U. S. DEPARTMENT OF THE INTERIOR
U. S. GEOLOGICAL SURVEY

THE 1992 BASIN & RANGE PROVINCE GPS SURVEY: 2. THE FIELD SURVEY

by

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Project and Survey Goals

The 1992 Basin & Range Province GPS survey was conducted as part of NASA's Dynamics of the Solid Earth (DOSE) program. The overall goal of the Basin & Range project is study of the crustal deformation of that province. The 1992 survey was designed specifically to establish a network and measure a first epoch survey that spans the deforming zone. Remeasurement of this network in the future will enable:

1. Determination of the rate of extension and shear and how they vary, across the entire Province at about latitude 39°N,
2. Determination of detailed movements in those zones that are deforming most rapidly.

The network

A network consisting of both pre-existing and new points was established, that spanned the Basin & Range Province from Lake Tahoe, CA in the west to the Wasatch Front, UT, in the east, i.e. at about latitude 39°N. The network was designed to consist of three east-west profiles, a northern, central and southern profile, which together comprise a chain of 7 quadrilaterals, each approximately 100 km square. A schematic idealization of the network is shown in Figure 1 and the actual geometry achieved is shown in Figure 2.

The northern and southern profiles comprise 8 points each, at approximately 100 km spacings. Many of these are newly-installed points (Julian and Foulger, 1994). The central profile comprises 48 points and lies along Highway 50. Most of those points are pre-existing leveling benchmarks and a few are new points. The points of this profile are spaced at approximately 15 km intervals in the two westernmost and two easternmost quadrilaterals (Quads A, B, F and G, Figure 1), where the deformation rate is anticipated to be greatest, and at approximately 25 km spacings in the middle three quadrilaterals (Quads C, D and E).

The entire network contains 64 points, and a point coding scheme was devised that will enable a logical point coding scheme to be maintained if additional densification points are added in the future (Figure 3). The network was tied to point Quincy, 80 km from the northwesternmost point of our profile (Figure 1). Quincy is a VLBI station where continuous GPS recording is conducted.

Network measurement

Logistics

Because of the scarcity of motel and restaurant services in the field area, and in order to

maintain close and centralized field headquarters, the survey was run from two trailers which served as headquarters and for regrouping, data archiving, cooking and sleeping. The trailers were parked at trailer parks selected to be as close as possible to the centers of the Quads, and moved every two days, as the survey proceeded (Tables 1 and 2). The trailer headquarters were staffed by Jim Richardson (Table 3) who was in charge of data archiving and equipment maintenance, and a person designated as cook and bottle-washer each day (rotated duty, Table 1).

Point selection, installation and point descriptions

Point reconnaissance was conducted simultaneously with the survey, by reconnaissance parties who worked in the network a few points ahead of the measurement parties. This proved to be a very successful strategy in this area, where most of the land is open access, many points were pre-existing and little permitting had to be done. The points were all flagged shortly before measurement and the descriptions were fresh, so the points were easily found by the receiver parties.

For each point, description materials were prepared, consisting of a map, a written description and (for some points) photographs (Foulger and Julian, 1994). These were stored in separate envelopes for each point, at the trailers. The reconnaissance personnel filed the completed descriptions in advance of the measurements so the required material was always available to the receiver parties when needed. A copy was made of each description as a backup.

The new points installed consisted of headless, stainless steel rods with central dots in their upper ends. They were cemented into bedrock flush with the surface. Some were marked by building cairns over them.

Measurement strategy

The network was occupied during the three-week period 5th - 23rd October 1992 by a team of about 14 people (Tables 1 and 3) using up to 12 TurboRogue GPS receivers (10 used daily, and 2 spares). Selective Availability (SA) was on at the weekends (Fridays - Sundays 1800 hrs PDT, i.e. GMT weekends), and measurements were thus made on weekdays only. Pacific Daylight Time was used throughout the survey (i.e. California local time at the time the survey started).

Fourteen days of measurements were made, and two days were spent measuring each Quad (Figure 1, Table 4). Three points were common to adjacent Quads and those points were thus measured on four consecutive days each (Figure 1). The other points of the network were mostly measured twice each, and a small number of the closely-spaced points at the ends of the network were measured once each. This strategy of multiple occupancy enabled the true repeatability of

point measurements to be determined and the random errors in the final results to be reduced by a factor of approximately 1.6, by averaging.

Five mobile field parties of one or two people in each, deployed the receivers. Each party was equipped with two receivers and measured two points per day. In the cases of four of the parties, these were a point on the central profile (on Highway 50), an average of one hour's driving time from the trailer headquarters, and one "remote" point on either the northern or the southern profile, an average of one hour's driving time from Highway 50. An average of 50 mph driving on paved road, and 30 mph for improved dirt roads was assumed. The usual daily procedure was to drive to and install a receiver at the remote point, and then to return to occupy and guard the point on Highway 50. All the remote points were selected to be "secure", i.e. sufficiently hidden or inaccessible such that the equipment was safe from human interference and need not be guarded. It was assumed that all of the points along Highway 50 needed to be guarded at all times. The fifth (two-person) receiver party measured two points on Highway 50 each day.

Because the points of the northern and southern profiles were occupied for four days each, the surveying naturally fell into four-day cycles. The typical daily schedules are listed in Table 5 and shown schematically in Figure 4. The observation plan for the whole network is tabulated in Table 1 and shown schematically in Figure 5. Individual schedules were designed to minimize driving times and to share out the difficult work e.g. the cooking.

Long observation periods of 6 - 48 hours were achieved with this schedule, with the majority of the remote points being occupied continuously for four days, which greatly reduced the criticality of correctly resolving the integer ambiguities at the data processing stage.

Four or more satellites were up for most of the day (Figure 6). A data collection rate of one measurement every 30 s was used, with a horizon mask of 0^{o}. All antennas were aligned to True North and tripod setup and receiver operation followed standard recommended practice (JPL, personal communication, 1992). The receivers were powered by lead-acid batteries which were recharged at the trailer headquarters by generators or 120 v electricity where available. Data from the returning receivers were archived to a PC each evening. Data from the receivers at the remote points were archived less frequently, as those receivers recorded continuously in the field for periods of up to four days.

Results

The survey was exceptionally successful. No planned occupations were missed and no point went unsurveyed. The plan shown in Table 5 held well for the most part, and little data were lost as a result of late receiver set-ups. One receiver malfunctioned on one day resulting in the loss of one occupation of a planned two-occupation point (point a200). The plan was modified at the

weekends, which disrupted the four-day cycle (Table 1). Apart from this, the most notable deviation from the ideal plan was the lengthened drive times home for parties observing the westernmost points of a Quad on days when the trailers were moved to the next campground further east.

The reconnaissance proceeded so well that those personnel were able to deploy the two spare receivers on the last four observation days, and increase to two the occupancy of many of the planned one-occupation points in the easternmost two Quads (c.f. Figs. 1 and 2). Of 140 planned receiver sessions, 146 were thereby achieved. A small amount of data were lost in the archiving process. The final data set available for processing is shown in Figure 7.

Data processing results

The data were processed using software based on the Bernese v. 3.2 GPS software. For the network as a whole, final point coordinate repeatabilities of about 0.24, 0.18 and 1.14 cm, and calculated accuracies (1-σ scaled formal errors) of about 0.25, 0.21 and 2.25 cm were achieved in the local north, east and up directions (Foulger, 1994b).

Acknowledgments

Jim Sutton was voted the most excellent cook for his seafood linguini in cream sauce with margaritas for which he was awarded a prize of a rusty frying-pan shot full of bullet holes that Bruce found at point C280. The project was funded by a NASA DOSE Grant. Karl Gross reviewed and improved the manuscript.

References

Foulger, G.R., The 1992 Basin & Range Province GPS Survey: 3. Data Processing and Results, U.S. Geological Survey Open-File Report OF 94-287, 1994.

Julian, B.R. and G.R. Foulger, The 1992 Basin & Range Province GPS Survey: 1. Point Descriptions, U.S. Geological Survey Open-File Report OF 94-285, 1994.

Gurtner, W. and G. Mader, "Receiver Independent Exchange Format Version 2", International Coordination of Space Techniques for Geodesy and Geodynamics GPS Bulletin, IAG, Vol 3, No 3, pp 1-8, Sept./Oct. 1990.

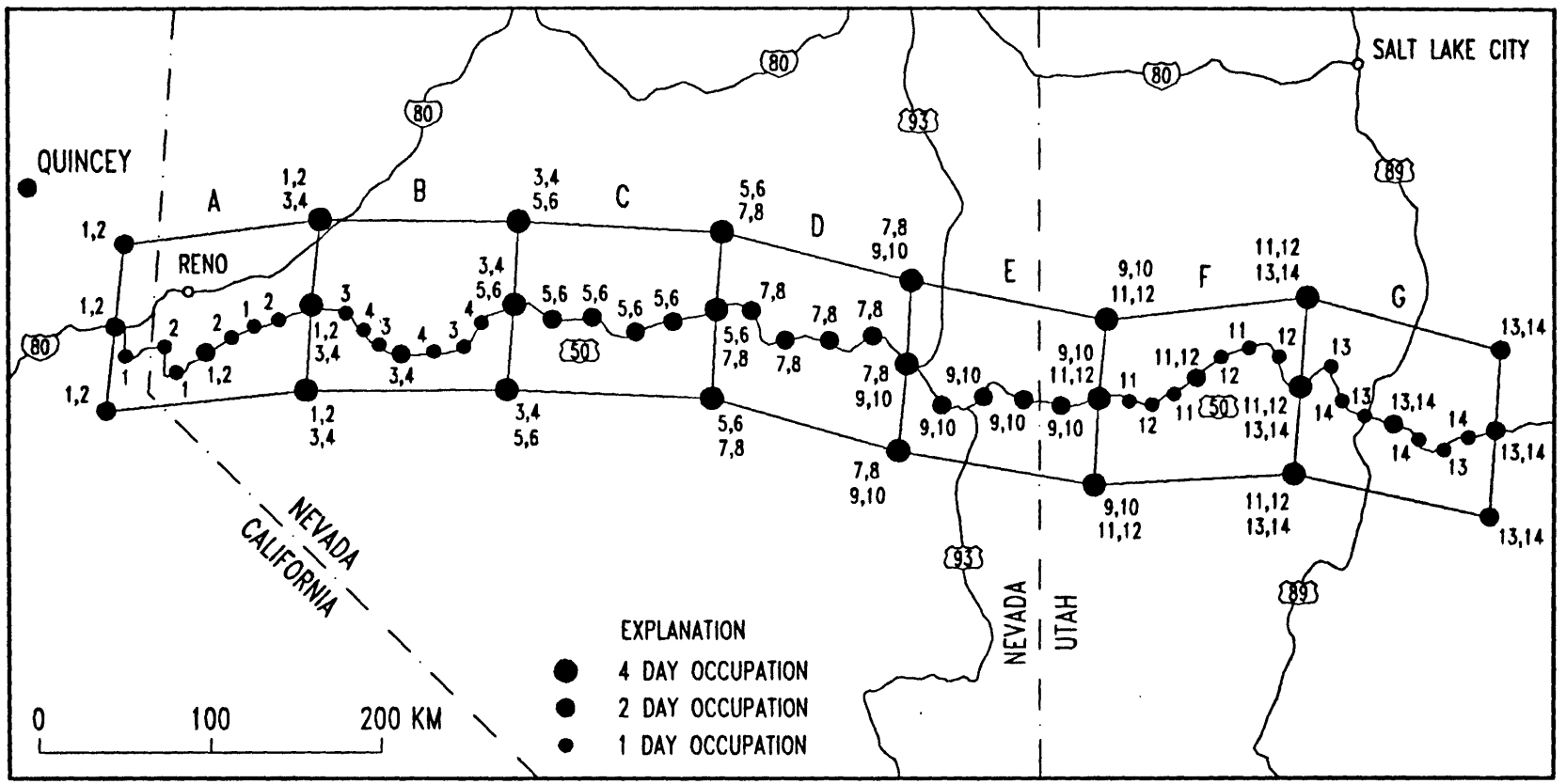


Figure 1 Schematic idealization of the Basin & Range GPS network. The numbers of the observation days (1-14) when each point was occupied are shown against each point. Major highways and state borders are indicated. Sizes of dots indicate the number of planned measurements of individual points.

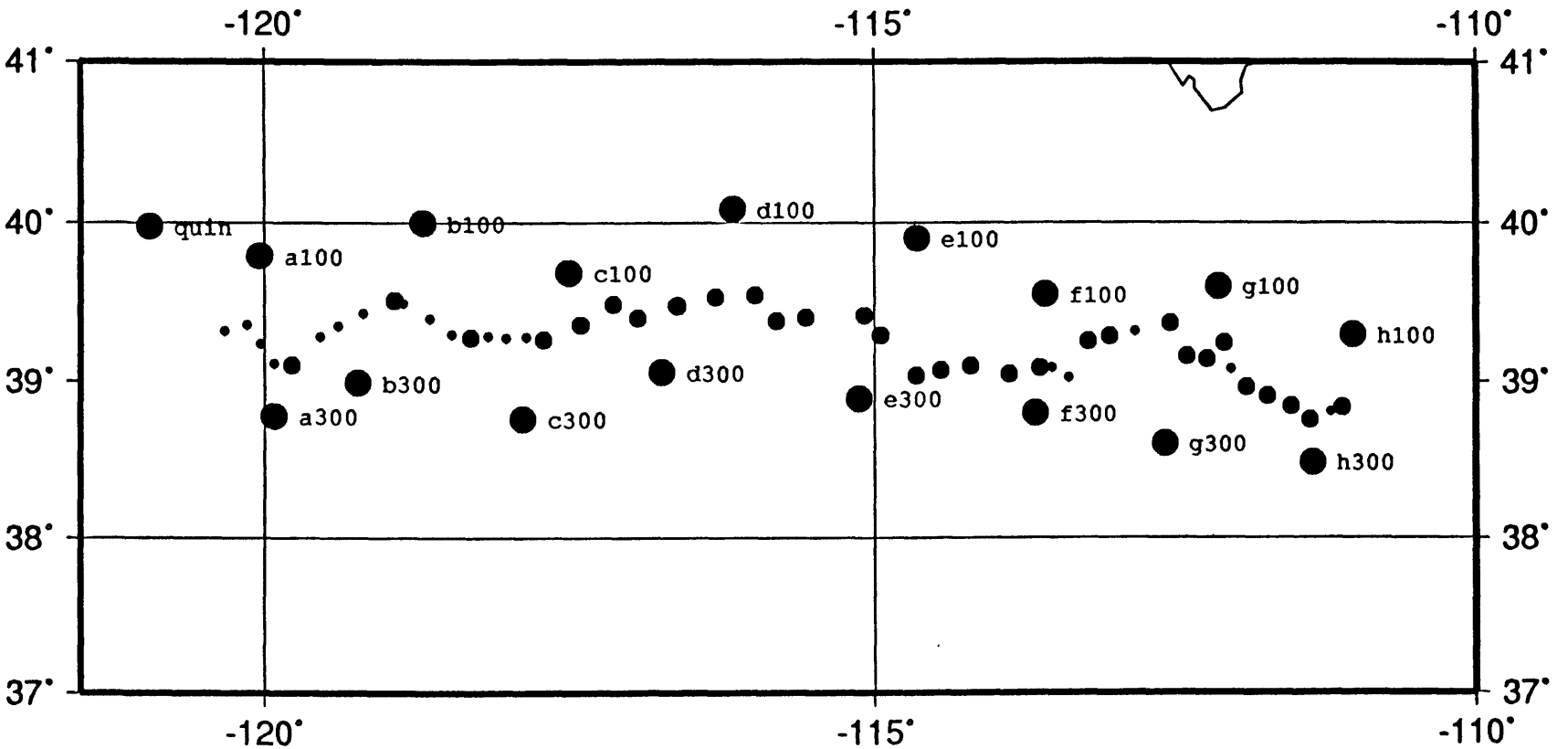


Figure 2 Map showing the actual network installed and measured. Sizes of dots indicate the number of actual measurements of individual points (same convention as for Figure 1).

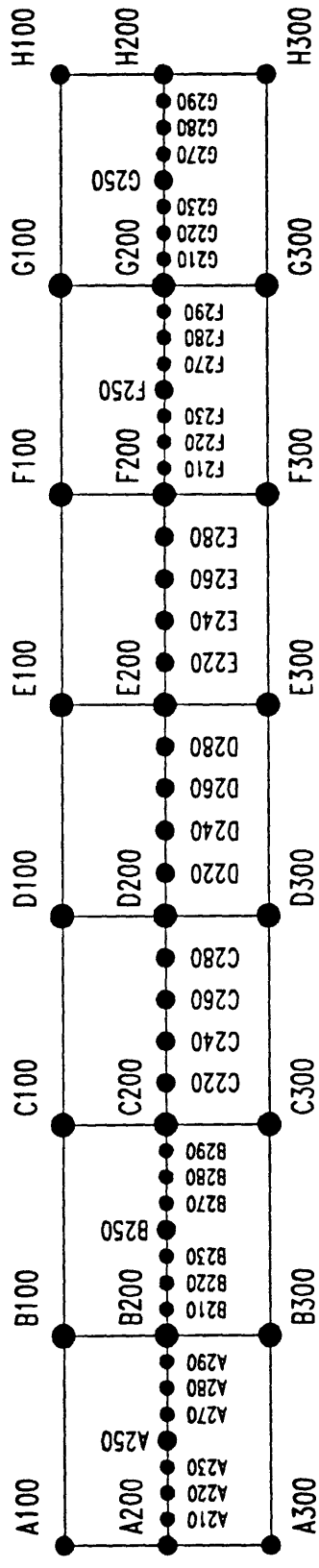


Figure 3 Schematic diagram of the network, showing the point coding system.

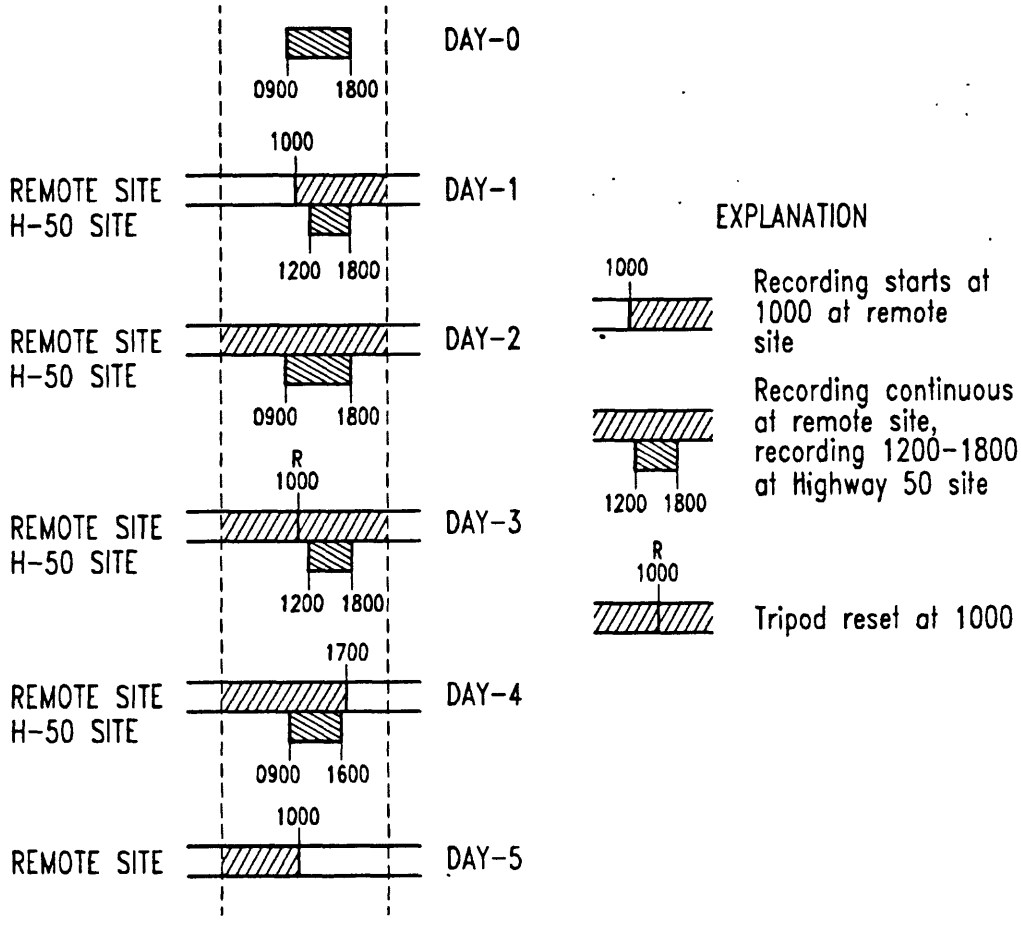


Figure 4 Schematic diagram showing the standard daily schedules. Hatched bars indicate planned recording periods.

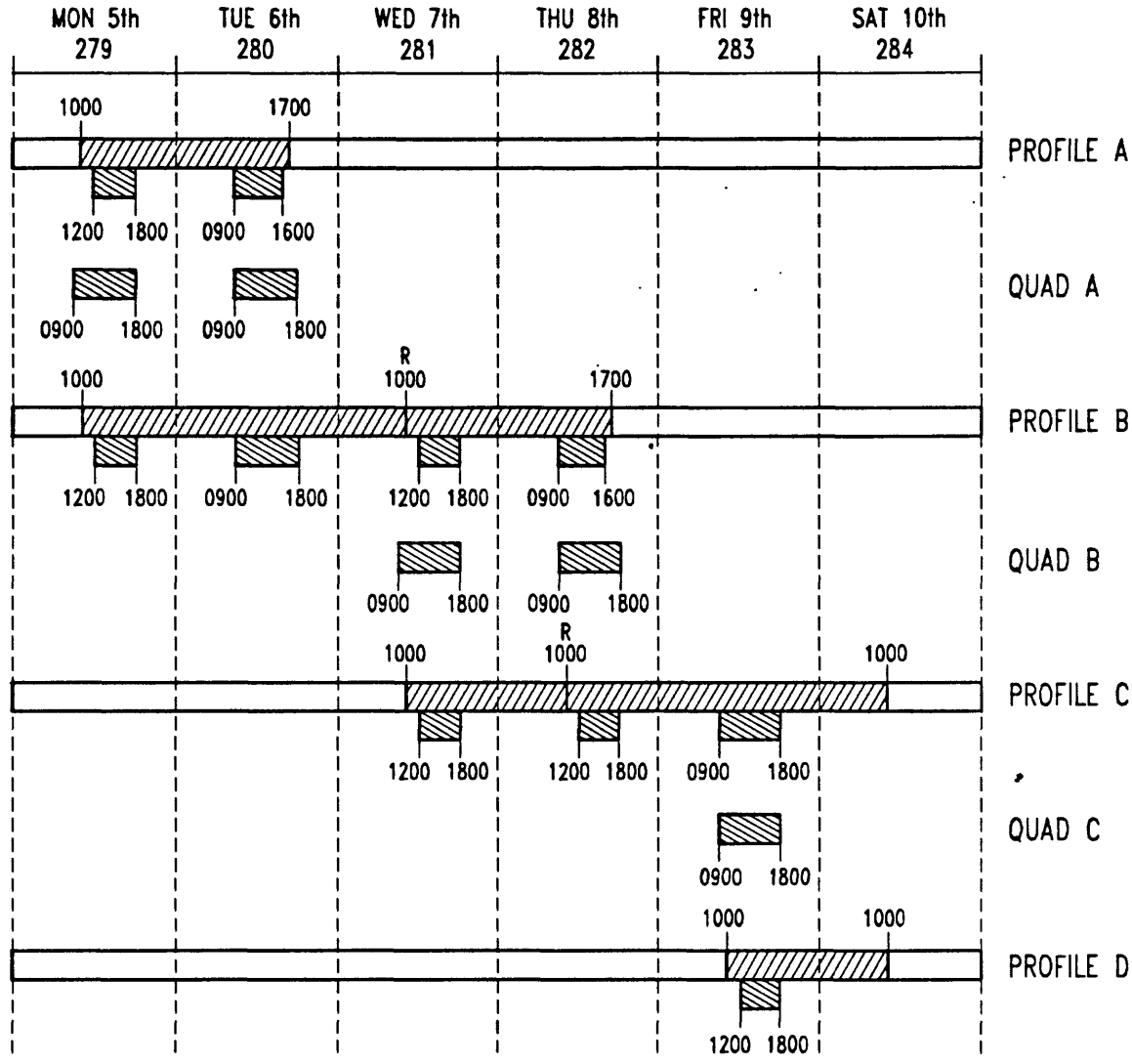


Figure 5 Schematic diagram showing the observation plan for the whole network. For explanation, see Figure 4.

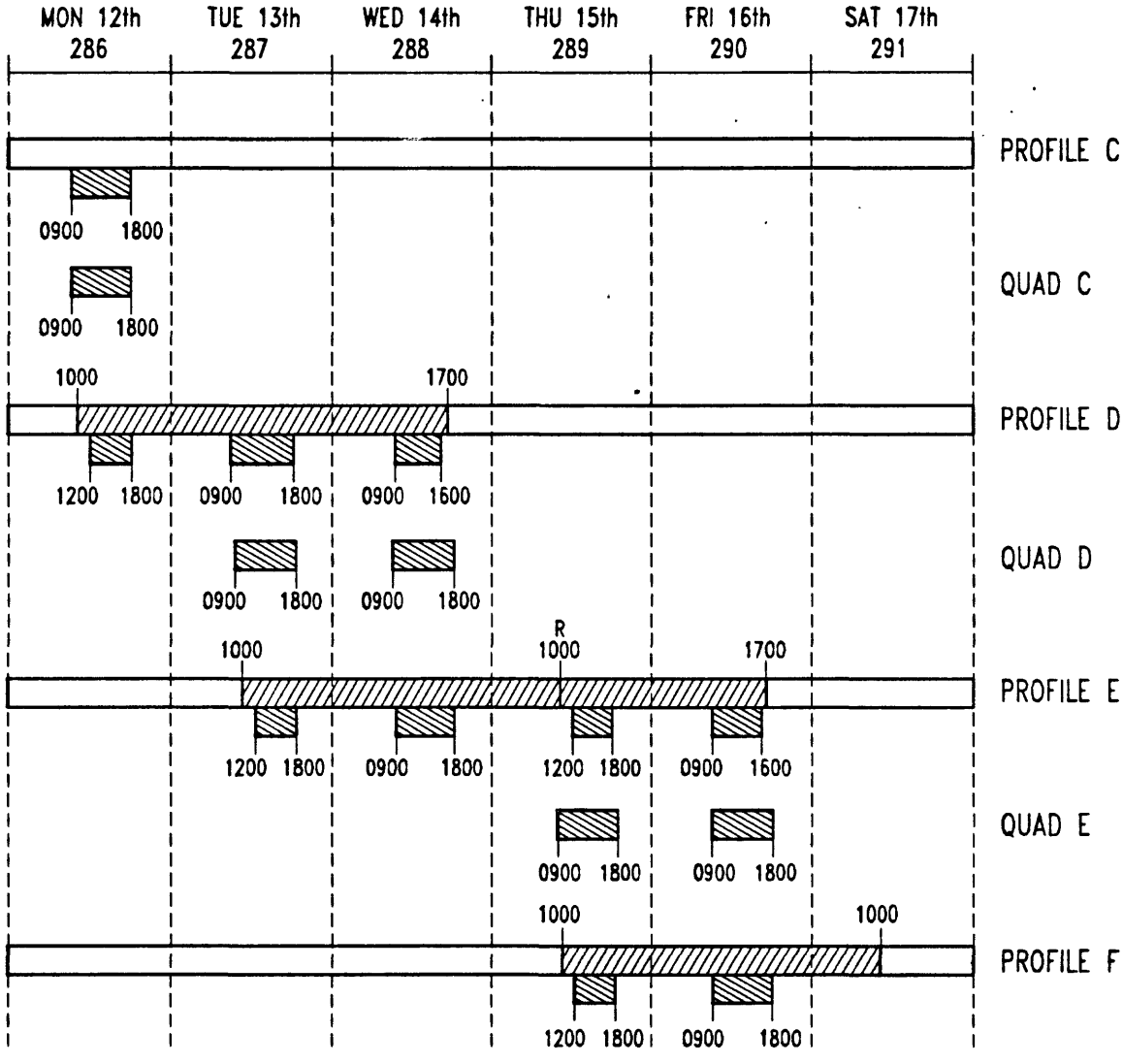
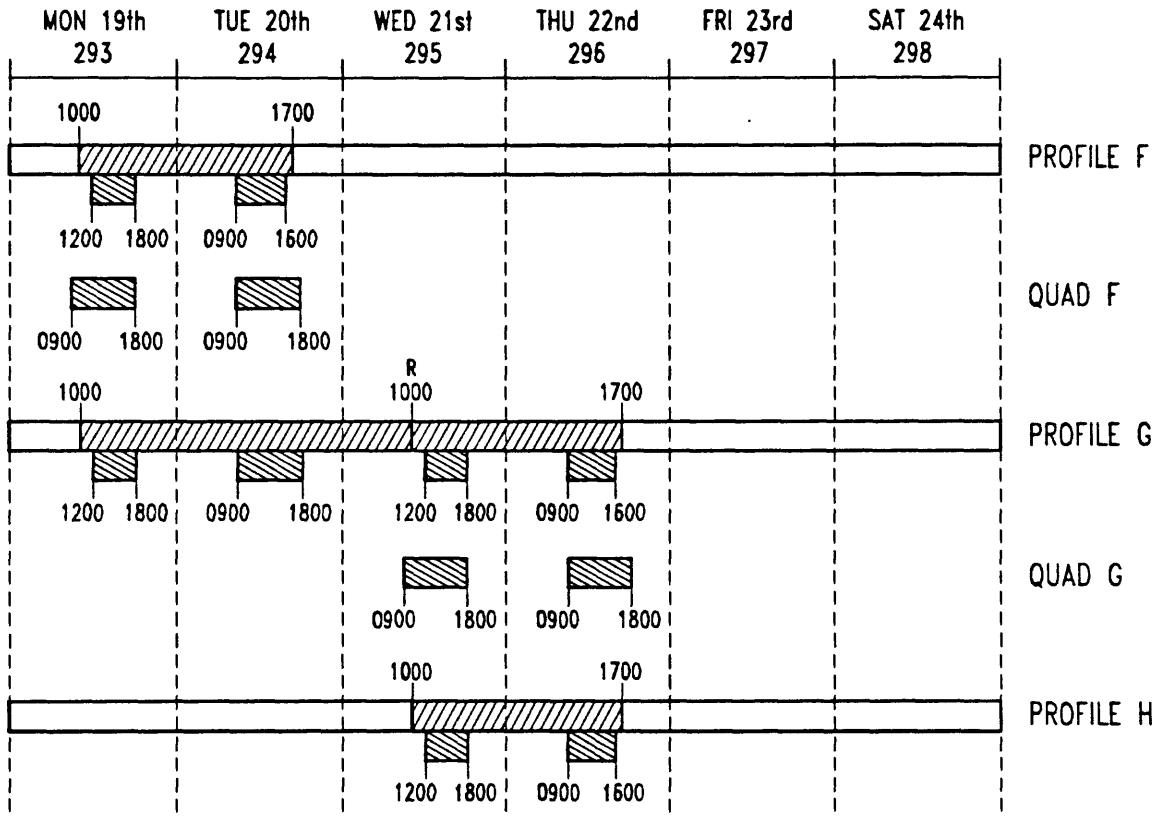


Figure 5 (continued)



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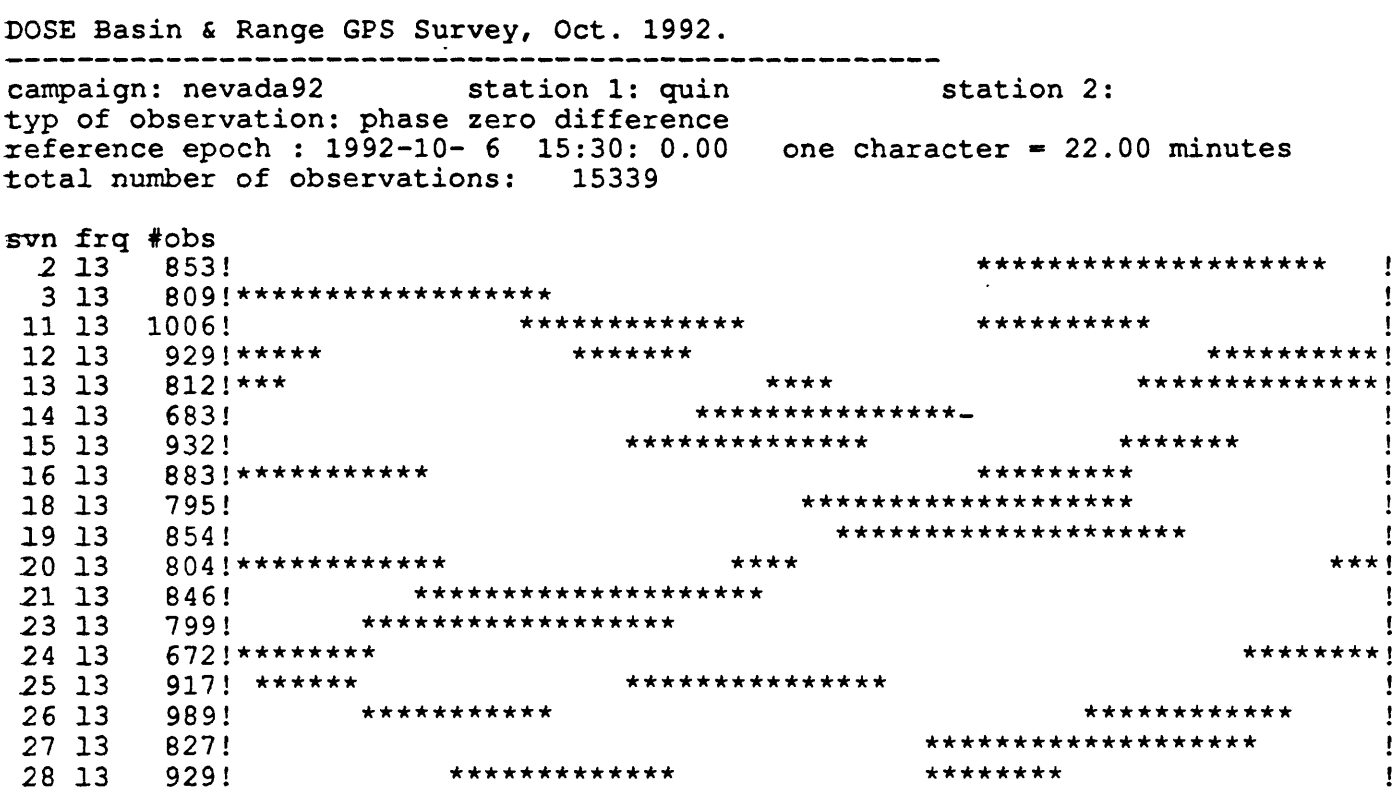

Figure 6 Typical data block recorded over a 24-hr period (Day 1:1500 hrs - Day 2:1500 hrs) showing satellite visibility.

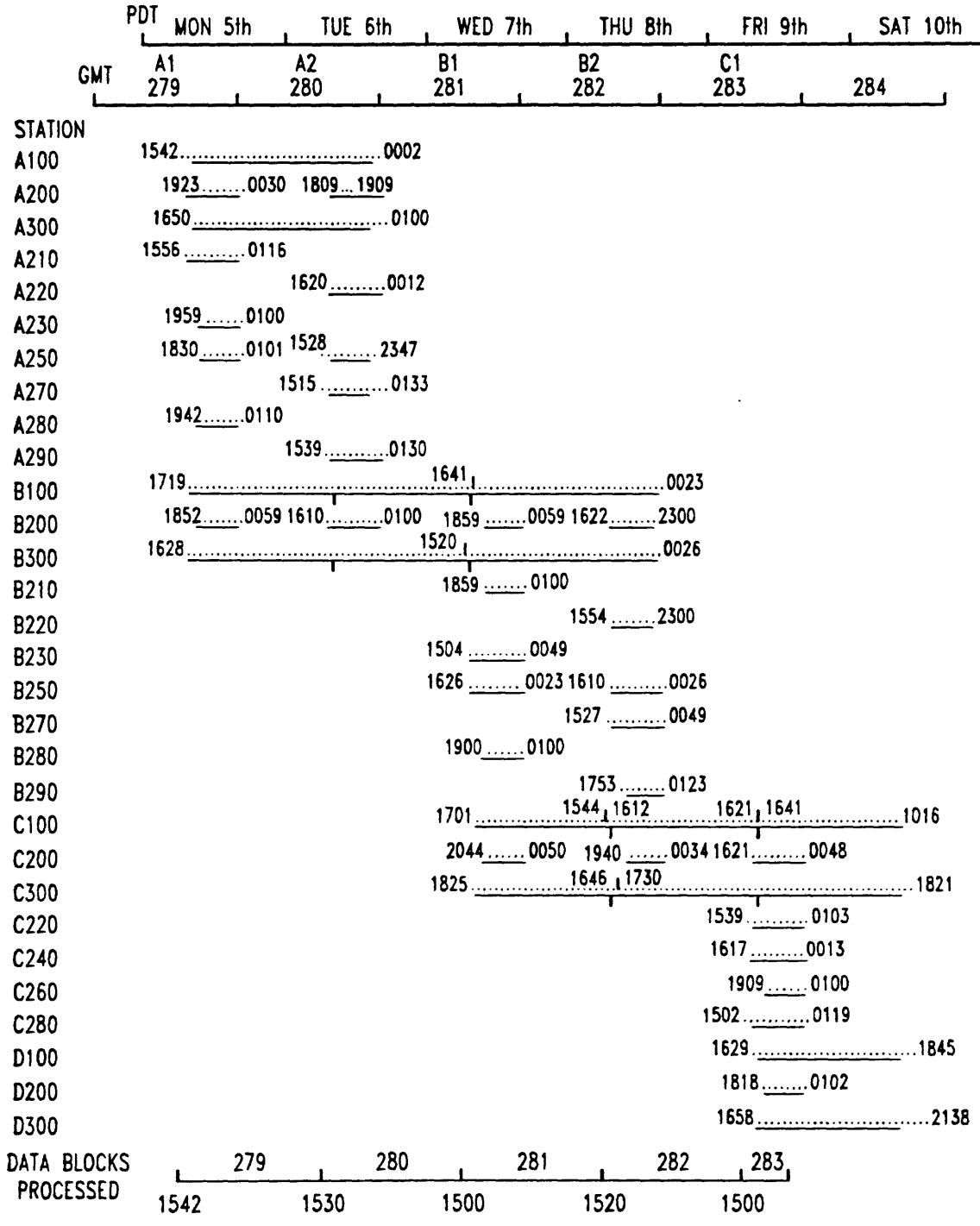

Figure 7 Measurement plan (dotted lines) and actual data archived (solid lines) for all the points.

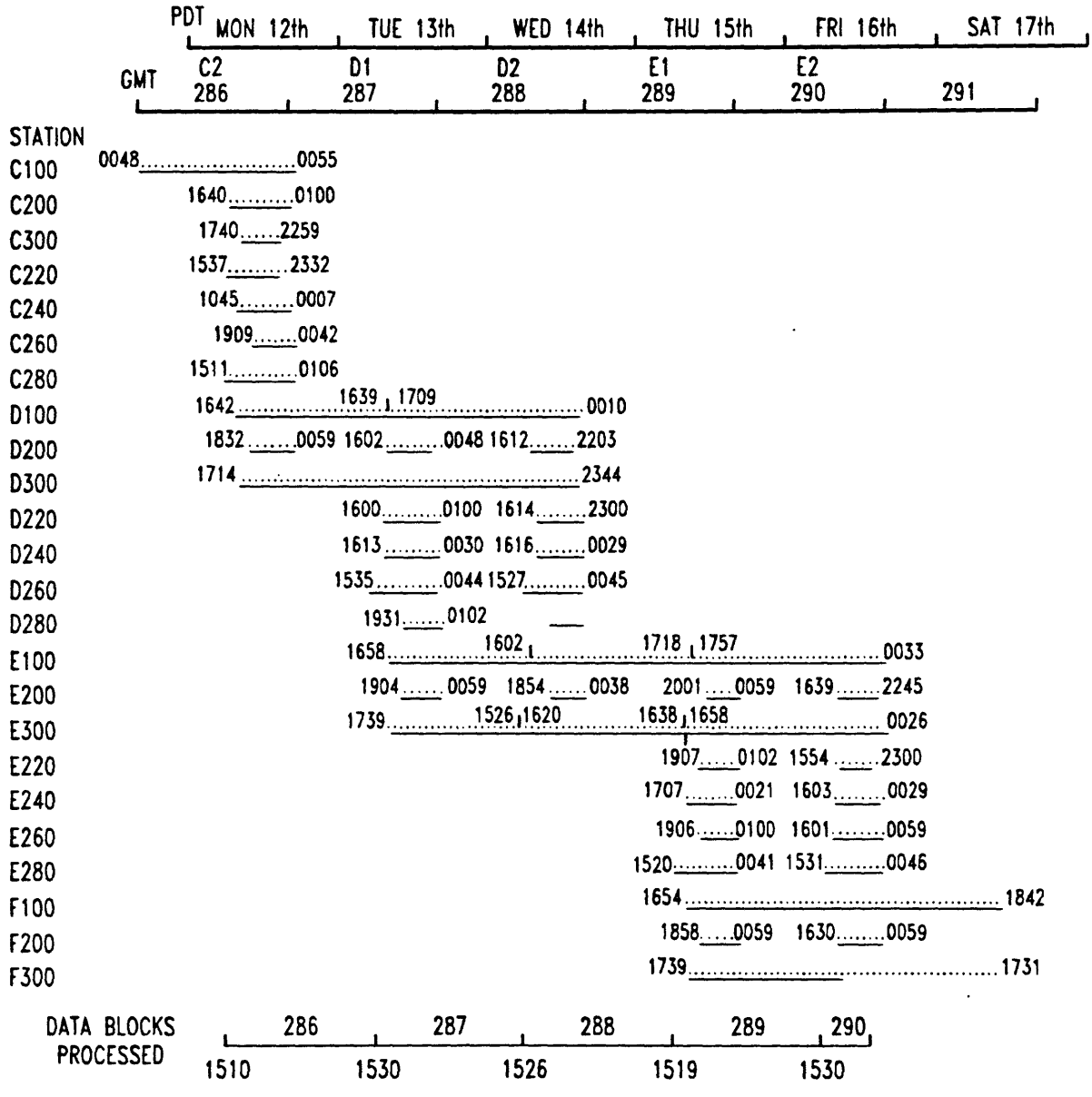

Figure 7 (continued)

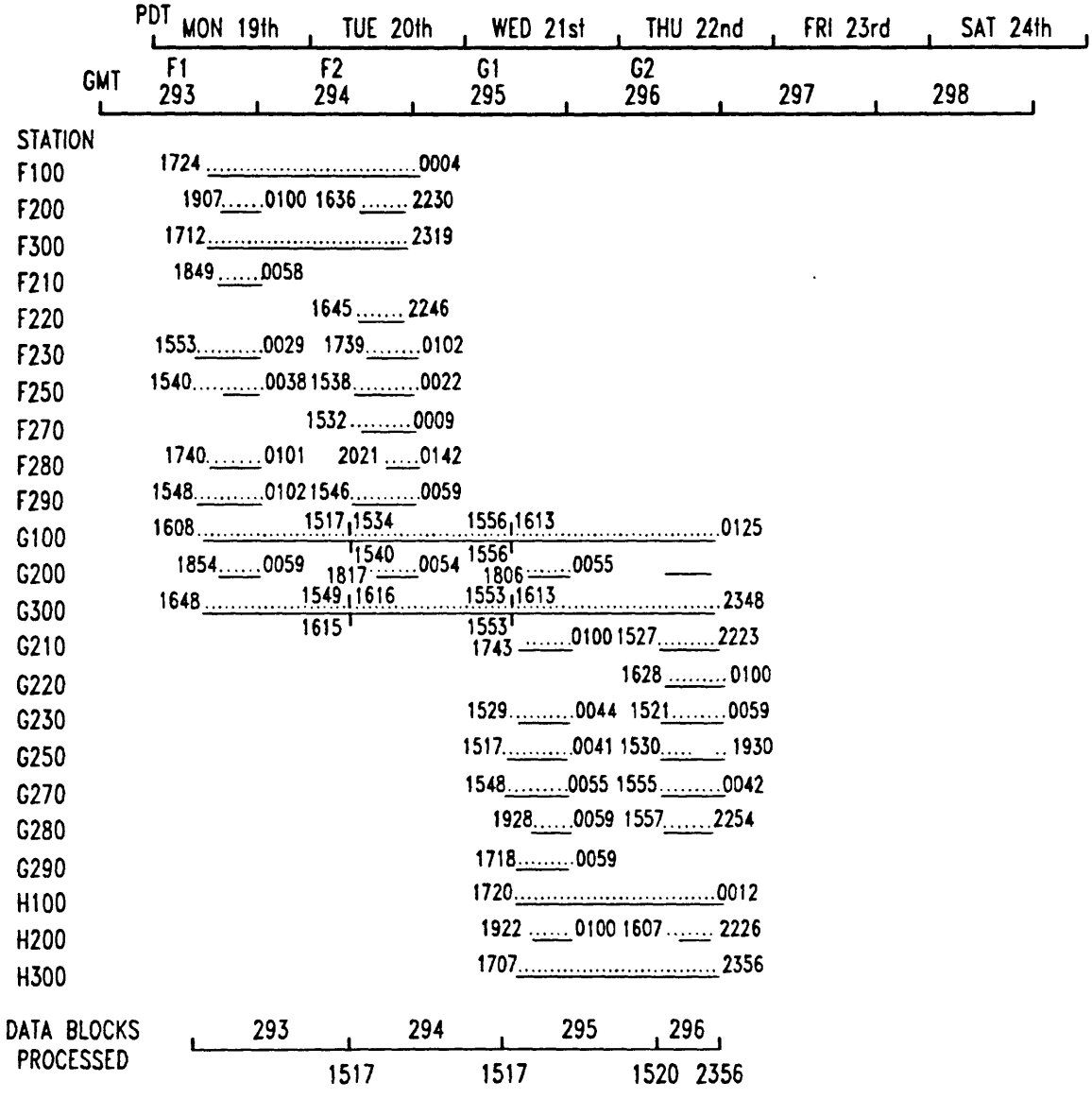

Figure 7 (continued)

day	date	Wayne	Bruce	Rosa	Grant		Gill		Gary/Kevin		Jim S/Chuck		Kathleen		Michelle		camp	Jim R	Steve	Garth	Sue	Brian
Sat	3rd	rec	rec	|	rec		train		train		train		train		train		A-A	train	train	train		|
Sun	4th	rec	rec	|	rec		train		train		train		train		train		A-A	train	train	train		|
Mon	5th	rec	rec	|	D0	A200	Q		*D1	B100	*D1	B300	*D1	A100	*D1	A300	A-A	data	D4	D5	|	|
						A210				A280		B200		A250		A230						
Tue	6th	tr/rec	rec	|	D0	A200	tr/Q		D2	B100	D2	B300	*D4	A100	*D4	A300	A-B	data	D4	|	D0	|
						A220				A290		B200		A250		A270						
Wed	7th	leave	rec	|	*D1	C300	Q		*D3	B210	*D3	B300	*D1	C100	D0	B230	B-B	data	D4	|	D0	|
						C200				B100		B200		B280		B250						
Thu	8th	|	tr/rec	arr ev	*D3	C300	*D3	C100	*D4	B220	*D4	B300	tr/Q		D0	B270	B-C	data	|	|	D0	|
						C200		B290		B100		B200				B250						
Fri	9th	|	rec	D1	D2	C300	D2	C100	*D1	D100	*D1	D300	Q		D0	C240	C-C	data	|	|	D0	|
						C200		C220		D200		C260				C280						
Sat	10th	arr	rec	Q	*D5	C300	*D5	C100	rec		*D5	D300	*D5	D100	*D5		C-C	data	|	|	*D5	|
Sun	11th			Q													C-C		|	|		|
Mon	12th	tr/rec	C300	*D1	D0	C200	D4	C220	*D1	D100	tr/Q		*D1	D300	D0	C240	C-D	data	|	|	|	|
						C300		C100		D200				C260		C280						
Tue	13th	rec	rec	D2	*D1	E100	*D1	E300	D2	D100	Q		D2	D300	D0	D240	D-D	data	|	|	|	|
						E200		D280		D220				D200		D260						
Wed	14th	tr/rec	rec	*D4	D2	E100	D2	E300	tr/Q		*D4	D100	*D4	D300	D0	D240	D-E	data	|	|	|	|
						E200		D280				D220		D200		D260						
Thu	15th	rec	rec	rec	*D3	E100	*D3	E300	*D1	F100	*D1	F300	D0	E240	Q		E-E	data	|	|	|	|
						E200		E220		E260		F200		E280								
Fri	16th	leave	rec	rec	*D4	E100	*D4	E300	D2	F100	D2	F300	D0	E240	Q		E-E	data	|	|	|	|
						E200		E220		F200		E260		E280								
Sat	17th	|	rec	*D5	Q				rec		rec		*D5	F100	*D5	F300	E-E	data	|	|	|	
Sun	18th	|		Q													E-F		|	|	|	
Mon	19th	|	F290	*D1	Q		*D1	G100	*D1	F100	*D1	F300	*D1	G300	D0	F230	F-F	data	|	|	|	D0
								F280		F200		F210		G200		F250						
Tue	20th	|	F290	D2	tr/Q		D2	G100	*D4	F100	*D4	F300	D3	G300	D0	F270	F-G	data	|	|	|	D0
			F280					F230		F200		F220		G200		F250						
Wed	21st	|	G270	*D3	*D1	H100	*D3	G100	Q		*D1	H300	*D3	G300	D0	G250	G-G	data	|	|	|	D0
			G290			G280		G210				H200		G200		G230						
Thu	22nd	|	G210	*D4	*D4	H100	*D4	G100	Q		*D4	H300	*D4	G300	D0	G250	G-G	data	|	|	|	D0
			G230			G290		G220				H200		G200		G270						
Fri	23rd	.....	....	pack	and	leave			.....		.....						G					
Sat	24th																					

Key:			
rec	point reconnaisance	¶	1 receiver only deployed
*	drive to remote point required	data	data download duty
Q	cook duty	A230, E300 etc	point codes
A-A, A-B etc	Campsite morning/evening		
D0, D1, D2, D3, D4, D5	type of schedule - day0 type, day 1 type, etc		
tr	trailer moving duty		

Table 1 Individual schedules for installation and measurement of the network. See key for explanation of the symbols.

Table 2 Trailer sites used in the 1992 survey.

A Oct. 2 (Fri.) - Oct. 6 (Tue.)
Washoe Lake State Park. Phone 702/687-4319
$5.00/trailer/day. Disposal station. No hookups. Can charge batteries.
4 miles N. of Carson City on US 395, 2 miles E on Eastlake Blvd. (SR 428).
Enter past fee booth (unstaffed). Right at stop sign. Continue past signs for campground loops A and B to equestrian area. Parking area near shelter. If ranger not about, pay via envelope system near entrance.

B Oct. 6 (Tue.) - Oct. 8 (Thur.)
Lahontan State Recreation Area. Phone 702/867-3500
Fee waived. Disposal station (probably closed). No hookups.
18 miles W of Fallon (10 miles E of Silver Springs) on US 50. From US 50 turnoff (signposted), follow dirt road about 1 mile S to park entrance. Road becomes paved near crossing of Carson River. At fee station follow sign toward right to "River Camp".

C Oct. 8 (Thur.) - Oct. 12 (Mon.)
Hickison Petraglyph Site (BLM).
Free. No potable water (available at USFS in Austin).
20 miles E of Austin on N side of US 50 (prominent sign).

D Oct. 12 (Mon.) - Oct. 14 (Wed.)
KOA of Ely. Phone 702/289-3413
About $25.00/trailer/day, $16.00/tent/day. Full hookups. Disposal station. Showers. Laundry.
3 miles S of Ely on US 6, 50 and 395.

E Oct. 14 (Wed.) - Oct. 18 (Sun.)
Great Basin National Park. Phone 702/234-7331
Free. Disposal station. No water. No electricity.
Drive E on US 50 past Sacramento Pass. At tavern called "The Y", turn right toward Baker and Great Basin NP (signposted). From Baker follow SR 488 toward the right (W) and uphill (signposted) about 5 miles to park and visitor center. "You can NOT get lost."

F Oct. 18 (Sun.) - Oct. 20 (Tue.)
Oak Creek (USFS). Phone 801/743-5721
$25.00/night (entire group). No hookups. No showers. Deer hunters. Water maybe.
From church in Oak City, follow SR 145 (FR 40089 in National Forest) 4.5 miles SE to campground.

G Oct. 20 (Tue.) - Oct. 23 (Fri.)
Butch Cassidy Campground (private). Phone 801/529-7400
$13.70/trailer/day. Disposal station. Coin laundry. Groceries. Heated pool.
1 mile E of I-70 (exit 54). 1100 State Street, Salina.

Table 3 Survey participants.

Name	Primary Responsibility	Affiliation
Wayne Thatcher	point reconnaissance (3rd - 15th)	USGS
Ross Stein	field measurements (8th - 23rd)	USGS
Gillian Foulger	field measurements	USGS/Univ. Durham, UK.
Bruce Julian	point rec./trailer logistics	USGS
Grant Marshall	field measurements	USGS
Kathleen Hodgkinson	field measurements	Univ. Durham, UK.
Michelle Hofton	field measurements	Univ. Durham, UK.
Gary Hamilton/Kevin Clark	field measurements	USGS
Jim Sutton/Chuck Stiffler	field measurements	USGS
Sue Larson	volunteer field assistant (6th - 10th)	USGS
Brian Kilgore	volunteer field assistant (19th - 23rd)	USGS
Steve Fisher	technical assistance (3rd - 7th)	JPL
Jim Richardson	data download/tech. assistance remote receiver visits	JPL
Garth Franklin	technical assistance (3rd - 5th)	JPL

Table 4 Framework of survey schedule.

Date (October)

Fri. 2nd	Drive to Camp A from Menlo Park.
Sat 3rd	0900 Assembly of all survey personnel at Camp A. General briefing. 10.30 Reconnaissance parties leave. Others assemble equipment, train.
Sun 4th	Reconnaissance, training, organization.
Mon 5th	} measure Quad A, day 1
Tue 6th	} measure Quad A, day 2
Wed 7th	} measure Quad B, day 1
Thu 8th	} measure Quad B, day 2
Fri 9th	} measure Quad C, day 1
Sat 10th	} retrieve receivers still in the field, reform
Sun 11th	} SA on - no measurements
Mon 12th	} measure Quad C, day 2
Tue 13th	} measure Quad D, day 1
Wed 14th	} measure Quad D, day 2
Thu 15th	} measure Quad E, day 1
Fri 16th	} measure Quad E, day 2
Sat 17th	} retrieve receivers still in the field, reform
Sun 18th	} SA on - no measurements
Mon 19th	} measure Quad F, day 1
Tue 20th	} measure Quad F, day 2
Wed 21st	} measure Quad G, day 1
Thu 22nd	} measure Quad G, day 2
Fri 23rd	Pack instruments, leave.

Table 5 Daily point occupation schedules.

Day 1 - Installation Day

0700 - 0900	Drive to remote point.
0900 - 1000	Set up remote point.
1000 - 1100	Drive back to highway 50 point.
1100 - 1200	Set up highway 50 point.
1200 - 1800	Guard highway 50 point.
1800	Take up highway 50 point.
1800 - 1900	Drive back to trailers.

Day 2 - Non-service Day

0700 - 0800	Drive to highway 50 point.
0800 - 0900	Set up highway 50 point.
0900 - 1800	Guard highway 50 point.
1800	Take up highway 50 point.
1800 - 1900	Drive back to trailers.

Jim Richardson visited the remote point and reset the tripod if he arrived at 1000 or earlier.

Day 3 - Service Day

0700 - 0900	Drive to remote site.
0900 - 1000	Service remote site (check, change battery, reset tripod).
1000 - 1100	Drive back to highway 50 point.
1100 - 1200	Set up highway 50 point.
1200 - 1800	Guard highway 50 point.
1800	Take up highway 50 point.
1800 - 1900	Drive back to trailers.

Day 4 - Takeup Day

0700 - 0800	Drive to highway 50 point.
0800- 0900	Set up highway 50 point.
0900 - 1600	Guard highway 50 point.
1600 - 1700	Drive to remote point.
1700	Take up remote point.
1700- 1900	Drive back to trailers.

Day 5 - Saturday Takeup Day

0800 - 1000	Drive to remote site.
1000	Take up remote site.
1000 - 1200	Drive back to trailers.

Day 0 - Highway 50 day (two members in receiver crew)

0700 - 0900	Set off from trailers to two highway 50 points. Set them up.
0900 - 1800	Guard both highway 50 points.
1800 - 1900	Take down both points, return to trailers.

This plan assumed:

1. A 1 hr driving time from the trailer headquarters to the highway 50 point,
2. A 1 hr driving time from the highway 50 point to the remote point,
3. 1 hr for each tripod and receiver setup.
4. A 1 hr driving time from the highway 50 point back to the trailers in the evening.
5. A few minutes for tripod takedown,
6. Short drive times for the party occupying the two highway 50 points.

Table 6 Time

Day	Date	DOY
Mon	5th	279
Tue	6th	280
Wed	7th	281
Thur	8th	282
Fri	9th	283
Sat	10th	284
Sun	11th	285
Mon	12th	286
Tue	13th	287
Wed	14th	288
Thu	15th	289
Fri	16th	290
Sat	17th	291
Sun	18th	292
Mon	19th	293
Tue	20th	294
Wed	21st	295
Thu	22nd	296
Fri	23rd	297

Time offset Pacific Daylight Time from UHT = - 7 hours