DEPARTMENT OF THE INTERIOR

U. S. GEOLOGICAL SURVEY

Digital Recordings of Aftershocks of the 1 October 1987 Whittier Narrows, California, Earthquake

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This report is preliminary and has not been reviewed for conformity with U. S. Geological Survey editorial standards. Any use of trade names is for descriptive purposes only and does not imply endorsement by the USGS.

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1988

INTRODUCTION

After the 1 October 1987 Whittier Narrows, southern California, earthquake (274 14:42 GMT, M_L = 5.9), the U.S. Geological Survey installed digital GEOS seismographs at 32 temporary sites in the mainshock meizoseismal area (Figure 1). Seismographs were installed in three deployments (Figure 2), each designed to fulfill a specific experimental goal. Deployment 1, the main Whittier experiment, consisted of stations ACO, ARC, BEC, BEL, ECP, ELM, GAR, HCH, HOO, KIN, LAC, LIN, MIL, MOT, NAR, OLV, ROS, SAG, SVS, and SWA, operating intermittently from 2 October to 9 November (275 to 313 GMT). The objective of Deployment 1 was to record aftershock ground motions over a broad range of earthquake magnitudes at small source-to-station distances. Such datasets can be used to study a broad range of current research questions in seismology, including earthquake source-scaling, and the influence of attenuation, scattering, and near-surface geological structure on seismic waves. In particular, many GEOS were co-sited with strong-motion accelerographs that recorded the Whittier Narrows mainshock; aftershock recordings from these sites can be used as empirical Green's functions in modeling the rupture process of the mainshock. Deployment 2 was designed to directly measure the structural response of the Millikan Library building (California Institute of Technology, Pasadena) to aftershock ground motions. It consisted of stations BSE, BNE, and BNW (Millikan basement), RSE, RNE, and RWC (Millikan roof), and STE and STW (Millikan steam tunnels) operating from 15 October to 9 November (288 to 313 GMT). Millikan Library has been thoroughly analyzed using traditional engineering methods; our goal was to compare the measured aftershock response with the response predicted using the traditional methods. Deployment 3 was designed to measure spatial ground-motion variations in a small area in downtown Whittier. It consisted of stations BWY, HOO, LTB, LTH, and RHD, operating from 23 October to 9 November (296 to 313 GMT). The objective of Deployment 3 was to compare local aftershock ground-motion variations with mainshock damage patterns.

From 2 October to 9 November (275 to 313 GMT) we recorded approximately 40 aftershocks at five or more stations and 100 aftershocks at two or more stations (Table 1), including the large aftershock on 4 October (277 10:59 GMT, M_L = 5.3). A calibration explosion (Perkins, 1988) on 8 November (312 12:10 GMT) was also recorded on several stations (Table 1).

This report is a summary of field and data-playback information, and is intended to

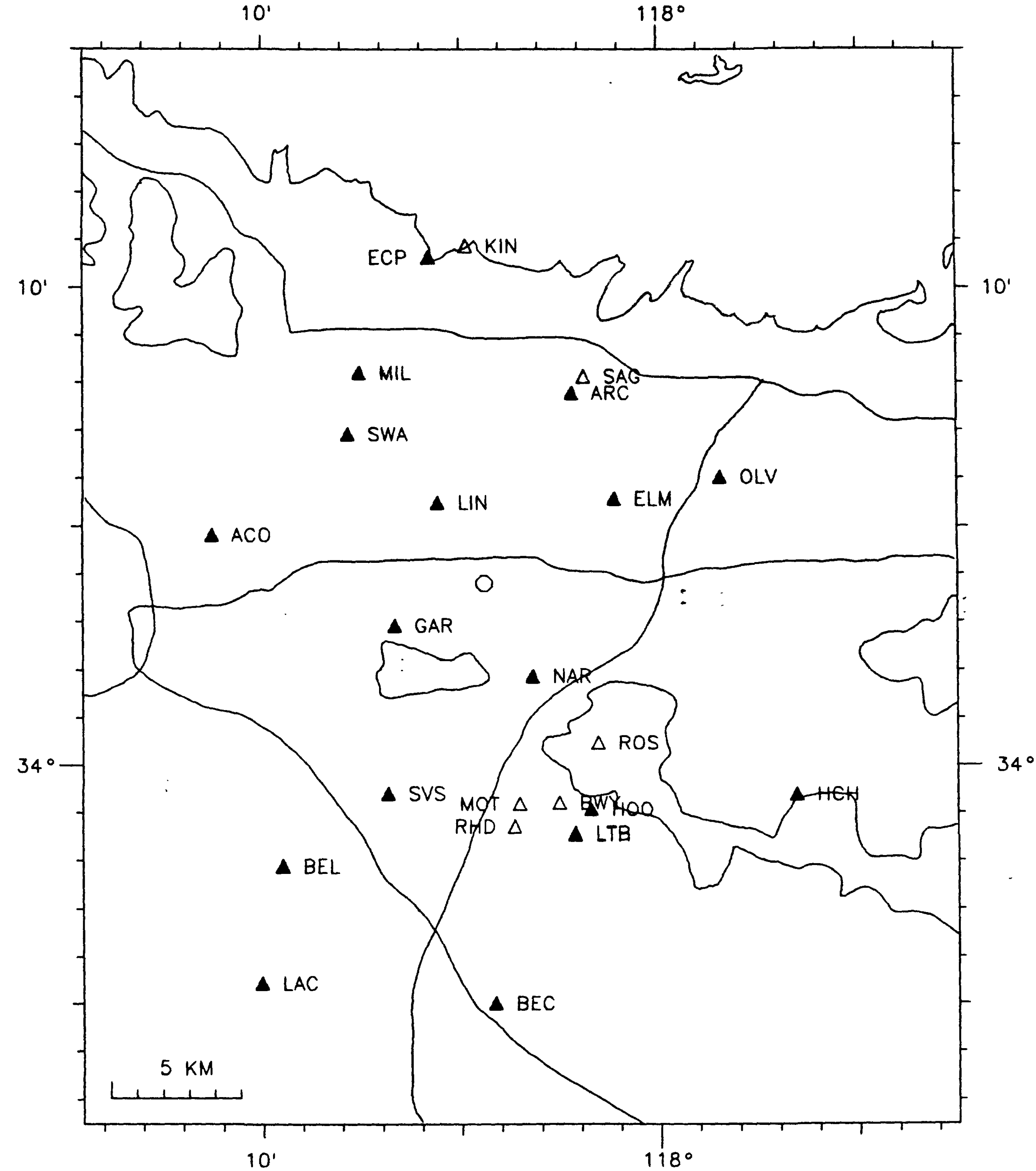

Figure 1. Map of the Whittier Narrows meizoseismal area showing mainshock epicenter (octagon), GEOS station locations (triangle - solid if co-sited with strong-motion accelerograph), and physiographic boundaries and roads (solid line).

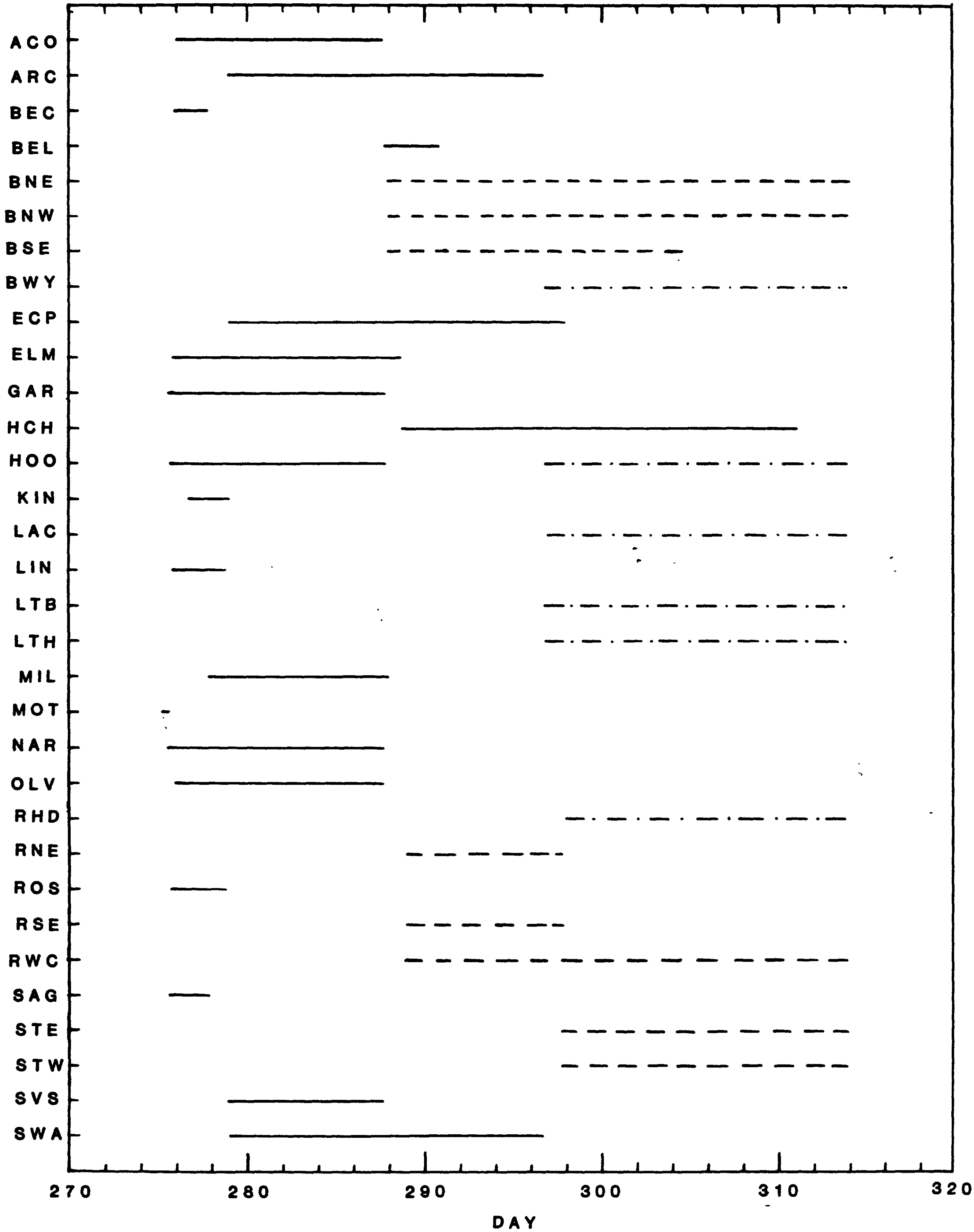

Figure 2. GEOS summary: Deployment 1 (solid line), Deployment 2 (dashed line), Deployment 3 (dashed-dotted line).

TABLE 1A – USGS Whittier Narrows Deployment 1

EVENT	ACO	ARC	BEC	BEL	ECP	ELM	GAR	HCH	HOO	KIN	LAC	LIN	MIL	MOT	NAR	OLV	ROS	SAG	SVS	SWA
2750651L														L						
2750711J														J						
2750724E														E						
2750821E														E						
2750938N														N						
2751023C														C						
2751047N														N						
2751222P														P						
2751654A							A								A					
2760044I			F*			I									I		I			
2760107E							E								E					
2760303N			L*			O	O								N		O			
2760957A						A	A					A			A					
2761752I	J					J	J								I			J		
2761805R							R								R					
2761819G	G														G					
2761825B	B														E					
2761829F	F						F											F		
2762220G	G					G	G										G	G		
2762304P	P									P										
2762323F						F	F		F	F					F	F	F	F		
2770238I	I					I	I		I			I			I		I	J		
2770246P							P								P					
2770255F	F					F	F		F	G		F			F	F	F	F		
2770255R							R		S	↑					R					
2770529N	N						N			N										
2771059M	M		N			M	M			M		M			M	N	M	M		
2771104N						N									N					
2771106K						K				K					K					
2771106S						S				↑					S			S		
2771108G	G					G				G					G			G		
2771108O	O					O	O			↑					O			O		
2771134C	C					C	C			C		C			C			C		
2771134M										↑					M					
2771137M															M			M		
2771140F						F				F					F			F		
2771142O						O									O					
2771154N	N					N				N					N			O		
2771227T						T				T		T								
2771339I						I	I			I		I			I					
2771405R	R					R	R			R		R			R	S				
2771431G						G				G					G					

⇒

Table 1A. Deployment 1 event times (GMT): early MOT triggers (see text) plus two-or-more triggers in sliding 10-second window in Deployment 1, 2, or 3. Letter code denotes seconds: A=0-3, B=3-6, ..., T=57-60.

TABLE 1A (continued)

EVENT	ACO	ARC	BEC	BEL	ECP	ELM	GAR	HCH	HOO	KIN	LAC	LIN	MIL	MOT	NAR	OLV	ROS	SAG	SVS	SWA
2771508B	B					C	B			C		B			B					
2771543M										M					M					
2771748P						P									P					
2771909L	L						L								L					
2772308L						L	L			L		L			L			L		
2780459F						G				G		F	F					G		
2780705D	D					E	D			E		D	D			E	E	E		
2781715A						B	B		A									C		
2782359H	H	H			H	H	H								H				H	
2790537G					H										H				H	G
2790957R						R									R				R	R
2791805F					F										F					
2792335T	T	T			A	T	T						T		T	A			A	T
2800650N					N	N									N				N	N
2801005B		B			B	B									B				B	B
2802000S		S													B					
2802226N															N					P
2802302B	B					C	C								C					C
2811111C	C																		C	
2820148G					G		G												G	
2820217S						S									T					
2820623J	J	L			J	J	J		J				J		J	J			J	J
2820716E	E	E			E	E	E						E		E					
2820958G					G										G					
2821822T						C									T					
2821939S	S						S								S				S	
2822127I	J				J	J	J								I				J	
2831030J	J				J		J						J		J				J	J
2832330H					H	H													H	
2840114G	G																		G	
2840319C	C				C								C		C				C	
2842234C	C	D			C	C	C		D				C		C				C	C
2850509E					E	F														
2850545L					L														L	
2851027F	F				F	F														
2862112T					T	T														
2870125E	E	E			E	E	E						E		E	F			E	E
2882343E																				
2890810O		O			O			O												O
2891121S					S			T												
2901300S					S															
2910724S																				
2930220E		E			E															E

⇒

Table 1A (continued).

TABLE 1A (continued)

EVENT	ACO	ARC	BEC	BEL	ECP	ELM	GAR	HCH	HOO	KIN	LAC	LIN	MIL	MOT	NAR	OLV	ROS	SAG	SVS	SWA
2930532N					O			O												N
2930950C					C			C												
2941255R					S															
2962258M											N									
2970120L											N									
2970822C											E									
2970908R											A									
2970946G											G									
2971659T																				
2972358P								Q			P									
2980846K								K												
3020515C																				
3022118D																				
3030143R																				
3041443S																				
3050804G																				
3081933C																				
3082242P																				
3100927H								H	H		H									
3101510D																				
3121159J									J		J									
3121209J											J									
3121210A									A											
3121259J									J		J									
3121309J											J									
3131159J									J		J									
3131209I											I									
3131259J									J		J									
3131309J											J									

* Anomalous trigger times are due to GEOS malfunction at BEC:
1900115F.BEC → 2760044
1900334L.BEC → 2760303.

† Event recorded on previous file.

Table 1A (continued).

TABLE 1B – USGS Whittier Narrows Deployment 2

EVENT	BSE	BNE	BNW	RSE	RNE	RWC	STE	STW
2882343E					E	G		
2890810O	O	O	O	O	O	O		
2891121S								
2901300S	S	S				S		
2910724S				S		S		
2930220E	E	E				E		
2930532N	O	O				O		
2930950C	C	C				C		
2941255R	R	R		R	R	S		
2962258M								
2970120L								
2970822C								
2970908R								
2970946G								
2971659T		T		T	T			
2972358P	P	P				Q	P	Q
2980846K								
3020515C							C	
3022118D								
3030143R								
3041443S	S					S	S	
3050804G			G			G	G	
3081933C								
3082242P		P	P			P	P	P
3100927H		H	H			H	H	H
3101510D								
3121159J								
3121209J								
3121210A		A	A			A	A	A

Table 1B. Deployment 2 event times (GMT): two-or-more triggers in sliding 10-second window in Deployment 1, 2, or 3. Letter code denotes seconds: A=0-3, B=3-6, ..., T=57-60.

TABLE 1C – USGS Whittier Narrows Deployment 3

EVENT	BWY	HOO	LTB	LTH	RHD
2962258M				M	
2970120L	L				
2970822C	C				
2970908R	R				
2970946G	J				
2971659T					
2972358P					Q
2980846K	K				K
3020515C	C			C	
3022118D			D	D	
3030143R			R	R	
3041443S	S			S	
3050804G					
3081933C			C	C	
3082242P					
3100927H	H	H	H	H	H
3101510D			D	D	
3121159J		J			
3121209J	J		J	J	J
3121210A		A			
3121259J		J			
3121309J	J		J	J	J
3131159J		J			
3131209I	J		J	J	J
3131259J		J			
3131309J	J		J	J	J

Table 1C. Deployment 3 event times (GMT): two-or-more triggers in sliding 10-second window in Deployment 1, 2, or 3. Letter code denotes seconds: A=0-3, B=3-6, ..., T=57-60.

facilitate the use of this dataset in seismological research. It includes station locations and times of operation, pertinent instrument parameters, and clock corrections.

FIELD PROCEDURE

Instrumentation and Station Installation

Instrumentation during the Whittier Narrows aftershock experiment consisted of GEOS digital recorders (Borcherdt and others, 1985), each typically recording six components of ground motion at 200 samples/second/channel: three components of ground acceleration with Kinemetrics FBA-13 triaxial force-balance accelerometers (fba), and three components of ground velocity with Mark Products L-22 triaxial geophones. Table 2 lists nominal trigger and recording parameters. Standard gain settings were 6 dB for acceleration and 18–36 dB for velocity, which provided a reasonable trade-off between the number of triggers and dynamic range. The largest ground motions clipped the geophone channels, but were well recorded on the fba channels; small motions were well recorded on the geophone channels, but below noise on the fba channels. Table 3 contains detailed station histories (location, time of operation, gain, orientation, *etc*). Appendix A contains maps showing instrument-location details at Bechtel Building (BEC), Whittier Lutheran Towers (LTB,LTH), and Millikan Library (MIL,BNE,BNW,BSE,RNE,RSE,RWC,STE,STW).

Standard field procedure was modified somewhat, due both to the exigencies of working in an urban area, and our desire to co-site GEOS with permanent strong-motion accelerographs operated by the U. S. Geological Survey (Etheredge and Porcella, 1987, 1988), the California Division of Mines and Geology (Shakal and others, 1987), and the University of Southern California (Anderson and others, 1981). For reasons of security, most instruments were emplaced either within structures or on private property adjacent to structures. Outdoors, sensors were buried in soil. Indoors, sensors were initially set on, but not otherwise attached to, building floors. The large aftershock at 277 10:59 was recorded this way, and preliminary examination of the recorded motions suggested that at least one indoor sensor (the fba at station ELM) might have slid during the earthquake. Between 279 19:00 and 280 00:00 all indoor sensors were affixed to floors using window glazing putty - a glob of putty was placed under each sensor foot, and sensors were pressed down until firm contact with the floor was established. Good sensor-floor contact appeared to be maintained in each case for the duration of the experiment. (We visually examined each indoor site after the large aftershock, and found no direct evidence of sliding. We have not examined the pre-putty

TABLE 2 – Nominal GEOS parameters

Channel 1,2,3 = Up,North,East acceleration

Channel 4,5,6 = Up,North,East velocity

Digitizing constant = 3276.8 count/V

Sample rate = 200 sample/second/channel

(100 s/s/c for some tapes at NAR)

(400 s/s/c for some tapes at BNE,BNW,RNE,RSE,RWC)

Trigger channel= 4

Short-term average = 0.2 second

Long-term average = 4, 6, or 10 second

Trigger ratio = 4:1 or 8:1

Pre-event memory ≈ 2.0 second

Duration ≥ 10 second

Anti-alias corner frequency = 50 Hz

Anti-alias rolloff = 42 dB/octave

Sensor	Sensitivity	Natural Freq.	Damping
FBA-13	0.0051 V/cm/s/s	50 Hz	0.7
L22	0.5 V/cm/s	2 Hz	0.7

Table 2. Nominal GEOS parameters.

TABLE 3 – Station Histories

ACO

Lat = 34°04.83′, Long = -118°11.25′, Elev = 203 m
Acosta residence, 4407 Jasper St., Los Angeles.
One-story wood-frame garage.
Co-sited with USGS smr #5244.

		FBA-13			L22			
Time (UTC)	GEOS	#	Gain	Orientation	#	Gain	Orientation	Tape
276 0030 - 276 1820	24	27	06dB	UP,000,090	303	18dB	UP,000,090	A
276 1820 - 280 1800	"	"	"	"	"	24dB	"	B-D
280 1800 - 287 1635	"	"	"	"	"	36dB	"	E-F

ARC

Lat = 34°07.78′, Long = -118°02.18′, Elev = 131 m
Arcadia High School, 180 Campus Dr., Arcadia.
One-story 8m×8m storage room.
Co-sited with USC smr #93.

		FBA-13			L22			
Time (UTC)	GEOS	#	Gain	Orientation	#	Gain	Orientation	Tape
278 2250 - 280 1955	6	54	06dB	UP,000,090	200	24dB	UP,000,090	A-B
280 1955 - 296 1545	"	"	"	"	"	30dB	"	C-E

BEC

Lat = 33°55.01′, Long = -118°04.15′, Elev = 32 m
Bechtel Building, Norwalk (see Figure A1).
Standard USGS free-field accelerograph pad (poorly coupled to ground?).
Co-sited with USGS smr #634 - smr not installed.

		FBA-13			L22			
Time (UTC)	GEOS	#	Gain	Orientation	#	Gain	Orientation	Tape
275 2330 - 277 1755	20	56	06dB	UP,000,090	189	18dB	UP,000,090	A-B

BEL

Lat = 33°57.89′, Long = -118°09.49′, Elev = 36 m
Grant Ward Latter Day Saints Church, 7420 Jaboneria St., Bell Gardens.
One-story brick building; closet near kitchen.
Co-sited with USC smr #94

		FBA-13			L22			
Time (UTC)	GEOS	#	Gain	Orientation	#	Gain	Orientation	Tape
287 1750 - 290 2000	42	32	06dB	UP,000,090	162	30dB	UP,000,090	A-B

Table 3. Station histories.

BNE

Lat = 34°08.21′, Long = -118°07.52′, Elev = 229 m
Millikan Library basement - northeast site, Pasadena (see Figure A3).

		FBA-13			L22			
Time (UTC)	GEOS	#	Gain	Orientation	#	Gain	Orientation	Tape
287 2250 - 297 1640	20	56	06dB	UP,000,090	189	36dB	UP,000,090	A-B
297 1640 - 297 1730	"	-	-	-	189	60dB	UP,000,090	B†
297 1730 - 313 2105	"	56	06dB	UP,000,090	189	36dB	UP,000,090	C-D

†400 sps/channel

BNW

Lat = 34°08.21′, Long = -118°07.52′, Elev = 229 m
Millikan Library basement - northwest site, Pasadena (see Figure A3).

		FBA-13			L22			
Time (UTC)	GEOS	#	Gain	Orientation	#	Gain	Orientation	Tape
287 2230 - 297 1630	26	11	06dB	UP,000,090	184	36dB	UP,000,090	A-B
297 1650 - 297 1705	"	-	-	-	184	60dB	UP,000,090	C†
297 1730 - 299 1700?	"	11	06dB	UP,000,090	184	36dB	UP,000,090	D
300 2225 - 303 2200	"	-	-	-	184	36dB	UP,000,090	E
303 2200 - 313 2100	"	11	06dB	UP,000,090	184	36dB	UP,000,090	E

†400 sps/channel
299 1700? Instrument was removed by ML personnel - exact time-off is unknown

BSE

Lat = 34°08.21′, Long = -118°07.52′, Elev = 229 m
Millikan Library basement - southeast site, Pasadena (see Figure A3).

		FBA-13			L22			
Time (UTC)	GEOS	#	Gain	Orientation	#	Gain	Orientation	Tape
287 2245 - 304 1445?	22	24	06dB	UP,000,090	305	36dB	UP,000,090	A-C

304 1445? Time of last trigger - exact time-off is unknown.

BWY

Lat = 33°59.21′, Long = -118°02.53′, Elev = 102 m
Castor residence. 12431 E. Broadway, Whittier.
3m×3m concrete pad abutting one-story wood-frame garage.
Heavily damaged residential area.

		FBA-13			L22			
Time (UTC)	GEOS	#	Gain	Orientation	#	Gain	Orientation	Tape
296 2030 - 313 1700	42	57	06dB	UP,000,090	197	36dB	UP,000,090	A-C

Table 3 (continued).

ECP

Lat = 34°10.63', Long = -118°05.77', Elev = 296 m
Eaton Canyon Park, Altadena.
One-story wood-frame park headquarters building; storage room.
Co-sited with CDMG smr #24402

		FBA-13			L22			
Time (UTC)	GEOS	#	Gain	Orientation	#	Gain	Orientation	Tape
278 2345 - 280 1900	15	21	06dB	UP,000,090	190	24dB	UP,000,090	A-B
280 1900 - 297 2045	"	"	"	"	"	36dB	"	C-F

ELM

Lat = 34°05.57', Long = -118°01.12', Elev = 97 m
El Monte Latter Day Saints Church, 11338 Fairview Ave., El Monte.
One-story wing of two-story stucco building; broom closet off Children's Chapel.
Co-sited with USC smr #66

		FBA-13			L22			
Time (UTC)	GEOS	#	Gain	Orientation	#	Gain	Orientation	Tape
275 2200 - 279 1705	13	09	06dB	UP,000,090	157	18dB	UP,014,104	A-C
279 1705 - 280 1820	"	"	"	"	"	24dB	"	D
280 1820 - 283 1755	"	"	"	"	"	30dB	"	E-F
283 1755 - 288 1540?	"	"	"	"	"	36dB	"	G-J

288 1540? Time of last trigger - exact time-off is unknown.

GAR

Lat = 34°02.92', Long = -118°06.66', Elev = 159 m
Garvey Reservoir, Monterey Park.
One-story concrete-block pump building.
Co-sited with USGS smr #709

		FBA-13			L22			
Time (UTC)	GEOS	#	Gain	Orientation	#	Gain	Orientation	Tape
275 1530 - 279 1745	26	52	06dB	UP,000,090	311	18dB	UP,000,090	A-C
279 1755 - 280 1655	"	"	"	"	"	24dB	"	D
280 1655 - 281 1600	"	"	"	"	"	30dB	"	E
281 1600 - 287 1730	"	"	"	"	"	36dB	"	E-F

Table 3 (continued).

HCH

Lat = 33°59.39′, Long = -117°56.56′, Elev = 159 m
First Ward Latter Day Saints Church, 16750 Colima Rd., Hacienda Heights.
One-story brick building; broom closet near center.
Co-sited with USC smr #73

		FBA-13			L22			
Time (UTC)	GEOS	#	Gain	Orientation	#	Gain	Orientation	Tape
288 1805 - 310 2315	13	09	06dB	UP,000,090	157	36dB	UP,000,090	A-D

HOO

Lat = 33°59.08′, Long = -118°01.73′, Elev = 140 m
Hoover School, 6302 S. Alta Dr., Whittier.
Old one-story stone building; storage room SE corner of the north building.
Co-sited with USC smr #75

		FBA-13			L22			
Time (UTC)	GEOS	#	Gain	Orientation	#	Gain	Orientation	Tape
275 1900 - 278 1655	22	29	06dB	UP,000,090	160	18dB	UP,000,090	A
278 1655 - 281 1530	"	"	"	"	"	24dB	"	B-C
281 1530 - 287 1815	"	"	"	"	"	36dB	"	C-D
296 1745 - 313 1745	06	55	06dB	UP,000,090	154	36dB	UP,000,090	E-F

KIN

Lat = 34°10.87′, Long = -118°04.84′, Elev = 441 m
Griffith residence, Kinneloa Ranch, 2254 N. Villa Rd, Pasadena.
Buried in ground 1–3 m behind one-story house.

		FBA-13			L22			
Time (UTC)	GEOS	#	Gain	Orientation	#	Gain	Orientation	Tape
276 1915 - 278 2300	15	21	06dB	UP,000,090	190	24dB	UP,014,104	A-B

LAC

Lat = 33°55.44′, Long = -118°10.02′, Elev = 27 m
L. A. County Roads Department, Downey.
Concrete pad; storeroom in tall metal warehouse (noisy site).
Co-sited with CDMG smr #14368

		FBA-13			L22			
Time (UTC)	GEOS	#	Gain	Orientation	#	Gain	Orientation	Tape
296 2250 - 313 1600	07	-	-	-	302	30,36,36dB	UP,000,090?	A-D

Seismometer rotated 45 degrees clockwise?

Table 3 (continued).

LIN

Lat = 34°05.49′, Long = -118°05.56′, Elev = 114 m
Lincoln School, 600 E. Grand Ave., San Gabriel.
Concrete floor; basement of two-story building.
Co-sited with USC smr #19

		FBA-13			L22			
Time (UTC)	GEOS	#	Gain	Orientation	#	Gain	Orientation	Tape
275 2040 - 278 1900	43	55	06dB	UP,000,090	154	18dB	UP,000,090	A

LTB

Lat = 33°58.57′, Long = -118°02.13′, Elev = 93 m
Whittier Lutheran Towers basement, 7215 Bright Ave., Whittier (see Figure A2).
Ten-story building.
Co-sited with USGS smr #804

		FBA-13			L22			
Time (UTC)	GEOS	#	Gain	Orientation	#	Gain	Orientation	Tape
296 1840 - 313 1740	43	54	06dB	UP,000,090	200	36dB	UP,000,090	A-B

LTH

Lat = 33°58.55′, Long = -118°02.13′, Elev = 93 m
Whittier Lutheran Towers free-field, 7215 Bright Ave., Whittier (see Figure A2).
Concrete floor; parking garage (64 m south of LTB).

		FBA-13			L22			
Time (UTC)	GEOS	#	Gain	Orientation	#	Gain	Orientation	Tape
296 1900 - 313 1725	40	32	06dB	UP,000,090	162	36dB	UP,000,090	A-D

MIL

Lat = 34°08.21′, Long = -118°07.52′, Elev = 229 m
Millikan Library basement, Caltech, Pasadena (see Figure A3).
Co-sited with USGS smr #?

		FBA-13			L22			
Time (UTC)	GEOS	#	Gain	Orientation	#	Gain	Orientation	Tape
277 2330 - 280 1905	20	56	06dB	UP,000,090	189	24dB	UP,000,090	A-B
280 1905 - 287 2240	"	"	"	"	"	36dB	"	C-D

Table 3 (continued).

MOT

Lat = 33°59.19′, Long = -118°03.53′, Elev = 57 m
Thrifty Luxury Motel, Whittier.
Ground floor of two-story stucco building; room 109.

		FBA-13			L22			
Time (UTC)	GEOS	#	Gain	Orientation	#	Gain	Orientation	Tape
275 0600 - 275 1330	26	51	06dB	UP,000,090?	311	18dB	UP,000,090?	A

NAR

Lat = 34°01.88′, Long = -118°03.19′, Elev = 67 m
Whittier Narrows Dam maintenance yard, Whittier.
Concrete pad in 1.5m×2m metal hut (noisy site?).
Co-sited with USGS smr #289 (upstream).

		FBA-13			L22			
Time (UTC)	GEOS	#	Gain	Orientation	#	Gain	Orientation	Tape
275 1510 - 279 2015	42	11	06dB	UP,340,070	196	18dB	UP,340,070	A-C
279 2025 - 280 1730	"	"	"	"	"	24dB	"	D
280 1730 - 282 2125	"	"	"	"	"	30dB	"	E-G
282 2125 - 285 2000	"	"	"	"	"	30dB	"	H-I†
285 2000 - 287 1605	"	"	"	"	"	30dB	"	I-J

Sensors aligned with smr.
†100 sps/channel

OLV

Lat = 34°06.02′, Long = -117°58.45′, Elev = 116 m
Olive Junior High School, 3699 North Holly Ave., Baldwin Park.
One-story 20m×30m gymnasium; heater room.
Co-sited with USC smr #69

		FBA-13			L22			
Time (UTC)	GEOS	#	Gain	Orientation	#	Gain	Orientation	Tape
276 0005 - 276 2140	28	32	06dB	UP,000,090	162	18dB	UP,014,104	A
276 2140 - 280 1755	"	"	"	"	"	24dB	"	A-C
280 1755 - 282 1600	"	"	"	"	"	30dB	"	D
282 1600 - 287 1630	"	"	"	"	"	36dB	"	D-E

Table 3 (continued).

RHD

Lat = 33°58.71′, Long = -118°03.66′, Elev = 50 m
Rogers residence, 11432 Rose Hedge Dr., Whittier.
5m×7m concrete patio behind one-story wood-frame house.
Lightly damaged residential area.

		FBA-13			L22			
Time (UTC)	GEOS	#	Gain	Orientation	#	Gain	Orientation	Tape
297 2305 - 313 1635	15	21	06dB	UP,000,090	190	36dB	UP,000,090	A-C

RNE

Lat = 34°08.21′, Long = -118°07.52′, Elev = 229 m
Millikan Library roof - northeast site, Pasadena (see Figure A4).

		FBA-13			L22			
Time (UTC)	GEOS	#	Gain	Orientation	#	Gain	Orientation	Tape
288 2225 - 297 1610	24	52	06dB	UP,000,090	303	30dB	UP,000,090	A-B
297 1610 - 297 1720	"	-	-	-	303	60dB	UP,000,090	B†

†400 sps/channel

ROS

Lat = 34°00.48′, Long = -118°01.54′, Elev = 268 m
Rose Hill Memorial Park, Whittier.
Sunken 10m×6m×6m concrete box abutting one-story brick warehouse.

		FBA-13			L22			
Time (UTC)	GEOS	#	Gain	Orientation	#	Gain	Orientation	Tape
275 1710 - 276 1620	15	12	06dB	UP,000,090	184	18dB	UP,014,104	A
276 1625 - 277 2300	21	"	"	"	"	"	"	B
277 2300 - 278?	"	"	"	"	305	"	"	C
278? - 278 2100	"	"	"	"	"	24dB	"	C

RSE

Lat = 34°08.21′, Long = -118°07.52′, Elev = 229 m
Millikan Library roof - southeast site, Pasadena (see Figure A4).

		FBA-13			L22			
Time (UTC)	GEOS	#	Gain	Orientation	#	Gain	Orientation	Tape
288 2335 - 297 1600	21	53	06dB	UP,000,090	196	30dB	UP,000,090	A-B
297 1600 - 297 1710	"	-	-	-	196	60dB	UP,000,090	B†

†400 sps/channel

Table 3 (continued).

RWC

Lat = 34°08.21′, Long = -118°07.52′, Elev = 229 m
Millikan Library roof - westcenter site, Pasadena (see Figure A4).

		FBA-13			L22			
Time (UTC)	GEOS	#	Gain	Orientation	#	Gain	Orientation	Tape
288 2340 - 297 1620	28	51	06dB	UP,000,090	311	30dB	UP,000,090	A-B
297 1620 - 297 1730	"	-	-	-	311	60dB	UP,000,090	B†
297 1740 - 313 2140	"	51	06dB	UP,000,090	311	36dB	UP,000,090	C-D

†400 sps/channel

SAG

Lat = 34°08.13′, Long = -118°01.88′, Elev = 139 m
Santa Anita Golf Course - old club house, Arcadia.
Concrete floor of 14m×30m two-story wood-frame building (demolished after earthquake).

		FBA-13			L22			
Time (UTC)	GEOS	#	Gain	Orientation	#	Gain	Orientation	Tape
275 1630 - 276 1720	06	54	06dB	UP,000,090	200	18dB	UP,000,090	A
276 1720 - 278 2200	"	"	"	"	"	24dB	"	A-B

STE

Lat = 34°08.21′, Long = -118°07.52′, Elev = 229 m
Millikan Library steam tunnel - southeast site, Pasadena (see Figure A5).

		FBA-13			L22			
Time (UTC)	GEOS	#	Gain	Orientation	#	Gain	Orientation	Tape
297 1835 - 313 2130	24	52	06dB	UP,000,090	196	36dB	UP,000,090	A-B

STW

Lat = 34°08.21′, Long = -118°07.52′, Elev = 229 m
Millikan Library steam tunnel - southwest site, Pasadena (see Figure A5).

		FBA-13			L22			
Time (UTC)	GEOS	#	Gain	Orientation	#	Gain	Orientation	Tape
297 1900 - 313 2020	21	53	06dB	UP,000,090	303	36dB	UP,000,090	A-B

Table 3 (continued).

SVS

Lat = 33°59.41′, Long = -118°06.83′, Elev = 56 m
Saint Vincent Seminary, 1105 Bluff Rd., Montebello.
Ground floor of two-story brick building; storage room.
Co-sited with USC smr #11

		FBA-13			L22			
Time (UTC)	GEOS	#	Gain	Orientation	#	Gain	Orientation	Tape
278 2205 - 280 1650	21	12	06dB	UP,000,090	184	24dB	UP,000,090	A-B
280 1650 - 280 1702	"	"	"	"	"	30dB	"	C
280 1702 - 282 1800	"	"	"	"	"	24dB	"	C
282 1800 - 287 1535	"	"	"	"	"	36dB	"	C-D

SWA

Lat = 34°06.92′, Long = -118°07.82′, Elev = 172 m
Southwestern Academy, San Marino.
One-story concrete-block shop building; storage room.
Co-sited with CDMG smr #24401.

		FBA-13			L22			
Time (UTC)	GEOS	#	Gain	Orientation	#	Gain	Orientation	Tape
279 0005 - 280 2220	43	55	06dB	UP,000,090	154	24dB	UP,000,090	A-C
280 2220 - 296 1615	"	"	"	"	"	36dB	"	C-D

Table 3 (continued).

data in detail for other evidence of sensor sliding, which might be detectable by comparing integrated fba records with response-corrected geophone records.)

Clock corrections.

Clock-drift measurements were obtained in the field by periodically comparing GEOS internal clocks to WWVB and/or portable master clock time standards. Each GEOS unit contains a WWVB receiver and software that can automatically evaluate WWVB quality and measure the time difference between the internal clock and WWVB at preprogrammed intervals. WWVB is usually our preferred time standard for measuring GEOS clock drifts. Portable master clocks are used to supplement WWVB, or as the sole time standard when WWVB reception is unreliable. GEOS clocks were not resynched to WWVB or master clock at each station visit (typically once per day), but rather were allowed to drift as long as possible before resynching in order to determine a consistent drift rate.

We encountered several problems in the field at Whittier Narrows that made it difficult to sort out timing relationships. First, WWVB reception was generally poor during the Whittier Narrows study, presumably because most of the recorders were installed in or near buildings. A tendency to compensate for poor WWVB reception by taking more measurements (say, by decreasing the programmed measurement interval from 12 to 3 hours), and a tendency of GEOS to accept rather than reject marginal WWVB data, conspired at Whittier Narrows to create a large, but largely useless, set of WWVB clock corrections. Second, during most of the experiment we used two master clocks (called TMC and CMC), but, unfortunately, neither clock ran uninterupted from beginning to end. TMC lost power twice during the experiment, and CMC was turned off during a period when field personnel were withdrawn from the field area. In these cases, both clocks had to be reset to other clocks (in one case, TMC was synched to one of the GEOS clocks). Finally, because we could not maintain personnel in the field during the entire experiment, there were several periods during which clock errors could not be measured manually.

These circumstances led to a complicated set of interrelated clock measurements, and we decided to solve for the clock corrections as a least-squares adjustment. Mathematically, GEOS clocks and master clocks were treated equally in the model. Each GEOS clock was assumed to drift at a constant rate between resynchs at a given site, but the rate could be different if the GEOS was moved to a different site. Each master clock was assumed to drift at an unknown constant rate throughout the whole experiment. Thus, a clock correction at

TABLE 4 – GEOS clock corrections (GEOS time + clock correction = true time)

Explanation of Table 4 ...

The model for each clock is divided into segments as described in the text.

The clock correction in milliseconds at time T is given by:

(CC $\pm$ Error) + (DriftRate $\pm$ Error) $\times$ (T - LastResetTime), for LastResetTime $\leq$ T $\leq$ NextResetTime.

Example and interpretation (Station ROS):

Station	Seg	ResetTime	CC	Error	DriftRate	Error
ROS	1	275.720	0.1	6.4	-22.272	12.236
	2	276.680*	0.0	9.1	5.882	25.106
	3	277.990	0.0	9.1	"	"

For 275.720 $\leq$ T $\leq$ 276.680, clock correction at T = 0.1 - 22.272 $\times$ (T - 275.720).

For 276.680 $\leq$ T $\leq$ 277.990, clock correction at T = 0.0 + 5.882 $\times$ (T - 276.680).

For T $\geq$ 277.990, clock correction at T = 0.0 + 5.882 $\times$ (T - 277.990).

* denotes artificial reset (see text).

Station	Seg	ResetTime (day)	CC (ms)	Error	DriftRate (ms/day)	Error
ACO	1	276.020	1.9	11.6	11.083	0.907
	2	276.300	0.8	5.8	"	"
ARC	1	278.960	7.7	8.6	-19.861	1.708
	2	285.680*	-125.6	10.1	-11.400	1.362
BEC - clock corrections not computed						
BEL	1	287.760	46.9	5.4	-0.353	3.423
BNE	1	287.941	37.1	5.8	"	"
	2	297.700	23.9	7.5	"	"
BNW	1	287.950	33.8	6.3	-13.051	1.030
	2	297.730	9.2	9.8	"	"
	3	300.940	24.8	9.8	"	"
BSE	1	287.950	33.6	6.8	13.414	1.033
	2	299.771	19.3	9.8	"	"
BWY	1	296.850	-1.5	3.5	3.707	0.395
ECP	1	278.990	-1.4	7.7	-10.094	2.360
	2	283.710*	-54.4	7.4	2.559	0.835
ELM	1	275.920	1.3	4.0	14.806	0.689
GAR	1	275.630	-0.6	7.9	-10.698	1.021
HCH	1	288.760	49.6	4.0	17.525	0.455
	2	299.951	19.7	3.9	"	"

$\Rightarrow$

Table 4. GEOS clock corrections.

TABLE 4 (continued)

Station	Seg	ResetTime (day)	CC (ms)	Error	DriftRate (ms/day)	Error
HOO	1	275.790	1.4	11.6	14.308	1.290
	2	278.710	11.7	9.1	"	"
HOO	1	296.740	-16.0	5.0	-7.436	0.455
KIN	1	276.800	-1.9	5.7	-11.174	5.159
LAC	1	296.940	0.8	4.3	-24.084	0.510
	2	311.010	-0.1	4.5	"	"
LIN	1	275.850	1.5	11.6	2.733	5.196
LTB	1	296.780	3.1	4.9	-0.031	0.451
LTH	1	296.790	-2.5	4.2	1.382	0.388
MIL	1	277.980	487.9	8.7	-5.927	0.625
	2	279.831	23.5	7.1	"	"
MOT - clock corrections not computed						
NAR	1	275.640	-5.6	6.0	1.617	0.834
OLV	1	276.000	-5.6	3.5	-10.362	0.498
RHD	1	297.970	10.0	3.2	-5.611	0.507
	2	299.521	-25.1	3.7	"	"
RNE	1	288.950	35.2	7.3	13.706	1.438
	2	297.681	9.0	9.8	"	"
ROS	1	275.720	0.1	6.4	-22.272	12.236
	2	276.680*	0.0	9.1	5.882	25.106
	3	277.990	0.0	9.1	"	"
RSE	1	288.980	34.1	4.0	4.738	0.796
	2	297.671	8.9	5.4	"	"
RWC	1	288.990	37.4	3.4	-10.013	0.398
	2	297.681	37.1	4.4	"	"
SAG	1	275.690	3.0	11.4	-31.193	4.565
STE	1	297.770	8.4	4.8	6.875	0.468
STW	1	297.790	8.9	4.8	7.070	0.470
SVS	1	278.920	3.9	6.4	6.674	1.228
SWA	1	279.000	13.9	8.7	-3.727	0.917
	2	280.920	187.7	8.3	"	"
	3	281.700	27.9	8.9	"	"
TMC	1	274.790	-0.7	4.1	2.124	0.298
	2	277.810	-23.8	3.8	"	"
	3	277.960	479.2	4.5	"	"
	4	278.641	13.0	3.4	"	"
CMC	1	274.790	-16.9	2.3	4.912	0.223
	2	296.630	3.8	2.2	"	"
	3	310.630	-2.3	2.9	"	"

* denotes artificial reset (see text)

Table 4 (continued).

time t has the form:

$$(cc_i \pm \sigma_{cc_i}) + (r \pm \sigma_r) \times (t - t_i^r) \quad \text{for} \quad t_i^r \leq t < t_{i+1}^r,$$

where t_i^r (Julian day) is the time of the most recent resynch, cc_i (ms) is the clock correction at the previous resynch t_i^r, σ_{cc_i} is the error of cc_i, r (ms/day) is the drift rate, and σ_r is the error of the drift rate.

This system of equations was solved by least squares for the unknowns cc_i, σ_{cc_i}, r, and σ_r for all stations. The results of this computation generally supported the assumption that each GEOS clock had a linear drift that varied when the GEOS was moved. Stations ARC, ECP, and ROS, however, showed obvious nonlinear drift rates. Thus, the clock model for each of these stations was artificially divided into two linear segments, with the clock correction constrained to be continuous at the dividing time. For example, the clock at station ARC was allowed to drift at different linear rates before and after day 285.680, where the time 285.680 was selected by visual inspection of the clock-drift data.

The system was solved again, and the resulting clock corrections are listed in Table 4. The complete system, including measured and predicted clock corrections and residuals, is tabulated in Appendix B. Clock corrections at most stations are well determined, with discrepancies between measured and predicted clock corrections (residuals) less than 5 ms. The largest residuals are 20 ms or greater; they occur near day 303, between two long periods when field personnel were withdrawn from the field, and may result from possible nonlinear clock drifts or accidental unrecorded clock resets that are not included in the model.

DATA HIGHLIGHTS

While it is impossible to give a complete overview in this report, we would like to point out several features of special interest in the Whittier Narrows dataset. The first GEOS station, MOT, was installed in Whittier approximately 15 hours after the mainshock, and recorded eight aftershocks early in the sequence (Table 1). (No clock corrections are available for MOT, however.) The largest aftershock (277 10:59 GMT, $M_L = 5.3$) was recorded by 10 GEOS stations; acceleration seismograms are plotted in Figure 3. Preliminary analysis of a subset of well recorded aftershocks shows that ground motions recorded around the L. A. basin during Deployment 1 generally appear to mimic the intensity distribution for the mainshock. Ground motions recorded in the local Whittier area (Deployment 3) showed strong site-to-site variations that seemed related to observed intensity patterns (P. Thenhaus,

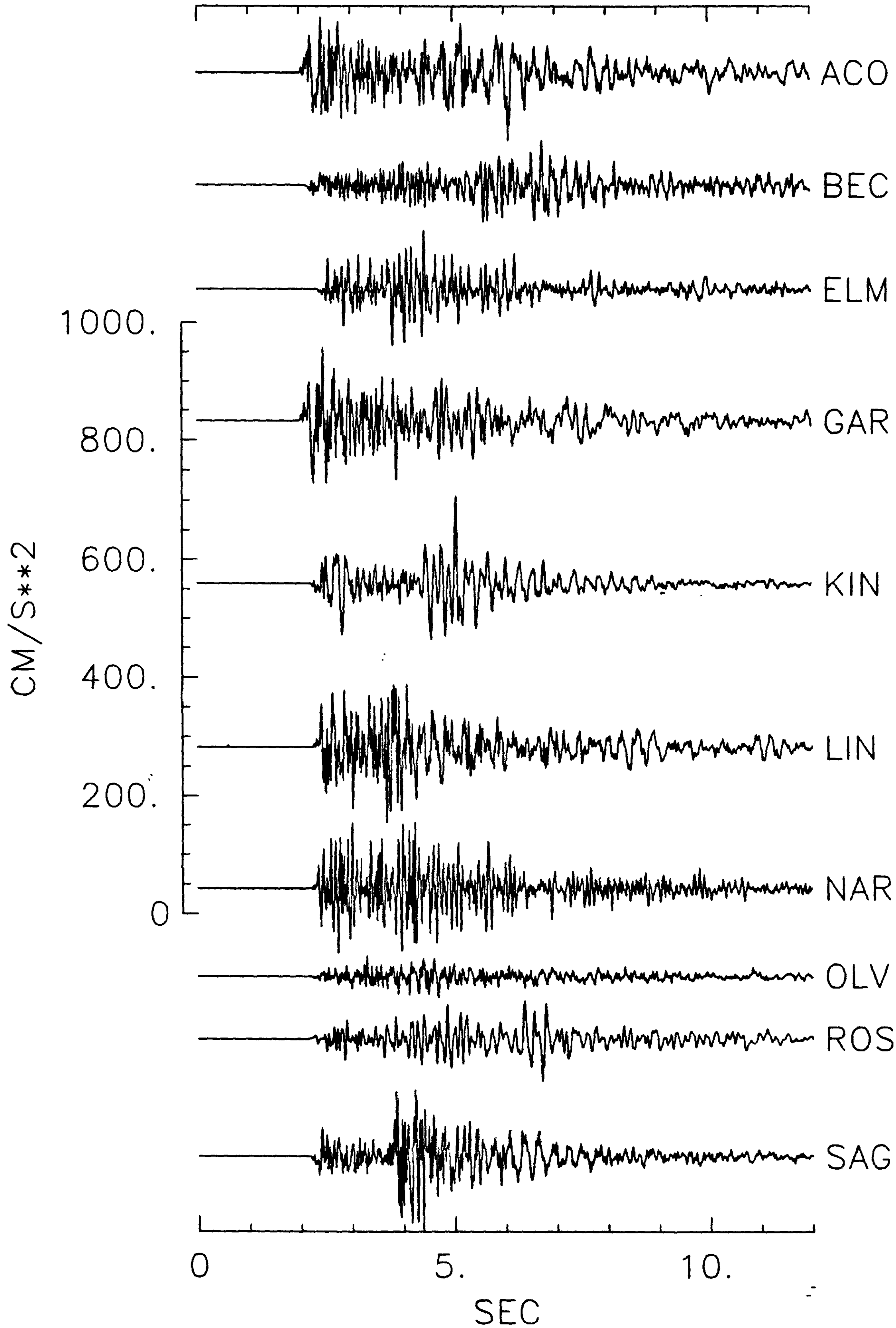

Figure 3a. UP-component acceleration seismograms from large aftershock at 277 10:59.

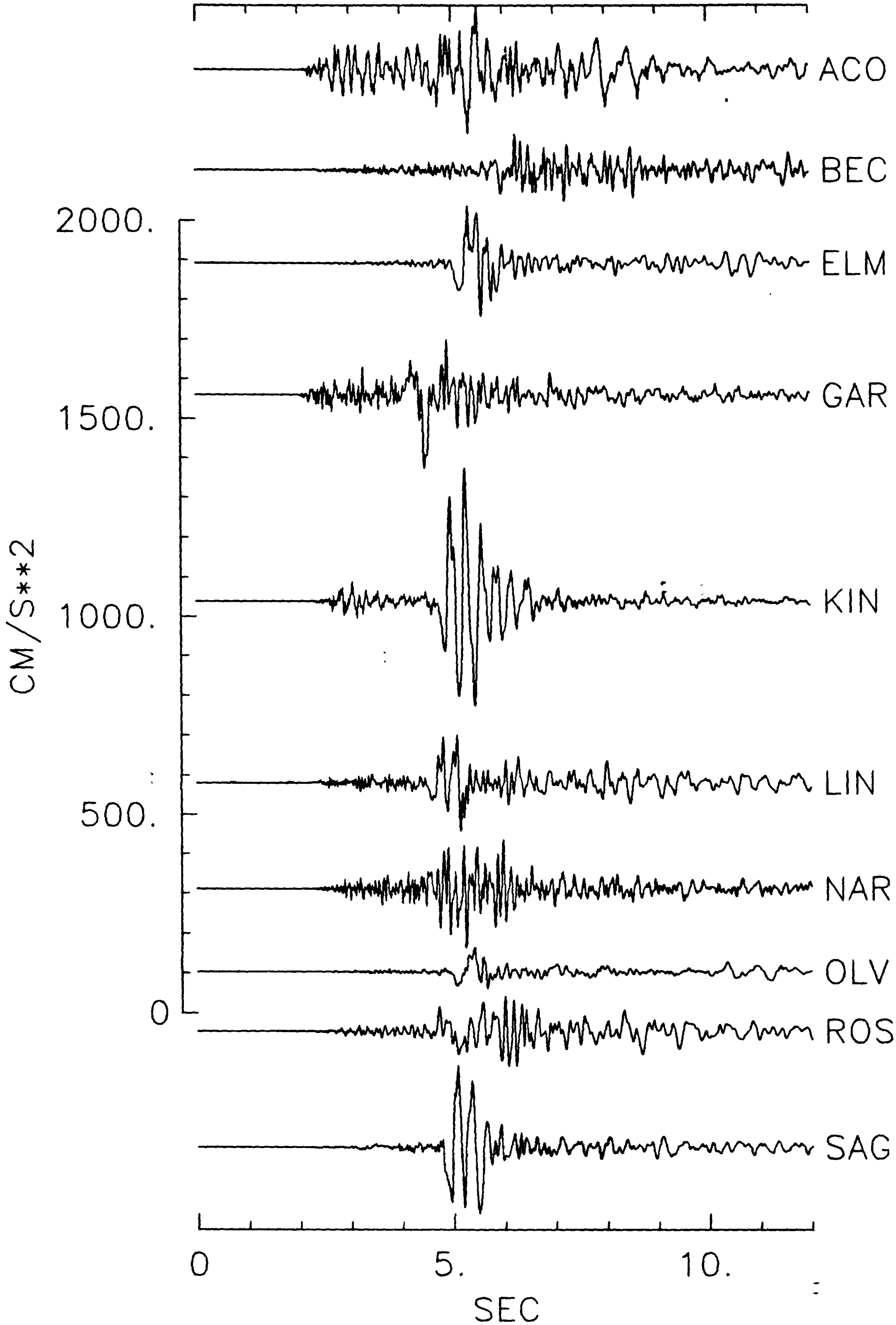

Figure 3b. H000-component acceleration seismograms from large aftershock at 277 10:59.

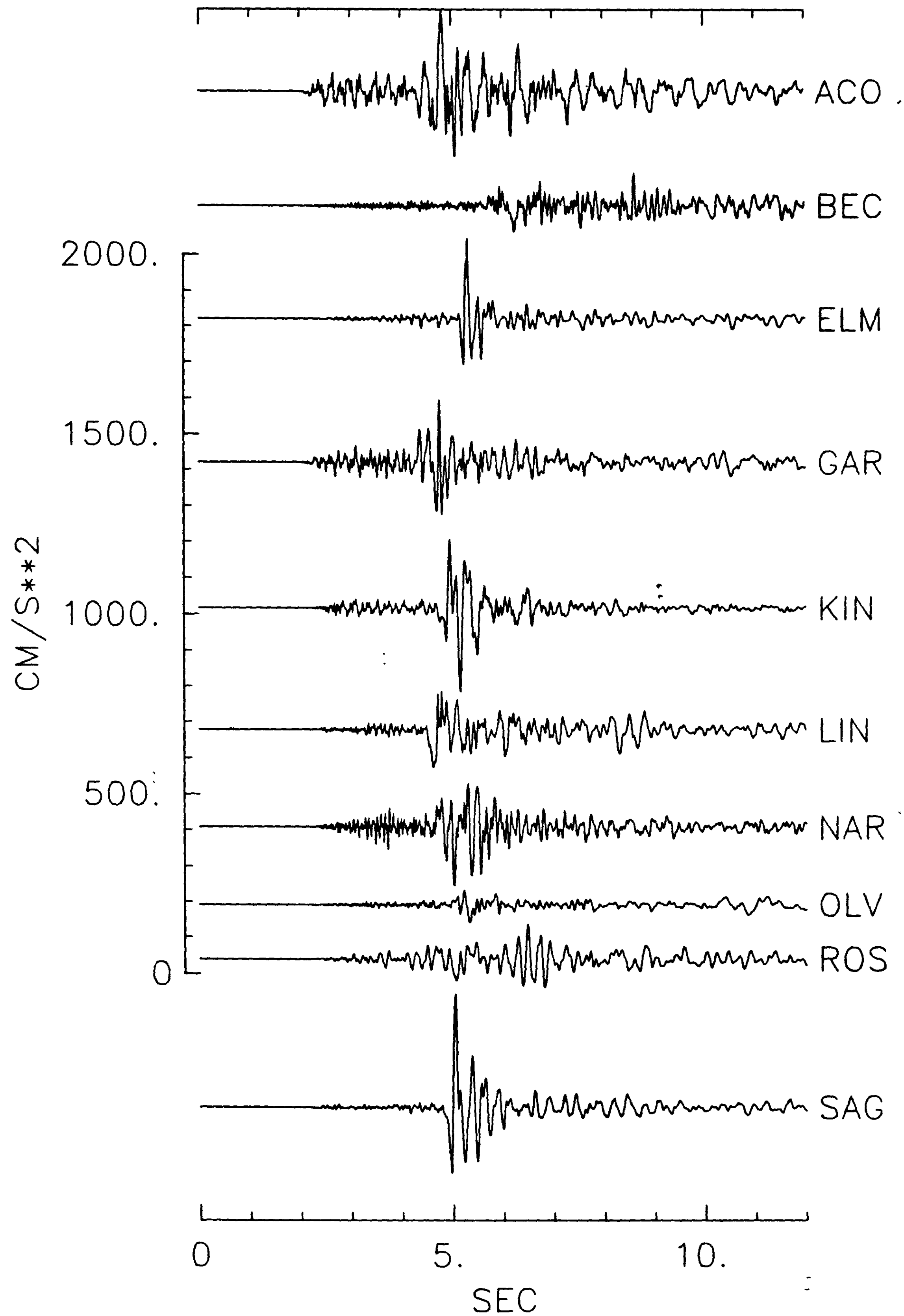

Figure 3c. H090-component acceleration seismograms from large aftershock at 277 10:59.

written communication, 1987).

PLAYBACK AND PROCESSING

Data tapes were returned to Menlo Park for final playback after preliminary analysis in the field. Complete and partial (records from events recorded on four-or-more stations) datasets have been archived on nine-track tape in a compact block-binary format (Mueller *et al*, 1988). These datasets are available from:

ES&G Data Project
US Geological Survey MS 977
345 Middlefield Rd.
Menlo Park, CA 94025.

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Appendix A

Maps showing instrument location details at selected stations.

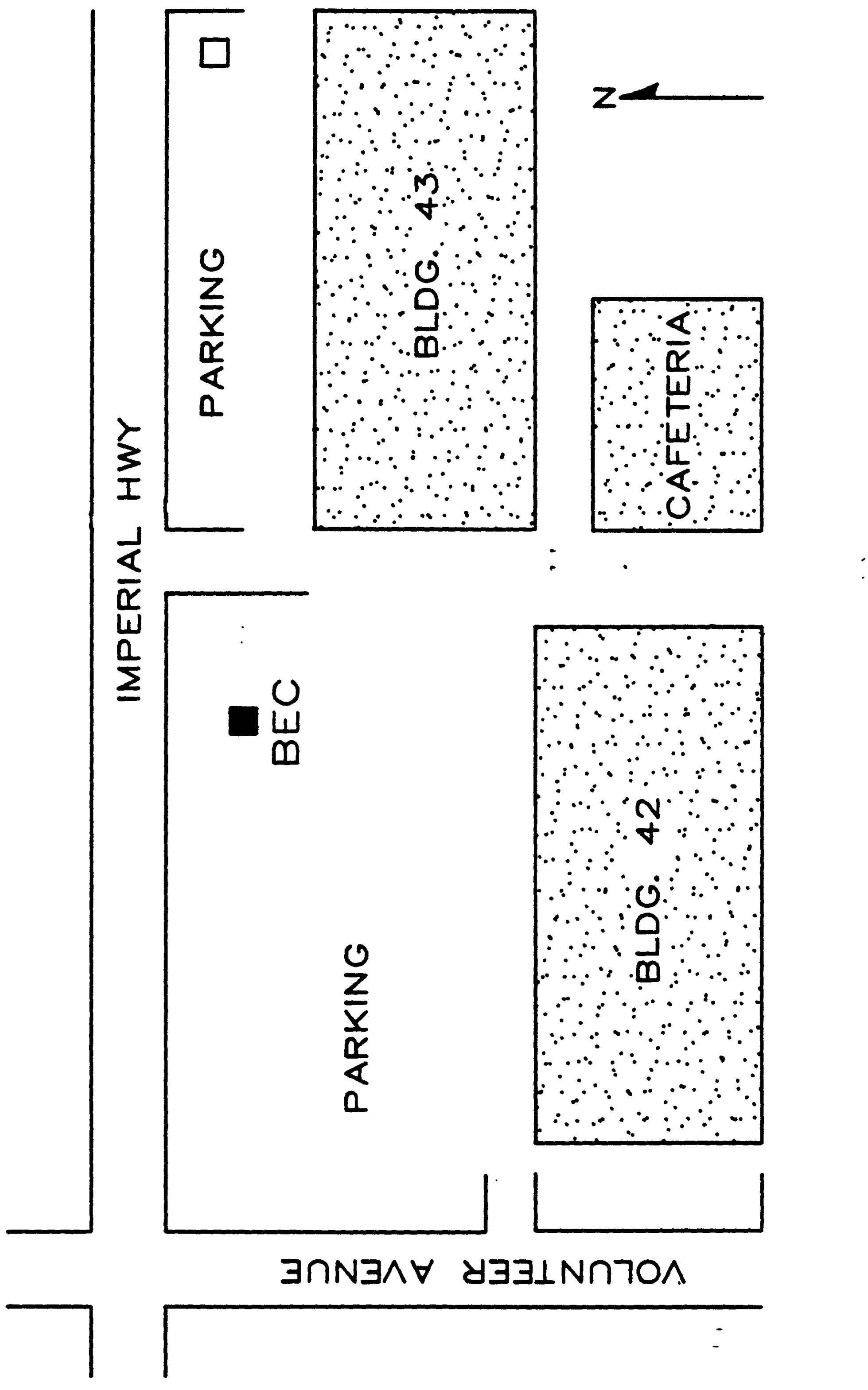

Figure A1. Bechtel Building (BEC) - instrument locations.

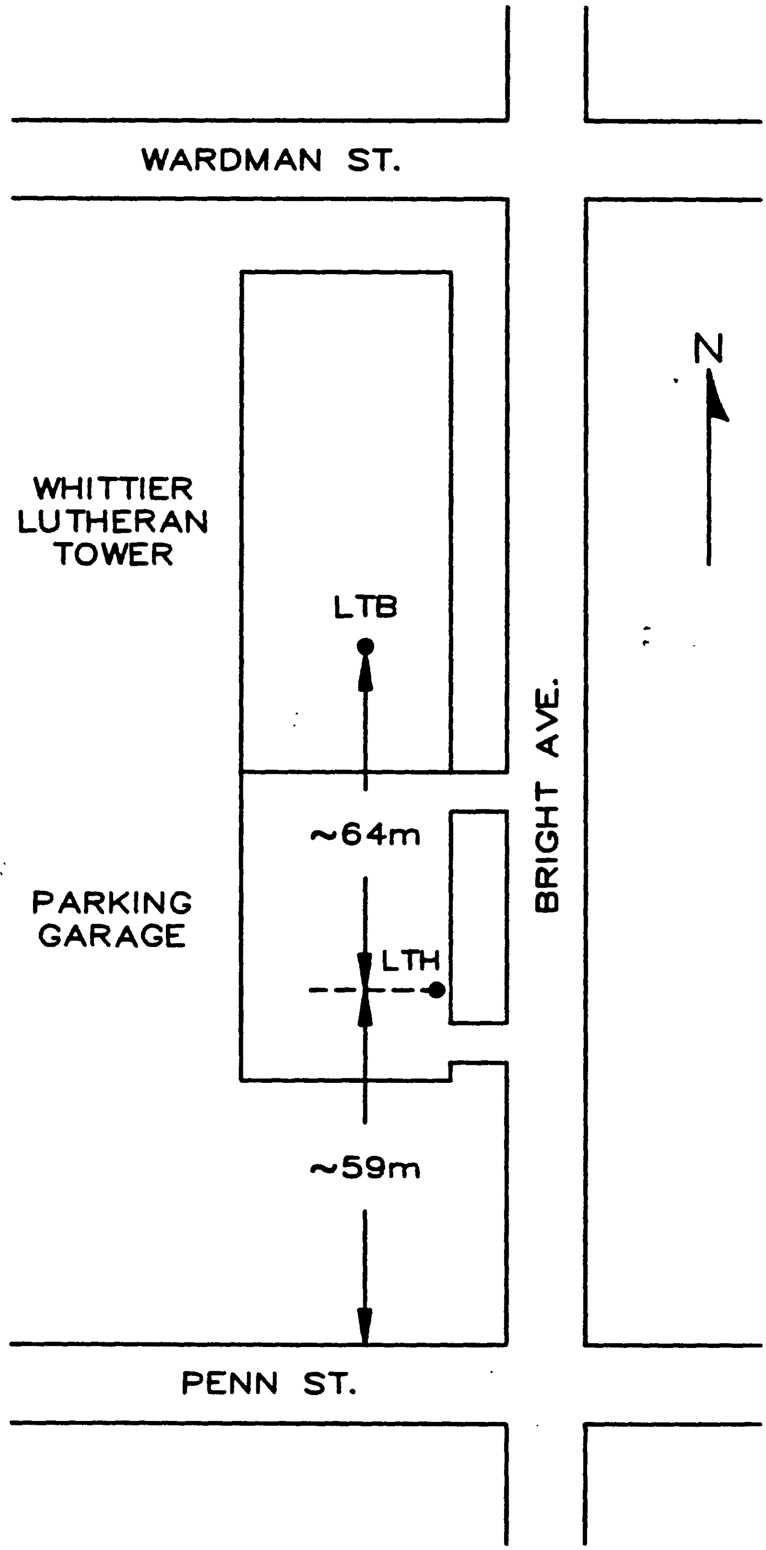

Figure A2. Whittier Lutheran Towers (LTB,LTH) - instrument locations.

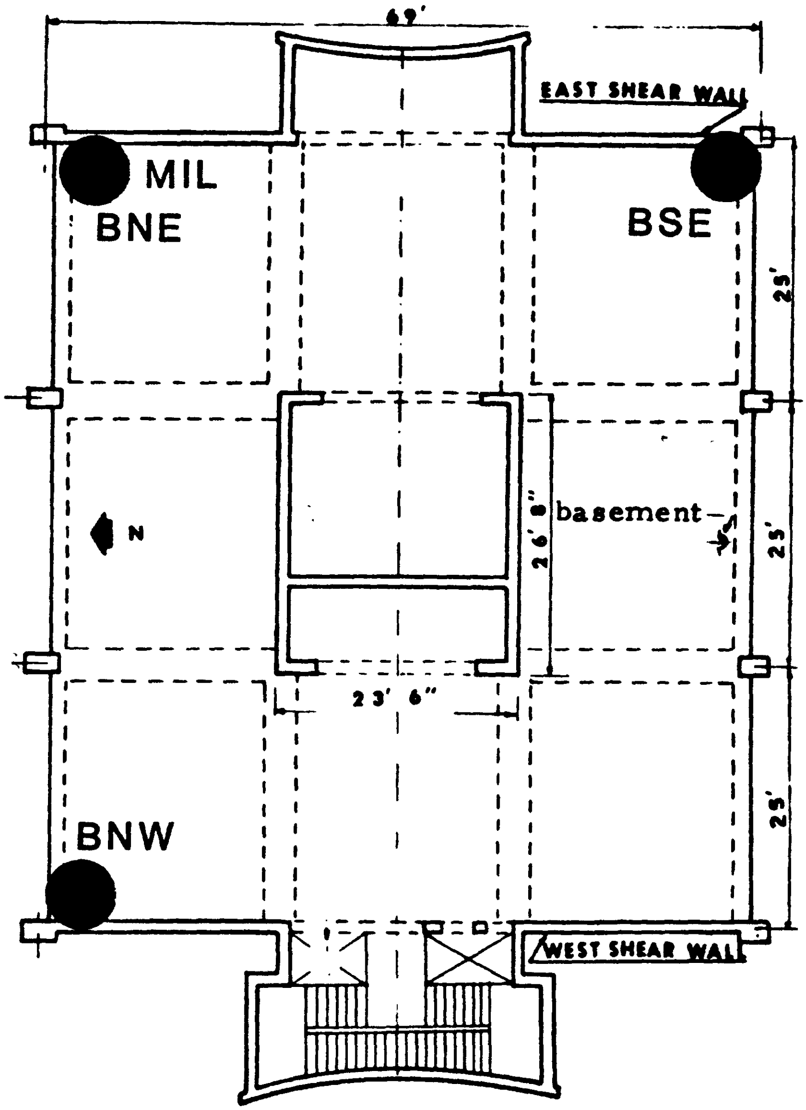

Figure A3. Millikan Library basement (MIL,BNE,BNW,BSE) - instrument locations.

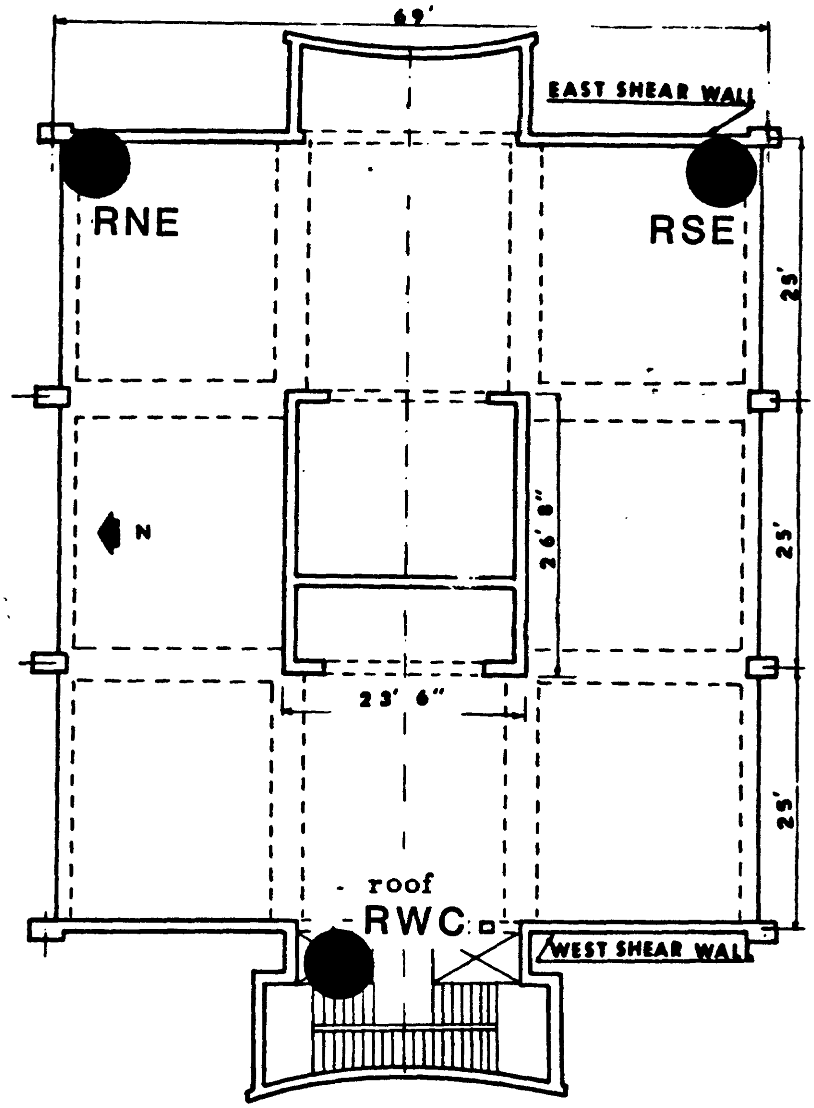

Figure A4. Millikan Library roof (RNE,BSE,RWC) - instrument locations.

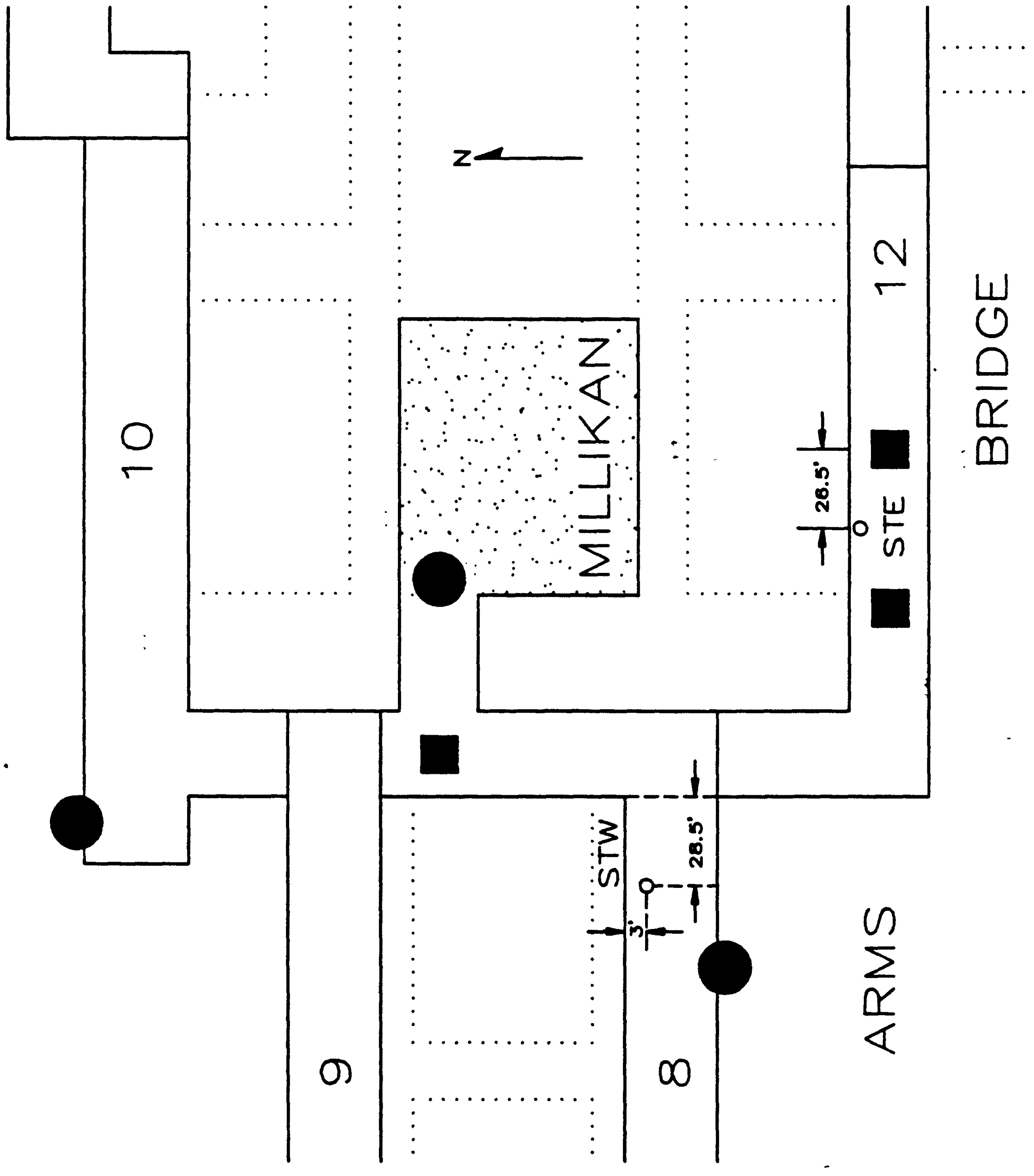

Figure A5. Millikan Library steam tunnels (STE,STW) - instrument locations.

Appendix B

Measured and predicted clock drifts.

GEOS	Clock#	Time (GMT)	Measured CC (ms)	Predicted CC (ms)	Error Weight (ms)	Reference Clock	Residual (ms)	Scaled Residual	Comment
ACO	24	276.020	0.0	0.0	5.0	-TMC	0.000	0.00	
ACO	24	276.300	0.0	0.8	5.0	-WWVB	-0.761	-0.15	
ACO	24	276.310	7.0	0.9	5.0	WWVB	6.128	1.23	
ACO	24	277.910	36.8	42.2	5.0	TMC	-5.395	-1.08	
ACO	24	282.300	65.0	67.3	10.0	WWVB	-2.260	-0.23	
ACO	24	283.180	-53.0	77.0	****	WWVB	-130.014	-0.65	
ACO	24	285.720	74.6	77.1	5.0	TMC	-2.488	-0.50	
ACO	24	287.690	97.9	94.7	5.0	TMC	3.162	0.63	
ARC	6	278.960	0.0	-6.0	5.0	-TMC	6.019	1.20	
ARC	6	279.930	-29.6	-27.3	5.0	TMC	-2.256	-0.45	
ARC	6	280.830	-52.8	-47.1	5.0	TMC	-5.670	-1.13	
ARC	6	285.670	-151.8	-153.5	5.0	TMC	1.737	0.35	
ARC	406	285.680	0.0	0.2	5.0	-6	-0.169	-0.03	
ARC	406	288.730	-194.6	-194.8	5.0	TMC	0.234	0.05	
ARC	406	296.660	-254.8	-254.7	5.0	CMC	-0.065	-0.01	
BEC - clock corrections not computed									
BEL	42	287.760	0.0	0.0	5.0	-CMC	0.000	0.00	
BEL	42	289.830	-10.9	-10.9	5.0	CMC	0.000	0.00	
BNE	120	287.941	0.0	4.3	5.0	-TMC	-4.267	-0.85	
BNE	120	288.750	-4.9	-2.2	5.0	TMC	-2.654	-0.53	
BNE	120	289.770	-11.3	-10.5	5.0	TMC	-0.841	-0.17	
BNE	120	290.670	-16.9	-17.7	5.0	TMC	0.806	0.16	
BNE	120	297.690	-22.8	-29.8	5.0	CMC	6.956	1.39	
BNE	120	297.700	0.0	14.8	5.0	-CMC	-14.799	-2.96	
BNE	120	303.040	-5.6	-43.1	5.0	CMC	37.486	7.50	bad datum?
BNE	120	313.880	-108.4	-85.7	5.0	CMC	-22.688	-4.54	bad datum?
BNW	26	287.950	0.0	1.0	5.0	-TMC	-1.022	-0.20	
BNW	26	288.750	-11.3	-11.1	5.0	TMC	-0.182	-0.04	
BNW	26	289.770	-26.2	-26.6	5.0	TMC	0.397	0.08	
BNW	26	290.680	-39.6	-40.4	5.0	TMC	0.806	0.16	
BNW	26	297.730	0.0	0.0	5.0	-CMC	0.000	0.00	
BNW	26	300.940	0.0	-0.2	5.0	-CMC	0.215	0.04	
BNW	26	313.880	-158.0	-157.8	5.0	CMC	-0.215	-0.04	
BSE	22	287.950	0.0	0.8	5.0	-TMC	-0.833	-0.17	
BSE	22	288.750	9.7	9.9	5.0	TMC	-0.164	-0.03	
BSE	22	289.780	21.9	21.5	5.0	TMC	0.408	0.08	
BSE	22	290.690	32.6	31.8	5.0	TMC	0.834	0.17	
BSE	22	299.770	172.7	172.9	5.0	CMC	-0.245	-0.05	
BSE	22	299.771	0.0	0.0	5.0	-CMC	0.000	0.00	
BWY	142	296.850	0.0	-6.4	5.0	-CMC	6.443	1.29	
BWY	142	297.940	-3.5	-7.8	5.0	CMC	4.257	0.85	
BWY	142	298.710	-7.5	-8.7	5.0	CMC	1.185	0.24	
BWY	142	299.670	-11.2	-9.8	5.0	CMC	-1.358	-0.27	
BWY	142	303.690	-32.1	-14.7	5.0	CMC	-17.413	-3.48	bad datum?
BWY	142	313.710	55.0	48.1	5.0	CMC	6.885	1.38	

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GEOS	Clock#	Time (GMT)	Measured CC (ms)	Predicted CC (ms)	Error Weight (ms)	Reference Clock	Residual (ms)	Scaled Residual	Comment
ECP	15	278.990	0.0	-1.4	5.0	-WWVB	1.406	0.28	
ECP	15	280.790	-31.7	-32.2	5.0	CMC	0.494	0.10	
ECP	15	281.500	-37.0	-26.7	10.0	WWVB	-10.259	-1.03	
ECP	15	282.500	-54.0	-36.8	10.0	WWVB	-17.165	-1.72	
ECP	15	282.710	-58.3	-61.0	5.0	CMC	2.706	0.54	
ECP	15	283.700	-68.3	-75.9	5.0	CMC	7.562	1.51	
ECP	415	283.710	0.0	-5.3	5.0	-15	5.312	1.06	
ECP	415	285.000	-45.0	-51.1	10.0	WWVB	6.058	0.61	
ECP	415	286.000	-58.0	-48.5	10.0	WWVB	-9.501	-0.95	
ECP	415	286.720	-91.9	-88.4	5.0	CMC	-3.493	-0.70	
ECP	415	288.010	-47.0	-43.4	15.0	WWVB	-3.645	-0.24	
ECP	415	290.510	-41.0	-37.0	10.0	WWVB	-4.043	-0.40	
ECP	415	291.510	-37.0	-34.4	10.0	WWVB	-2.603	-0.26	
ECP	415	293.510	-34.0	-29.3	10.0	WWVB	-4.721	-0.47	
ECP	415	294.510	-25.0	-26.7	10.0	WWVB	1.719	0.17	
ECP	415	295.520	-28.0	-24.1	10.0	WWVB	-3.865	-0.39	
ECP	415	296.020	-36.0	-22.9	10.0	WWVB	-13.145	-1.31	
ECP	415	297.860	-21.9	-28.0	5.0	CMC	6.112	1.22	
ELM	13	275.920	0.0	1.3	5.0	-WWVB	-1.344	-0.27	
ELM	13	276.410	7.0	8.6	5.0	WWVB	-1.599	-0.32	
ELM	13	276.910	17.0	16.0	5.0	WWVB	0.998	0.20	
ELM	13	277.410	23.0	23.4	5.0	WWVB	-0.404	-0.08	
ELM	13	277.910	33.0	30.8	5.0	WWVB	2.193	0.44	
ELM	13	279.410	49.0	53.0	5.0	WWVB	-4.016	-0.80	
ELM	13	279.720	55.1	50.2	5.0	CMC	4.857	0.97	
ELM	13	280.760	63.6	60.5	5.0	CMC	3.068	0.61	
ELM	13	281.420	79.0	82.8	5.0	WWVB	-3.776	-0.76	
ELM	13	281.970	74.0	72.5	5.0	CMC	1.497	0.30	
ELM	13	283.750	90.0	90.1	5.0	CMC	-0.113	-0.02	
ELM	13	284.830	100.1	100.8	5.0	CMC	-0.698	-0.14	
ELM	13	285.900	110.5	111.4	5.0	CMC	-0.884	-0.18	
ELM	13	286.760	119.1	119.9	5.0	CMC	-0.793	-0.16	
ELM	13	288.710	140.2	139.2	5.0	CMC	1.015	0.20	
GAR	126	275.630	0.0	-1.7	5.0	-TMC	1.699	0.34	
GAR	126	276.690	-14.5	-15.3	5.0	TMC	0.791	0.16	
GAR	126	279.740	-61.2	-60.0	5.0	TMC	-1.218	-0.24	
GAR	126	280.700	-75.0	-72.3	5.0	TMC	-2.708	-0.54	
GAR	126	285.750	-138.1	-137.0	5.0	TMC	-1.055	-0.21	
GAR	126	287.730	-160.1	-162.4	5.0	TMC	2.333	0.47	
HCH	113	288.760	0.0	-2.1	5.0	-CMC	2.128	0.43	
HCH	113	289.770	12.0	10.6	5.0	CMC	1.389	0.28	
HCH	113	299.950	222.1	225.6	5.0	CMC	-3.517	-0.70	
HCH	113	299.951	0.0	-0.5	5.0	-CMC	0.455	0.09	
HCH	113	302.790	30.1	35.4	5.0	CMC	-5.252	-1.05	
HCH	113	310.970	218.2	213.4	5.0	CMC	4.797	0.96	
HOO	122	275.790	0.0	0.0	5.0	-TMC	0.000	0.00	
HOO	122	278.710	0.0	-1.5	5.0	-TMC	1.478	0.30	
HOO	122	279.710	9.8	10.7	5.0	TMC	-0.906	-0.18	
HOO	122	285.790	81.7	84.8	5.0	TMC	-3.084	-0.62	
HOO	122	287.760	111.3	108.8	5.0	TMC	2.513	0.50	

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GEOS	Clock#	Time (GMT)	Measured CC (ms)	Predicted CC (ms)	Error Weight (ms)	Reference Clock	Residual (ms)	Scaled Residual	Comment
HOO	106	296.740	0.0	-20.4	5.0	-CMC	20.350	4.07	bad datum?
HOO	106	303.710	-141.2	-106.4	5.0	CMC	-34.780	-6.96	bad datum?
HOO	106	313.540	-138.5	-152.9	5.0	CMC	14.429	2.89	
KIN	115	276.800	0.0	-1.9	5.0	-WWVB	1.893	0.38	
KIN	115	276.810	-5.0	-2.0	5.0	WWVB	-2.995	-0.60	
KIN	115	277.310	-6.0	-7.6	5.0	WWVB	1.592	0.32	
KIN	115	278.810	-41.0	-24.4	15.0	WWVB	-16.646	-1.11	
KIN	115	278.960	-28.3	-29.7	5.0	CMC	1.359	0.27	
LAC	7	296.940	0.0	-4.6	5.0	-CMC	4.582	0.92	
LAC	7	299.900	-90.3	-90.4	5.0	CMC	0.110	0.02	
LAC	7	302.880	-184.8	-176.8	5.0	CMC	-7.981	-1.60	
LAC	7	311.000	-334.1	-337.4	5.0	CMC	3.289	0.66	
LAC	7	311.010	0.0	0.3	5.0	-CMC	-0.315	-0.06	
LAC	7	313.670	-76.5	-76.8	5.0	CMC	0.315	0.06	
LIN	43	275.850	0.0	0.0	5.0	-TMC	0.000	0.00	
LIN	43	278.780	-3.8	-3.8	5.0	TMC	0.000	0.00	
LTB	143	296.780	0.0	-1.4	5.0	-CMC	1.444	0.29	
LTB	143	303.740	-38.3	-35.9	5.0	CMC	-2.450	-0.49	
LTB	143	313.740	-9.4	-10.4	5.0	CMC	1.005	0.20	
LTH	40	296.790	0.0	-7.1	5.0	-CMC	7.120	1.42	
LTH	40	298.750	-11.0	-14.0	5.0	CMC	3.040	0.61	
LTH	40	303.730	-48.2	-31.6	5.0	CMC	-16.580	-3.32	bad datum?
LTH	40	310.850	18.0	18.1	5.0	CMC	-0.124	-0.02	
LTH	40	313.730	14.5	8.0	5.0	CMC	6.543	1.31	
MIL	120	277.980	0.0	8.6	5.0	-TMC	-8.625	-1.73	
MIL	120	279.830	470.0	461.4	5.0	TMC	8.625	1.73	
MIL	120	279.831	0.0	7.9	5.0	-TMC	-7.948	-1.59	
MIL	120	280.880	-4.5	-0.5	5.0	TMC	-4.002	-0.80	
MIL	120	285.700	-35.7	-39.3	5.0	TMC	3.607	0.72	
MIL	120	287.940	-49.0	-57.3	5.0	TMC	8.342	1.67	change to BNE
MOT - clock corrections not computed									
NAR	242	275.640	0.0	-5.6	5.0	-WWVB	5.635	1.13	
NAR	242	276.150	-4.0	-4.8	10.0	WWVB	0.811	0.08	
NAR	242	277.150	-8.0	-3.2	10.0	WWVB	-4.806	-0.48	
NAR	242	278.720	-3.0	-0.7	10.0	WWVB	-2.345	-0.23	
NAR	242	279.840	-6.0	-6.8	5.0	CMC	0.796	0.16	
NAR	242	280.230	-5.0	1.8	10.0	WWVB	-6.787	-0.68	
NAR	242	280.730	-10.6	-9.7	5.0	CMC	-0.871	-0.17	
NAR	242	281.780	-14.4	-13.2	5.0	CMC	-1.211	-0.24	
NAR	242	282.760	-18.1	-16.4	5.0	CMC	-1.681	-0.34	
NAR	242	282.890	-20.9	-16.8	5.0	CMC	-4.053	-0.81	
NAR	242	283.230	4.0	6.6	10.0	WWVB	-2.638	-0.26	
NAR	242	283.730	3.0	7.4	10.0	WWVB	-4.447	-0.44	
NAR	242	285.750	-26.1	-26.3	5.0	CMC	0.172	0.03	
NAR	242	286.780	-27.5	-29.7	5.0	CMC	2.166	0.43	
NAR	242	287.670	-28.5	-32.6	5.0	CMC	4.099	0.82	

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GEOS	Clock#	Time (GMT)	Measured CC (ms)	Predicted CC (ms)	Error Weight (ms)	Reference Clock	Residual (ms)	Scaled Residual	Comment
OLV	28	276.000	0.0	-5.6	5.0	-WWVB	5.642	1.13	
OLV	28	276.500	-10.0	-10.8	5.0	WWVB	0.824	0.16	
OLV	28	277.000	-14.0	-16.0	5.0	WWVB	2.005	0.40	
OLV	28	277.500	-21.0	-21.2	5.0	WWVB	0.186	0.04	
OLV	28	278.000	-27.0	-26.4	5.0	WWVB	-0.633	-0.13	
OLV	28	278.510	-32.0	-31.7	5.0	WWVB	-0.348	-0.07	
OLV	28	279.010	-41.0	-36.8	5.0	WWVB	-4.167	-0.83	
OLV	28	279.510	-45.0	-42.0	5.0	WWVB	-2.986	-0.60	
OLV	28	279.780	-48.1	-52.5	5.0	CMC	4.370	0.87	
OLV	28	280.510	-54.0	-52.4	5.0	WWVB	-1.623	-0.32	
OLV	28	280.750	-64.7	-67.3	5.0	CMC	2.586	0.52	
OLV	28	281.010	-59.0	-57.6	5.0	WWVB	-1.442	-0.29	
OLV	28	281.510	-66.0	-62.7	5.0	WWVB	-3.261	-0.65	
OLV	28	282.510	-76.0	-73.1	5.0	WWVB	-2.899	-0.58	
OLV	28	283.010	-79.0	-78.3	5.0	WWVB	-0.718	-0.14	
OLV	28	283.510	-87.0	-83.5	5.0	WWVB	-3.536	-0.71	
OLV	28	284.010	-90.0	-88.6	5.0	WWVB	-1.355	-0.27	
OLV	28	284.510	-96.0	-93.8	5.0	WWVB	-2.174	-0.43	
OLV	28	285.020	-99.0	-99.1	5.0	WWVB	0.111	0.02	
OLV	28	285.520	-104.0	-104.3	5.0	WWVB	0.292	0.06	
OLV	28	285.730	-142.5	-143.4	5.0	CMC	0.855	0.17	
OLV	28	286.020	-110.0	-109.5	5.0	WWVB	-0.527	-0.11	
OLV	28	286.520	-115.0	-114.7	5.0	WWVB	-0.346	-0.07	
OLV	28	287.020	-114.0	-119.8	5.0	WWVB	5.835	1.17	
OLV	28	287.520	-124.0	-125.0	5.0	WWVB	1.016	0.20	
OLV	28	287.690	-171.0	-173.3	5.0	CMC	2.293	0.46	
RHD	215	297.970	0.0	-0.4	5.0	-CMC	0.439	0.09	
RHD	215	298.720	-5.5	-8.3	5.0	CMC	2.832	0.57	
RHD	215	299.520	-2.0	1.3	5.0	WWVB	-3.271	-0.65	
RHD	215	299.521	0.0	-25.1	5.0	-WWVB	25.117	5.02	bad datum?
RHD	215	302.250	-52.0	-40.4	15.0	WWVB	-11.572	-0.77	
RHD	215	302.410	-49.0	-41.3	10.0	WWVB	-7.674	-0.77	
RHD	215	302.530	-55.0	-42.0	10.0	WWVB	-13.001	-1.30	
RHD	215	303.760	-107.0	-87.7	5.0	CMC	-19.250	-3.85	bad datum?
RHD	215	304.550	-71.0	-53.3	10.0	WWVB	-17.668	-1.77	
RHD	215	307.310	-86.0	-68.8	10.0	WWVB	-17.183	-1.72	
RHD	215	307.440	-87.0	-69.5	10.0	WWVB	-17.453	-1.75	
RHD	215	313.690	-103.7	-117.4	5.0	CMC	13.664	2.73	
RNE	124	288.950	0.0	0.2	5.0	-TMC	-0.233	-0.05	
RNE	124	289.790	10.1	10.0	5.0	TMC	0.138	0.03	
RNE	124	290.740	21.1	21.0	5.0	TMC	0.136	0.03	
RNE	124	297.680	145.8	145.8	5.0	CMC	-0.041	-0.01	
RNE	124	297.681	0.0	0.0	5.0	-CMC	0.000	0.00	
ROS	315	275.720	0.0	0.1	5.0	-WWVB	-0.111	-0.02	
ROS	315	275.730	0.0	-0.1	5.0	WWVB	0.112	0.02	
ROS	315	276.680	-13.7	-13.7	5.0	CMC	-0.001	0.00	
ROS	21	276.680	0.0	0.0	5.0	-WWVB	0.000	0.00	
ROS	21	277.990	0.0	0.0	5.0	-WWVB	0.000	0.00	
ROS	21	278.500	3.0	3.0	5.0	WWVB	0.000	0.00	
RSE	121	288.980	0.0	-0.9	5.0	-TMC	0.860	0.17	
RSE	121	289.790	0.5	1.3	5.0	TMC	-0.758	-0.15	

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GEOS	Clock#	Time (GMT)	Measured CC (ms)	Predicted CC (ms)	Error Weight (ms)	Reference Clock	Residual (ms)	Scaled Residual	Comment
RSE	121	290.730	3.5	3.7	5.0	TMC	-0.216	-0.04	
RSE	121	297.670	66.5	66.4	5.0	CMC	0.114	0.02	
RSE	121	297.671	0.0	0.0	5.0	-CMC	0.000	0.00	
RWC	128	288.990	0.0	2.4	5.0	-TMC	-2.369	-0.47	
RWC	128	289.780	-8.5	-7.2	5.0	TMC	-1.281	-0.26	
RWC	128	290.730	-19.0	-18.7	5.0	TMC	-0.251	-0.05	
RWC	128	297.680	-54.7	-58.6	5.0	CMC	3.900	0.78	
RWC	128	297.681	0.0	28.1	5.0	-CMC	-28.109	-5.62	bad datum?
RWC	128	303.030	-6.8	-51.7	5.0	CMC	44.926	8.99	bad datum?
RWC	128	313.900	-155.9	-139.1	5.0	CMC	-16.817	-3.36	bad datum?
SAG	206	275.690	0.0	1.8	5.0	-TMC	-1.767	-0.35	
SAG	206	277.830	-34.8	-40.0	5.0	TMC	5.237	1.05	
SAG	206	278.920	-104.7	-101.2	5.0	CMC	-3.470	-0.69	
STE	224	297.770	0.0	-1.0	5.0	-CMC	1.019	0.20	
STE	224	302.980	7.7	9.2	5.0	CMC	-1.505	-0.30	
STE	224	313.900	106.0	105.5	5.0	CMC	0.486	0.10	
STW	221	297.790	0.0	-0.6	5.0	-CMC	0.637	0.13	
STW	221	302.970	9.6	10.5	5.0	CMC	-0.941	-0.19	
STW	221	313.850	109.2	108.9	5.0	CMC	0.303	0.06	
SVS	321	278.920	0.0	0.5	5.0	-CMC	-0.490	-0.10	
SVS	321	279.820	1.9	2.1	5.0	CMC	-0.175	-0.04	
SVS	321	280.700	3.9	3.6	5.0	CMC	0.274	0.05	
SVS	321	281.800	6.1	5.6	5.0	CMC	0.536	0.11	
SVS	321	285.780	12.9	12.6	5.0	CMC	0.325	0.06	
SVS	321	287.650	15.4	15.9	5.0	CMC	-0.470	-0.09	
SWA	243	279.000	0.0	0.1	5.0	-TMC	-0.074	-0.01	
SWA	243	279.880	-5.0	-5.1	5.0	TMC	0.074	0.01	
SWA	243	280.920	0.0	-0.2	****	-999	0.161	0.00	
SWA	243	280.921	167.9	169.8	5.0	TMC	-1.891	-0.38	
SWA	243	281.670	167.3	165.4	5.0	TMC	1.891	0.38	
SWA	243	281.700	0.0	8.3	5.0	-TMC	-8.340	-1.67	
SWA	243	285.690	-3.5	-15.0	5.0	TMC	11.505	2.30	
SWA	243	296.670	-35.1	-31.9	5.0	CMC	-3.166	-0.63	
TMC	TMC	274.790	0.0	-0.7	5.0	-WWVB	0.723	0.14	
TMC	TMC	277.810	0.0	0.2	5.0	-126	-0.158	-0.03	
TMC	TMC	277.960	0.0	239.7	****	-999	-239.717	-0.02	
TMC	TMC	278.640	470.0	478.6	5.0	CMC	-8.625	-1.73	
TMC	TMC	278.641	0.0	11.0	5.0	-CMC	-10.978	-2.20	
TMC	TMC	285.630	-2.2	-8.5	5.0	CMC	6.310	1.26	
TMC	TMC	287.600	-10.6	-14.0	5.0	CMC	3.403	0.68	
TMC	TMC	288.670	-15.2	-17.0	5.0	CMC	1.787	0.36	
TMC	TMC	290.580	-23.5	-22.3	5.0	CMC	-1.188	-0.24	
TMC	TMC	294.840	47.3	47.4	5.0	WWVB	-0.148	-0.03	
CMC	CMC	274.790	0.0	-16.9	5.0	-WWVB	16.855	3.37	bad datum?
CMC	CMC	296.630	0.0	3.8	5.0	-WWVB	-3.824	-0.76	
CMC	CMC	310.630	0.0	-2.3	5.0	-WWVB	2.281	0.46	
CMC	CMC	316.900	37.8	28.5	5.0	WWVB	9.280	1.86	