The USGS Parkfield, California, Dense Seismograph Array (UPSAR) Data Collection

By Lawrence M. Baker

Data Series 869

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Preface

Several cautions appear in this report. They are mentioned here to emphasize their importance to the reader.

- The GPS locations in table 2 should be used in place of the original surveyed locations contained in the data files.

The Global Positioning System (GPS) did not exist when UPSAR was installed. The coordinates of the stations were determined by shooting from station to station with a total station theodolite, with the probable accumulation of errors. No least-squares adjustment of the final station locations was performed. When UPSAR was dismantled, a GPS survey was done. The GPS survey was not subject to accumulation of errors and was more accurate.
Always use the coordinates in table 2 ("UPSAR station locations, based on World Geodetic System 84"). Do not use the locations contained within the data files themselves.

- Rely only on the values in the data file headers for the time of the first data sample.

The name given to a data file is a convention only. Do not rely on the name, for example, as the time of the first data sample; the values in the data file headers must be used.

- Do not assume the time of the first data sample is the same in all the data files for a single event.

The time of the first data sample in a data file can, and, usually does, vary from one station to another.

- Analysis programs must examine the time-series data for undefined values and handle them properly.

Invalid or missing data in the data files is encoded using a special "undefined data" value. Analysis programs must identify and properly handle missing data.

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Introduction

The Parkfield Dense Seismograph Array (UPSAR) was an array of fourteen six-component seismographs (three components of velocity and three components of acceleration) located approximately 10 km west of the San Andreas Fault near Parkfield, California (Fletcher and others, 1992). The array was designed to capture the strong shaking of an anticipated earthquake along the Parkfield section of the fault, based on observations of the approximately 22-year period of recurrence of an *M*5.5–6.0 earthquake in that vicinity (http://earthquake.usgs.gov/research/parkfield, accessed September 18, 2013).

Surface ground motions were simultaneously sampled at every seismograph site (or station) 200 times per second using 16-bit analog-to-digital (A/D) converters. Data from each seismograph were transmitted in real time via an ARCnet (Rohling, 1983) local-area network (LAN) to a data acquisition minicomputer system for seismic event detection and permanent recording.

UPSAR operated from late March 1989 until mid-February 2005. Except for a few brief periods when data were recorded continuously, only data that exceeded a certain ground motion threshold—called triggered or event data—were recorded. Significant earthquakes recorded by the array include the *M*6.5 December 22, 2003 San Simeon and *M*6.0 September 28, 2004 Parkfield earthquakes.

This data release consists of approximately 21,000 triggered events. There are approximately 1.4 million USGS DR100 format (binary) data files (totaling 25 GB). Also included are printable error and event summary files, PDF format plot files, and software for reading DR100 format data files.

Datasets

The UPSAR data collection consists of four datasets, designated “PKDA”, “SAFOD”, “PKTA”, and “PKT2” (table 1):

- The PKDA data are the standard triggered data recorded by the array during its lifetime. All 6 components of ground motion at each site were sampled 200 times per second.
- The SAFOD data include both triggered and continuous recordings made during an experiment over several days in late 2003 for the SAFOD (San Andreas Fault Observatory at Depth) drilling project (http://earthquake.usgs.gov/research/parkfield/safod_pbo.php, accessed September 18, 2013). During this experiment, the array recorded continuous data during preset time intervals when explosive sources were scheduled for detonation. Outside these preset

time intervals, the array operated normally, that is, recorded triggered data only. The array was not capable of operating in continuous mode and triggered mode simultaneously; while the array was operating in continuous mode, there were no separate triggered recordings—seismic events that occurred during the preset time intervals are contained within the continuous data records.
The triggered data from this time period are not in the PKDA dataset; the SAFOD dataset must be combined with the PKDA dataset to complete the set of triggered recordings. This dataset also contains all 6 components of ground motion sampled 200 times per second.

- The PKTA and PKT2 datasets are continuous recordings of the velocity ground motion components collected during the last month of operation of UPSAR (January 20 through February 14, 2005). These recordings were made to investigate possible non-volcanic tremor activity, at depth, near the rupture zone of the Parkfield earthquake (Nadeau and Dolenc, 2005). The sampled data were digitally filtered and decimated to 40 samples per second (PKTA) and 50 samples per second (PKT2) by the data acquisition minicomputer system.

Table 1. Datasets in the UPSAR data collection.

[Vel, velocity; Acc, Acceleration]

Dataset	From	To	Components	Sample rate	Continuous	Triggered
PKDA	Mar. 30, 1989[1]	Jan. 20, 2005[1]	Vel + Acc	200/s	No	Yes
SAFOD	Nov. 19, 2003	Nov. 24, 2003	Vel + Acc	200/s	Partial	Partial
PKTA	Jan. 20, 2005	Feb. 1, 2005	Vel only	40/s	Yes	No
PKT2	Feb. 1, 2005	Feb. 14, 2005	Vel only	50/s	Yes	No

[1]Except during the SAFOD experiment.

Dataset Organization

The UPSAR data collection is available in several distribution formats: DVD images (58 GB), ZIP archives (13 GB), Apple disk images (9 GB), and Linux SquashFS images (12 GB). ZIP-compressed DVD images are also available (13 GB) (the other formats are already compressed). See the appendix for a catalog of the available distributions.

The collection is organized into annual volumes by dataset—data from the four datasets are not mixed. The DVD images contain as many annual volumes as will fit on each DVD. If a volume is too large to fit on a single DVD, it is split across multiple DVDs. The other distributions contain a single annual volume per image or archive file (except the PKTA and PKT2 ZIP archives, as these volumes are too large to fit in a single ZIP archive, and are split into multiple ZIP archives).

Each volume of data is named for the dataset, the year the data were collected, and, if necessary, the range of Julian days it contains. The file type extension identifies the volume format. For example, the SAFOD dataset is completely contained in a volume named "SAFOD_2003(323-328).ext", where "ext" is replaced with "iso" for a DVD image, "zip" for a ZIP archive, "dmg" for an Apple disk image, or "sqsh" for a Linux SquashFS image.

Figure 1 illustrates the organization of the data collection within a volume, using the *M*6.0 September 28, 2004 Parkfield earthquake mainshock data from the PKDA_2004(270-366) DVD volume as an example.

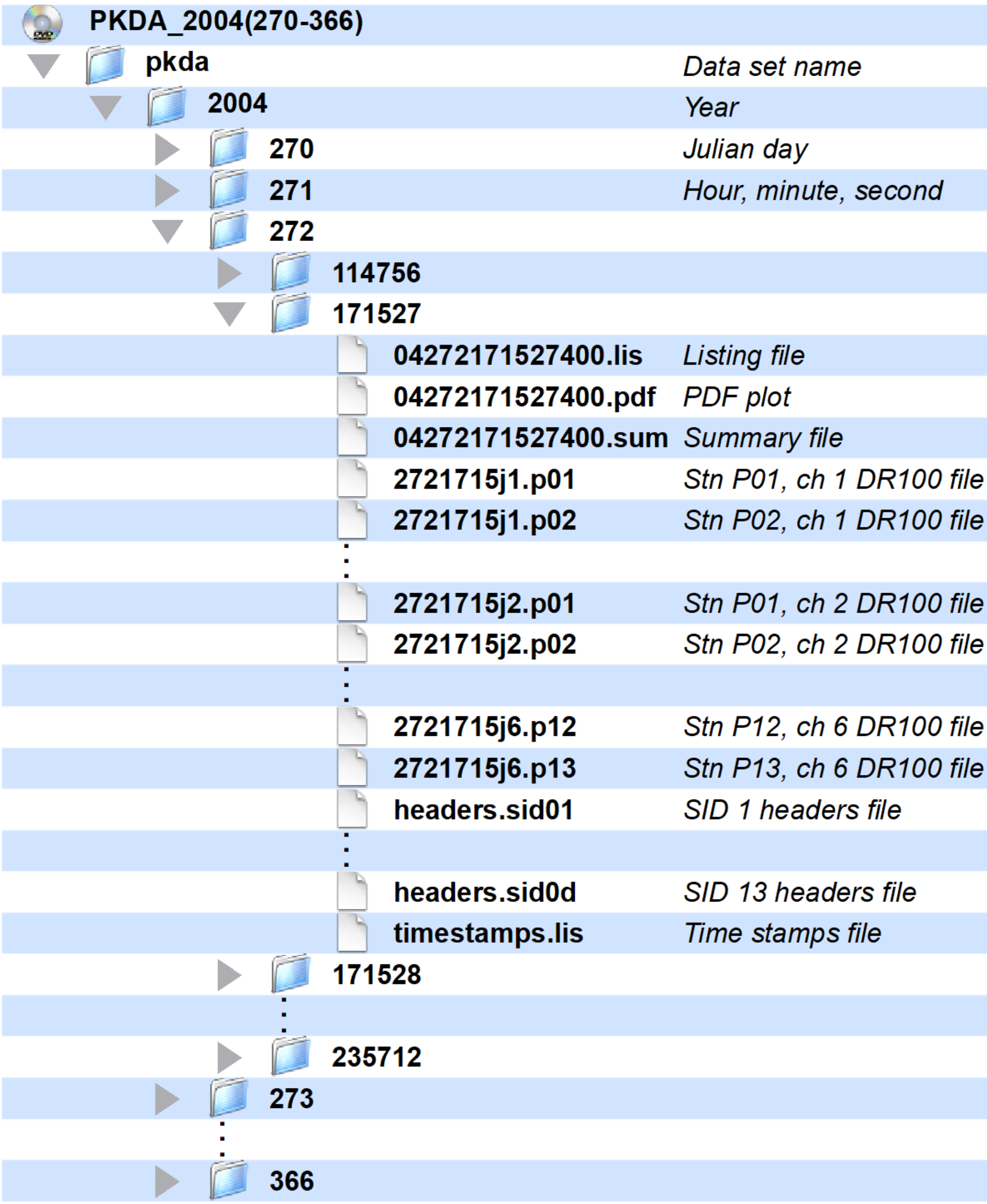

Figure 1. Image showing data organization for the *M*6.0 September 28, 2004 Parkfield earthquake mainshock. The mainshock triggered the data recording to start at 17:15:27.400 UTC.

The top-level directory is named for the dataset, in lower case: “pkda”, “safod”, “pkta”, or “pkt2”. Within each dataset, the data are organized chronologically by the UTC trigger time of each event (triggered data) or the UTC start time of a data segment (continuous data). The second-level directories are named for the year (1989–2005). The third-level directories are named for the Julian day (001–366). Beneath those directories are the directories containing the UPSAR data files, named for the time, in the form *HHMMSS*.

For example, the recording of the *M*6.0 September 28, 2004 Parkfield earthquake was triggered at 17:15:27.400 UTC. PKDA data for the Parkfield mainshock is in the directory named “pkda/2004/272/175727”.

In a few rare instances, multiple triggers occurred within the same second (usually due to artillery practice at nearby Camp Roberts). In those cases, the earlier trigger, at time *YYYY DDD-HH:MM:SS.mmm*, is moved to a directory named “pkda/*YYYY*/*DDD*/*HHMMSS*/*mmm*”, and can be ignored.

The lowest level directories contain the (binary) ground motion data files and several additional files created by the UPSAR raw data Playback program. The ground motion data files are in USGS DR100 format (also known as VFBB format, or blocked-binary format, described in the DR100 Data File Format section).

Each DR100 data file contains a single component (or channel) of motion from a single site (or station). By convention, component numbers 1–3 are acceleration and 4–6 are velocity. The 14 sites were named P01, P02, continuing to P14. (UPSAR station names, which are geographic, should not be confused with ARCnet station IDs, which are electronic. Station IDs are discussed in the Telemetry section.)

As many as 84 DR100 data files may exist for a single trigger: 6 components of ground motion at 14 stations, if all 14 stations were operating. (This was typically not the case, because station P04 was permanently removed on April 30, 1993.)

The DR100 data files are named for the UTC trigger time (or segment start time, when operating in continuous mode) to the second (without the year), the component number, and the station name. For historical reasons, the seconds value of the trigger time is encoded into a single character; letters of the alphabet are used to represent each 3-second interval in time: “A” for 0–2 seconds, “B” for 3–5 seconds, and so forth. For example, given a trigger at time *YYYY DDD-HH:MM:SS.mmm*, the DR100 data file name for component “*c*” from station name “*stn*” is “*DDDHHMMSc.stn*”, where *S* is the mapping of seconds described above. All data files for a single trigger will have the same encoded trigger time in their file names.

DR100 data file names follow a convention to group data files by a unique event name. The trigger time is not stored in the DR100 data file headers. Care must be taken with data file names to preserve a record of the trigger time, and which data files belong to which event.

In addition to the data captured during an event trigger, each data file includes a predetermined amount of pre-event and post-event data. (This also results in the overlap of adjacent segments of continuously recorded data.) Thus, the time of the first data sample in a data file is prior to the trigger time. The time of the first data sample in each data file is stored in the DR100 data file headers.

Because the amount of pre-event data can vary, and the times of the first data samples from different stations are not aligned (discussed in the Seismographs section), file names should be used only to identify components that belong to the same event. The DR100 data file headers must be used to compute the time of the first data sample in every file.

In addition to the DR100 data files, there is a (text) listing file, a (text) summary file, and a PDF plot file. These three files are named for the time of the trigger, using a 2-digit year: *YYDDDHHMMSSmmm*, and so forth. In the first year or so of operation, UPSAR did not keep time to the millisecond. The files for those triggers are missing the *mmm* part in their names.

The listing files (extension “.lis”) have detailed information about the trigger, and a report of the data quality checks performed when the raw data was converted to DR100 format.

The summary files (extension ".sum") contain only a few of the lines from the listing files, along with a table of peak A/D counts.

The PDF plot files (extension ".pdf") contain a fixed scale plot of the first 12 seconds (2 seconds before and 10 seconds after the trigger) of the vertical velocity component (number 4) data from all stations.

To aid in deciding whether the data are reliable enough to be used in any analysis (typically, whether the A/D sample clocks are properly synchronized across the array), there are text files containing the time stamps from each ARCnet data packet from each station ("timestamps.lis"), and the decoded headers of each data packet from each station ("headers.sid*NN*", where *NN* is the hexadecimal ARCnet network station ID.) Normally, it is not necessary to examine these files—the information in the listing files is typically sufficient to decide whether the data are reliable.

Instrumentation

A brief explanation of the operation of the array will be useful to understand the terminology in the Dataset File Formats section, and the meaning of any data quality errors that might be reported by the UPSAR raw data Playback program.

Layout

The method used to select the locations for each of the 14 seismograph sites (named P01, P02, and so forth) is described in Fletcher and others (1992). Figure 2 is a map showing the layout of the array.

When the array was laid out, the sites were manually surveyed and their coordinates were determined relative to site P06, near the geographic center (Fletcher and others, 1992, table 1). These are the coordinates that are in the DR100 data file headers.

When the array was dismantled in 2005, the sites were resurveyed using a Global Positioning System (GPS) receiver (Fletcher and others, 2006). The GPS locations are given in table 2 (see the Additional Material, GPS Locations section). ***The GPS locations in table 2 should be used in place of the original surveyed locations contained in the DR100 files.***

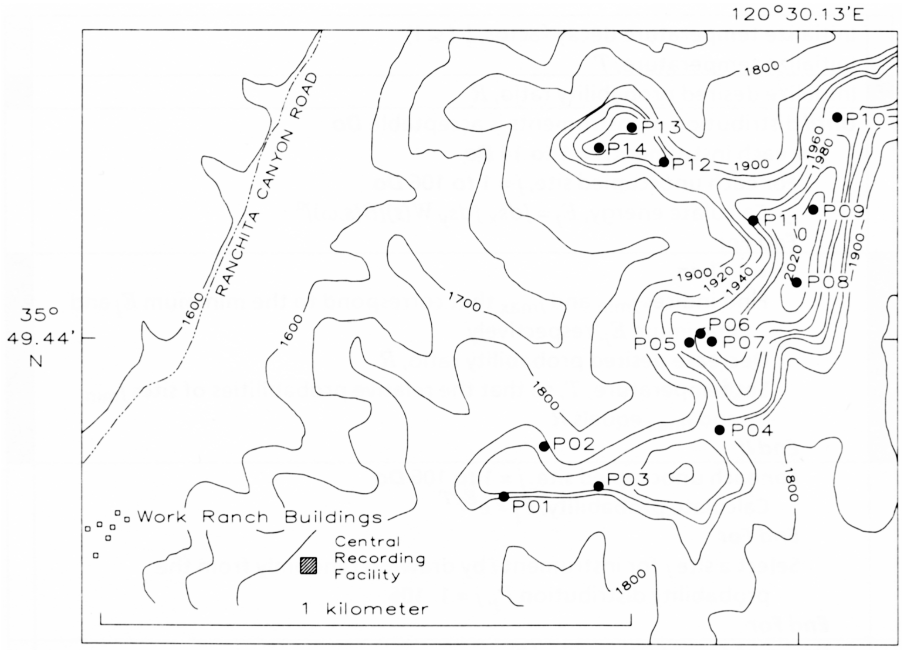

Figure 2. Map of Parkfield Dense Seismograph Array, California. Below 1,900-ft elevation, the contour interval is 100 ft and above 1,900-ft the contour interval is 20 ft. From Fletcher and others (1992).

Table 2. UPSAR station locations, based on World Geodetic System 84.

[From Fletcher and others, 2006. Latitude and longitude are in degrees and minutes north and east. These GPS locations should be used in place of the original surveyed locations contained in the DR100 files]

Station	Latitude[1]	Longitude[1]	Elevation[1] (m)	Accuracy[1] (m)	East offset[2] (m)	North offset[2] (m)	Elevation difference[2] (m)
P01	35 49.272	−120 30.432	576	1.2	−371	−302	−25
P02	35 49.323	−120 30.383	577	1.3	−298	−208	−24
P03	35 49.282	−120 30.313	585	1.5	−192	−284	−16
P04	35 49.338	−120 30.160	583	2.3	38	−180	−18
P05	35 49.428	−120 30.200	597	1.3	−23	−13	−4
P06	35 49.435	−120 30.185	601	1.4	0	0	0
P07	35 49.430	−120 30.170	603	1.3	23	−9	2
P08	35 49.488	−120 30.067	619	3.6	177	98	18
P09	35 49.562	−120 30.043	613	1.2	213	235	12
P10	35 49.657	−120 30.012	604	1.5	260	411	3
P11	35 49.550	−120 30.120	600	1.3	98	213	−1
P12	35 49.612	−120 30.233	585	−	−72	328	−16
P13	35 49.647	−120 30.272	597	1.5	−131	393	−4
P14	35 49.627	−120 30.315	599	1.2	−195	356	−2

[1]Output from Garmin 76 Global Positioning System receiver.

[2]Offset from P06 determined from latitude and longitude in a locally Cartesian frame.

Figure 3 is a diagram of the major components of the array. At each site, a concrete vault was poured into the ground to be flush with the grade and a utility box was installed to house the surface sensor packages and seismograph. Passing through each vault were cables for power, timing, and the ARCnet LAN. These cables originated at the building containing the data acquisition minicomputer system (“Central Recording Facility” in fig. 2) and terminated at the farthest site (P14), approximately 2,400 m away.

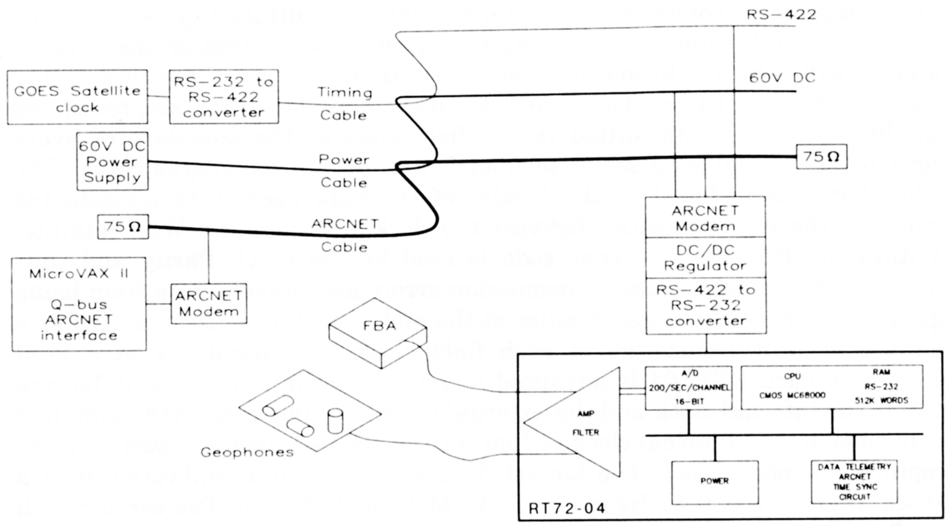

Figure 3. Diagram showing major components of the Parkfield Dense Seismic Array. Figure from Fletcher and others (1992).

Seismographs

The seismographs at each site were controlled by a CMOS Motorola 68000-series microprocessor (Refraction Technology, 1988). The microprocessor programmed an A/D converter to sample and digitize each channel of data every 5 ms (200 samples per second). Forty 16-bit samples of data from each of the 6 components of ground motion (480 bytes), along with a time stamp and status header (32 bytes), were assembled into 512-byte packets to be sent via the ARCnet LAN every 200 ms to the data acquisition minicomputer system.

Filled packets were queued for transmission to the data acquisition minicomputer system over the ARCnet LAN. Filling of data packets was overlapped with the transmission of queued packets. When all the data packets were queued, such that none were available for new A/D data, the microprocessor removed all pending data packets from the transmission queue and restarted (or reset) A/D sampling so that all packets were again made available. Data in pending packets was discarded, resulting in a gap in the stream of data from a station.

Data gaps are represented in the DR100 data format using a reserved “missing data” value, the most negative 16-bit integer, −32768. The Playback program changes any actual A/D values of −32768 to −32767, and it supplies −32768 when A/D data is missing. In the DR100 data files, A/D data are either missing (−32768), negative off-scale (−32767), positive off-scale (+32767), or on-scale (−32766 through +32766).

The data packets also included time and status information for each seismograph, such as the preamplifier gain settings, battery voltage, the number of buffers waiting for transmission, and flags for a network reconfiguration or reset (A/D buffer starvation, also termed data overflow). Later versions of the firmware added sequence numbers, the firmware version number, a flag when the time-code was received, and the current amount of the adjustment to the 1-kHz oscillator (see the Timing section).

The data packets from the seismographs were not time-aligned across the array. However, the A/D sample clock was always a multiple of 5 ms. The time of the first sample in a data packet from one site could differ from that at another site, but the difference was always a multiple of 5 ms.

Timing

The seismographs in the array used a common UTC time reference so that ground motions were simultaneously sampled across the array. A 1-pulse-per-second (pps) time-code reference signal from a GOES (Kinemetrics/TrueTime, 1986; later, GPS, TrueTime, Inc., 1995) satellite receiver was distributed throughout the array ("Timing Cable" in fig. 3). Within each seismograph, a CMOS Motorola 6801-compatible microcontroller synchronized an internal 1-kHz sample clock to the 1-pps signal. The microcontroller was constantly advancing or retarding an oscillator circuit to keep the 1-kHz sample clock synchronized with the 1-pps signal. The output of the 1-kHz sample clock was used to gate a divide-by-5 counter, which then triggered the A/D conversions, thus synchronizing sampling across the array.

The time-code reference signal also contained the ASCII representation of UTC time (days, hours, minutes, seconds, and milliseconds in the current year) corresponding to the 1-pps pulse. This was read by the main Motorola 68000 microprocessor to update the clock calendar used to time stamp each data packet.

The 1-kHz oscillator circuit was temperature compensated and could maintain accurate timing for the array in the absence of the 1-pps reference. Worst-case drift was ±0.6 seconds over 24 hours. However, the array was not operated without a reliable time reference signal. Repairs were made immediately whenever there was loss of UTC time synchronization (usually due to faults in the timing cable).

Digitizer

Eight input channels (six seismometers, channels 1–6; internal air pressure, channel 7; and battery voltage, channel 8) were digitized every 5 ms. The input signals were routed through a multiplexor circuit to the input of a sample-and-hold amplifier (SHA) connected to the input of a 16-bit A/D converter.

When an A/D sweep was initiated, the input signals were gated in reverse order to the SHA input. The time between successive conversions (or sample skew) was 400 µs. Thus, the skew between data samples in the same sweep ranged from 400 µs (between any two successive channels) to 2 ms (between channels 1 and 6). The conversion time for each sample was less than 50 µs.

Firmware

The firmware for both the 68000 microprocessor and the 6801 microcontroller went through several iterations in the first few years of operation, mainly to improve the time synchronization logic, and to identify lapses in time synchronization. Table 3 tracks the firmware changes for each seismograph by ARCnet network station ID (described in the Telemetry section). A description of the firmware versions is in table A1 in the appendix.

Table 3. Seismograph firmware versions and deployment dates.

[SID, station ID; dates are in YY-DDD format]

SID	Firmware version									
	1.52	1.60	1.61	1.62	1.7	1.8	1.9	2.0	2.1	2.2
1	89-088	89-244	91-264	93-268	–	93-274	93-300	93-328	94-202	94-209
2	89-088	89-244	–	93-233	–	93-274	93-300	93-328	–	94-279
3	89-097	89-244	92-260	93-268	–	93-274	93-300	93-328	–	94-292
4 [1]	89-097	89-244								
5	89-097	89-244	–	93-232	93-274	–	93-300	93-328	–	94-292
6	89-117	89-244	–	93-232	93-274	–	93-300	93-328	–	94-300
7	89-117	89-244	93-167	93-261	93-274	–	93-300	93-328	–	94-209
8	89-117	89-351	92-260	93-261	93-274	–	93-300	93-328	94-202	94-209
9	89-117	89-304	91-353	93-261	93-274	–	93-300	93-328	–	94-300
10	89-117	89-244	93-167	93-261	93-274	–	93-300	93-328	94-202	94-209
11 [2]		89-351	93-167	93-261	93-274	–	93-300	93-328	–	94-300
12	89-117	89-244	93-167	93-261	93-274	–	93-300	93-328	–	94-300
13	89-117	89-244	93-167	93-261	93-274	–	93-300	93-328	–	94-300
14	89-117	89-244	93-167	93-261	93-274	–	93-300	93-328	–	94-300
15 [2]	89-131	89-244								

[1]SID 4 was removed from the array on April 30, 1993 (93-120).

[2]SID 15 was rewired to be SID 11 on December 17, 1989 (89-351).

Telemetry

UPSAR used a modified ARCnet local-area network (Rohling, 1983) for communication between the seismographs at each site and the data acquisition minicomputer system (“ARCNET Cable” in fig. 3). Each node in the ARCnet network was assigned a unique network ID number (1–254) that was stored in the hardware. Messages, such as commands, responses, and seismometer data, were sent in packets labeled with the Source ID and a Destination ID. All messages were acknowledged.

ARCnet is a “token-passing” network. Permission to send a message is granted only when a node receives a special message, called a token. The token circulates from node to node, in order, by network ID number.

When a node is added or removed from an ARCnet network, the network automatically reconfigures itself. A network “reconfiguration” also occurs if a node does not receive the token after the expected period of time. A network reconfiguration forces the generation of a new token, which restores normal operation.

An occasional reconfiguration of the UPSAR ARCnet network was normal. Packets were automatically retransmitted by the ARCnet controller when a reconfiguration occurred. When there was a problem with the network, the reconfiguration rate increased. Serious network problems (cable faults or electronic component failures) caused the seismographs to reset, as discussed above. When that occurred, repairs were made to restore normal network operation.

Real-Time Data Processing

The real-time seismic detection and recording software kept time in 200 ms intervals (the ARCnet data packet arrival rate), called “slot” times. When an ARCnet data packet arrived, its slot time was calculated from the time stamp in the packet header, with some allowance for jitter.

Data packets with the same slot time were collected into a single data buffer, and that data buffer was then labeled with its own time stamp and sequence number. After the arrival of all the data packets for a given slot time, the data buffer was queued for processing.

Each data buffer reserved a location for the ARCnet data packet from every station with a matching slot time. If any seismographs were not operating properly, after a 30-second wait, any missing data packets in the data buffer were flagged and the incomplete data buffer was queued for processing. Since data buffers were always queued in order by slot time, any data buffer with missing data packets would delay the queuing of filled data buffers behind it until the 30-second wait period expired.

Real-Time System Data Files

The data acquisition software created five kinds of files, identified by a unique single-character suffix:

When the data acquisition software was started, the software created a

- *S* station parameter file, describing the instrument settings, and a
- *L* console log file.

For each seismic event detected (or continuous recording interval), the software created a

- *C* system common file, containing a snapshot of the system data area (a system-wide Fortran COMMON data block), a
- *T* trigger common file, containing a snapshot of the trigger data area (a system-wide Fortran COMMON data block), and a
- *D* raw data file, containing the sequence of data buffers that caused the trigger, plus a fixed number of data buffers before (leader) and after (trailer) the trigger time window.

All file names incorporated a UTC time stamp. Names for the console log file (L file) and the station parameter file (S file) were generated from the 2-digit year, followed by the time (to the second) when the data acquisition system software was started. Names for the event files (C, T, and D files) were generated from the 2-digit year, followed by the trigger time of the event (originally to the second; later, to the millisecond).

Log files were created in a disk directory named “LOG_FILES” (fig. 4). The remaining files were originally written directly to an ANSI-format cartridge tape. Later, they were written to a disk directory named “DATA” (fig. 5).

```
Directory BOR3:[PKDA.2004.LOG_FILES]

040010003.54L;1         3784/3786      1-JAN-2004 00:01:51.74
040072334.21L;1         2208/2214      7-JAN-2004 23:32:14.59
040822042.57L;1         8714/8721     22-MAR-2004 20:40:06.20
041351952.12L;1          221/225      14-MAY-2004 19:48:43.97
042612135.35L;1           41/45       17-SEP-2004 21:30:40.73
042662139.30L;1           59/63       22-SEP-2004 21:34:32.69
042681918.36L;1         1005/1008     24-SEP-2004 19:13:37.73
043102152.28L;1           26/36        5-NOV-2004 21:47:18.69
043140008.08L;1            8/9         9-NOV-2004 00:02:52.80
043142153.47L;1           18/18        9-NOV-2004 21:48:29.17
043172117.30L;1          223/225      12-NOV-2004 21:12:06.36

Total of 11 files, 16307/16350 blocks.
```

Figure 4. Image showing a directory listing of UPSAR real-time system LOG_FILES for 2004.

```
Directory BOR3:[PKDA.2004.DATA]

040010003.54S;1            53/54       1-JAN-2004 00:01:59.57
040010033.12800C;1         17/18       1-JAN-2004 00:31:06.73
040010033.12800D;1       2286/2286     1-JAN-2004 00:31:07.37
040010033.12800T;1          6/6        1-JAN-2004 00:31:07.08
:
040072213.30000C;1         17/18       7-JAN-2004 22:11:19.98
040072213.30000D;1       2188/2190     7-JAN-2004 22:11:20.64
040072213.30000T;1          6/6        7-JAN-2004 22:11:20.34
040072334.21S;1            53/54       7-JAN-2004 23:32:22.84
040080014.58800C;1         17/18       8-JAN-2004 00:12:48.76
040080014.58800D;1       4754/4755     8-JAN-2004 00:12:49.46
040080014.58800T;1          6/6        8-JAN-2004 00:12:49.19
:
043662306.25000C;1         17/18      31-DEC-2004 23:00:28.75
043662306.25000D;1       2514/2520    31-DEC-2004 23:00:29.46
043662306.25000T;1          6/9       31-DEC-2004 23:00:29.10

Total of 12924 files, 8656619/8687628 blocks.
```

Figure 5. Image showing a directory listing of UPSAR real-time system DATA (abbreviated) for 2004.

As the data acquisition software was started up and shut down, and events were recorded, an alphabetical listing of the directories provided a chronological record of UPSAR's operation. Further automated processing, such as remote file transfers, and the UPSAR raw data Playback program, relied on this naming scheme to access the data in chronological order.

Real-Time System Data Files for the San Simeon and Parkfield Earthquakes

The real-time seismic event detection algorithm analyzed the vertical velocity ground motions at several sites to detect seismic events. During the two largest nearby earthquakes—the *M*6.5 December 22, 2003 San Simeon earthquake and the *M*6.0 September 28, 2004 Parkfield earthquake—the ground motions exceeded the limits of the velocity sensors long enough to cause the data acquisition system to stop and restart the recording of these events two or three times. The records for these two earthquakes are in several overlapping segments.

The PKDA dataset contains the records of the San Simeon and Parkfield earthquakes in multiple segments as they were recorded. However, in the Additional Material collection of significant earthquakes (see the Plum List section), these records have been spliced into a single record for each earthquake.

The ground shaking during those two earthquakes continued unabated for so long that the records contain data not only from the mainshock, but the embedded data from immediate aftershocks and other locally triggered seismicity as well.

Dataset File Formats

The UPSAR raw data Playback program reads the raw data files produced by the data acquisition minicomputer system. All the files in the DATA directory (S, C, T, and D files) are processed in alphabetical order, which must also be chronological order. For each event, a number of quality checks are performed on the data, some simple statistics are calculated, the first few seconds of raw vertical velocity data (A/D counts) are plotted, and the ground motion time series data are written to USGS DR100 format data files.

There is no database of instrument parameters; they are refreshed every time the UPSAR raw data Playback program reads a station parameter file (S file). Those instrument parameter values are used to fill in the header fields in the DR100 data files for every event until another station parameter file is read (for this reason, all files in the DATA directory must be processed in chronological order).

The format of each file generated by the UPSAR raw data Playback program is described below. Most of the examples are taken from the original (unspliced) *M*6.0 September 28, 2004 Parkfield earthquake mainshock record.

Listing File (.lis) Format

The listing file has 12 sections. However, section 9 appears only if there are errors. Figure 6 shows excerpts of a file with no errors ("04272171527400.lis"). Figure 7 shows excerpts of a file with errors ("89291000442.lis").

Station Parameter File (S File) Sections

The first five sections in the listing file are from the station parameter file (S file) that was used to obtain the site and instrument parameters for the DR100 data files (the S file encountered most recently in the DATA directory):

- Section 1 is the heading listing the station parameter file name.
- Sections 2–5 contain the site and instrumentation parameters (tables 4–7). As previously noted, ***the GPS locations in table 2 should be used in place of the original surveyed locations contained in the DR100 files.***

```
USGS Parkfield Dense Array Playback Program                  29-MAR-2009 06:41:39.08                         Page    1
File 042681918.36S

File 042681918.36S                                                                                                  1
```

```
Site ? _SID __Latitude _Longitude _Elevation N-offset E-offset V-offset
P01  Y    1    35.8240  -120.5021      602.3   -304.7   -370.2    -19.0
P02  Y    2    35.8240  -120.5021      602.3   -210.6   -296.3    -22.1
P03  Y    3    35.8240  -120.5021      602.3   -285.1   -191.9    -19.2
P04  N    4    35.8240  -120.5021      602.3   -180.7     37.0    -12.9
P05  Y    5    35.8240  -120.5021      602.3    -14.8    -20.1     -2.1
P06  Y    6    35.8240  -120.5021      602.3      0.0      0.0      0.0
P07  Y    7    35.8240  -120.5021      602.3    -10.1     22.9      3.7                                          2
```

```
Site Comp Type Serial Theta Phi ____Freq ____Damp ____Coil          Site Comp Type Serial Theta Phi ____Freq ____Damp ____Coil
P01     1 FBA   23478     0   0    101.2     0.66    .0051                   3 FBA   22153    90  90    100.4     0.65    .0051
        2 FBA   23477    90   0    100.2     0.65    .0051                   4 VEL    1498     0   0    2.233      0.7    1.169
        3 FBA   23479    90  90    101.8     0.63    .0051                   5 VEL    1530    90   0    2.357      0.7    1.164
        4 VEL    1492     0   0    2.228      0.7    1.120                   6 VEL    1521    90  90    2.056      0.7    1.082
        5 VEL    1516    90   0    2.264      0.7    1.177          P08      1 FBA   23472     0   0    102.9     0.64    .0051
        6 VEL    1517    90  90    2.175      0.7    1.046                   2 FBA   23471    90   0    101.9     0.64    .0051
P02     1 FBA   23448     0   0    100.4     0.64    .0051                   3 FBA   23473    90  90     98.4     0.64    .0051
        2 FBA   23447    90   0    101.8     0.65    .0051                   4 VEL    1497     0   0    2.211      0.7    1.124      3
```

```
_SID Serial
   1    013
   2    014                                                                                                         4
```

```
_SID Comp __XAtten ___XGain Corner Roll Counts/V                     _SID Comp __XAtten ___XGain Corner Roll Counts/V
   1    1        1        1     50    6   4000.0                             5        1      128     50    6   4000.0
        2        1        1     50    6   4000.0                             6        1      128     50    6   4000.0
        3        1        1     50    6   4000.0                        7    1        1        1     50    6   4000.0
        4        1      128     50    6   4000.0                             2        1        1     50    6   4000.0
        5        1      128     50    6   4000.0                             3        1        1     50    6   4000.0
        6        1      128     50    6   4000.0                             4        1      128     50    6   4000.0
   2    1        1        1     50    6   4000.0                             5        1      128     50    6   4000.0
        2        1        1     50    6   4000.0                             6        1      128     50    6   4000.0     5
```

Figure 6. Image showing excerpts from a listing file with no errors (04272171527400.lis). The numerals in the lower-right corners are the section numbers discussed in the text.

```
USGS Parkfield Dense Array Playback Program                        29-MAR-2009 06:41:39.08                         Page    4
File 042721715.27400D

File 042721715.27400D
```

6

```
Recording  on at 272-17:15:25.400
Trigger       at 272-17:15:27.400
Recording off at 272-17:15:38.200

Duration                 0:13.000
```

7

```
Name        P01  P02  P03  P04  P05  P06  P07  P08  P09  P10  P11  P12  P13
Alive?      Yes  Yes  Yes  No   Yes  Yes  Yes  Yes  Yes  Yes  Yes  Yes  Yes
Station ID  01   02   03   04   05   06   07   08   09   0A   0B   0C   0D
Firmware    2.20 2.20 2.20      2.20 2.20 2.20 2.20 2.20 2.20 2.20 2.20 2.20
Reconfigs     0    0    0         0    0    0    0    0    0    0    0    0
Resets        0    0    0         0    0    0    0    0    0    0    0    0
Errors        0    0    0         0    0    0    0    0    0    0    0    0

  65 blocks read,    0 with missing data or timestamp errors.
```

8

```
Name SID Ch   Clipped       Glitch     Total Bad      Frozen    Total Good  Intercept      Slope        Peak        Recon Reset

P01    1  1     0 (   0)      0 (   0)     0 (   0)    269 ( 10)   2599 (100)    623.5           0.0        1802          0     0
          2     0 (   0)      0 (   0)     0 (   0)    234 (  9)   2599 (100)    -82.3           0.0        2746
          3     0 (   0)      0 (   0)     0 (   0)    301 ( 11)   2599 (100)    382.9           0.0        3674
          4   917 ( 35)*    329 ( 12)*  1246 ( 47)*    952 ( 36)*  1353 ( 52)* -5789.9    *   -14.4     * 38474      *
          5   847 ( 32)*    390 ( 15)*  1237 ( 47)*    987 ( 37)*  1362 ( 52)* -4312.2    *   -15.2     * 36898      *
          6   907 ( 34)*    322 ( 12)*  1229 ( 47)*   1036 ( 39)*  1370 ( 52)* -4422.1    *   -15.2     * 37143      *
P02    2  1     0 (   0)      0 (   0)     0 (   0)    267 ( 10)   2599 (100)    106.9           0.0        1748          0     0
          2     0 (   0)      0 (   0)     0 (   0)    246 (  9)   2599 (100)   -633.4           0.0        3475
```

10

Figure 6. Image showing excerpts from a listing file with no errors (04272171527400.lis).—Continued

```
USGS Parkfield Dense Array                                      UTC 272-17:15:27

Log File: PUB1:[PKDA.LOG_FILES]042681918.36L;1                  Up  003-21:56:51

Process    SAMPLR   TRIGGR   DELAY    WRITER   MONITR   BUFMGR   MSGMGR
Buffers        2        0       11       12        0      571        0
Pending        0        0        0       11        0        0        0
Pct Busy       0       21        0      545        0        0       57

    Auto Trg Mode      585 Buffers     300.0 STA (ms)        4 Trg Votes
  Eqk On Trg State    6668 Bufr size    20.0 LTA (sec)       2 Vote Lasts
      24 Triggers       10 Leader         On LTA Hold      100 Max pendng
Disabled Mon State      50 Trailer      12.0 STA/LTA        40 Max FS
       0 Errors                         50.0 Detrg Pct       3 Median

Name Stn/Cmp Vote STA   LTA   Pct FS    Name Stn/Cmp Vote STA   LTA   Pct FS
P01    1/4   * 1  2636     2  93/  0    P04    4/4           0 32767 100/100
P02    2/4   * 1  2452     1  95/  0    P05    5/4        2229     2  90/  0
P03    3/4   * 1  2899     2  98/  0    P06    6/4        2720     1  93/  0
P07    7/4   * 1  1165     1  98/  0    P09    9/4        1092     1  95/  0
P08    8/4     1   665     1  98/  0    P12   12/4        3065     1  88/  0
P10   10/4     1  1158     1  98/  0
P11   11/4   * 1  2428     1  85/  0
P13   13/4     1  2505     1 100/  0
P14   14/4     1     0 32767   0/  0
```

11

```
Creating 2721715J1.P01.          Creating 2721715J1.P05.          Creating 2721715J1.P08.          Creating 2721715J1.P11.
Creating 2721715J2.P01.          Creating 2721715J2.P05.          Creating 2721715J2.P08.          Creating 2721715J2.P11.
Creating 2721715J3.P01.          Creating 2721715J3.P05.          Creating 2721715J3.P08.          Creating 2721715J3.P11.
```

12

Figure 6. Image showing excerpts from a listing file with no errors (04272171527400.lis).—Continued

```
USGS Parkfield Dense Array Playback Program                    22-MAR-2009 00:42:08.39              Page    4
File 892910004.42D
File 892910004.42D
```
6

```
Recording  on at 291-00:04:40.830
Trigger       at 291-00:04:42
Recording off at 291-00:07:09.600
Duration                2:29.000
```
7

```
Name         P01  P02  P03  P04  P05  P06  P07  P08  P09  P10  P11  P12  P13  P14
Alive?       Yes  Yes  Yes  Yes  Yes  Yes  Yes  Yes  No   No   No   Yes  Yes  Yes
Station ID   01   03   05   07   06   0D   0F   02   04   09   08   0A   0C   0E
Firmware     1.60 1.60 1.60 1.60 1.60 1.60 1.60 1.60                1.60 1.60 1.60
Reconfigs     13   13   13   13   13   13   13   13                  13   13   13
Resets         0    0    0    0    0    0    0    0                   0    0    0
Errors         0    0    0    5    7   20    0    0                   0    0    0

Note: Firmware versions prior to 1.61 do not define a time sync status flag in the data packet header.
 745 blocks read,   28 with missing data or timestamp errors.
```
8

```
Block   47, sid 0D (P06 ):  expecting 291-00:04:50.165
                            found     291-00:04:50.170
Block   92, sid 06 (P05 ):  expecting 291-00:04:59.070
                            found     291-00:04:59.075
Block  117, sid 07 (P04 ):  expecting 291-00:05:04.065
                            found     291-00:05:04.070
Block  132, sid 06 (P05 ):  expecting 291-00:05:07.075
                            found     291-00:05:07.080
Block  162, sid 07 (P04 ):  expecting 291-00:05:13.070
                            found     291-00:05:13.075
Block  177, sid 0D (P06 ):  expecting 291-00:05:16.170
                            found     291-00:05:16.175
Block  232, sid 06 (P05 ):  expecting 291-00:05:27.080
                            found     291-00:05:27.085
Block  232, sid 0D (P06 ):  expecting 291-00:05:27.175
                            found     291-00:05:27.180
Block  247, sid 0D (P06 ):  expecting 291-00:05:30.180
                            found     291-00:05:30.185
Block  262, sid 0D (P06 ):  expecting 291-00:05:33.185
                            found     291-00:05:33.180
Block  292, sid 06 (P05 ):  expecting 291-00:05:39.085
                            found     291-00:05:39.090
Block  317, sid 07 (P04 ):  expecting 291-00:05:44.075
                            found     291-00:05:44.080
Block  377, sid 0D (P06 ):  expecting 291-00:05:56.180
                            found     291-00:05:56.185
Block  432, sid 06 (P05 ):  expecting 291-00:06:07.090
                            found     291-00:06:07.095
Block  452, sid 0D (P06 ):  expecting seqnum 620F
                            found     seqnum 6214
Block  457, sid 0D (P06 ):  missing   291-00:06:12.185
                            through   291-00:06:12.985
Block  462, sid 07 (P04 ):  expecting 291-00:06:13.080
                            found     291-00:06:13.085
Block  462, sid 0D (P06 ):  expecting seqnum 621E
                            found     seqnum 6219
Block  532, sid 0D (P06 ):  expecting 291-00:06:27.185
                            found     291-00:06:27.190
Block  547, sid 0D (P06 ):  expecting 291-00:06:30.190
                            found     291-00:06:30.195
Block  562, sid 0D (P06 ):  expecting 291-00:06:33.195
                            found     291-00:06:33.190
Block  577, sid 0D (P06 ):  expecting 291-00:06:36.190
                            found     291-00:06:36.195
Block  592, sid 06 (P05 ):  expecting 291-00:06:39.095
                            found     291-00:06:39.100
Block  617, sid 07 (P04 ):  expecting 291-00:06:44.085
                            found     291-00:06:44.090
Block  716, sid 0D (P06 ):  missing   291-00:07:03.995
Block  717, sid 0D (P06 ):  expecting 291-00:07:04.195
                            found     291-00:07:04.000
Block  717, sid 0D (P06 ):  expecting seqnum 6318
                            found     seqnum 6317
Block  732, sid 06 (P05 ):  expecting 291-00:07:07.100
                            found     291-00:07:07.105
```
9

Figure 7. Image showing excerpts from a listing file with errors (89291000442.lis). The numerals in the lower-right corners are the section numbers discussed in the text.

Data File (D File) Sections

The last seven sections in the listing file describe the event raw data file (D file):

- Section 6 is the heading listing the raw data file name.
- Section 7 contains the start time, stop time, trigger time, and duration. The start time and stop time are obtained from the time stamps in the headers of the data buffers in the raw data file. The trigger time is inferred from the raw data file name; UPSAR did not separately record the trigger time within the raw data file.
- Section 8 contains information about the seismographs (stations) that were operating and summarizes the quality of the data from each one (table 8). The "Alive?" entry indicates whether a station was supposed to be operating. The entries for "Firmware", "Reconfigs", "Resets", and "Errors" appear only if a station was actually operating.
- Section 9 is the error log. It appears only if errors were found. It is discussed separately in the sections that follow.
- Section 10 is a table of statistics (table 9).
- Section 11 is a simulation of the UPSAR Display program console status screen. It approximates what the status display would have looked like at the time of the trigger.
- Section 12 is a log of the names of the DR100 data files created.

Table 4. Station parameter file section 2: site parameters.

Site	Site (station) name (P01, P02, and so forth)
?	Site operating status (Y, yes; N, no)
SID[1]	ARCnet network station ID (1–15)
Latitude[2]	Latitude of reference site (P06)
Longitude[2]	Longitude of reference site (P06)
Elevation[2]	Meters elevation of reference site (P06)
N-offset[2]	Meters north of reference site (P06)
E-offset[2]	Meters east of reference site (P06)
V-offset[2]	Meters up from reference site (P06)

[1]SID 15 was rewired to be SID 11 on December 17, 1989 (89-351).

[2]Obsolete values from the original site survey (Fletcher and others, 1992). ***The GPS locations in table 2 should be used in place of the original surveyed locations contained in the DR100 files.***

Table 5. Station parameter file section 3: sensor parameters.

[A/D, analog-to-digital]

Site	Site (station) name (P01, P02, and so forth)
Comp	Component (A/D channel) number (1–6)
Type	Sensor type (FBA for accelerometer or VEL for geophone)
Serial	Sensor serial number
Theta[1]	Vertical orientation (positive direction, degrees down from up)
Phi[1]	Horizontal orientation (positive direction, degrees clockwise from north)
Freq[2]	Natural frequency (in Hertz)
Damp[2]	Damping coefficient (percent of critical)
Coil[2]	Coil constant (volts/motion-unit: volts/cm/s^2 or volts/cm/s)

[1]The FBA and geophone assemblies were oriented so that the first horizontal component pointed to geographic north (Fletcher and others, 1992).

[2]The method of Asten (1977) was used to calibrate the geophones. Factory calibrations were used for the FBAs (Fletcher and others, 1992).

Table 6. Station parameter file section 4: seismograph parameters.

SID	ARCnet network station ID (1–15)
Serial	Seismograph serial number

Table 7. Station parameter file section 5: digitizer parameters.

[A/D, analog-to-digital]

SID	ARCnet network station ID (1–15)
Comp	Component (A/D channel) number (1–6)
XAtten[1]	Fixed preamplifier attenuation (ratio)
XGain[1]	Programmable preamplifier gain (ratio)
Corner[1]	Butterworth anti-alias filter corner frequency (in Hertz)
Roll[1]	Butterworth anti-alias filter roll-off (in decibels/octave)
Counts/V[1]	Digitizing constant (counts/volt)

[1]Values are from the manufacturer (Fletcher and others, 1992).

Table 8. Data file section 8: station operation and data quality summary.

[A/D, analog-to-digital]

Name	Site (station) name (P01, P02, and so forth)
Alive?	Station should be alive? (Yes or No; from the station parameter file)
Station ID	ARCnet network station ID (1–15)
Firmware	Seismometer firmware version number
Reconfigs	Number of ARCnet network reconfiguration events
Resets	Number of seismograph resets (A/D buffer starvation)
Errors	Number of errors

Table 9. Data file section 10: data statistics.

[A/D, analog-to-digital]

Name	Site (station) name (P01, P02, and so forth)
SID	ARCnet network station ID (1–15)
Ch	Component (A/D channel) number (1–6)
Clipped	Number of positive and negative full-scale values
Glitch	Number of jumps in the data value (more than 2000 or less than −2000 counts from the previous data value)
Total Bad	Sum of Clipped and Glitch
Frozen	Number of frozen values (consecutive good values that are the same)
Total Good	Total number of values minus the number of Total Bad values
Intercept	Intercept of linear fit
Slope	Slope of linear fit
Peak	Peak absolute value (counts) of the differences from the linear fit
Recon	Number of ARCnet network reconfiguration events
Reset	Number of seismograph resets (A/D buffer starvation)

Data File Errors Section

The UPSAR raw data Playback program examines the sequence of ARCnet data packets from every station for errors. Not all errors make the time-series data unusable. If there are errors, however, caution must be exercised before proceeding to use the data.

Errors are reported (fig. 7, section 9) in order by the raw data file record (block) number, station ID (in hexadecimal) and site name (in parentheses). For example,

```
Block   47, sid 0D (P06 ):  expecting 291-00:04:50.165
                            found     291-00:04:50.170
```

Each block of data contains a single data buffer from the minicomputer data acquisition system. (The data acquisition system originally wrote data files directly to tape. A physical record on a tape is called a block. The Playback program reads raw data from either tape or disk, and preserves the original terminology for both cases.)

Multiple errors in the same data block appear consecutively,

```
Block  232, sid 06 (P05 ):  expecting 291-00:05:27.080
                            found     291-00:05:27.085
Block  232, sid 0D (P06 ):  expecting 291-00:05:27.175
                            found     291-00:05:27.180
```

As do multiple errors from the same station in the same block,

```
Block  717, sid 0D (P06 ):  expecting 291-00:07:04.195
                            found     291-00:07:04.000
Block  717, sid 0D (P06 ):  expecting seqnum 6318
                            found     seqnum 6317
```

Some errors can span multiple blocks. When that happens, a second line with the ending time appears below the line with the error message text and the starting time,

```
Block  457, sid 0D (P06 ):  missing   291-00:06:12.185
                            through   291-00:06:12.985
```

The following sections describe the types of errors reported by the UPSAR raw data Playback program, along with a sample error message. Only data dropouts, bad gains, and time sequence errors are included in the count of blocks "with missing data or timestamp errors" (fig. 7, section 8).

Data dropout

```
Block  457, sid 0D (P06 ):  missing   291-00:06:12.185
                            through   291-00:06:12.985
```

Missing data (dropouts) are flagged in a DR100 data file with a special "undefined" data value (see the DR100 Data File Format section). The data can still be used, as long as the analysis program correctly handles undefined values in the time-series data.

Data dropouts are counted as missing data.

Bad gain

```
Block 1011, sid 0C (P12 ):  bad gain  025-21:43:20.000
                            through   025-21:50:09.000
```

The preamplifier gains were programmable and were set by the data acquisition software to match the settings in the current station parameter file. They should never have changed while the array was operating. If a gain changed, a malfunction occurred.

Bad gains are counted as missing data.

There were instances in which the preamplifier gain value did not change, but was not the expected value. In those cases, no error occurs. Instead, a warning message is printed indicating the gain value found will be used instead of the expected value.

```
Warning: Station ID 01 (P01 ), channel 1: expecting XGain   1, found   8
(actual XGain will be used).
```

Wrong slot time

```
Block    1, sid 01 (P01 ):  slot time 089-02:21:04.960
                            found     089-02:01:04.940
```

The slot time calculated for the time stamp in the ARCnet data packet header does not match the slot time of the data buffer. This could have been caused by a fault in the reception of the serial time code (for example, in the error shown above, the `01` in the minutes position should have been `21`) or erroneous behavior of the satellite time-code receiver. The data might still be usable, as long as there is no evidence of loss of time sync. However, the time stamp in the DR100 data file might be wrong if the error occurs in the first data block.

Time sequence

```
Block   47, sid 0D (P06 ):  expecting 291-00:04:50.165
                            found     291-00:04:50.170
```

The header time stamps in consecutive ARCnet data packets should sequentially increase by 200 ms. The Playback program predicts the time stamp in the next data packet header and reports when the sequence is broken.

Time sequence errors are counted as timestamp errors.

Small time sequence breaks, such as the occasional ±5 ms shift, can be ignored if there are no other indications of serious problems. The entire error log must be examined to make the best judgment.

Sequence number (firmware version 1.60 and later)

```
Block  452, sid 0D (P06 ):  expecting seqnum 620F
                            found     seqnum 6214
```

Firmware version 1.60 added a sequence number to the ARCnet data packet header. The Playback program predicts the sequence number in the next data packet header and reports when the sequence is broken. As long as there are no time sequence errors, this error is safe to ignore.

Reset (buffer overflow)

```
Block  124, sid 08 (P04 ):   1 reset(s) (buffer overflow)
```

Resets occurred when there were no free ARCnet data packet buffers for the next A/D conversion. This indicates that there was a problem with the ARCnet network. It is likely that data was lost, which would result in data dropout and time sequence errors.

Poor time-code quality (firmware version 1.60 and later)

```
Block    1, sid 01 (P01 ):  poor time 298-13:01:07.000
                            through   298-13:02:26.800
```

The time reference signal distributed throughout the array originated from a GOES (later GPS) satellite time-code receiver. Included with the serial time code (Julian day and time; no year) was a character indicating the quality of the time code. Firmware version 1.60 included the time-code quality character in the ARCnet data packet header. The Playback program reports whenever the time-code quality character changed to one of the values used to indicate that the receiver has lost its satellite signal. The satellite time-code receiver also maintained time internally using a high precision, temperature compensated oscillator. Thus, a change in time-code quality usually had no effect on the serial time code sent out. As long as there are no time sequence errors, this error is safe to ignore.

Missing time sync (firmware version 1.61 and later)

```
Block   20, sid 01 (P01 ):  no sync   265-09:51:21.400
                            through   265-09:51:23.000
```

Firmware version 1.61 added an indicator for time synchronization to the ARCnet data packet header. The Playback program expects to see the time synchronization flag within a certain period of time and reports when that does not happen. This can be caused by problems with the RS-422 time-code signal. As long as the time sequence is correct, this error is safe to ignore.

Raw Data Archive Corruption

The errors described above are the result of problems with the UPSAR instrumentation. A separate source of errors is the corruption of the raw data files themselves.

For the first few years of operation, raw data files were manually retrieved using cartridge tapes and, later, using magneto-optical cartridge disks. Raw data files were archived on magneto-optical cartridge disks. Beginning in 1996, raw data files were transmitted electronically and stored permanently online.

A few of the raw data files archived on magneto-optical disks were corrupted. When they were restored from the archive disks, they were read without any errors. However, some of the disk sectors in the files contain all zeros or all nonsense characters. When those files were read by the Playback program, several errors occurred at once, with strange symptoms, such as an ARCnet data packet header time of all zeros (not possible) and many data dropouts. (See section 6 in dr100_data.txt, described in the Additional Material, Notes section for more information.)

For example, the following few lines from file “91284025639400.lis” show two timing errors (wrong slot time and a time sequence error) for station ID 2 at block 42, caused by a disk sector containing all zeros.

```
Block   42, sid 02 (P08 ):  bad gain  284-02:56:45.600
Block   42, sid 02 (P08 ):  slot time 284-02:56:45.600
                            expecting 284-02:56:45.630
                            found     000-00:00:00.000
Block   42, sid 02 (P08 ):  expecting seqnum F617
                            found     seqnum 8000
Block   42, sid 02 (P08 ):  poor time 284-02:56:45.600
Block   42, sid 03 (P02 ):  missing   284-02:56:45.630
Block   43, sid 02 (P08 ):  expecting 000-00:00:00.200
                            found     284-02:56:45.830
Block   43, sid 02 (P08 ):  expecting seqnum 8001
                            found     seqnum F618
```

The following events were affected:

- pkda/1989/311/234309
- pkda/1990/209/110207
- pkda/1990/210/023934
- pkda/1991/047/123300
- pkda/1991/283/172036
- pkda/1991/283/185121
- pkda/1991/284/025639
- pkda/1993/171/175829
- pkda/1993/171/175900
- pkda/1993/171/181919
- pkda/1993/171/201719

The data that was recovered for these events is likely correct, but the missing parts of the time-series data in the DR100 files have been encoded as “undefined” data values that must be properly handled.

Summary File (.sum) Format

The summary file has six sections. Figure 8 shows the summary file (“04272171527400.sum”) for the same event as the listing file in figure 6.

- Section 1 lists the station parameter file name.
- Section 2 lists the raw data file name and provides space to write notes on a paper copy, such as the earthquake latitude (Lat), longitude (Lon), and magnitude (Mag).
- Sections 3 and 4 are the same as sections 7 and 8 in the listing file, respectively.
- Section 5 is a table of the station names, station IDs, unsigned peak A/D counts (maximum deviation from the average value) by channel number, and the reconfiguration and reset counts by site (station) from section 10 of the listing file.
- Section 6 is the number of raw data files processed by the UPSAR raw data Playback program.

```
042681918.36S                                                                                    1
```

```
 042721715.27400D  Trigger Eqk ___  Man ___  mW ___  VHF ___

                   Lat __________  Lon __________  Mag _____                                      2
```

```
                   Recording  on at 272-17:15:25.400
                   Trigger       at 272-17:15:27.400
                   Recording off at 272-17:15:38.200

                   Duration                0:13.000                                               3
```

```
                   Name        P01  P02  P03  P04  P05  P06  P07  P08  P09  P10  P11  P12  P13
                   Alive?      Yes  Yes  Yes  No   Yes  Yes  Yes  Yes  Yes  Yes  Yes  Yes  Yes
                   Station ID  01   02   03   04   05   06   07   08   09   0A   0B   0C   0D
                   Firmware    2.20 2.20 2.20      2.20 2.20 2.20 2.20 2.20 2.20 2.20 2.20 2.20
                   Reconfigs     0    0    0         0    0    0    0    0    0    0    0    0
                   Resets        0    0    0         0    0    0    0    0    0    0    0    0
                   Errors        0    0    0         0    0    0    0    0    0    0    0    0

                     65 blocks read,    0 with missing data or timestamp errors.                  4
```

```
                   Name SID  Ch 1  Ch 2  Ch 3  Ch 4  Ch 5  Ch 6 Recon Reset
                   ---- --- ----- ----- ----- ----- ----- ----- ----- -----
                   P01    1  1802  2746  3674 38474 36898 37143     0     0
                   P02    2  1748  3475  6132 27206 27737 37368     0     0
                   P03    3  2133  2952  5080 30474 32389 32309     0     0
                   P05    5  3677  4776  7333 38222 37205 38813     0     0
                   P06    6  2248  4511  4935 37847 38255 38292     0     0
                   P07    7  3821  7523  6516 31344 37660 26361     0     0
                   P08    8  2694  3714  5154 31283 34161 26570     0     0
                   P09    9  2723  4090  5616 26384 35155 37117     0     0
                   P10   10  3463  5549  6146 25446 26953 26068     0     0
                   P11   11  4802  7200  9421 32951 27180 25372     0     0
                   P12   12  2300  4947  4563 36984 37285 31044     0     0
                   P13   13  3322  4631  5950 25806 33879 25668     0     0                      5
```

```
  1 raw data files processed.                                                                    6
```

Figure 8. Image showing a summary file (04272171527400.sum) for the same event as the listing file in figure 6. The numerals in the lower-right corners are the section numbers discussed in the text.

PDF Plot File (.pdf)

Figure 9 shows the PDF plot file ("04272171527400.pdf") for the same event as the listing file in figure 6. Only the first twelve seconds (two seconds before and ten seconds after the trigger) of the vertical velocity component (number 4) data is plotted. Dotted vertical lines bracket the time window during which the trigger threshold was crossed. The vertical scale is fixed at 4,000 counts/in. The traces are artificially clipped to prevent overlap in the plots. (The data in traces that are clipped in the plot are not necessarily off-scale.)

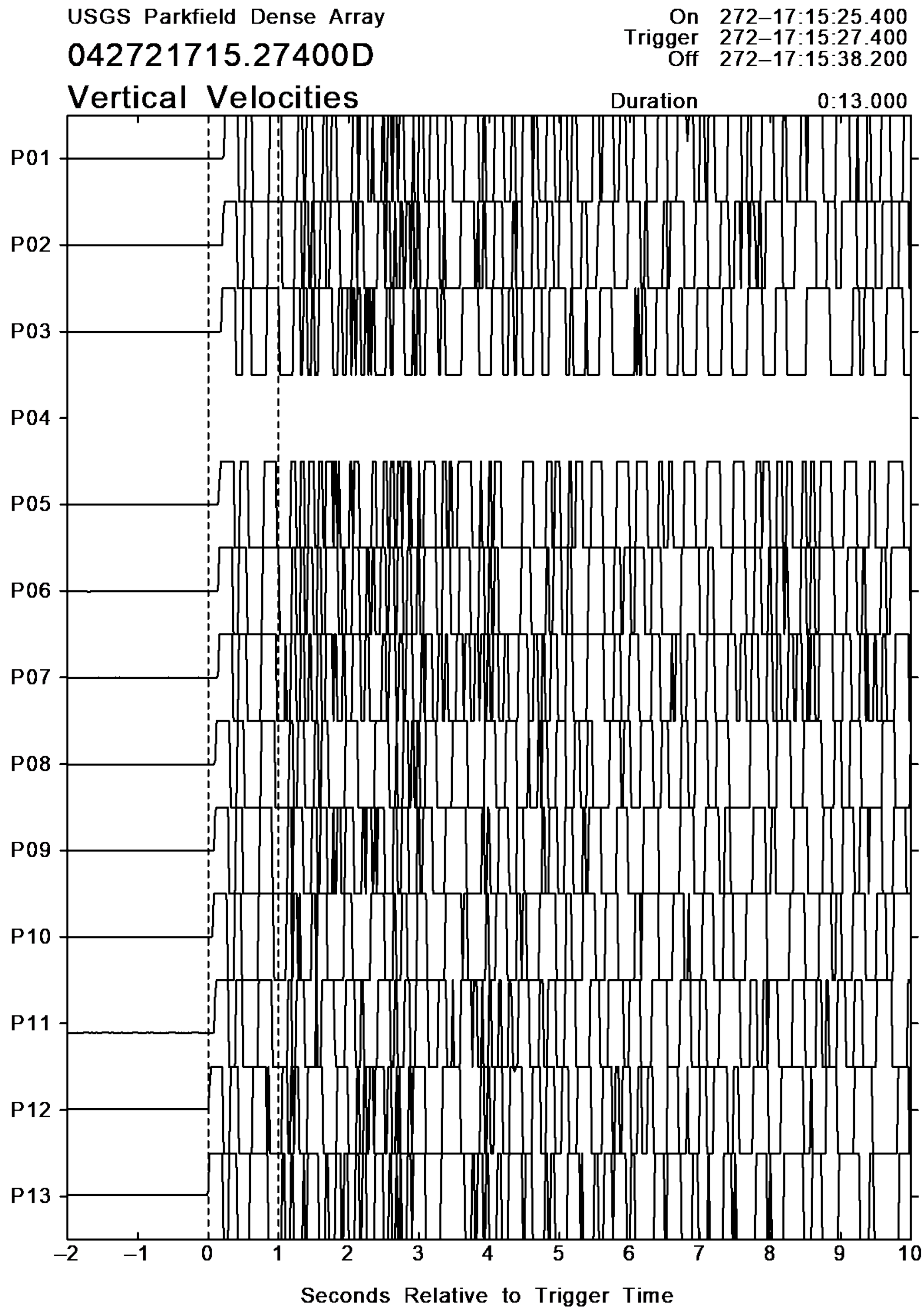

Figure 9. Image showing a PDF plot file (04272171527400.pdf) for the same event as the listing file in figure 6.

ARCnet Headers File (headers.sid*NN*) Format

An excerpt of an ARCnet headers file for station ID 10 (hexadecimal 0A) is shown in figure 10. The first few lines identify the UPSAR raw data file name, ARCnet network station ID, and the firmware version of the seismograph.

The early firmware versions did not include a firmware version field in the ARCnet data packet header. The firmware version was deduced from the packet header values by the UPSAR raw data Playback program. Until an ARCnet data packet from a station is found, the Playback program lists the station's firmware version as "unknown". Each time the Playback program changed its interpretation of a station's firmware version, it wrote a line in the ARCnet headers file noting the change.

Following the firmware version are column headings for the ARCnet data packet header fields. The fields in the headers (table 10) depend on the firmware version. Beneath the headings, the header fields are dumped, in hexadecimal, along with the decoded time, battery voltage, and status fields, for each block (or data buffer) in the file.

Time Stamps File (timestamps.lis) Format

An excerpt of a time stamps file is shown in figure 11. The first few lines identify the UPSAR raw data file name. Following that are column headings for the data buffer slot time and the ARCnet network station IDs ("sid *nn*"). Beneath the headings are the data buffer slot time and the binary-coded decimal (BCD) time stamps from the ARCnet data packet headers for each station.

```
---------------------------------------------------------------------------------------------------------------------------

File 042721715.27400D, Station ID 0A

---------------------------------------------------------------------------------------------------------------------------

Firmware version is 2.2

         did     serno                                     sync   d/a    batt   txerr reset                          E  T NR
block sid  length           time            gains      revno rxerr  qual     press  wait  stat     time stamp   volts .V..S.XC
----- -- -- ---- ---- -------------- ----------------- ---- -- -- -- -- ---- ---- -- -- -- --  ---------------- ---- --------
    1  0A F1 0400 000A 2127 5271 2554 00 00 00 03 03 03 CD46 22 00 95 20 69BE 5E42 00 00 00 00  272-17:15:25.425 13.5 ........
    2  0A F1 0400 000A 2127 5271 2556 00 00 00 03 03 03 CD47 22 00 95 20 69C2 5E44 00 00 00 00  272-17:15:25.625 13.5 ........
    3  0A F1 0400 000A 2127 5271 2558 00 00 00 03 03 03 CD48 22 00 95 20 69C4 5E43 00 00 00 00  272-17:15:25.825 13.5 ........
    4  0A F1 0400 000A 2127 5271 2560 00 00 00 03 03 03 CD49 22 00 97 20 69C1 5E44 00 00 00 08  272-17:15:26.025 13.5 ....T...
    5  0A F1 0400 000A 2127 5271 2562 00 00 00 03 03 03 CD4A 22 00 97 20 69C0 5E44 00 00 00 00  272-17:15:26.225 13.5 ........
    6  0A F1 0400 000A 2127 5271 2564 00 00 00 03 03 03 CD4B 22 00 97 20 69C3 5E43 00 00 00 00  272-17:15:26.425 13.5 ........
    7  0A F1 0400 000A 2127 5271 2566 00 00 00 03 03 03 CD4C 22 00 97 20 69C2 5E43 00 00 00 00  272-17:15:26.625 13.5 ........
    8  0A F1 0400 000A 2127 5271 2568 00 00 00 03 03 03 CD4D 22 00 97 20 69C2 5E43 00 00 00 00  272-17:15:26.825 13.5 ........
    9  0A F1 0400 000A 2127 5271 2570 00 00 00 03 03 03 CD4E 22 00 97 20 69C5 5E44 00 00 00 08  272-17:15:27.025 13.5 ....T...
   10  0A F1 0400 000A 2127 5271 2572 00 00 00 03 03 03 CD4F 22 00 97 20 69C4 5E43 00 00 00 00  272-17:15:27.225 13.5 ........
```

Figure 10. Image showing an excerpt from an ARCnet headers file for Station ID 10 (hexadecimal 0A).

```
-----------------------------------------------------------------------------------------------------------------------------

File 042721715.27400D

-----------------------------------------------------------------------------------------------------------------------------

block      slot time         sid 01       sid 02       sid 03       sid 04       sid 05       sid 06       sid 07       sid 08
-----  ----------------  ------------ ------------ ------------ ------------ ------------ ------------ ------------ ------------
    1  272-17:15:25.400  272171525420 272171525420 272171525425              272171525425 272171525425 272171525425 272171525425
    2  272-17:15:25.600  272171525620 272171525620 272171525625              272171525625 272171525625 272171525625 272171525625
    3  272-17:15:25.800  272171525820 272171525820 272171525825              272171525825 272171525825 272171525825 272171525825
    4  272-17:15:26.000  272171526020 272171526020 272171526025              272171526025 272171526025 272171526025 272171526025
    5  272-17:15:26.200  272171526220 272171526220 272171526225              272171526225 272171526225 272171526225 272171526225
```

Figure 11. Image showing an excerpt from a time stamps file.

Table 10. ARCnet header file data packet header fields.

[D/A, digital-to-analog; BCD, binary-coded decimal]

Byte	Label	C variable name	Description
0	sid	char sid	ARCnet Source ID (ARCnet network station ID)
1	did	char did	ARCnet Destination ID (should always be `F1`)
2–3	length	short length	ARCnet packet data field offset/length (should always be `0400`)
4–5	serno	short ser_num	Seismograph serial number
6–11	time	Binary format: long sec short msec BCD format: char time[6]	Time (ver. 1.8 and earlier: binary format; ver. 1.9 and later: BCD format) (N.b., ver. 1.6x and earlier actually used the sec/msec time-code format in their ARCnet data packets, and ver. 1.7 and later used the BCD time-code format. The data acquisition software reformatted the time stamps for ver. 1.7 and ver. 1.8 on the fly to the ver. 1.6x format while there were still ver. 1.6x seismographs in use.)
12–17	gains	char gain[6]	Preamplifier gain settings
18–23	unknown	–	Undefined (firmware version cannot be determined)
18–23	relays	char relay[6]	Test relay settings (ver. 1.5x; should always be `00`)
18–19	seqno	short seq_num	Sequence number (ver. 1.60 and later; mislabeled as revno for ver. 1.7 and later)
20	sync	char tim_rcv_flg	Time synchronization occurred (ver. 1.61 and ver. 1.62)
20	revno	char ver_number	Firmware version (ver. 1.7 and later; mislabeled as sync)
21	rxerr	char ser_err_cnt	Time-code RS-422 receive error count (ver. 1.61 and later)
22	d/a	char da_val	D/A correction value in 1-Hz oscillator circuit (ver. 1.61 and later)
23	qual	char q_factor	Time-code quality from satellite receiver (ver. 1.60 and later)
24–25	batt	short batvlt	Battery voltage
26–27	press	short presur	Internal case air pressure (not used)
28	txerr	char xmt_cnt	ARCnet data packet retransmit count
29	wait	char buf_wt	Number of ARCnet data packets waiting
30	reset	char atd_rst	Seismograph reset count
31	stat	char status	Status bits (broken out on the right): EV Event trigger (not used) TS Time synchronization occurred (ver. 1.7 and later) NX ARCnet unsuccessful transmit occurred RC ARCnet reconfiguration occurred

DR100 Data File (*DDDHHMMSc.stn*) Format

Each DR100 data file contains a single component of ground motion.

DR100 data files are named by the UTC trigger time (or segment start time for continuous data), in the form *DDDHHMMSc.stn*, where *DDD* is the Julian day, *HH* is the hour, *MM* is the minute, the single character *S* is an abbreviation for the second, using the alphabet from A through T to represent the three-second intervals from 0–2, 3–5, and so forth. *c* is the component (channel) number (1–6): 1–3 are acceleration and 4–6 are velocity. *stn* is the 3-character station name: P01, P02, and so forth. Letter case is not significant.

The name given to a DR100 data file is a convention only. Do not rely on the name, for example, as the time of the first data sample; the values in the headers must be used. ***Rely only on the values in the DR100 data file headers for the time of the first data sample.***

DR100 data files are a sequence of 512-byte records (blocks), as shown in figure 12. The first block is an integer header (256 16-bit values). The second block is a real (floating-point) header (128 32-bit values). The rest of the blocks contain binary data, in either 16- or 32-bit integer format, or 32-bit floating-point format. The headers also have some ASCII text mixed in, as Fortran-style Hollerith data. All header values and time-series data are stored in Digital VAX binary format (Baker, 2005).

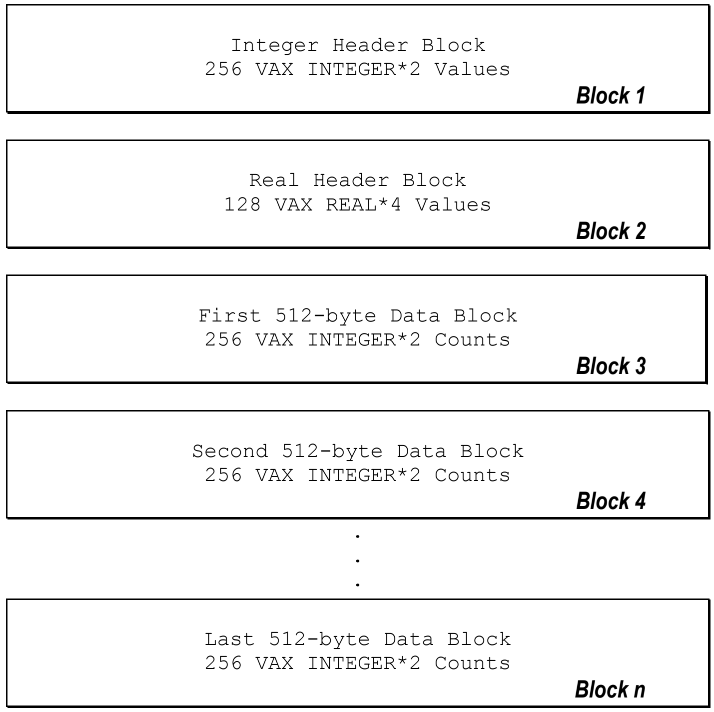

Figure 12. Image showing the UPSAR DR100 data file layout.

The integer and real header fields filled in by the UPSAR raw data Playback program are described below. Included in the data collection is a program, "dhead", that prints a summary of the DR100 data file headers (see the Additional Material, Software section). Another program, "dfile", prints the contents of a DR100 data file block by block.

DR100 format data files use centimeters (cm) as the standard unit of ground motion; units of acceleration are centimeters per second per second (cm/s^2), units of velocity are centimeters per second (cm/s), and units of displacement are centimeters.

The seismographs in the Parkfield Dense Seismograph Array independently assembled their data into 200 ms data packets, and there was no requirement for data packets to be aligned to any particular time (for example, 0, 200, 400, 600, 800 ms of each second). Thus, the time of the first data sample in a data packet can, and, usually does, vary from one station to another. The time of the first data sample in every DR100 data file must be obtained from the values in the headers of that file. ***Do not assume all the times of the first data sample are the same in all the data files for a single event.***

The DR100 data file headers contain the original (inaccurate) surveyed site locations. ***The GPS locations in table 2 should be used in place of the original surveyed locations contained in the DR100 files.***

DR100 Data File Integer Header

The first 512-byte block in a DR100 data file is the integer header. The integer header is a VAX Fortran INTEGER*2 (16-bit) array of 256 elements (table 11). Unused header fields are filled with the “undefined” integer value, element 3 (−32768).

Table 11. UPSAR DR100 data file integer header fields.

[Footnotes are shared between tables 11 and 12]

Index	Value	Description
1	0	Number of extra Integer header blocks (block size is 512 bytes)
2	0	Number of ASCII header blocks (block size is 512 bytes)
3	−32768	“Undefined” Integer value (INULL)
4	−2	Data type (+, Real; −, Integer: ABS(), bytes/sample)
5	1	DR100 Header version number
		Time of the first data sample (not including the sample lag from Real header 6):
10	time[1]	Year
11	time[1]	Julian day
12	time[1]	Hour
13	time[1]	Minute
14	time[1]	Second
15	time[1]	Millisecond
16	0	Microsecond
20	Serial[4]	Serial number of recording unit
27	1	First active channel number recorded on unit
28	*	Actual channel number as recorded on unit
29	6	Total number of channels recorded on unit
30	6	Total number of components recorded for station ID
31	*	Number of data records that follow
32	*	Index of last sample in last record
33	512	Record size (in bytes)
34	3	Playback program ID
35	2	Playback program version
36	2	Playback program sub-version
37	3	Recorder type
38	revno[1,*]	Recorder version (firmware version)
39	revno[1,*]	Recorder sub-version (firmware sub-version)
40	Serial[3]	Sensor unit serial number
41	Theta[3]	Vertical orientation (degrees down from up)
42	Phi[3]	Horizontal orientation (degrees clockwise from north)
208	401	Directory # (Study ID #)
210–216	*DDDHHMMSc.stn*[*]	ASCII filename (14 Hollerith characters)
217–219	*dataset name*[*]	ASCII study name (6 Hollerith characters)
254	Type[3]	Motion type (1, Acceleration in cm/s^2; 2, Velocity in cm/s; 3, Displacement in cm; 50, Volumetric strain)
255	*	Component number (1–3 are Acceleration, 4–6 are Velocity, 7–9 are Displacement, 1, 4, 7 Vertical)
256	*	Number of samples in event (valid *iff* Integer header 31 ≤ 128)

[1]From the first ARCnet data packet header.

[3]From the station parameter file, sensor parameters section (fig. 6, section 3).

[4]From the station parameter file, seismograph parameters section (fig. 6, section 4).

*Calculated or determined by the Playback program.

DR100 Data File Real Header

The second 512-byte block in a DR100 data file is the real header. The real header is a VAX Fortran REAL*4 (32-bit) array of 128 elements (table 12). Unused header fields are filled with the “undefined” real value, element 2 (−1E+38).

Table 12. UPSAR DR100 data file real header fields.

[Footnotes are shared between tables 11 and 12. A/D, analog-to-digital]

Index	Value	Description
1	`0`	Number of extra Real header blocks (block size is 512 bytes)
2	`-1E38`	“Undefined” Real value (RNULL)
5	`200`	Sample rate (samples per second)
6	400 µs/ch*	Component sample lag (A/D sample skew) (in seconds)
39	Type[3]	Transducer type (4 Hollerith characters)
40	Latitude[2]	Latitude (in degrees)
41	N-offset[2]	Local coordinate x (in meters north)
42	Longitude[2]	Longitude (in degrees)
43	E-offset[2]	Local coordinate y (in meters east)
44	Elevation[2]	Elevation (in meters)
45	−V-offset[2]	Local coordinate z (in meters depth)
46	Counts/V[5]	Digitizing constant (in counts/volt)
47	Corner[5]	Anti-aliasing filter corner frequency (in Hertz)
48	Roll[5]	Anti-aliasing filter roll off (in decibels/octave)
49	Freq[3]	Transducer natural frequency (in Hertz)
50	Damp[3]	Transducer damping coefficient (in percent of critical)
51	Coil[3]	Coil constant (in volts/motion-unit)
52	20 × *Log*(XAtten × XGain)[5]	Amplifier gain (in decibels)

[2]From the station parameter file, site parameters section (fig. 6, section 2). These values are inaccurate. ***The GPS locations in table 2 should be used in place of the original surveyed locations contained in the DR100 files.***

[3]From the station parameter file, sensor parameters section (fig. 6, section 3).

[5]From the station parameter file, digitizer parameters section (fig. 6, section 5).

*Calculated or determined by the Playback program.

DR100 Data File Digital Time-Series Data

In the DR100 data files created by the UPSAR raw data Playback program, the remaining 512-byte blocks are the digitized ground motion data (A/D counts), in VAX Fortran INTEGER*2 (16-bit) format (256 per block). The integer header “undefined” integer value (element 3, −32768) is used to encode missing data. ***Analysis programs must examine the time-series data for undefined values and handle them properly.***

A potential problem exists for raw data whose value is the most negative A/D counts value (NEGFS = −32768), which is the same as the value used for the “undefined” integer value. To eliminate this ambiguity, the Playback program replaces any NEGFS values with NEGFS+1.

Additional Material

In addition to the datasets described above, additional material is provided with the UPSAR data collection. This material is contained in the volume named UPSAR.

GPS Locations

The data from table 2, “UPSAR station locations, based on World Geodetic System 84” have been copied into a file named “gps_locations.txt”.

Event Lists

Four text files contain all the trigger times for each dataset: “pkda_events.lis”, “safod_events.lis”, “pkta_events.lis”, and “pkt2_events.lis”. The trigger times are to the second, one entry per line. For example, the trigger times for the three segments of the 2004 Parkfield earthquake in the file “pkda_events.lis” are:

```
2004 272-17:15:27
2004 272-17:15:28
2004 272-17:15:35
```

Plum List

Several significant earthquakes were recorded at the array (table 13). The records for these events have been copied into a directory named “plum_list”. The directory named “plum_list_CRLF” contains the same files, except the text files have MS-DOS-style line endings (an ASCII CR-LF pair) instead of Unix-style line endings (an ASCII LF) to simplify their use on a Microsoft Windows system.

The original piecemeal records of the *M*6.5 December 22, 2003 San Simeon earthquake (four segments) and the *M*6.0 September 28, 2004 Parkfield earthquake (three segments) have been spliced together there into a single record for each earthquake.

Nuclear Tests

Thirty-two nuclear tests were conducted at the Nevada Test Site during the time the array was operating (U.S. Department of Energy, 2000). Of those tests, 15 were recorded by the array (table 14). The records for these events have been copied into a directory named “nts_tests”.

Table 13. Significant earthquakes recorded by the Parkfield Dense Seismic Array.

[Latitude and longitude in decimal degrees north and west; Mag, magnitude]

Date[1]	UTC[1]	Latitude[1]	Longitude[1]	Depth[1] (m)	Mag[1]	Description	Path	Duration	Errors[2]	Clean[3]
1989/10/18	00:04:15	37.0362	121.8798	17.43	7.00	Loma Prieta mainshock	1989/291/000442	2:29.0	28	8
1992/04/25	18:06:05	40.3353	124.2287	10.55	6.69	Petrolia mainshock	1992/116/180724	6:09.2	0	9
1992/06/28	11.57:35	34.1860	116.4612	20.12	7.39	Landers mainshock	1992/180/115832	15:02.6	1	9
1992/10/20	05:28:08	35.9283	120.4740	10.08	4.36	1st 92–94 event	1992/294/052812	3:15.0	1	5
1993/04/04	05:21:25	35.9417	120.4930	7.53	4.25		1993/094/052128	3:21.8	31	0
1993/11/14	12:25:34	35.9525	120.4980	11.52	4.65	2nd 92–94 event	1993/318/122538	3:43.2	2	0
1994/01/17	12:30:54	34.2250	118.5515	14.26	6.89	Northridge mainshock	1994/017/123131	14:58.4	10	10
1994/12/20	10:27:47	35.9177	120.4647	8.98	4.90	3rd 92–94 event	1994/354/102750	4:15.8	3	12
2003/12/22	19:15:56	35.7005	121.1005	8.70	6.50	San Simeon mainshock[4]	2003/356/191606	58:56.2	0	13
2003/12/25	11:50:01	35.5438	120.8453	6.30	4.40		2003/359/115010	2:23.4	0	13
2004/09/28	17:15:24	35.8182	120.3660	8.58	5.97	Parkfield mainshock[5]	2004/272/171527	15:58.4	0	12
2004/09/28	17:24:15	35.8045	120.3498	6.44	4.71	Immediate aftershock[6]	–	–	–	–
2004/09/28	19:31:27	35.8385	120.3880	9.19	4.03	Parkfield aftershock	2004/272/193130	2:07.2	0	12
2004/09/29	17:10:04	35.9537	120.5022	11.37	5.00	Parkfield aftershock	2004/273/171007	4:24.6	0	12
2004/09/30	18:54:28	35.9880	120.5378	10.55	4.88	Parkfield aftershock	2004/274/185433	4:22.6	0	12
2004/11/19	02:56:00	35.8600	120.4083	9.17	3.72	Parkfield aftershock	2004/324/025603	2:12.2	0	12
2004/11/29	01:54:14	35.9448	120.4923	10.23	4.17	Parkfield aftershock	2004/334/015417	3:06.6	0	12

[1]Event time, hypocenter location, and magnitude from the Northern California Earthquake Data Center (2012).

[2]Number of “missing data or timestamp errors” reported by the Playback program.

[3]Number of stations with zero errors.

[4]Recorded in four segments; manually spliced into a single record.

[5]Recorded in three segments; manually spliced into a single record.

[6]Contained within the Parkfield mainshock record.

Table 14. Nuclear tests recorded by the Parkfield Dense Seismic Array.

[Latitude and longitude in decimal degrees north and west]

Date[1]	UTC[1]	Latitude[1]	Longitude[1]	Depth[2] (m)	Yield[1] (kt)	Name[1]	Path	Duration	Errors[3]	Clean[4]
1989/05/15	13:10:00	37.108	116.122	–	<20	Palisade-1/2/3 [5]	1989/135/131109–1989/135/131200	1:08.4	0	12
1989/06/27	15:30:00	37.275	116.354	–	20-150	Amarillo	1989/178/153058	2:29.4	2	12
1989/10/31	15:30:00	37.263	116.492	0.564	20-150	Hornitos	1989/304/153057	2:46.8	64	8
1989/12/08	15:00:00	37.231	116.410	0.601	20-150	Barnwell	1989/342/150104	2:57.4	0	11
1990/03/10	16:00:00	37.112	116.056	0.469	20-150	Metropolis	1990/069/160101	2:01.4	0	13
1990/06/13	16:00:00	37.262	116.421	0.674	20-150	Bullion	1990/164/160058	3:04.2	1	12
1990/07/25	15:00:00	37.207	116.215	0.389	<20	Mineral Quarry/ Randsburg	1990/206/150059	2:00.8	1	12
1990/10/12	17:30:00	37.248	116.495	0.600	20-150	Tenabo	1990/285/173057	3:28.8	1	12
1990/11/14	19:17:00	37.227	116.372	0.594	20-150	Houston	1990/318/191758	2:25.2	1	12
1991/04/04	19:00:00	37.296	116.314	0.629	20-150	Bexar	1991/094/190059	3:17.8	1	11
1991/04/16	15:30:00	37.245	116.443	0.642	20-150	Montello	1991/106/153057	2:46.8	1	10
1991/10/18	19:12:00	37.063	116.046	0.457	20-150	Lubbock	1991/291/191301	2:21.8	0	11
1991/11/26	18:35:00	37.096	116.070	0.457	<20	Bristol	1991/330/183601	0:15.0	0	10
1992/03/26	16:30:00	37.272	116.361	0.622	20−150	Junction	1992/086/163058	3:29.4	0	9
1992/09/18	17:00:00	37.207	116.211	0.385	<20	Hunters Trophy	1992/262/170100	1:05.8	0	6

[1]U.S. Department of Energy, 2000.

[2]Sean Ford, Lawrence Livermore National Laboratory, written commun., 2010.

[3]Number of "missing data or timestamp errors" reported by the Playback program.

[4]Number of stations with zero errors.

[5]Recorded in nine segments; the first arrival may be missing.

Console Log Files (L Files)

The "log_files" directory contains the console log files (L files) from the data acquisition minicomputer system. The file names were generated from the two-digit year, followed by the time (to the second) when the data acquisition system software was started.

Not every log file was preserved. In some cases, so many error messages were written to the log file that it filled all the disk space, making the data acquisition minicomputer system unusable. (This might happen, for example, when the internal batteries in a seismograph could no longer hold a charge or the battery charging circuit failed.) The only way to recover operation of the array until repairs could be made was to delete the console log file, disable the failing station in the station parameter file, and restart the array. This could be done remotely, but the log file could not be salvaged in that case.

Station Parameter Files (S Files)

The "station_parameter_files" directory contains copies of the station parameter (that is, metadata) files (S files) from the data acquisition minicomputer system. Whenever changes were made to the array, a master station parameter file, "pkda.sta", was hand edited. When the data acquisition system software was started, the contents of pkda.sta were copied for reference, along with the contents of the data acquisition system software compilation options file, "pkda.inc".

In a few cases, a required S file was missing or corrupted. In that case, the missing S file was reconstructed by hand and named with an X suffix in place of an S (see section 8 in "dr100_data.txt", described in the Additional Material, Notes section for more information).

Like the console log files, the file names were generated from the two-digit year, followed by the time (to the second) when the data acquisition system software was started.

The copies in the "station_parameter_files" directory differ slightly from the originals, which were fixed-length 80-character records with no line endings. Line endings were added to make the copies compatible with Unix, Windows PC, and Macintosh text file formats.

Software

The "software" directory contains C programs and library functions and MatLab functions to read DR100 format data files, and the Fortran data acquisition system software source.

C Programs and Library Functions

The "vfbb" subdirectory includes two command-line programs, "dhead" and "dfile", and a Fortran-callable C library, "libvfbb", with routines for reading DR100 data file headers and time-series data. There are system-specific directories for Mac OS X, Windows, Linux, and OpenVMS systems, named "macosx", "win32", "linux", and "vms", respectively. These directories contain the makefiles or command-file scripts to build the libvfbb library and dhead and dfile programs. The programs and library source files are in the "src" directory.

dhead Program

"dhead" is a command-line program that prints the DR100 data file header values (a description of all the integer and real header fields in DR100 format data files is in the C header file, "src/dr100.h"). Figure 13 shows the dhead output for one of the original records from the Parkfield earthquake (channel 1, vertical acceleration, at station P06).

```
VFBB/DR100 File Header Dump Utility V2.0                     09/23/2013 16:07:37
/Volumes/PKDA_2004(270-366)/pkda/2004/272/171527/2721715j1.p06

Start time:    2004 272-17:15:25.425000  Component no./No. components:       1/6
No. samples:                       2600  This channel no.:                     1
Block count/index:                11/40  First/total channels:               1/6
Sample rate:                      200/s  Experiment/event no.:         null/null
Sample lag:                    0.0028 s  Location number:                   null
Motion:                    Acceleration  Instrument type:                 RefTek
Transducer type:                    FBA  Recorder serial no.:                 18
Orientation--V/H (deg):             0/0  Version--instr/softw:              2/20
Sens model/ser. no.:         null/23445  Event type:                        null
Trans natural freq:              106 Hz  Trigger algorithm:                 null
Trans damping coef:                0.67  Trigger--STA/LTA:             null/null
Coil constant:                   0.0051  Trigger--chan/ratio:          null/null
Anti-alias corner freq:           50 Hz  Pre-event/post trig:          null/null
Poles of AAF:                         6  Clock standard:                    null
Amplifier gain:                    0 dB  Time since clock corr.:            null
Digitizing constant:               4000  Clock correction:                  null
Playback pgm/Data fmt:     ANZA 2.2/VAX  Battery charge:                    null
Latitude (degrees):              35.824  X offset (north):                   0 m
Longitude (degrees):          -120.5021  Y offset (east):                    0 m
Elevation:                      602.3 m  Z offset (down):                    0 m
Poles: null
Zeros: null
```

Figure 13. Image showing sample output from the dhead program.

dfile Program

"dfile" is a command-line program that prints the contents of a DR100 data file, block by block. The integer header block (block 1) and the 16-bit integer data blocks (blocks 3 to *n*) are formatted 10 entries to a line in fixed, 8-character fields (256 entries per block). The real header block (block 2) is formatted 5 entries to a line in fixed, 16-character fields (128 entries per block). Figure 14 shows a portion of the dfile output for the same record in figure 13. Shown are the DR100 data file header blocks and the first two and last time-series data blocks (A/D counts). The shaking from the Parkfield earthquake is just beginning to arrive at the end of the second data block. The last data block is padded with the "undefined" integer value (−32768) to fill out the block.

```
       0       0  -32768      -2       1  -32768  -32768  -32768  -32768    2004
     272      17      15      25     425       0  -32768  -32768  -32768      18
  -32768  -32768  -32768  -32768  -32768  -32768       1       1       6       6
      11      40     512       3       2       2       3       2      20   23445
       0       0      ??      ??      ??      ??      ??      ??      ??  -32768
  -32768  -32768  -32768  -32768  -32768  -32768  -32768  -32768  -32768  -32768
  -32768  -32768  -32768  -32768  -32768  -32768  -32768  -32768  -32768  -32768
  -32768  -32768  -32768  -32768  -32768  -32768  -32768  -32768  -32768  -32768
  -32768  -32768  -32768  -32768  -32768  -32768  -32768  -32768  -32768  -32768
  -32768  -32768  -32768  -32768  -32768  -32768  -32768  -32768  -32768  -32768
      ??      ??      ??      ??      ??      ??      ??      ??      ??      ??
      ??      ??      ??      ??      ??      ??      ??      ??      ??      ??
      ??      ??      ??      ??      ??      ??      ??      ??      ??      ??
      ??      ??      ??      ??      ??      ??      ??      ??      ??      ??
      ??      ??      ??      ??      ??      ??      ??      ??      ??      ??
      ??      ??      ??      ??      ??      ??      ??      ??      ??      ??
      ??      ??      ??      ??      ??      ??      ??      ??      ??      ??
      ??      ??      ??      ??      ??      ??      ??      ??      ??      ??
      ??      ??      ??      ??      ??      ??      ??      ??      ??      ??
      ??      ??      ??      ??      ??      ??      ??      ??      ??      ??
  -32768  -32768  -32768  -32768  -32768  -32768  -32768     401  -32768      27
      21      71      5J      1.      P0       6      PK      DA          -32768
  -32768  -32768  -32768  -32768  -32768  -32768  -32768  -32768  -32768  -32768
  -32768  -32768  -32768  -32768  -32768  -32768  -32768  -32768  -32768  -32768
  -32768  -32768  -32768  -32768  -32768  -32768  -32768  -32768  -32768  -32768
  -32768  -32768  -32768       1       1    2600
               0          -1E+38          -1E+38          -1E+38             200
          0.0028          -1E+38          -1E+38          -1E+38          -1E+38
          -1E+38          -1E+38          -1E+38          -1E+38          -1E+38
          -1E+38          -1E+38          -1E+38          -1E+38          -1E+38
          -1E+38          -1E+38          -1E+38          -1E+38          -1E+38
          -1E+38          -1E+38          -1E+38          -1E+38          -1E+38
          -1E+38          -1E+38          -1E+38          -1E+38          -1E+38
          -1E+38          -1E+38          -1E+38             FBA          35.824
               0       -120.5021               0           602.3               0
            4000              50               6             106            0.67
          0.0051               0          -1E+38          -1E+38          -1E+38
          -1E+38          -1E+38          -1E+38          -1E+38          -1E+38
          -1E+38          -1E+38          -1E+38          -1E+38          -1E+38
          -1E+38          -1E+38          -1E+38          -1E+38          -1E+38
          -1E+38          -1E+38          -1E+38          -1E+38          -1E+38
          -1E+38          -1E+38          -1E+38          -1E+38          -1E+38
          -1E+38          -1E+38          -1E+38          -1E+38          -1E+38
          -1E+38          -1E+38          -1E+38          -1E+38          -1E+38
          -1E+38          -1E+38          -1E+38          -1E+38          -1E+38
          -1E+38          -1E+38          -1E+38          -1E+38          -1E+38
          -1E+38          -1E+38          -1E+38          -1E+38          -1E+38
          -1E+38          -1E+38          -1E+38          -1E+38          -1E+38
          -1E+38          -1E+38          -1E+38          -1E+38          -1E+38
          -1E+38          -1E+38          -1E+38          -1E+38          -1E+38
          -1E+38          -1E+38          -1E+38          -1E+38          -1E+38
          -1E+38          -1E+38          -1E+38
     341     341     342     341     341     341     341     341     342     341
     341     341     341     341     341     342     340     340     341     341
     341     341     342     341     340     341     341     341     342     341
     342     341     341     341     341     341     340     341     340     340
     340     341     341     342     341     341     342     341     341     341
     341     341     341     341     341     341     341     341     341     342
     341     341     342     341     341     341     341     341     341     341
     340     341     341     341     341     341     341     341     341     341
     341     340     341     341     341     342     341     341     341     341
     341     341     341     341     341     341     341     341     341     340
     341     341     341     341     341     341     341     341     341     341
     341     341     340     341     341     340     339     341     341     342
     340     341     342     342     341     341     342     341     342     342
     341     341     341     342     342     341     341     341     341     341
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     341     341     341     341     341     341     341     341     341     341
     341     341     341     341     341     341     342     340     341     341
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     341     342     340     341     342     341     342     341     341     341
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     341     341     340     341     341     341     342     341     341     341
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     341     340     341     341     341     340     341     341     341     342
     343     346     347     348     348     349     354     361     371     389
     421     470     523     563     575     565     547     526     490     437
     394     409     497     611     685     693     654     595     535     490
     478     494     507     509     515     538     543     495     413     350
     303     207      14    -211    -339    -319    -195     -41     122     282
     402     448     457     514     647     777     797     709     620     630
     709     779     819     838     803     707     639     663     719     720
     706     769     919    1100    1264    1345    1239     914     477      58
    -298    -567    -707    -720    -671    -566
                                            .
                                            .
     849     863     870     871     874     876     873     864     861     876
     898     914     918     914     912     926     953     972     968     940
     888     811     713     618     535     450     353     252     169     109
      70      50      52      72     107     149     189     218     234     247
  -32768  -32768  -32768  -32768  -32768  -32768  -32768  -32768  -32768  -32768
  -32768  -32768  -32768  -32768  -32768  -32768  -32768  -32768  -32768  -32768
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  -32768  -32768  -32768  -32768  -32768  -32768
```

Figure 14. Image showing sample output (abbreviated) from the dfile program.

libvfbb Library

The dhead and dfile programs, and the MatLab function decribed below, call functions in the libvfbb library to convert the VAX-format binary headers and time-series data in DR100 format data files. The libvfbb VAX-format binary data conversion routines are taken from the libvaxdata library (Baker, 2005).

Several C language header files in the “src” directory document the functions in the library. All the library routines are callable from both C and Fortran.

MatLab Functions

The “matlab” subdirectory contains two MatLab M-files, “load_bbdata.m” and “merge_bbdata.m”, to load matrices with slices of time-series data from DR100 data files. load_bbdata.m and merge_bbdata.m call the MatLab MEX-file functions “bbihdr()”, “bbrhdr()”, and “bbdata()”. The “bbihdr.m”, “bbrhdr.m”, “bbthdr.m”, and “bbdata.m” M-files in the “matlab” directory contain only the text printed by the MatLab “help” command; the corresponding executable MatLab MEX files are in the “vfbb” system-specific directories.

To use load_bbdata.m and merge_bbdata.m, copy all the M-files from the “matlab” directory to a directory in the MatLab search path, such as “matlab_root/toolbox/local”, along with the appropriate binary MEX files from the “vfbb” system-specific directory (for example, the “.dll” files under “vfbb/win32” for Windows PCs, or the “.mexmaci64” files under “vfbb/macosx” for 64-bit Mac OS X systems). Consult the MatLab documentation or GUI help dialog for more information about the MatLab search path and how to customize it.

Operating system or MatLab versions released since the system-specific MEX files were built may make the files unusable. In that case, follow the instructions in the MatLab documentation for rebuilding the MEX files from the supplied C source and the makefiles in the “vfbb” system-specific directories.

Fortran Data Acquisition System

The “anza” directory contains the data acquisition system software. The data acquisition system was written in Fortran and ran on a Digital Equipment Corp. (DEC) MicroVAX minicomputer system under the VAX/VMS operating system (Levy, 1980).

Several seismic arrays used this software. The configuration files and other source files that were unique to each array are contained in subdirectories named with the 4-character acronym assigned to each array. These are “pkda” for the PKDA and SAFOD datasets, “pkta” for the PKTA dataset, and “pkt2” for the PKT2 dataset. The “anza”, “gvda”, “knet”, “saa2”, and “saa3” subdirectories were used by the other seismic arrays.

The “programs” directory contains the Fortran source for the programs, the “commons” directory contains the Fortran source for the shared COMMON block data areas, and the “command_files” directory contains the DCL command procedures for building the data acquisition software programs (into the array-specific directories).

The “utilities” directory contains useful utility programs.

The raw data Playback program is in the “playback” directory. There are versions that run on both VAX/VMS and OpenVMS/Alpha systems.

A few other programs, such as a real-time status Display program, have versions that run on both VAX/VMS and OpenVMS/Alpha systems. For those programs, the “bin_alpha” subdirectory was used to hold the Alpha-format object files. The executables were always stored in the array-specific directories.

The “lz” directory contains the data compression and decompression programs used by the remote file transfer feature to bundle the files recorded for an event into a single compressed package for transfer over a dial-up telephone line or a computer network.

Notes

The “notes” directory contains three text files with notes that describe the

- “raw_data.txt”—recovery and assembly of the original raw data recordings,
- “dr100_data.txt”—conversion of the raw data recordings to DR100 format, and
- “dvds.txt”—assembly of the data collection on to DVDs and other formats.

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Appendix

Distribution Formats

The UPSAR data collection is available in several formats.

DVD

The UPSAR data collection is available for download as a set of 18 DVD images (approximately 58 GB) or ZIP-compressed archives containing the DVD images (approximately 13 GB):

1. UPSAR.iso (see the Additional Material section)
2. PKDA_1989-1990.iso
3. PKDA_1991-1992.iso
4. PKDA_1993-1994.iso
5. PKDA_1995-1997.iso
6. PKDA_1998-2002.iso
7. PKDA_2003.iso
8. SAFOD_2003(323-328).iso
9. PKDA_2004(001-269).iso
10. PKDA_2004(270-366).iso
11. PKDA_2005.iso
12. PKTA_2005(020-024).iso
13. PKTA_2005(025-028).iso
14. PKTA_2005(029-032).iso
15. PKT2_2005(032-035).iso
16. PKT2_2005(036-039).iso
17. PKT2_2005(040-043).iso
18. PKT2_2005(044-045).iso

The DVDs are written in the industry-standard UDF format (version 1.02), which is readable on Windows PCs, Macintosh PCs, and on Unix/Linux computers.

ZIP

The UPSAR data collection is available for download as a set of 23 ZIP archives (approximately 13 GB):

1. UPSAR.zip (see the Additional Material section)
2. PKDA_1989.zip
3. PKDA_1990.zip
4. PKDA_1991.zip
5. PKDA_1992.zip
6. PKDA_1993.zip
7. PKDA_1994.zip
8. PKDA_1995.zip
9. PKDA_1996.zip
10. PKDA_1997.zip

11. PKDA_1998.zip
12. PKDA_1999.zip
13. PKDA_2000.zip
14. PKDA_2001.zip
15. PKDA_2002.zip
16. PKDA_2003.zip
17. SAFOD_2003(323-328).zip
18. PKDA_2004.zip
19. PKDA_2005.zip
20. PKTA_2005(020-025).zip
21. PKTA_2005(026-032).zip
22. PKT2_2005(032-038).zip
23. PKT2_2005(039-045).zip

The data for the tremor experiments, PKTA and PKT2, are split across multiple ZIP archives because of the limitation that a single ZIP file cannot be larger than 2 GB.

DMG

The UPSAR data collection is available for download as a set of 21 Apple disk images (approximately 9 GB):

1. UPSAR.dmg (see the Additional Material section)
2. PKDA_1989.dmg
3. PKDA_1990.dmg
4. PKDA_1991.dmg
5. PKDA_1992.dmg
6. PKDA_1993.dmg
7. PKDA_1994.dmg
8. PKDA_1995.dmg
9. PKDA_1996.dmg
10. PKDA_1997.dmg
11. PKDA_1998.dmg
12. PKDA_1999.dmg
13. PKDA_2000.dmg
14. PKDA_2001.dmg
15. PKDA_2002.dmg
16. PKDA_2003.dmg
17. SAFOD_2003(323-328).dmg
18. PKDA_2004.dmg
19. PKDA_2005.dmg
20. PKTA_2005.dmg
21. PKT2_2005.dmg

SquashFS

The UPSAR data collection is available for download in 21 Linux Squash file system (compressed disk image) format files (approximately 12 GB):

1. UPSAR.sqsh (see the Additional Material section)
2. PKDA_1989.sqsh
3. PKDA_1990.sqsh
4. PKDA_1991.sqsh
5. PKDA_1992.sqsh
6. PKDA_1993.sqsh
7. PKDA_1994.sqsh
8. PKDA_1995.sqsh
9. PKDA_1996.sqsh
10. PKDA_1997.sqsh
11. PKDA_1998.sqsh
12. PKDA_1999.sqsh
13. PKDA_2000.sqsh
14. PKDA_2001.sqsh
15. PKDA_2002.sqsh
16. PKDA_2003.sqsh
17. SAFOD_2003(323-328).sqsh
18. PKDA_2004.sqsh
19. PKDA_2005.sqsh
20. PKTA_2005.sqsh
21. PKT2_2005.sqsh

Support for SquashFS (http://en.wikipedia.org/wiki/SquashFS, visited September 18, 2013) is included in many Linux systems.

For example, to mount "UPSAR.sqsh" at "/mnt/upsar", type (from an account with suitable privilege)

```
$ mount UPSAR.sqsh /mnt/upsar -t squashfs -o loop
```

Firmware Versions

Most firmware changes were not documented; the changes described in table A1 were mostly inferred from an analysis of the ARCnet data packets. Assembly language source code for the 68000 microprocessor was used to inform the analysis of versions 1.5, 2.0, and 2.1.

Table A1. Firmware versions.

[D/A, digital-to-analog; BCD, binary-coded decimal]

1.52	Original firmware used in the seismographs. Header bytes 19–24 contained the relay settings (unsigned char relay[6]), which were only used for factory testing; when operating, the relay settings were required to be 0x00.
1.60	The relay settings field (unsigned char relay[6]) was replaced by an ARCnet packet sequence number (unsigned short seq_num), the current GOES time code quality byte (unsigned char q_factor), and filler (unsigned char filler3[3]).
1.61	The filler bytes (unsigned char filler3[3]) were replaced by a time sync received flag byte (0xAA) (unsigned char tim_rcv_flg), time code serial port error count (unsigned char ser_err_cnt), and the high byte of the 16-bit D/A value in the 1-kHz phase-locked sample clock from the microcontroller (unsigned char da_val). The time sync logic waits for three consecutive time code values before it forces a re-sync of the sample clock. It then resets its counter for another three consecutive time code values before it forces another re-sync of the sample clock. Thus, the time sync logic received flag is set to 0xAA once every three seconds. Except, for some unexplained reason, the counter is reset every 20 seconds (100 records) on a 10-second boundary (usually :00, :20, :40). Both the microcontroller and the main microprocessor read the time code via an RS-232 serial port. The microcontroller is dedicated to managing the 1-kHz sample clock, which synchronizes A/D sampling across the entire array with the serial GOES (later GPS) time reference. The main microprocessor runs a simple multi-tasking operating system, which can cause a slight amount of jitter in the receipt of the 1-Hz serial time code. When the start of the ARCnet data packet is aligned to the second (000 ms offset), this jitter can cause the time sync received flag to be delayed by one packet (200 ms). To account for this, the Playback program adds 200 ms to the expected arrival time between successive time sync flags.
1.62	The time sync logic was modified to continuously force a re-sync of the sample clock after the first three consecutive time code values, as long as consecutive time code values arrived. Except, only the low-order seconds digit was being watched, which caused the time sync logic to lose sync every 10 seconds.
1.7	The time sync received flag was moved to bit 3 of the status byte (unsigned char status) and replaced by the BCD firmware version number (unsigned char ver_number). The time code format in the ARCnet packet header was changed from binary sec/msec (unsigned long sec, unsigned short msec) to BCD *DDDHHMMSSMMM* (unsigned char time[6]). However, the RTSampler program converted the BCD format time stamps back to sec/msec format on the fly until support for BCD format time stamps was added to the Playback program in October 1993. The time sync logic still loses sync every 10 seconds.
1.8	Same as 1.7.
1.9	Support for BCD format time stamps was completed; RTSampler no longer converted the time stamp format to sec/msec. The time sync logic still loses sync every 10 seconds.
2.0	The time sync logic was repaired; there are no longer any unexpected missing time syncs.
2.1	Same as 2.0.
2.2	Same as 2.0.