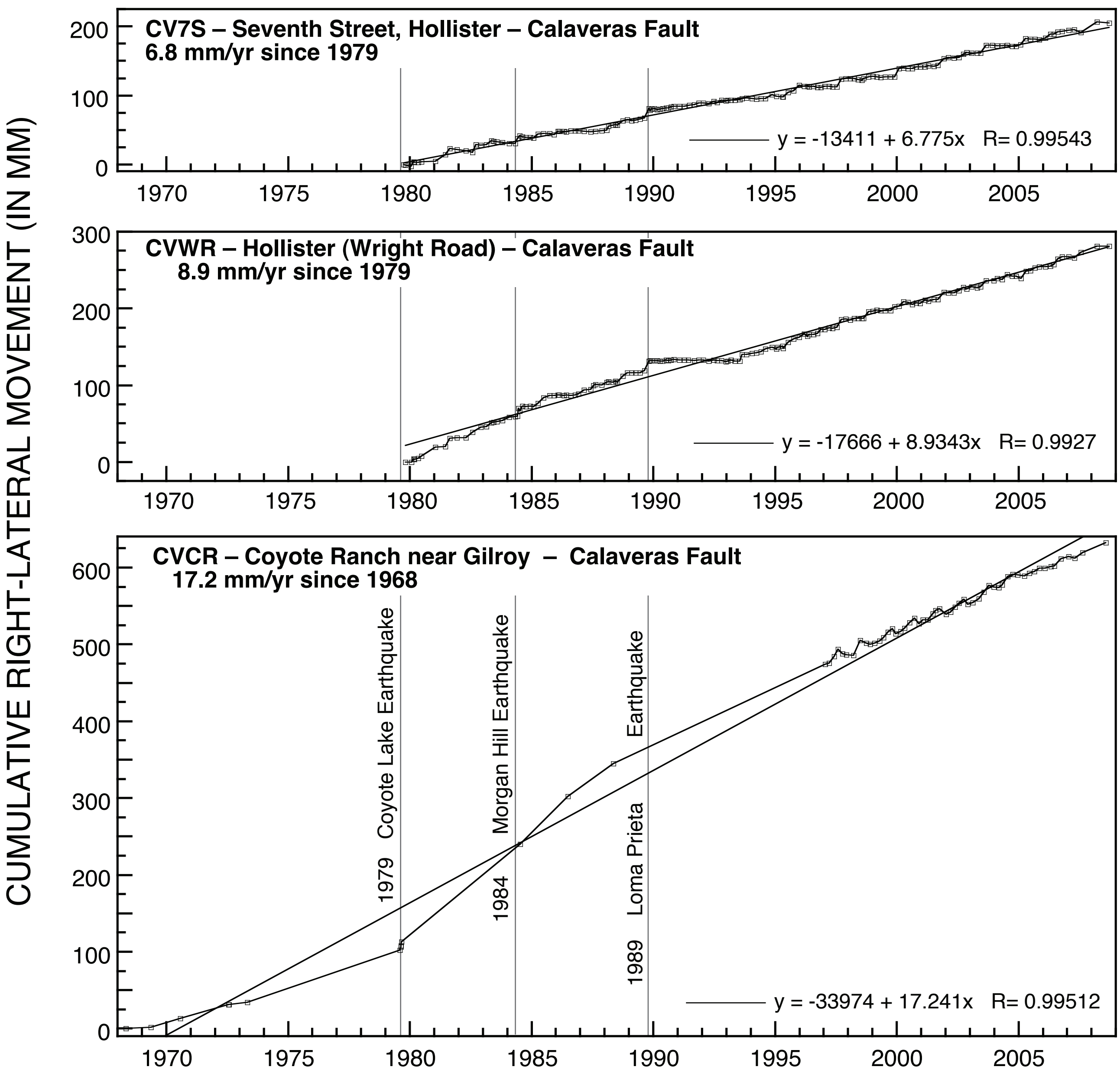

Figure 3. Alinement-array measurements, Calaveras Fault. Straight line through the data indicates linear regression fit to data given by associated equations y (creep, mm); x (time, yr); R, correlation coefficient

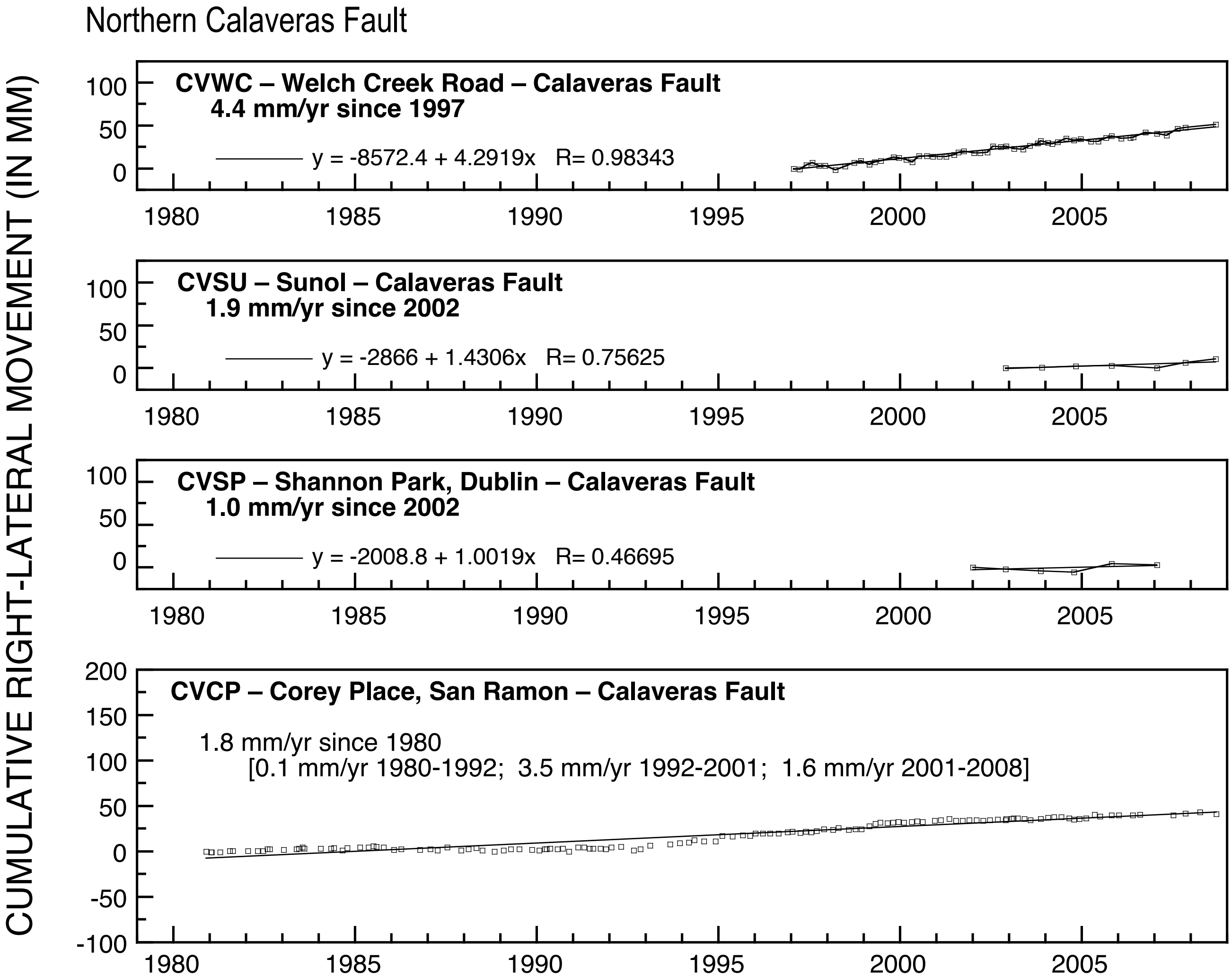

Figure 4. Alinement-array measurements, Northern Calaveras Fault.

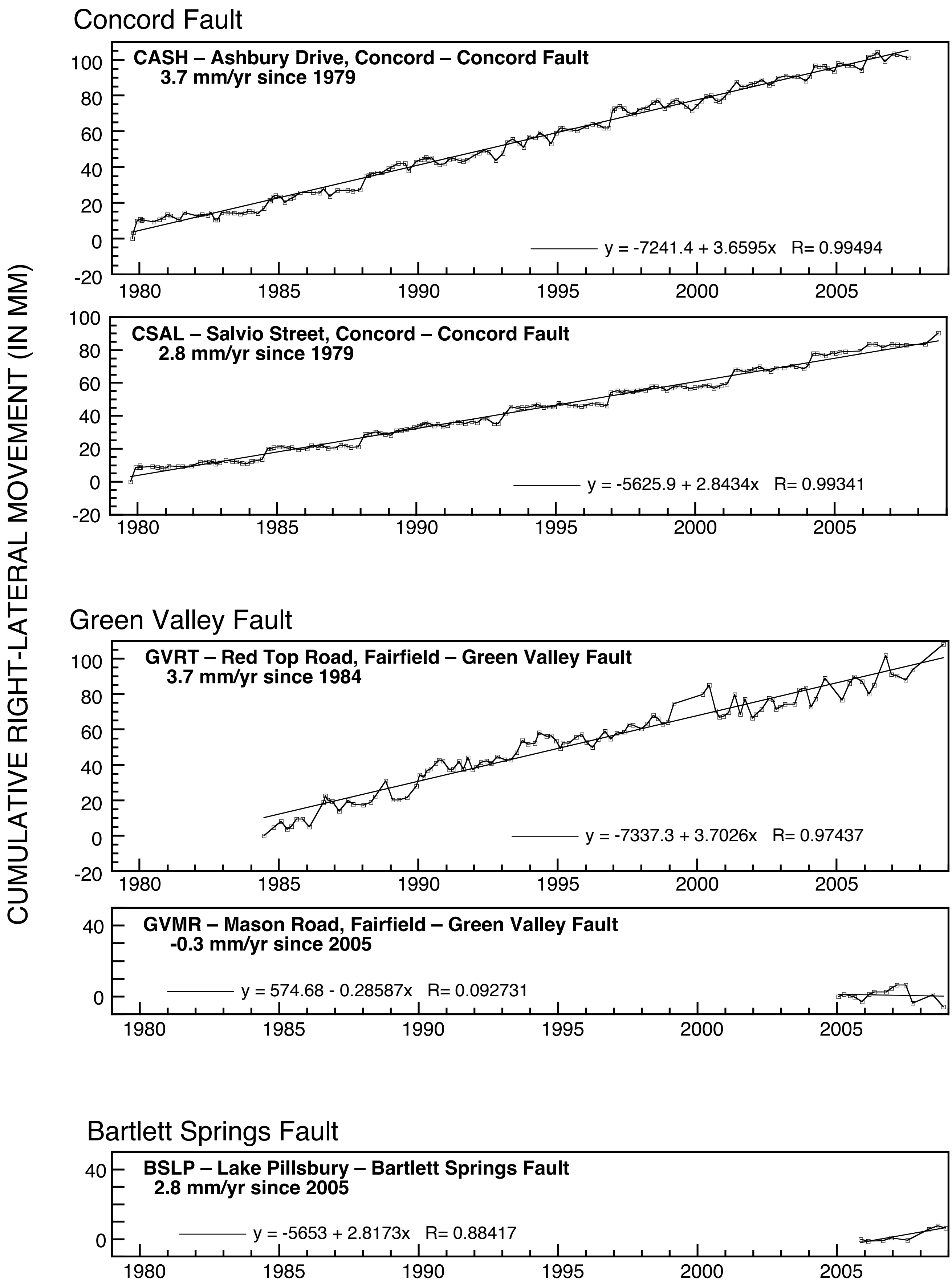

Figure 5. Alinement-array measurements, Concord-Green Valley and Bartlett Springs Faults.

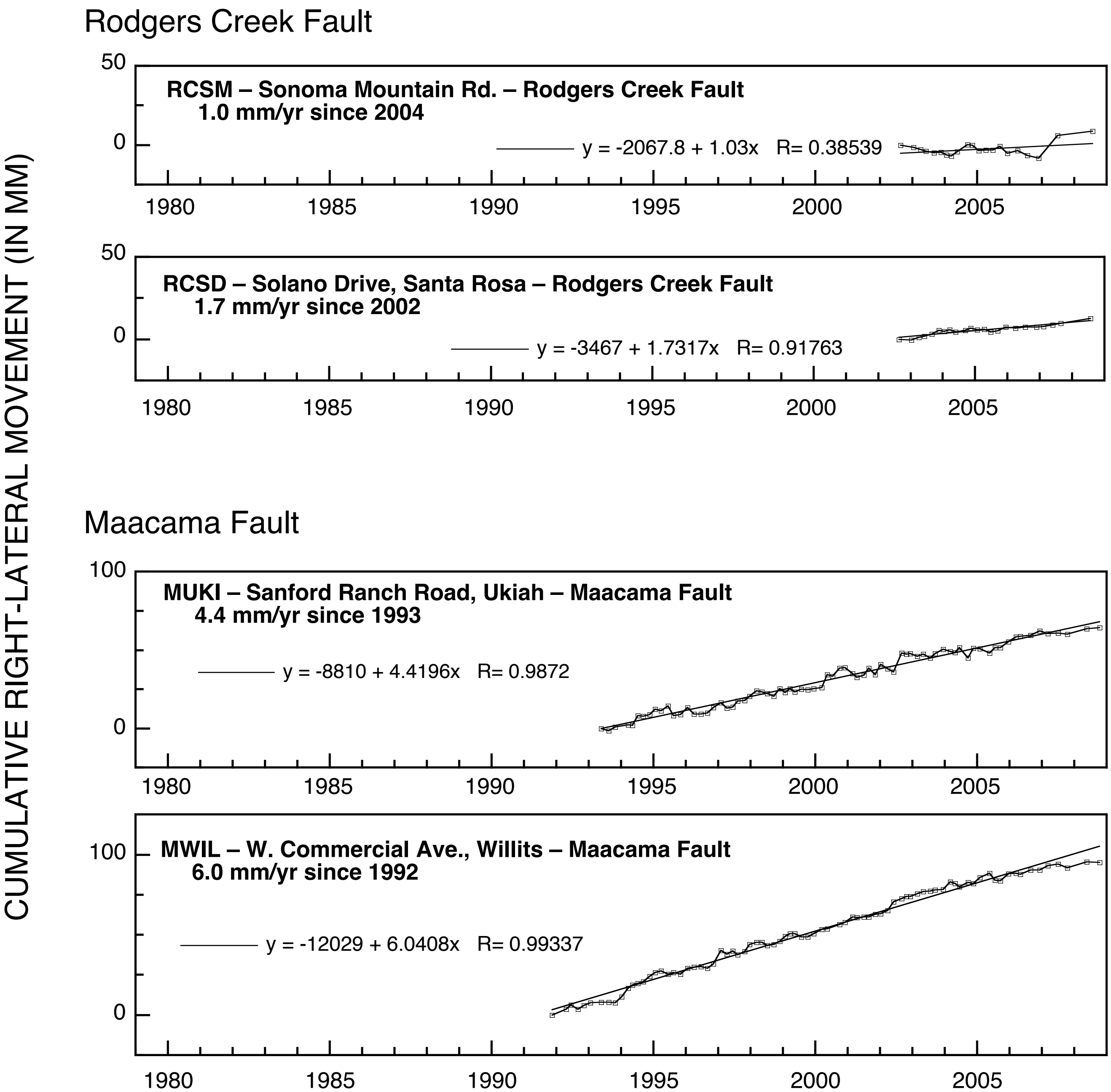

Figure 6. Alinement-array measurements, Rodgers Creek and Maacama Faults.

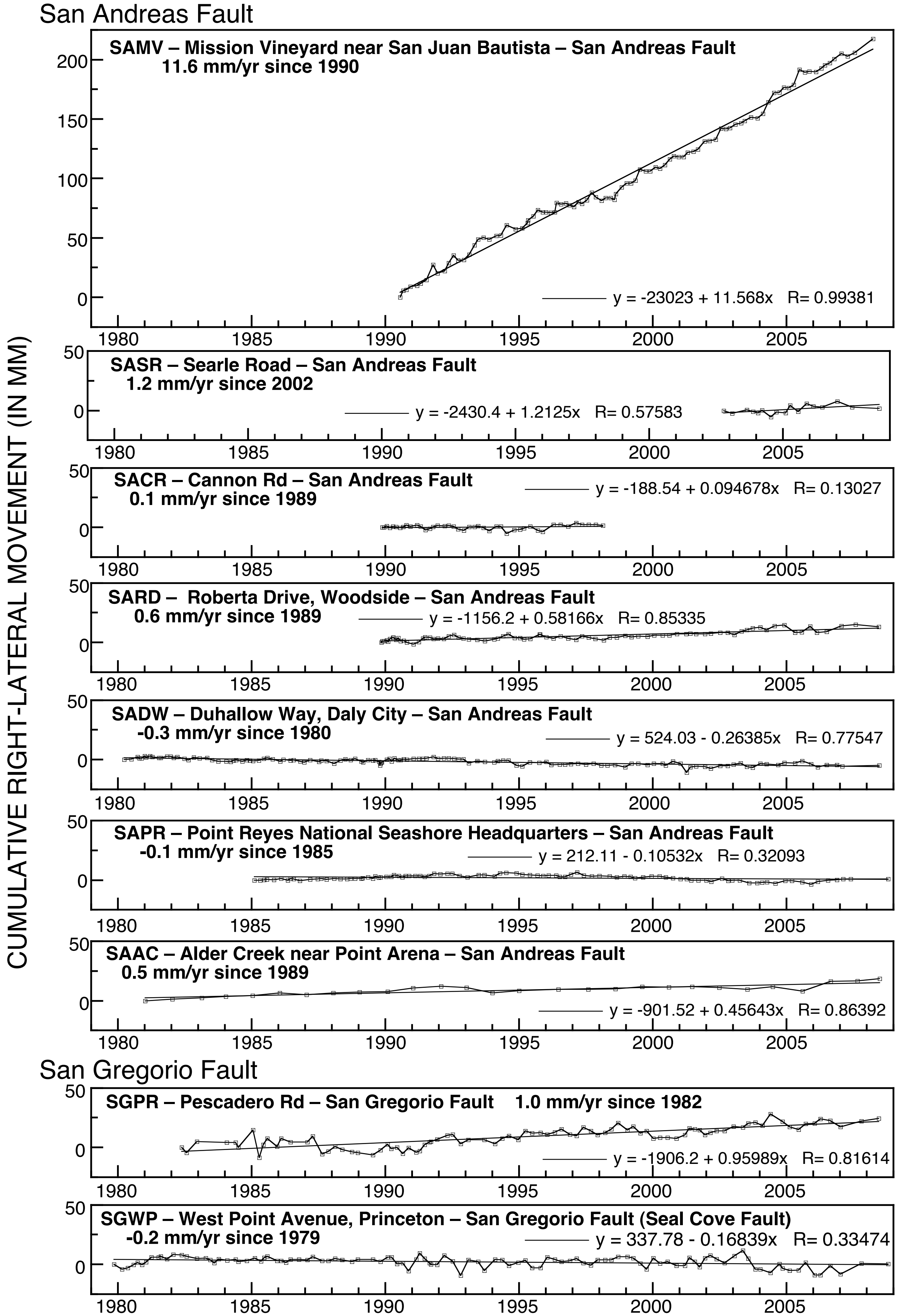

Figure 7. Alinement-array measurements, San Andreas and San Gregorio Faults.

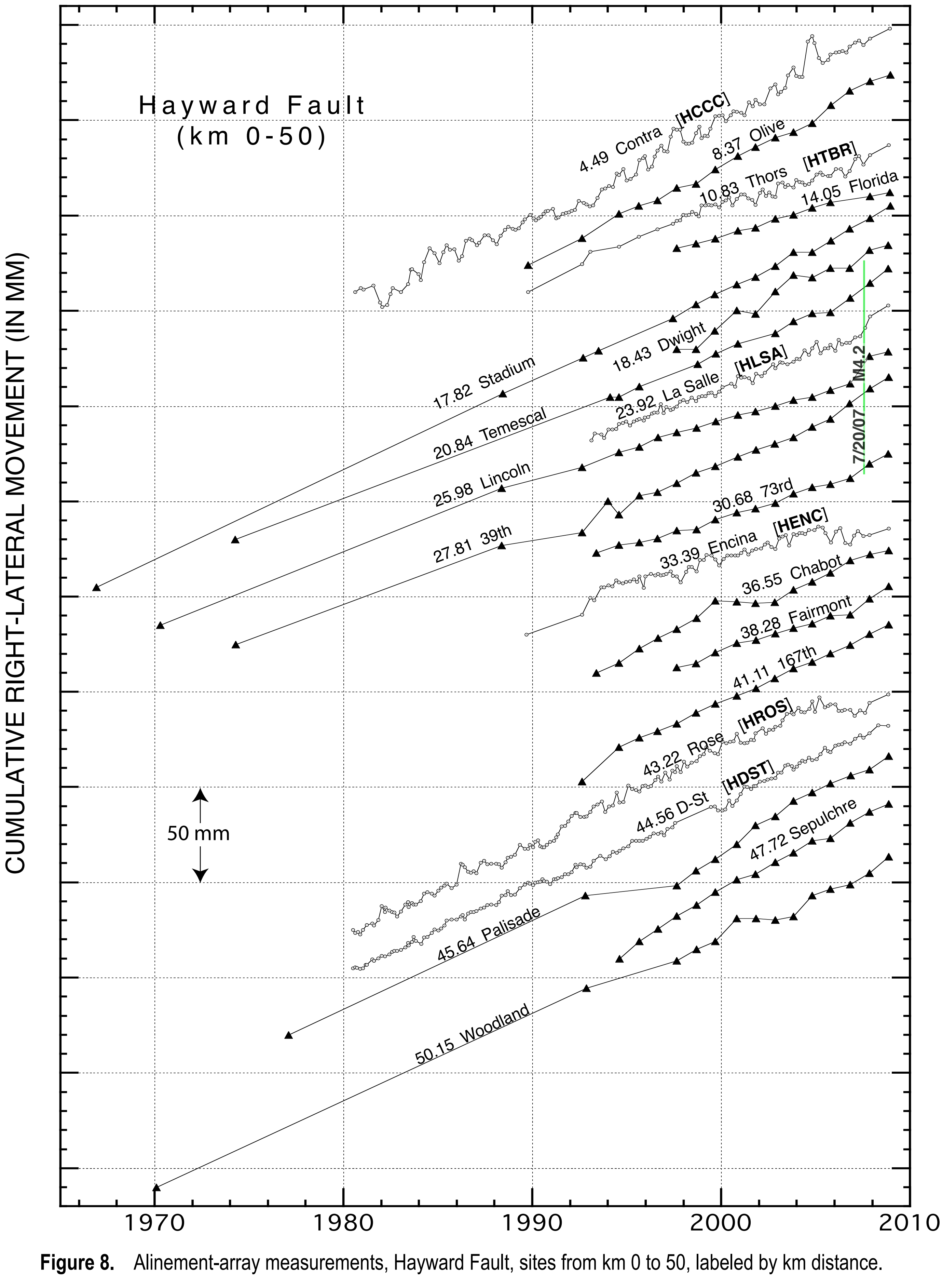

Figure 8. Alinement-array measurements, Hayward Fault, sites from km 0 to 50, labeled by km distance.

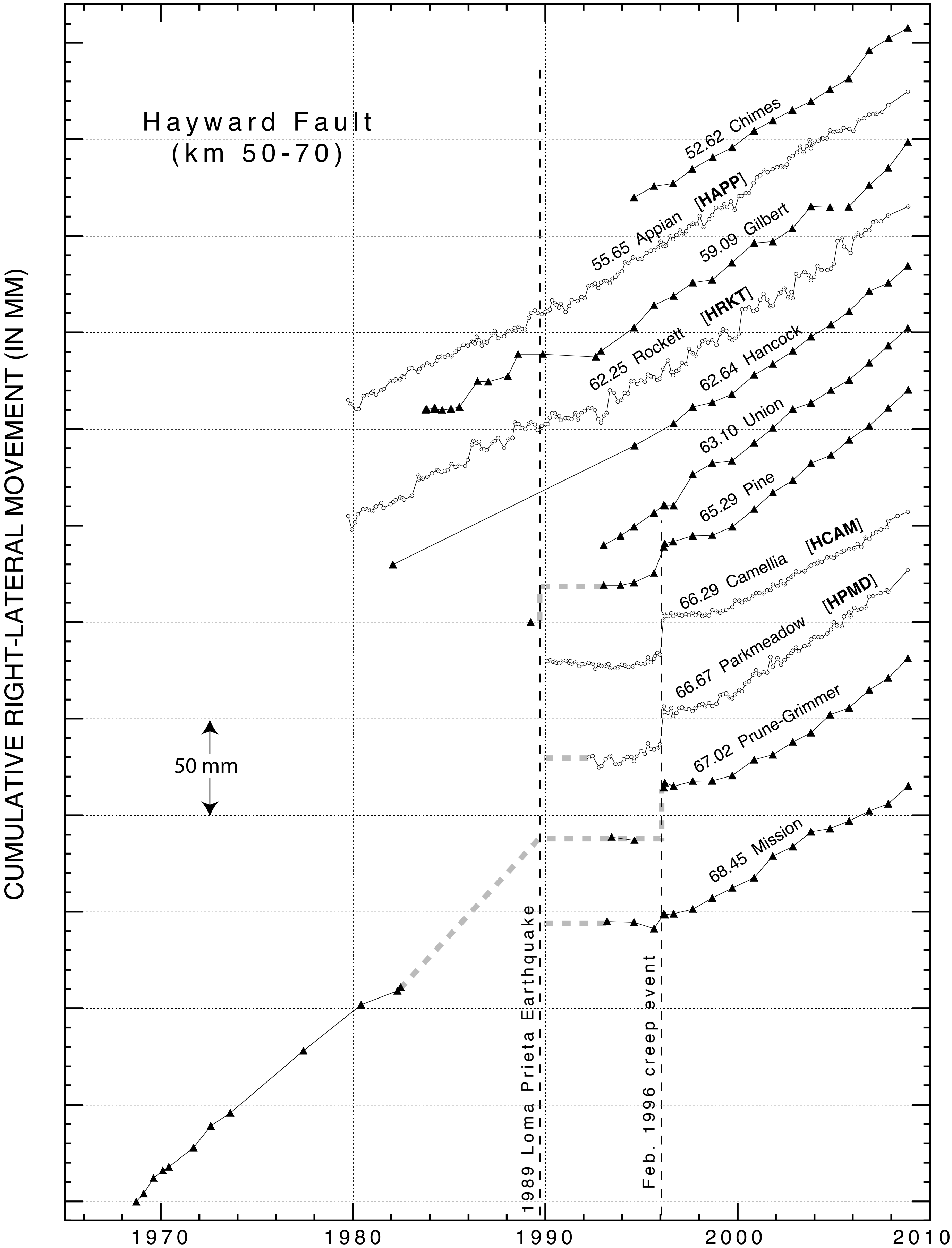

Figure 9. Alinement-array measurements, Hayward Fault, sites from km 50 to 70.

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

Site Code	Fault	Site Name	Longitude (WGS84)	Latitude (WGS84)	Length (m)	Linear regression average creep rate (mm/yr)	± (mm/yr)	Ave.* creep rate (mm/yr)	yr[2]	
BSLP	Bartlett Springs	Lake Pillsbury	-122.95726	39.44560	102.186	2.8	0.61	2.1	3.0	
BSNW	Bartlett Springs	Newman Springs	-122.71436	39.19380	141	—	—	—	0.0	
BSRV	Bartlett Springs	Round Valley	-123.22755	39.74003	182	—	—	—	0.0	
CASH	Concord	Ashbury Drive	-122.03524	37.97189	133.206	3.7	0.03	3.6	27.8	
CSAL	Concord	Salvio Street	-122.03824	37.97569	57.110	2.8	0.03	3.1	29.0	
CV7S	Calaveras	Seventh Street	-121.40631	36.84952	89.656	6.8	0.05	7.1	29.0	
CVCP	Calaveras, Northern	Corey Place	-121.96083	37.74569	111.066	1.8	0.06	1.5	27.8	2.3 mm/yr since 1992.5
CVCR	Calaveras	Coyote Ranch	-121.52521	37.06981	99.280	17.2	0.21	15.7	40.3	
CVSP	Calaveras, Northern	Shannon Park	-121.93713	37.70649	149.730	1.0	0.09	0.6	5.1	
CVSU	Calaveras, Northern	Sunol	-121.87693	37.59850	243.224	1.4	0.55	1.9	5.8	
CVWC	Calaveras, Northern	Welch Creek Rd	-121.85183	37.53570	158.534	4.3	0.11	4.4	11.6	
CVWR	Calaveras	Wright Rd	-121.41381	36.86982	108.700	8.9	0.09	9.7	28.9	
GVCL	Green Valley	Crystal Lake	-122.24806	38.47626	95.1	—	—	0.8	1.3	
GVMR	Green Valley	Mason Rd	-122.16186	38.23603	143.137	-0.3	0.89	-1.6	3.8	
GVPR	Green Valley	Parrish Rd	-122.11316	38.11413	139.500	—	—	3.6	1.4	
GVRT	Green Valley	Red Top Rd	-122.15054	38.19848	343.750	3.7	0.08	4.4	24.4	
HUCR	Hunting Creek	Hunting Creek	-122.38873	38.81388	179.4	—	—	1.8	1.0	
MAMR	Maacama	Middle Ridge	-123.05070	38.93464	144.3	—	—	—	0.0	
MASR	Maacama	Skipstone Ranch	-122.82647	38.70320	111	—	—	—	0.0	
MUKI	Maacama	Sanford Ranch Rd	-123.16748	39.13906	288.753	4.4	0.08	4.2	15.4	
MWIL	Maacama	W. Commercial Ave	-123.35699	39.41235	125.864	6.0	0.08	5.6	16.9	
RCSD	Rodgers Creek	Solano Drive	-122.69446	38.43687	90.502	1.7	0.16	2.1	5.9	
RCSM	Rodgers Creek	Sonoma Mtn. Rd	-122.59046	38.30928	137.926	1.0	0.55	1.5	5.9	
SAAC	San Andreas	Alder Creek	-123.69059	38.99986	265.982	0.5	0.05	0.7	27.5	
SACR	San Andreas	Cannon Road	-121.58611	36.88261	88.0	0.1	0.10	0.2	8.2	
SADW	San Andreas	Duhallow Way	-122.46564	37.64419	205.637[1]	-0.3	0.02	-0.2	28.2	
SAMV	San Andreas	Mission Vineyard Rd	-121.52171	36.83502	134.663	11.5	0.13	12.3	17.7	
SAPR	San Andreas	Point Reyes	-122.79796	38.04398	70.880	-0.1	0.03	0.0	22.0	
SARD	San Andreas	Roberta Dr	-122.26154	37.41700	91.176	0.6	0.04	0.7	18.6	
SASR	San Andreas	Searle Rd	-121.57280	36.87453	262.687	1.2	0.44	0.3	5.8	
SGPR	San Gregorio	Pescadero Rd	-122.37294	37.25450	454.793[1]	0.9	0.07	0.9	26.1	
SGWP	San Gregorio, Seal	West Point Ave	-122.49664	37.50369	262.033	-0.2	0.05	0.0	28.9	

*Average = total slip/total time

[1]Combined ESE and ESW lengths

[2]Number of years of observation

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

Distance from Pt. Pinole (km)	Site Code	Site Name	Longitude (WGS84)	Latitude (WGS84)	Length (m)	Linear regression average creep rate (mm/yr)	± (mm/yr)	Average* creep rate (mm/yr)	yr†	Note
4.49	HCCC	Contra Costa College	-122.33902	37.96918	146.04	5.2	0.06	4.9	28.9	
8.37	HOLV	Olive Drive	-122.30959	37.94252	149.07	5.2	0.08	5.2	19.2	
10.83	HTBR	Thors Bay Road	-122.29294	37.92449	119.54	3.4	0.09	4.0	19.1	
14.05	HFLO	Florida Avenue	-122.27340	37.89980	126.11	2.7	0.09	2.6	11.3	1
17.82	HSTA	Memorial Stadium	-122.25061	37.87066	165.46	4.7	0.04	4.8	42.0	
18.43	HDWT	Dwight Way	-122.24107	37.86447	131.59	5.1	0.32	4.9	11.2	
20.84	HTEM	Temescal	-122.23137	37.84853	153.92	4.0	0.10	4.1	34.6	
23.92	HLSA	LaSalle Ave	-122.21005	37.82638	182.84	3.9	0.05	4.5	15.7	
25.98	HLNC	Lincoln	-122.19863	37.80999	110.41	3.5	0.09	3.7	38.5	
27.81	H39A	39th	-122.18931	37.79504	137.81	4.0	0.13	4.1	34.6	
30.68	H73A	73rd	-122.16977	37.77426	89.81	3.2	0.11	3.4	15.4	1
33.39	HENC	Encina Way	-122.15148	37.75453	123.80	2.5	0.09	2.9	19.2	
36.55	HCHB	Chabot Park	-122.12993	37.73184	230.44	4.0	0.19	4.2	15.5	
38.28	HFMT	Fairmont	-122.12131	37.71749	166.60	3.5	0.17	3.8	11.2	1
41.11	H167	167th	-122.10578	37.69495	90.18	4.7	0.11	5.1	16.2	
43.22	HROS	Rose Street	-122.09121	37.67983	153.77	4.7	0.04	4.4	28.4	
44.56	HDST	D Street	-122.08162	37.67021	112.32	4.5	0.02	4.5	28.4	
45.64	HPAL	Palisade	-122.07397	37.66270	174.22	4.5	0.20	4.5	31.8	
47.72	HSEP	Sepulchre	-122.05902	37.64798	107.14	5.5	0.12	5.7	14.3	
50.15	HWDL	Woodland	-122.04140	37.63097	66.58	4.3	0.10	4.5	38.8	1
52.60	HCHM	Chimes	-122.02325	37.61422	118.65	6.2	0.19	6.2	14.3	
55.65	HAPP	Appian Way	-122.00193	37.59240	124.89	5.7	0.04	5.5	29.1	
59.09	HGIL	Gilbert	-121.98094	37.56645	89.26	5.2	0.13	5.5	25.1	2
62.25	HRKT	Rockett Drive	-121.96187	37.54210	103.23	5.3	0.06	5.5	29.1	
62.64	HHAN	Hancock	-121.95914	37.53942	88.51	5.8	0.18	5.8	26.8	2
63.10	HUNI	Union	-121.95584	37.53614	168.10	7.0	0.11	7.1	15.8	2
65.29	HPIN	Pine	-121.94181	37.51973	97.65	6.2	0.20	6.1	19.6	2
66.29	HCAM	Camellia Drive	-121.93528	37.51235	88.35	4.4	0.10	4.1	18.7	
66.67	HPMD	Parkmeadow Drive	-121.93262	37.50960	156.91	6.1	0.09	5.9	16.6	
67.02	HSGR	S. Grimmer	-121.93046	37.50720	129.54	5.9	0.26	6.5	26.4	2
67.21	HONO	Onondaga	-121.92894	37.50516	72.88	2.7	0.22	2.9	26.5	2,3
68.45	HMSS	Mission	-121.92182	37.49629	168.94	5.0	0.21	4.5	15.7	2

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
†Number of years observed