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Pacific Northwest National Laboratory
Operated by Battelle for the U.S. Department of Energy

Second and Third Quarter Hanford Seismic Report for Fiscal Year 2001

PNNL Seismic Monitoring Team

September 2001

Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RL01830

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Second and Third Quarter Hanford Seismic Report for Fiscal Year 2001

Pacific Northwest National Laboratory Seismic Monitoring Team
D. C. Hartshorn
S. P. Reidel
A. C. Rohay
M. M. Valenta

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Pacific Northwest National Laboratory
Richland, Washington 99352

Summary

Hanford Seismic Monitoring provides an uninterrupted collection of high-quality raw and processed seismic data from the Hanford Seismic Network (HSN) for the U.S. Department of Energy and its contractors. Hanford Seismic Monitoring also locates and identifies sources of seismic activity and monitors changes in the historical pattern of seismic activity at the Hanford Site. The data are compiled, archived, and published for use by the Hanford Site for waste management, Natural Phenomena Hazards assessments, and engineering design and construction. In addition, the seismic monitoring organization works with the Hanford Site Emergency Services Organization to provide assistance in the event of a significant earthquake on the Hanford Site.

The HSN and the Eastern Washington Regional Network (EWRN) consist of 41 individual sensor sites and 15 radio relay sites maintained by the Hanford Seismic Monitoring staff.

For the HSN, there were 333 triggers during the second quarter of fiscal year (FY) 2001 and 587 triggers during the third quarter on the data acquisition system. Of these triggers, 153 were earthquakes during the second quarter and 190 were earthquakes during the third quarter.

Nineteen earthquakes were located in the HSN area during the second quarter and 18 during the third quarter. For the second and third quarters, respectively, 8 and 12 occurred in the Columbia River basalt, 5 and 0 were earthquakes in the pre-basalt sediments, and 6 and 6 were earthquakes in the crystalline basement. Geographically, 14 earthquakes occurred in swarm areas in the second quarter and 8 in the third quarter. No earthquakes were associated with major structures in the second quarter but 4 were in the third quarter. There were 5 random events in the second quarter and 6 in the third quarter.

The February 28, 2001 Nisqually earthquake triggered the Hanford Strong Motion Accelerometers during the second quarter of FY 2001. There were no triggers during the third quarter.

Acronyms

BWIP	Basalt Waste Isolation Project
CRBG	Columbia River Basalt Group
DMIN	closest distance from the epicenter to a station
DOE	U.S. Department of Energy
ETNA	strong motion accelerometer manufactured by Kinemetrics
EWRN	Eastern Washington Regional Network
FY	fiscal year
GAP	largest gap in event-station azimuth distribution
GPS	Global Positioning System
HSN	Hanford Seismic Network
M_c	Coda Length Magnitude
M_L	Local Magnitude
M_w	Moment Magnitude
NP	number of p-wave and s-wave phases
NS	number of stations
PNNL	Pacific Northwest National Laboratory
RAW	Rattlesnake Mountain-Wallula Alignment
RMS	root-mean-square residual
SMA	strong motion accelerometer
USGS	United States Geological Survey
UTC	Universal Time, Coordinated
UW	University of Washington
WG4	Wallula Gap 4 site
WHC	Westinghouse Hanford Company
YPT	Yellepit site

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1.0 Introduction

This report is the second and third quarter Hanford seismic activity report for fiscal year (FY) 2001. In this report, we summarize earthquake activity from the Hanford Site and vicinity that occurred between January 1, 2001 and June 30, 2001 and our geologic interpretation of the sources of the earthquakes.

1.1 Mission

The principal mission of seismic monitoring at the Hanford Site is to insure compliance with DOE Order 420.1, Facility Safety. This order establishes facility safety requirements related to nuclear safety design, criticality safety, fire protection, and natural phenomena hazards mitigation. With respect to seismic monitoring, the order states:

> 4.4.5 Natural Phenomena Detection.
> Facilities or sites with hazardous materials shall have instrumentation or other means to detect and record the occurrence and severity of seismic events.

In addition, seismic monitoring provides an uninterrupted collection of high-quality raw seismic data from the Hanford Seismic Network (HSN) located on and around the Hanford Site, and provides interpretations of seismic events from the Hanford Site and vicinity. Hanford Seismic Monitoring locates and identifies sources of seismic activity, monitors changes in the historical pattern of seismic activity at the Hanford Site, and builds a "local" earthquake database (processed data) that is permanently archived. The focus of this report is the precise location of earthquakes proximal to or on the Hanford Site, specifically between 46 degrees and 47 degrees north latitude and between 119 degrees and 120 degrees west longitude. Data from the Eastern Washington Regional Network (EWRN) and other seismic networks in the northwest provide the Seismic Monitoring Project with necessary regional input for the seismic hazards analysis at the Hanford Site.

The seismic data are used by the Hanford Site contractors for waste management activities, Natural Phenomena Hazards assessments, and engineering design and construction. In addition, the Seismic Monitoring Project works with Hanford Site Emergency Services Organization to provide assistance in the event of an earthquake on the Hanford Site.

1.2 History of Seismic Monitoring at Hanford

Seismic monitoring at the Hanford Site was established in 1969 by the United States Geological Survey (USGS) under a contract with the U.S. Atomic Energy Commission. In 1975, the University of Washington (UW) assumed responsibility for the network and subsequently expanded it. In 1979, the Basalt Waste Isolation Project (BWIP) became responsible for collecting seismic data for the Hanford Site as part of site characterization activities. Rockwell Hanford Operations, followed by Westinghouse Hanford Company (WHC), operated the local network and were the contract technical advisors for the EWRN operated and maintained by UW. Funding ended for BWIP in December 1988. Seismic monitoring and responsibility for the UW contract were then transferred to WHC's Environmental Division. Maintenance responsibilities for the EWRN were also assigned to WHC who made major upgrades to EWRN sites.

Effective October 1, 1996, seismic monitoring was transferred to the Pacific Northwest National Laboratory (PNNL).[1] Seismic monitoring is part of PNNL's Applied Geology and Geochemistry Group, Environmental Technology Division.

The Hanford Strong Motion Accelerometer (SMA) network was constructed during 1997 and came on line in May 1997. It operated continuously until September 30, 1997 when it was mothballed due to lack of funding. Funding was restored on October 1, 1998 by joint agreement between the U.S. Department of Energy (DOE) and PNNL. Operation of the free-field sites resumed on November 20, 1999 and has operated continuously since that time.

1.3 Documentation and Reports

The Seismic Monitoring Project issues quarterly reports of local activity, an annual catalog of earthquake activity on and near the Hanford Site, and special-interest bulletins on local seismic events. The annual catalog includes the fourth quarter report for the fiscal year. Hanford Seismic Monitoring also provides information and special reports to other functions as requested. Earthquake information provided in these reports is subject to revisions if new data become available. In addition, an archive of all seismic data from the HSN is maintained by PNNL.

[1] Pacific Northwest National Laboratory is operated by Battelle Memorial Institute for the U.S. Department of Energy.

2.0 Network Operations

2.1 Seismometer Sites

The seismic monitoring network consists of two designs of equipment and sites: seismometer sites and strong motion accelerometer (SMA) sites. Seismometer sites are designed to locate earthquakes and determine their magnitude and hypocenter location. SMA sites are designed to measure ground motion.

The HSN and the EWRN consist of 41 sensor sites. Most sites are in remote locations and require solar panels and batteries for power. The HSN uses 21 sites (Table 2.1 and Figure 2.1) and the EWRN uses 36 sites (Table 2.2 and Figure 2.2); both networks share 16 sites. The networks have 46 combined data channels because Gable Butte and Frenchman Hills East are three-component sites, each consisting of one vertical, one north-south horizontal, and one east-west horizontal data channel. Both networks use 15 additional telemetry relay sites. Data from all sites or relays are transmitted to the Sigma V building, Richland, Washington.

During FY 2000, the Wallula Gap 4 site (WG4), located on the east side of Wallula Gap, was replaced with Yellepit (YPT), located on the west side of Wallula Gap. The east side of Wallula Gap had been moved four times to reduce noise and vandalism. During FY 2000, it was decided to abandon the site in favor of a more remote site on the west side of the gap. Comparison of the two sites showed YPT to be a marked improvement.

2.1.1 Station Maintenance

The HSN's maintenance records for the seismic sensor and relay sites are filed in the Hanford Seismic Monitoring office.

2.1.2 Data Acquisition

The signals from the seismometer sites are monitored for changes in signal amplitude that are expected from earthquakes. The seismic network is subdivided into spatial groupings of stations that are monitored for nearly simultaneous amplitude changes, resulting in triggering a permanent recording of the events. The groupings and associated weighting schemes are designed to allow very small seismic events to be recorded and to minimize false triggers. Events are classified as locals (south-central Washington near the Hanford Site), regionals (Western U.S. and Canada), and teleseisms (from farther distances around the world). Local and regional events are usually earthquakes, but mining explosions are also recorded. The latter can usually be identified from wave characteristics, time of day, and through confirmation with local government agencies and industries. Frequently, military exercises at the U.S. Army's Yakima Training Center produce a series of acoustic shocks that unavoidably trigger the recording system. Sonic booms and thunder also produce acoustic signals that trigger the recording system.

Table 2.1. Seismic Stations in the Hanford Seismic Network

The first column is the three-letter seismic station designator. The latitude and longitude, elevation above sea level in meters; and the full station name follow this. An asterisk before the three-letter designator means it is a three-component station. The locations of the stations are all in Washington; locations were derived from a Global Positioning System (GPS).

Station	Latitude Deg.Min.N	Longitude Deg.Min.W	Elevation (m)	Station Name
BEN	46N31.13	119W43.02	340	Benson Ranch
BRV	46N49.12	119W59.47	920	Black Rock Valley
BVW	46N48.66	119W52.99	670	Beverly
CRF	46N49.50	119W23.22	189	Corfu
ET3	46N34.64	118W56.25	286	Eltopia Three
*FHE	46N57.11	119W29.82	455	Frenchman Hills East
*GBB	46N36.49	119W37.62	177	Gable Butte
GBL	46N35.92	119W27.58	330	Gable Mountain
H2O	46N23.75	119W25.38	158	Water
LOC	46N43.02	119W25.85	210	Locke Island
MDW	46N36.79	119W45.66	330	Midway
MJ2	46N33.45	119W21.54	146	May Junction Two
OT3	46N40.14	119W13.98	322	Othello Three
PRO	46N12.73	119W41.15	550	Prosser
RED	46N17.92	119W26.30	366	Red Mountain
RSW	46N23.67	119W35.48	1,045	Rattlesnake Mountain
SNI	46N27.85	119W39.60	312	Snively Ranch
WA2	46N45.32	119W33.94	244	Wahluke Slope
WIW	46N25.76	119W17.26	128	Wooded Island
WRD	46N58.20	119W08.69	375	Warden
YPT[a]	46N02.93	118W57.73	325	Yellepit

(a) YPT replaced Wallula Gap 4 (WG4) starting the fourth quarter of FY 2000.

A PC-based system adapted from a USGS program and the UW system was implemented at Hanford during FY 1999. One new system has been in continuous operation since January 6, 1999. A second, backup PC system was installed in mid-March 1999, and both new systems have been running in parallel since that time. Although the two new systems are practically identical, there is enough granularity in the trigger timing that they sometimes record exclusive events. In nearly all cases, these exclusive triggers are "false" triggers, not earthquakes or quarry blasts (i.e., from acoustic sources). The remainders are from barely detectable, small signals from regional and teleseismic earthquakes.

The types and numbers of triggers recorded in the second and third quarters of FY 2001 by the seismic acquisition system are summarized in Table 2.3.

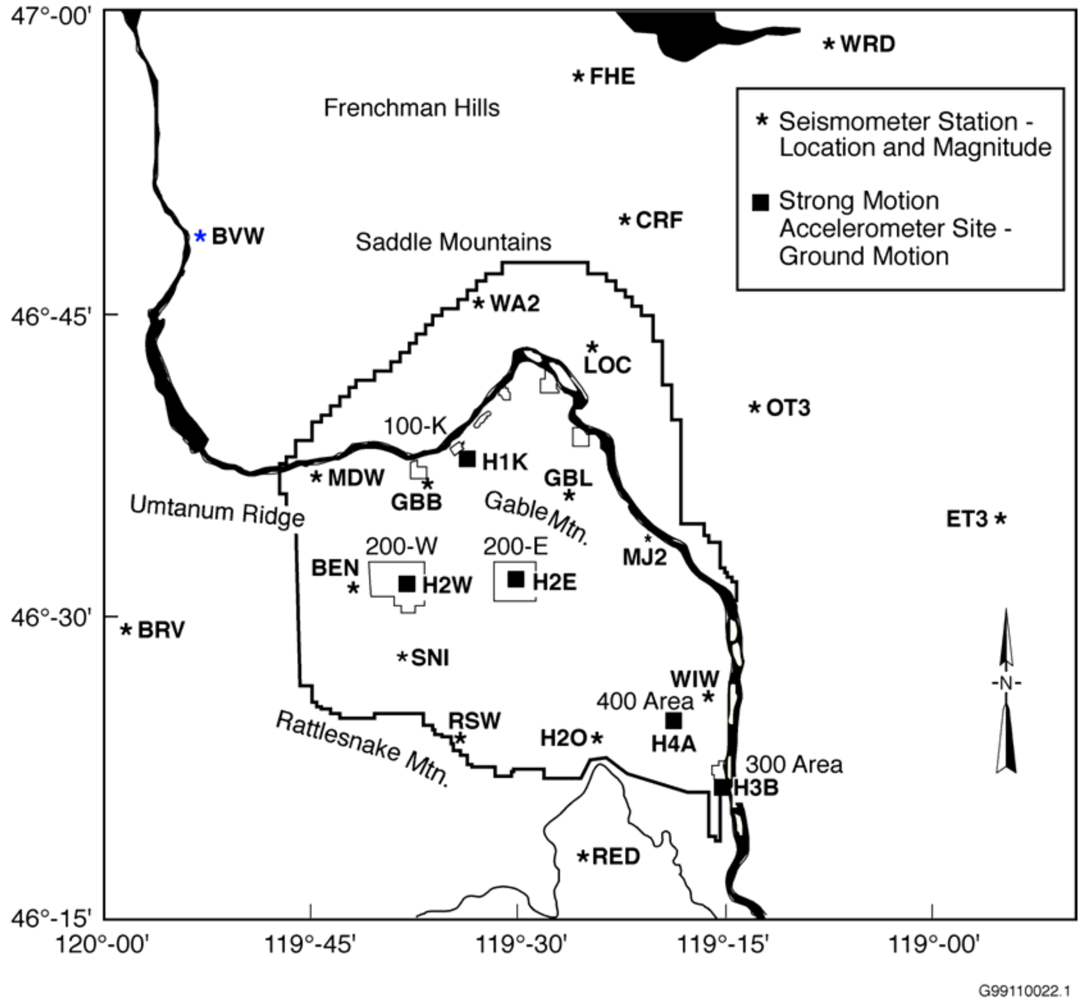

Figure 2.1. Locations of Seismograph Stations and Strong Motion Accelerometer Sites in the Hanford Seismic Network (see Table 2.1 for description of locations). Locations for Prosser (PRO) and Yellepit (YPT) are not shown. See Figure 2.2 for the locations of those sites.

2.2 Strong Motion Accelerometer Sites

2.2.1 Location

The Hanford SMA network consists of five free-field SMA sites (Figure 2.1) (Table 2.4). There is one free-field SMA located in each of the 200 Separations Areas, one adjacent to the K Basins in the 100-K Area, one adjacent to the 400 Area where the Fast Flux Test Reactor is located, and one at the south end of the 300 Area.

Table 2.2. Seismic Stations in the Eastern Washington Regional Network

The first column is the three-letter seismic station designator. The latitude and longitude, elevation above sea level in meters, and the full station name follow this. An asterisk before the three-letter designator means it is a three-component station. The locations of the stations are all in Washington unless otherwise indicated; locations were determined from a Global Positioning System (GPS).

Station	Latitude Deg.Min.N.	Longitude Deg.Min.W.	Elevation (m)	Station Name
BRV	46N29.12	119W59.47	920	Black Rock Valley
BVW	46N48.66	119W52.99	670	Beverly Washington
CBS	47N48.26	120W02.50	1,067	Chelan Butte, South
CRF	46N49.50	119W23.22	189	Corfu
DPW	47N52.25	118W12.17	892	Davenport
DY2	47N59.11	119W46.28	890	Dyer Hill Two
ELL	46N54.58	120W33.98	789	Ellensburg
EPH	47N21.38	119W35.76	661	Ephrata
ET3	46N34.64	118W56.25	286	Eltopia Three
ETW	47N36.26	120W19.94	1,477	Entiat
*FHE	46N57.11	119W29.82	455	Frenchman Hills East
*GBL	46N35.92	119W27.58	330	Gable Mountain
LNO	45N52.31	118W17.11	771	Lincton Mountain, Oregon
LOC	46N43.02	119W25.85	210	Locke Island
MDW	46N36.79	119W45.66	330	Midway
MJ2	46N33.45	119W21.54	146	May Junction Two
MOX	46N34.64	120W17.89	501	Moxee City
NAC	46N43.99	120W49.42	728	Naches
NEL	48N04.21	120W20.41	1,500	Nelson Butte
OD2	47N23.26	118W42.58	553	Odessa Two
OT3	46N40.14	119W13.98	322	Othello Three
PAT	45N52.92	119W45.14	262	Paterson
PRO	46N12.73	119W41.15	550	Prosser
RSW	46N23.67	119W35.48	1,045	Rattlesnake Mountain
SAW	47N42.10	119W24.03	701	St. Andrews
SNI	46N27.85	119W39.60	312	Snively Ranch
TBM	47N10.20	120W35.88	1,006	Table Mountain
TRW	46N17.32	120W32.31	723	Toppenish Ridge
TWW	47N08.29	120W52.10	1,027	Teanaway
VT2	46N58.04	119W58.95	1,270	Vantage Two
WA2	46N45.32	119W33.94	244	Wahluke Slope Two
WAT	47N41.92	119W57.24	821	Waterville
WIW	46N25.76	119W17.26	128	Wooded Island
WRD	46N58.20	119W08.69	375	Warden
YA2	46N31.60	120W31.80	652	Yakima Two
YPT[(a)]	46N02.93	118W57.73	325	Yellepit

(a) YPT replaced site Wallula Gap 4 (WG4) the fourth quarter of FY 2000.

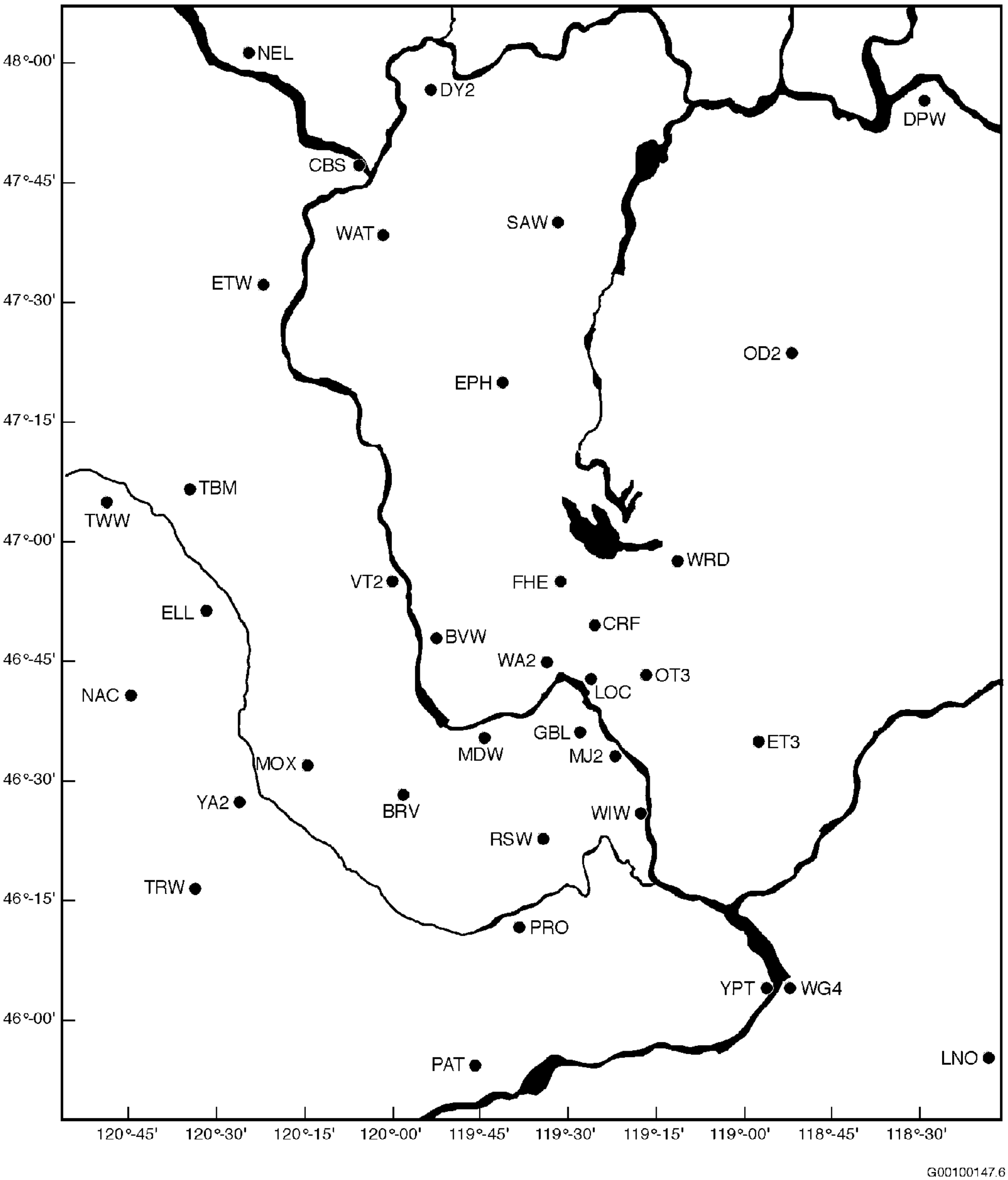

Figure 2.2. Locations of Seismograph Stations in the Eastern Washington Regional Network (see Table 2.2 for location descriptions). YPT replaced site WG4.

Table 2.3. Acquisition System Recorded Triggers

Event Type	First Quarter	Second Quarter	Third Quarter	Fourth Quarter	Total	Remarks
South-central Washington	61	30	31	-	122	Seismic events in southcentral Washington and northcentral Oregon that triggered the HSN
Regional	35	41	58	-	134	Seismic events in the Western United States and Canada
Teleseism	80	82	101	-	263	Seismic events at farther distances from around the world
Total Earthquake Events	176	153	190		519	
Explosions	2	3	1		6	Typically quarry blasts.
Local Earthquakes	45	19	18	-	82	Seismic events within the 46-47 degrees north latitude and 119-120 degrees west longitude
Total Triggers on Primary System	477	333	587	-	1,397	Total number of triggers examined. Includes all sources of triggers.

Table 2.4. Free-Field Strong Motion Accelerometer Sites

Site	Site ID	Location	Latitude Longitude Elevation
100-K Area	H1K	South of K Basins outside 100 Area fence lines.	46° 38.51' 119° 35.53' 152 m
200 East Area	H2E	East of B Plant; north of 7th Street and east of Baltimore Avenue.	46° 33.58' 119° 32.00' 210 m
200 West Area	H2W	Northeast of Plutonium Finishing Plant (PFP); north of 19th street and east of Camden Avenue.	46° 33.23' 119° 37.51' 206 m
300 Area	H3A	South end of 300 Area inside fence lines. (NE 1/4, SW 1/4, Sec. 11, T10N, R28E).	46° 21.83' 119° 16.55' 119 m
400 Area	H4A	500 feet from fence line on east side of facility and north of parking area).	46° 26.13' 119° 21.30' 171 m

The instrumentation locations were chosen based on two criteria (Moore and Reidel 1996): 1) instruments should be located in areas having the highest densities of people and 2) instruments should be located in areas having hazardous facilities. Some of the highest concentrations of employees at Hanford are 200 East and West Areas, 100-K Area, the Fast Flux Test Facility (400 Area), and the 300 Areas. The

200 Areas are where all high-level radioactive waste from past processing of fuel rods has been stored in single-shell and double-shell tanks. In addition, the Canister Storage Facility that will hold encapsulated spent fuel rods is in 200 East Area. The 100-K Area contains the K Basins where all spent fuel rods from the N Reactor are stored prior to encapsulation. The Cold Vacuum Drying Facility, located in the 100-K Area, is used to encapsulate spent fuel rods from the K Basins prior to shipment to the Canister Storage Building in 200 East Area.

2.2.2 Site Design

All free-field SMA sites consist of two 30-gallon drums set in the ground such that the base of the drum is about 1 meter below the surface. One drum houses only the SMA; the other drum houses the electronics and communications equipment. A distance of 1 to 2.16 meters (40 to 85 inches) separates the drum containing the electronics and communications equipment from the SMA drum; a sealed conduit connects the two drums.

The SMA instruments are three-component units consisting of one vertical, one north-south horizontal, and one east-west horizontal data channel. The instruments in use are the ETNA™ system (registered trademark of Kinemetrics, Inc.). Instrument specifications are summarized in Table 2.5. In addition to the three-component SMA's, each ETNA SMA unit contains a computer, Global Positioning System (GPS) receiver and a modem (Figure 2.3). These systems are housed in a watertight box.

Table 2.5. Instrument Parameters for the Kinematics ETNA System in the Hanford SMA Network

Parameter	Value or Range
Sensor	
Type	Tri-axial Force Balance Accelerometer orthogonally oriented with internal standard
Full-Scale	±2 g[a]
Frequency Range	0-50 Hz
Damping	Approximately 70% critical[a]
Data Acquisition	
Number of Channels	3
Sample Rate	18-bit resolution @ 200 samples/second
Digital Output	Real-time, RS-232 Output Stream
Seismic Trigger	
Filter	0.1 - 12.5 Hz
Trigger level	0.05% - 0.20% g[b]
Alarm (call-out) Threshold	4.00% g
Pre-event Memory	10 sec
Post-event Time	40 sec

(a) Setting is dependent on instrument calibration.
(b) See Section 2.2.4 for discussion of trigger thresholds.

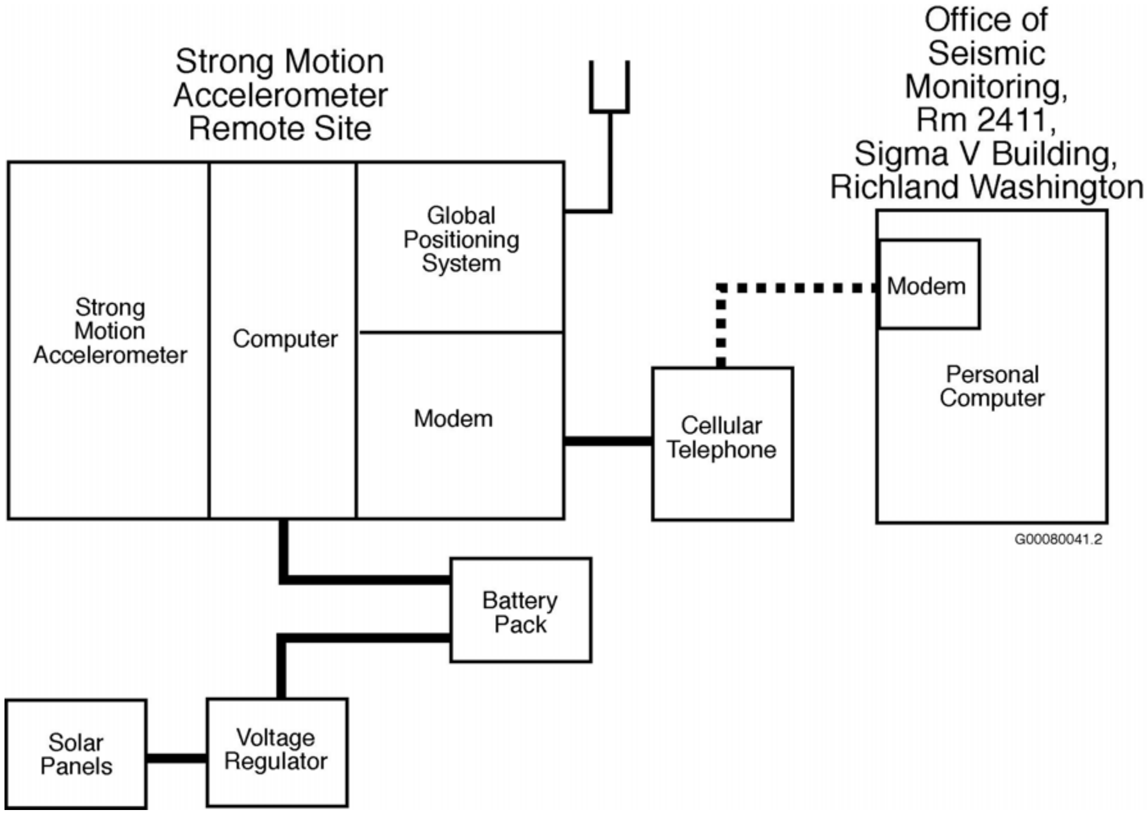

Figure 2.3. Schematic Diagram of a Strong Motion Accelerometer Installation

Two 100 amp-hour batteries that are housed in the equipment and communications drum (see Figure 2.3) power the SMAs. The batteries are charged by four solar panels; a regulator is located between the solar panels and the batteries.

The communication link between the SMAs and the data analysis computer system housed in the Sigma V building is a cellular telephone/modem connection. The built-in modem in the SMA allows the system to use a cellular telephone to call an accelerometer or for the accelerometer to call out in the event it is triggered. The cellular telephone system is in the process of being upgraded to ensure greater reliability. It the event of a cellular telephone failure, the SMAs can be directly accessed at the site using a built-in RS232 cable connection.

The SMAs have an internal GPS receiver used principally to link it to the National Bureau of Standards timing system. The GPS is internally activated approximately every 4 hours and checks the "location of the instrument" and the time. Any differences between the internal clock and the GPS time are recorded and saved by the SMA. Any corrections to the internal timing are made automatically. Typically, the greatest correction recorded is approximately 4 milliseconds.

2.2.3 Strong Motion Accelerometer Operations Center

The combined operations, data recording, data interpretation, and maintenance facility is located in the Sigma V building and is operated by the PNNL Seismic Monitoring Team.

2.2.4 Strong Motion Operational Characteristics

The signals from the three-accelerometer channels at each site are digitized with a 24-bit digitizer and temporarily stored in a memory buffer. The sampling rate of the digitizer is set to 200 Hz. The three channels are monitored for signals that equal or exceed a programmable trigger threshold. When one accelerometer channel is triggered, the other channels automatically record. The nominal threshold used is 0.05% of the full-scale range of 2.0 g (g is the acceleration of gravity, 9.8 m/s^2 or 32 ft/s^2) or 0.001 g. Threshold trigger levels are being adjusted to trigger infrequently on the noise sources (e.g., vehicles, sonic booms) near each site. This will provide ground motion data for smaller, non-damaging earthquakes that is useful in estimating the ground motion expected from larger earthquakes, and to confirm correct operation of the instruments by analyzing the smaller-amplitude triggers. The recorders store information for 10 seconds before the trigger threshold is exceeded and for 40 seconds after the trigger ceases to be exceeded.

3.0 Magnitude, Velocity Models, and Quality Factors

3.1 Coda Length Magnitude

Coda-length magnitude (M_c), an estimate of local magnitude (M_L) (Richter 1958), is calculated using the coda-length/magnitude relationship determined for Washington State by Crosson (1972).

3.2 Velocity Model

The program XPED uses the velocities and layer depths given in Table 3.1. XPED was developed at UW and the velocity model used in XPED is based on Rohay et al. (1985). XPED is an interactive earthquake seismogram display program used to analyze seismic events.

3.3 Quality Factors (Q)

XPED assigns a two-letter **Quality factor** (Table 3.2) that indicates the general reliability of the solution (**A** is best quality, **D** is worst). Similar quality factors are used by the USGS for events located with the computer program HYPO71. The first letter of the quality code is a measure of the hypocenter quality based primarily on travel time residuals. For example: Quality **A** requires a root-mean-square residual (**RMS**) less than 0.15 seconds while a **RMS** of 0.5 seconds or more is **D** quality (other estimates of the location uncertainty also affect this quality parameter). The second letter of the quality code is related to the spatial distribution of stations that contribute to the event's location, including the number of stations (**NS**), the number of p-wave and s-wave phases (**NP**), the largest gap in event-station azimuth distribution (**GAP**), and the closest distance from the epicenter to a station (**DMIN**). Quality **A** requires a solution with **NP** >8, **GAP** <90°, and **DMIN** <5 km (or the hypocenter depth if it is greater than 5 km). If **NP** ≤5, **GAP** >180°, or **DMIN** >50 km, the solution is assigned Quality **D**.

Table 3.1. Seismic Velocities for Columbia Basin Stratigraphy (from Rohay et al. 1985)

Depth to Top of Velocity Layer (km)	Stratigraphy	Velocity (km/sec)
0.0	Saddle Mountains and Wanapum Basalts and intercalated Ellensburg Formation	3.7
0.4	Grande Ronde Basalt and pre-basalt sediments	5.2
8.5	Crystalline Basement, Layer 1	6.1
13.0	Crystalline Basement, Layer 2	6.4
23.0	Sub-basement	7.1
38.0	Mantle	7.9

Table 3.2. Local Earthquake Data, October 1, 2000 to June 30, 2001

Event ID	Type	Date	Time	Latitude	Longitude	Depth	Mag	NS/NP	Gap	DMIN	RMS	Q	Location
00100318002		00/10/03	18:00 51.12	46N14.57	119W35.21	7.95	0.1	8/13	209	8	0.06	AD	14.5 km ENE of Prosser
00100715291	P	00/10/07	15:29 40.95	46N12.49	119W24.45	0.58	1.1	8/11	250	10	0.23	BD	12.2 km SW of Richland
00101712231		00/10/17	12:23 33.49	46N05.45	119W36.73	10.16	0.7	10/13	306	14	0.11	AD	17.7 km SE of Prosser
00102323391		00/10/23	23:39 25.37	46N38.32	119W55.63	0.34	0.7	6/6	126	13	0.26	BC	23.9 km WNW of 200 West
00102415322	P	00/10/24	15:32 46.52	46N14.51	119W27.07	0.05	2.0	14/14	179	6	0.23	BC	13.1 km WSW of Richland
00110200004		00/11/02	00:01 08.12	46N11.69	119W32.50	9.46	0.1	7/10	304	11	0.07	AD	17.5 km E of Prosser
00110200034		00/11/02	00:04 11.15	46N12.24	119W33.04	8.08	0.4	7/13	235	10	0.06	AD	16.8 km E of Prosser
00113010391		00/11/30	10:39 33.21	46N03.44	119W42.36	18.25	0.5	6/8	174	17	0.22	BC	17.3 km SSE of Prosser
00121214131		00/12/12	14:13 37.59	46N13.50	119W36.34	6.33	0.4	8/14	287	6	0.08	AD	12.7 km E of Prosser
00121214132		00/12/12	14:13 52.18	46N12.41	119W36.16	9.11	1.6	18/21	146	6	0.07	AC	12.8 km E of Prosser
00121214133		00/12/12	14:14 07.58	46N12.90	119W36.29	8.09	1.6	12/16	142	6	0.09	AC	12.6 km E of Prosser
00121214145		00/12/12	14:15 37.84	46N12.64	119W35.80	8.34	0.9	14/16	87	6	0.08	AA	13.2 km E of Prosser
00121214402		00/12/12	14:40 48.23	46N12.38	119W35.90	10.65	1.7	20/37	82	6	0.15	AA	13.1 km E of Prosser
00121214434		00/12/12	14:44 07.62	46N12.43	119W35.83	8.30	0.2	8/9	224	6	0.05	AD	13.2 km E of Prosser
00121214443		00/12/12	14:45 00.94	46N12.51	119W36.24	8.97	0.3	8/12	221	6	0.07	AD	12.7 km E of Prosser
00121214445		00/12/12	14:45 25.69	46N12.19	119W36.10	9.00	-0.2	3/9	311	6	0.06	AD	12.9 km E of Prosser
00121214473		00/12/12	14:48 03.51	46N12.50	119W35.69	9.87	2.1	28/42	88	7	0.13	AA	13.4 km E of Prosser
00121214482		00/12/12	14:48 51.19	46N12.64	119W36.63	9.60	-0.1	5/8	218	5	0.08	AD	12.2 km E of Prosser
00121214572		00/12/12	14:57 44.72	46N12.15	119W36.45	10.29	0.7	13/19	170	6	0.14	AC	12.4 km E of Prosser
00121215374		00/12/12	15:38 09.10	46N12.29	119W35.85	8.30	0.3	8/13	227	6	0.06	AD	13.2 km E of Prosser
00121217430		00/12/12	17:43 26.52	46N12.33	119W35.88	9.18	0.3	10/16	226	6	0.08	AD	13.1 km E of Prosser
00121219402		00/12/12	19:40 53.13	46N12.28	119W35.69	9.71	2.1	32/46	82	7	0.20	BA	13.4 km E of Prosser
00121220081		00/12/12	20:08 31.77	46N11.86	119W36.38	9.79	0.1	6/13	235	6	0.08	AD	12.5 km E of Prosser
00121220453		00/12/12	20:46 10.56	46N12.87	119W35.90	7.88	0.4	11/11	214	6	0.11	AD	13.1 km E of Prosser
00121220455		00/12/12	20:46 48.79	46N12.17	119W36.19	8.95	-0.2	6/10	229	6	0.07	AD	12.7 km E of Prosser
00121223352		00/12/12	23:35 44.80	46N12.85	119W36.00	7.80	0.5	10/19	214	6	0.12	AD	13.0 km E of Prosser

Table 3.2. (contd)

Event ID	Type	Date	Time	Latitude	Longitude	Depth	Mag	NS/NP	Gap	DMIN	RMS	Q	Location
00121303480		00/12/13	03:48 28.41	46N12.90	119W36.06	7.82	0.7	13/18	87	6	0.09	AA	12.9 km E of Prosser
00121308024		00/12/13	08:03 13.37	46N12.20	119W36.09	9.76	1.3	23/27	88	6	0.18	BA	12.9 km E of Prosser
00121308222		00/12/13	08:22 51.10	46N13.19	119W36.38	7.61	0.2	8/12	206	6	0.03	AD	12.6 km E of Prosser
00121308245		00/12/13	08:25 15.58	46N12.17	119W35.86	8.38	0.4	8/11	229	6	0.03	AD	13.2 km E of Prosser
00121308274		00/12/13	08:28 03.67	46N12.88	119W36.30	7.75	0.3	8/11	213	6	0.06	AD	12.6 km E of Prosser
00121309042		00/12/13	09:04 51.59	46N13.15	119W36.13	7.62	0.5	8/10	208	6	0.03	AD	12.9 km E of Prosser
00121309085		00/12/13	09:09 18.87	46N12.79	119W36.24	7.87	0.3	8/11	215	6	0.04	AD	12.7 km E of Prosser
00121310091		00/12/13	10:09 39.10	46N12.35	119W36.06	9.53	2.0	29/34	82	6	0.09	AA	12.9 km E of Prosser
00121311474		00/12/13	11:48 06.63	46N12.70	119W35.84	7.88	0.8	13/21	87	6	0.11	AA	13.2 km E of Prosser
00121311545		00/12/13	11:55 12.80	46N12.52	119W36.17	7.86	0.2	7/10	221	6	0.07	AD	12.8 km E of Prosser
00121312105		00/12/13	12:11 16.32	46N11.95	119W36.16	9.99	1.5	22/28	88	6	0.19	BA	12.8 km E of Prosser
00121314060		00/12/13	14:06 32.47	46N12.28	119W36.14	10.02	1.9	29/37	82	6	0.14	AA	12.8 km E of Prosser
00121401252		00/12/14	01:25 52.01	46N12.69	119W36.05	8.30	1.6	20/24	144	6	0.07	AC	12.9 km E of Prosser
00121401514		00/12/14	01:52 06.38	46N12.54	119W35.92	8.76	0.4	10/19	163	6	0.14	AC	13.1 km E of Prosser
00121402173		00/12/14	02:18 02.68	46N12.39	119W35.96	9.16	1.2	15/21	83	6	0.06	AA	13.0 km E of Prosser
00121407280		00/12/14	07:28 30.62	46N12.18	119W36.06	10.25	0.7	9/17	169	6	0.08	AC	12.9 km E of Prosser
00121422571		00/12/14	22:57 43.12	46N11.22	119W36.06	11.11	1.9	24/29	146	7	0.13	AC	13.1 km E of Prosser
00121817443		00/12/18	17:44 55.87	46N12.72	119W36.26	7.93	0.2	9/11	217	6	0.05	AD	12.7 km E of Prosser
00121819191		00/12/18	19:19 34.56	46N12.98	119W36.37	8.08	0.3	6/7	290	6	0.04	AD	12.5 km E of Prosser
00121820064		00/12/18	20:07 05.01	46N12.80	119W36.00	8.15	0.9	16/21	144	6	0.14	AC	13.0 km E of Prosser
00123013033		00/12/30	13:04 02.21	46N12.41	119W36.88	6.83	0.4	8/11	292	5	0.07	AD	11.8 km E of Prosser
01010601414		01/01/06	01:41 57.01	46N07.29	119W48.36	23.63	0.6	15/18	135	13	0.05	AB	10.0 km SSW of Prosser
01010906351		01/01/09	06:35 42.66	46N11.26	119W35.84	11.57	1.2	15/16	209	7	0.09	AD	13.4 km E of Prosser
01010907460		01/01/09	07:46 25.53	46N13.03	119W36.10	7.87	1.1	11/11	210	6	0.07	AD	12.9 km E of Prosser
01010908553		01/01/09	08:55 55.15	46N12.03	119W36.12	9.89	1.5	20/24	172	6	0.08	AC	12.8 km E of Prosser
01010912560		01/01/09	12:56 27.53	46N13.22	119W36.12	7.59	1.2	10/10	206	6	0.08	AD	12.9 km E of Prosser

Table 3.2. (cont)

Event ID	Type	Date	Time	Latitude	Longitude	Depth	Mag	NS/NP	Gap	DMIN	RMS	Q	Location
01010914153		01/01/09	14:15 51.24	46N02.64	119W39.76	4.47	0.5	9/10	169	18	0.14	BC	19.9 km SSE of Prosser
01010917130		01/01/09	17:13 31.19	46N13.27	119W36.08	7.06	1.0	8/8	205	6	0.08	AD	13.0 km E of Prosser
01011814003		01/01/18	14:00 50.09	46N18.49	119W32.50	13.74	-0.2	6/9	231	8	0.06	AD	19.5 km W of Richland
01011904380		01/01/19	04:38 23.72	46N03.82	119W50.47	0.02	1.8	22/31	98	20	0.24	BC	16.9 km SSW of Prosser
01012014191		01/01/20	14:19 37.28	46N27.57	119W43.05	16.46	-0.1	9/15	219	6	0.08	AD	12.5 km SSW of 200 West
01012305560		01/01/23	05:56 29.43	46N50.62	119W44.28	4.15	1.3	19/21	67	11	0.13	AC	22.6 km SE of Vantage
01012623262	X	01/01/26	23:27 27.99	46N07.19	119W01.32	0.03	2.3	17/18	151	9	0.14	AC	12.1 SE of Kennewick
01013023232		01/01/30	23:24 23.03	46N25.31	119W17.41	0.02	-0.6	5/9	240	0	0.24	BD	5.4 km ESE of 400 Area
01020721394	P	01/02/07	21:40 00.53	46N07.89	119W00.36	0.03	0.0	11/11	111	9	0.12	AB	12.1 km SE of Kennewick
01021317251		01/02/13	17:25 43.69	46N26.65	119W38.14	16.58	-0.1	10/14	131	2	0.07	AB	12.7 km S of 200 West
01022122262		01/02/21	22:26 52.15	46N44.24	119W25.53	0.03	0.2	7/11	100	2	0.08	AB	16.9 km NE of 100-K Area
01030410244		01/03/04	10:25 05.66	46N44.21	119W25.91	0.03	0.6	12/20	126	2	0.14	AB	16.5 km NE of 100-K Area
01030812391		01/03/08	12:39 32.81	46N18.57	119W40.55	0.45	0.2	11/14	165	10	0.15	AC	13.4 km NNE of Prosser
01031218263	P	01/03/12	18:26 46.40	46N03.96	119W27.50	0.70	0.0	4/6	340	25	0.04	AD	27.4 km SSW of Richland
01031300300		01/03/13	00:30 22.30	46N32.20	119W47.04	23.22	0.2	10/13	121	5	0.09	AB	11.5 km WSW of 200 West
01031303011		01/03/13	03:01 37.70	46N13.09	119W36.19	7.31	0.0	7/9	289	6	0.05	AD	12.8 E of Prosser
01031616463		01/03/16	16:46 55.75	46N05.48	119W54.39	0.03	1.8	22/25	73	21	0.16	BC	16.7 km SW of Prosser
01040322051		01/04/03	22:05 42.87	46N44.74	119W24.86	0.04	1.1	12/13	155	3	0.10	AC	18.1 km NE of 100-K Area
01040505114		01/04/05	05:12 11.17	46N53.18	119W37.36	15.39	0.7	23/30	57	12	0.12	AA	27.3 km N of 100-K Area
01040714464		01/04/07	14:47 09.99	46N23.02	119W14.74	2.53	-0.3	5/10	269	6	0.15	BD	3.8 km NE of 300 Area
01041505571		01/04/15	05:57 43.18	46N44.69	119W25.33	0.02	0.4	9/12	204	3	0.16	BD	17.6 km NE of 100-K Area
01041520213		01/04/15	20:21 58.66	46N44.27	119W25.22	0.02	0.1	8/9	103	2	0.09	AB	17.2 km NE of 100-K Area
01042504163		01/04/25	04:16 54.65	46N24.18	119W45.81	14.36	0.2	9/16	245	10	0.08	AD	19.8 km SSW of 200 West
01042808094		01/04/28	08:10 13.40	46N44.67	119W25.45	0.05	0.8	18/25	76	3	0.15	AA	17.5 km NE of 100-K Area
01043003472		01/04/30	03:47 49.12	46N35.83	119W46.64	16.79	0.5	22/29	80	2	0.14	AA	11.5 km WNW of 200 West
01050308484		01/05/03	08:49 06.79	46N44.54	119W24.45	0.03	1.0	8/9	160	3	0.10	AC	18.3 km NE of 100-K Area

Table 3.2. (contd)

Event ID	Type	Date	Time	Latitude	Longitude	Depth	Mag	NS/NP	Gap	DMIN	RMS	Q	Location
01050411191		01/05/04	11:19 31.90	46N44.79	119W24.91	0.03	0.7	5/6	154	3	0.16	BD	18.1 km NE of 100-K Area
01050417073	P	01/05/04	17:07 55.35	46N01.26	119W34.58	0.46	1.5	7/8	252	22	0.12	AD	25.5 km SE of Prosser
01050904325		01/05/09	04:33 15.79	46N44.09	119W25.53	0.03	0.8	4/6	194	2	0.16	BD	16.7 km NE of 100-K Area
01060311513		01/06/03	11:51 58.55	46N43.43	119W18.33	13.65	1.6	21/30	88	8	0.15	AA	15.6 km SW of Othello
01060712452		01/06/07	12:45 42.64	46N57.76	119W31.39	19.99	2.3	33/38	48	2	0.12	AA	25.8 km SW of Moses Lake
01060815053		01/06/08	15:06 03.62	46N36.31	119W40.29	0.02	1.8	23/26	47	3	0.14	AA	5.8 km NNW of 200 West
01060904195		01/06/09	04:20 19.36	46N36.52	119W40.24	0.03	0.0	8/16	175	3	0.17	BC	6.2 km NNW of 200 West
01061203283		01/06/12	03:29 01.34	46N43.46	119W37.68	12.08	0.2	8/12	194	5	0.03	AD	9.5 km NNW of 100-K Area
01062416473		01/06/24	16:47 54.72	46N21.33	119W31.10	4.22	0.1	6/9	171	7	0.05	AC	15.2 km SW of 400 Area
01062503425		01/06/25	03:43 14.17	46N37.75	119W39.42	3.24	-0.6	4/6	238	3	0.08	AD	4.8 km WSW of 100-K Area

Explanation of Table 3.2

EVENT ID: The Earthworm Recording System creates the identification number. XPED uses the year, month, day and time to create a unique number for each event.

TYPE: P is Probable Blast; X is Confirmed Blast; F is Felt Earthquake; S is surficial event (rockslide, avalanche) and not a explosion or tectonic earthquake; blank is local earthquake**.**

DATE: The year and day of the year in Universal Time Coordinated (UTC). UTC is used throughout this report unless otherwise indicated.

TIME: The origin time of the earthquake given in UTC. To covert UTC to Pacific Standard Time, subtract eight hours; to Pacific Daylight Time, subtract seven hours.

LATITUDE: North latitude, in degrees and minutes, of the earthquake epicenter.

LONGITUDE: West longitude, in degrees and minutes, of the earthquake epicenter.

DEPTH: The depth of the earthquake in kilometers (km).

MAG: The magnitude is expressed as Coda-Length magnitude M_c, an estimate of local magnitude M_L (Richter 1958). If magnitude is blank no determination could be made.

NS/NP: Number of stations/number of phases used in the solutions.

GAP: Azimuthal gap. The largest angle (relative to the epicenter) containing no stations.

DMIN: The distance from the earthquake epicenter to the closest station

RMS: The root-mean-square residual (observed arrival times minus the predicted arrival times) at all stations used to locate the earthquake. It is only useful as a measure of quality of the solution when five or more well-distributed stations are used in the solution. Good solutions are normally characterized by RMS values of less than about 0.3 seconds.

Q: The Quality Factors indicate the general reliability of the solution/location (**A** is best quality, **D** is worst). See Section 3.3 of this report: Quality Factors.

4.0 Geology and Tectonic Analysis

The Hanford Site lies within the Columbia Basin, which is an intermontane basin between the Cascade Range and the Rocky Mountains that is filled with Cenozoic volcanic rocks and sediments. This basin forms the northern part of the Columbia Plateau physiographic province (Fenneman 1931) and the Columbia River flood-basalt province (Reidel and Hooper 1989). In the central and western parts of the Columbia Basin, the Columbia River Basalt Group (CRBG) overlies Tertiary continental sedimentary rocks and is overlain by late Tertiary and Quaternary fluvial and glaciofluvial deposits (Campbell 1989; Reidel and others 1989; DOE 1988). In the eastern part, a thin (<100 m) sedimentary unit separates the basalt and underling crystalline basement and a thin (<10 m) veneer of eolian sediments overlies the basalt (Reidel and others 1989).

The Columbia Basin has two structural subdivisions or subprovinces: the Yakima Fold Belt and the Palouse Slope. The Yakima Fold Belt includes the western and central parts of the Columbia Basin and is a series of anticlinal ridges and synclinal valleys with major thrust faults along the northern flanks (Figure 4.1). The Palouse Slope is the eastern part of the basin and is less deformed than the Yakima Fold Belt with only a few faults and low amplitude, long wavelength folds on an otherwise gently westward dipping paleoslope. Figure 4.2 shows north-south and east-west cross sections through the Columbia Basin based on surface mapping, deep boreholes, geophysical data (including the work of Rohay et al. [1985]), and magnetotelluric data obtained as part of BWIP (DOE 1988).

4.1 Earthquake Stratigraphy

Studies of seismicity at the Hanford Site have shown that the seismicity is related to crustal stratigraphy (layers of rock types) (Rohay et al. 1985; DOE 1988). The main geologic units important to earthquakes at Hanford and the surrounding area are:

- The Miocene CRBG
- The Paleocene, Eocene, and Oligocene sediments
- The crystalline basement (Precambrian and Paleozoic craton; Mesozoic accreted terranes).

4.2 Geologic Structure Beneath the Monitored Area

Between the late 1950s and the early 1980s, deep boreholes were drilled for hydrocarbon exploration in the Columbia Basin. These boreholes provided accurate measurements of the physical properties of the CRBG and the pre-basalt sediments (Reidel et al. 1994, 1989), but the thickness of the pre-basalt sediments and nature of the crystalline basement are still poorly understood. The difference between the thicknesses listed in Table 4.1 and the thicknesses of the crustal layers in the velocity model in Table 3.1 reflect data specific to UW's crustal velocity model for eastern Washington. Table 4.2 is derived from Figure 4.2 and was developed for the geologic interpretation in this report. The thicknesses of these units are variable across the monitored area. Table 4.1 summarizes the approximate thickness at the borders of the monitored area.

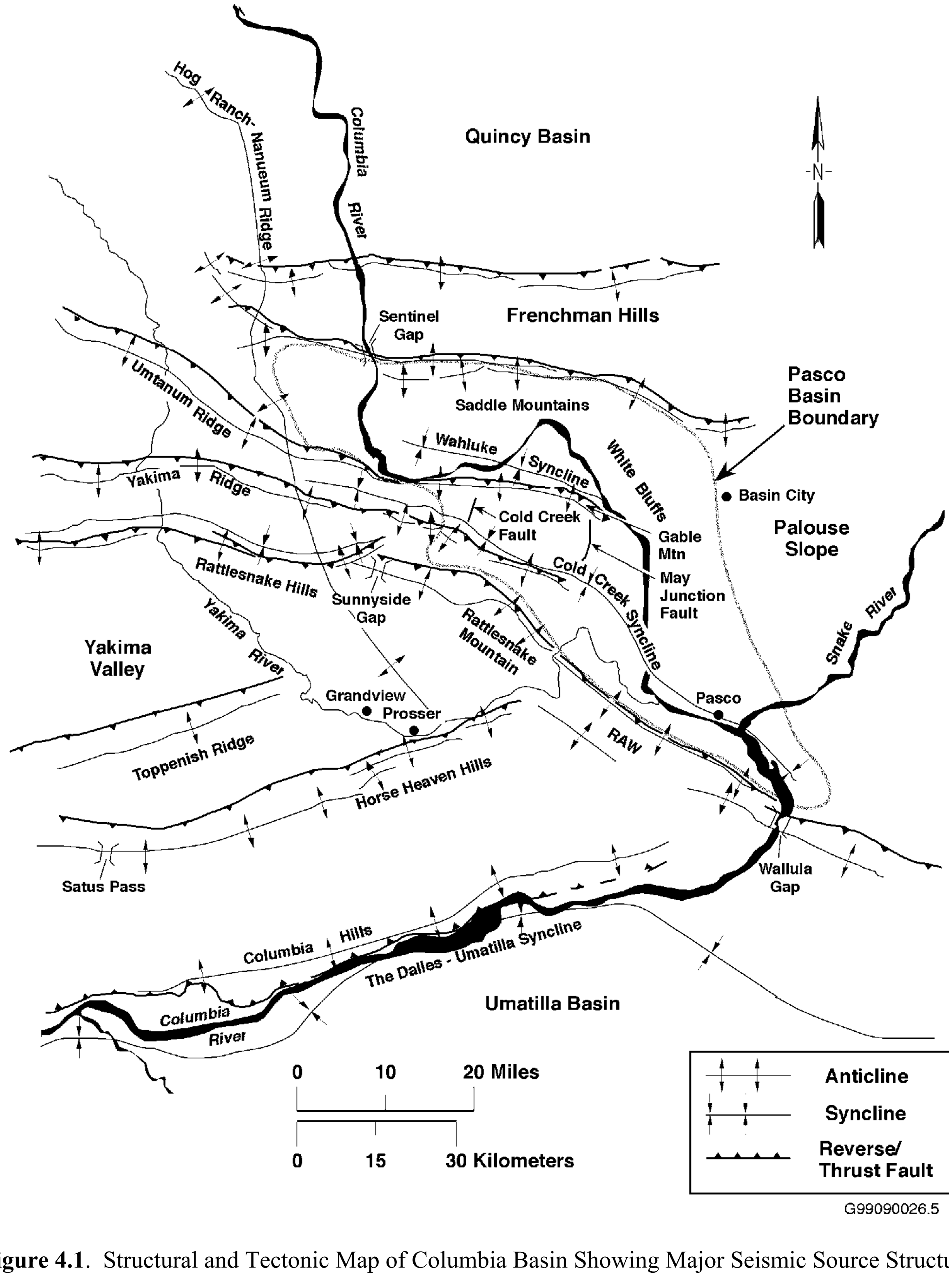

Figure 4.1. Structural and Tectonic Map of Columbia Basin Showing Major Seismic Source Structures

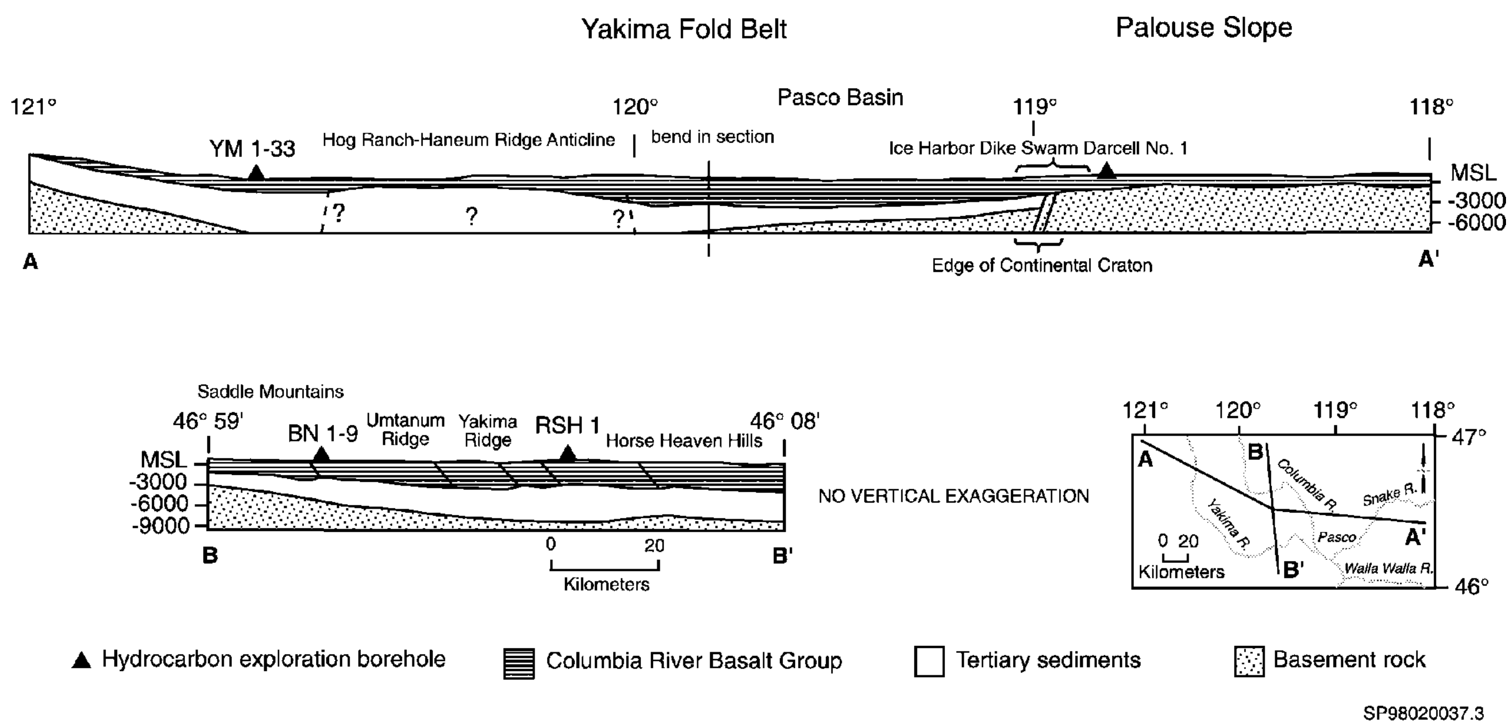

Figure 4.2. Geologic Cross Sections Through the Columbia Basin

Table 4.1. Thicknesses of Stratigraphic Units in the Monitoring Area

Stratigraphy	North	South	East	West
Columbia River Basalt Group (includes suprabasalt sediments)	3.0 km	4.5 km	2.2 km	4.2 km
Pre-basalt Sediments	3.0 km	>4.5 km	0	>6.0 km

The thickness of the basalt and the pre-basalt sediments varies as a result of different tectonic environments. The western edge of the North American craton (late Precambrian/Paleozoic continental margin and Precambrian craton) is located in the eastern portion of the monitored area. The stratigraphy on the craton consists of CRBG overlying crystalline basement; the crystalline basement is continental crustal rocks that underlie much of the western North America. The stratigraphy west of the craton consists of 4-5 km of CRBG overlying greater than 6 km of pre-basalt sediments. This in turn overlies accreted terranes of Mesozoic age. The area west of the craton was subsiding during the Eocene and Oligocene, accumulating great thickness of pre-CRBG sediments. Continued subsidence in this area during the Miocene resulted in thicker CRBG compared to that on the craton. Subsidence continues today but at a greatly reduced rate (Reidel et al. 1994).

4.3 Depth of Earthquakes

Since records have been kept, most of the earthquakes at the Hanford Site have originated in the CRBG layer. The crystalline basement has had the next greatest amount followed by the pre-basalt sediments. The stratigraphic units for local earthquakes recorded during the second and third quarters of FY 2001 are listed in Table 4.2. During the second quarter of FY 2001, eight earthquakes occurred in the basalt, five in the pre-basalt sediments, and six in the crystalline basement. During the third quarter of FY 2001, twelve earthquakes occurred in the basalt and six in the crystalline basement.

Table 4.2. Number of Local Earthquakes Occurring in Stratigraphic Units

Unit	First Quarter	Second Quarter	Third Quarter	Fourth Quarter	FY 2001
Basalt	1	8	12	-	21 (26%)
Pre-basalt Sediments	43	5	0	-	48 (58%)
Crystalline Basement	1	6	6	-	13 (16%)
Total	45	19	18	-	82

4.4 Tectonic Pattern

Studies have concluded that earthquakes can occur in the following six different tectonic environments (earthquake sources) at the Hanford Site (Geomatrix 1996).

- **Reverse/thrust faults**. Reverse/thrust faults in the CRBG associated with major anticlinal ridges such as Rattlesnake Mountain, Yakima Ridge, and Umtanum Ridge could produce some of the largest earthquakes in the Hanford area and Columbia Basin.

- **Secondary faults**. These are associated with the major anticlinal ridges.

- **Swarm areas**. Small geographic areas of unknown geologic structure produce clusters of events (swarms), usually in the CRBG in synclinal valleys. These clusters consist of a series of small shocks with no outstanding principal event. Swarms occur over a period of days or months and the events may number into the hundreds and then quit, only to start again at a later date. This differs from the sequence of foreshocks, mainshock, and trailing-off aftershocks that have the same epicenter or are associated with the same fault system. Three principal swarm areas are known at the Hanford Site. One is the Wooded Island Swarm Area along the Columbia River near the 300 Area. The second area, the Coyote Rapids Swarm Area, extends from the vicinity of the 100-K Area north-northeast along the Columbia River Horn to the vicinity of the 100-N Area. The third major swarm area is along the Saddle Mountains on the northern boundary of the Hanford Site. Other earthquake swarm areas are typically present, but activity is less frequent.

- **The entire Columbia Basin**. The entire basin, including the Hanford Site, could produce a "floating" earthquake. A floating earthquake is one that, for seismic design purposes, can happen anywhere in a tectonic province and is not associated with any known geologic structure. Seismic Monitoring classifies it as a random event for purposes of seismic design and vibratory ground motion studies.

- **Basement source structures**. Studies (Geomatrix 1996) suggest that major earthquakes can originate in tectonic structures in the crystalline basement. Because little is known about geologic structures in the crystalline basement beneath the Hanford Site, earthquakes cannot be directly tied to a mapped fault. Earthquakes occurring in the crystalline basement without known sources are treated as random events for seismic hazards analysis and seismic design.

- **The Cascadia Subduction Zone**. This source has been postulated to be capable of producing a magnitude 9 earthquake. Because this source is along the western boundary of Washington State and outside the HSN, the Cascadia Subduction Zone is not an earthquake source that is monitored at the Hanford Site, so subduction zone earthquakes are not reported here. Because any earthquake along the Cascadia Subduction zone can have a significant impact on the Hanford Site (Geomatrix 1996), UW monitors and reports on this earthquake source for DOE. Ground motion from any moderate or larger Cascadia Subduction Zone earthquake is detected by seismometers in the HSN.

4.5 Tectonic Activity

Nineteen earthquakes occurred in the local area during the second quarter of FY 2001 and eighteen earthquakes occurred during the third quarter (Table 4.3). These earthquakes are described in the following sections.

Table 4.3. Summary of Earthquake Locations

Seismic Sources		First Quarter	Second Quarter	Third Quarter	Fourth Quarter	FY 2001
Geologic Structure		1	0	4	-	5 (6%)
Swarm Areas	Saddle Mountains/ Royal	0	1	0	-	1(1%)
	Coyote Rapids	0	0	0	-	0
	Wooded Island	0	1	1	-	2 (2%)
	Wahluke Slope	0	2	7	-	9 (11%)
	Horse Heaven Hills	44	10	0	-	54 (66%)
	Cold Creek	0	0	0	-	0
	Total for swarms	44	14	8	-	66 (80%)
Random Events		0	5	6	-	11 (14%)
Total for all earthquakes		45	19	18	-	82

4.5.1 Second Quarter of FY 2001

The locations of all mapped earthquakes that occurred between January 1, 2001 and March 31, 2001 are shown on Figure 4.3.

4.5.1.1 Earthquake Swarm Areas

During the second quarter of FY 2001, we interpret 14 seismic events to have occurred in swarm areas. One event occurred in the Saddle Mountains swarm area, two were on the Wahluke Slope, one in Wooded Island and ten were in the Horse Heaven Hills area.

4.5.1.1.1 Saddle Mountain Swarm Area. One small (1.3 M_c) earthquake occurred on January 23rd in the Saddle Mountain swarm area on the north side of the Saddle Mountains. This event occurred in the CRBG layer (4.2 km).

4.5.1.1.2 Wahluke Slope Swarm Area. Two small (0.2 and 0.6 M_c, respectively), shallow events occurred on February 21st and March 4th. These events occurred on the south side of the Saddle Mountains east of the horn of the Columbia River. This area has been active in the past, most recently in 1999.

4.5.1.1.3 Horse Heaven Hills Swarm Area. Ten events occurred within the Horse Heaven Hills swarm area during this quarter (Figure 4.3). We defined the Horse Heaven Hills as a new swarm area during FY 2000 because of increased activity south of Prosser, Washington that began during FY 1999. These earthquakes appear to be a continuation of activity from the first quarter of FY 2001.

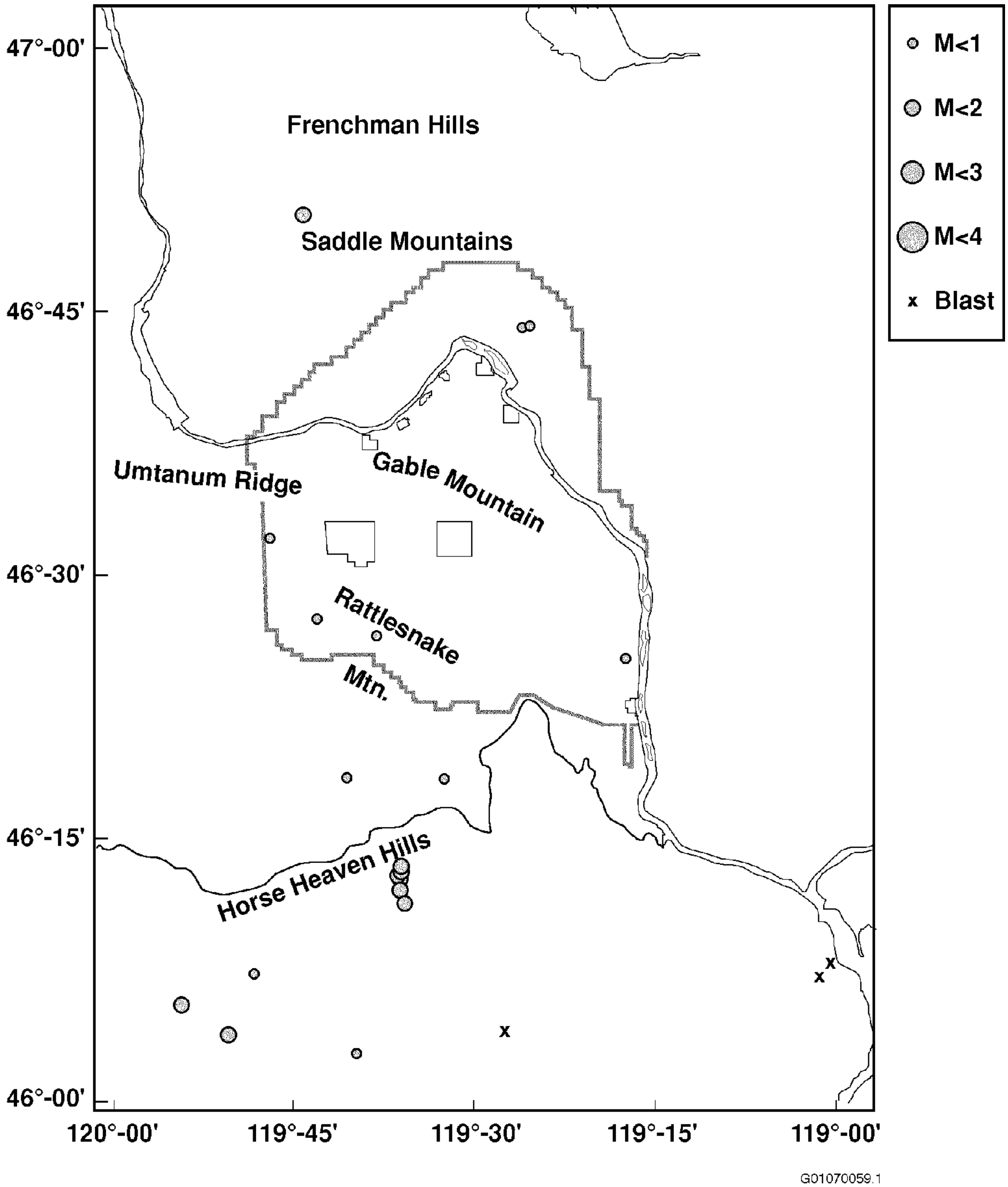

Figure 4.3. Locations of All Events Between January 1, 2001 and March 31, 2001 (Coda Length Magnitude (M_c) scale is shown at the side of the map)

Magnitudes of these earthquakes ranged from 0 to 1.8. Four of the earthquakes were spread across the south side of the area and six were clustered together. Three occurred in the basalt (one was 4 km deep and the other two were near surface), three in the crystalline basement (12 to 24 km), and five earthquakes occurred within the pre-basalt sediments.

The activity here began on January 6th with the first (0.6 M_c, 24 km) of the four events that were spread around the swarm area. The second event occurred on January 9th (0.5 M_c, 4.5 km) followed by one on the 19th (1.8 M_c, near surface) to the southwest of the swarm area. After a brief lull in activity, the last event occurred on the 16th of March (1.8 M_c, near surface) on the west side of the swarm.

The tight earthquake swarm that became active in the first quarter continued into the second quarter. On January 9th, three events occurred that were approximately an hour apart, followed by two more events later on the same day (Figure 4.4). The last event occurred on March 31st, and there was no activity there during the third quarter. The depth of all these swarm events was 7-12 km in the pre-basalt sediments.

4.5.1.1.4 Wooded Island Swarm Area. One earthquake occurred in the Wooded Island swarm area near Johnson Island. This event was very small (approximately 0 M_c) and shallow.

4.5.1.2 Random or Floating Events

During the second quarter, five events were classified as random events because they did not occur in known earthquake swarms or along known geologic structures. Four events occurred in the crystalline basement and one occurred in the CRBG. No geologic structure has been identified below the basalt, so events in the crystalline basement are classified as random events. The fifth event did not occur in a known earthquake swarm area or along known geologic structures, so it has been classified as a floating event.

On January 18th, a small event (M_c <1) occurred on the south flank of Rattlesnake Mountain. This event was in the crystalline basement and was 14 km deep. The next two events (M_c <1) were on January 20th and February 13th and occurred below the Rattlesnake Hills in the crystalline basement (16-23 km). On March 8th, a small (M_c 0.2) shallow (1 km deep) earthquake occurred below the south flank of Rattlesnake Mountain. The last event (0.2 M_c) occurred on March 13th and was in the crystalline basement below Yakima Ridge (23 km).

4.5.2 Third Quarter of FY 2001

The locations of all mapped earthquakes that occurred between April 1, 2001 and June 30, 2001 are shown on Figure 4.5.

4.5.2.1 Major Anticlinal Ridges

During the third quarter of FY 2001, we interpret four seismic events to have occurred on major ridges. On June 8th, a small (1.8 M_c) earthquake occurred along the Umtanum Ridge anticline south of

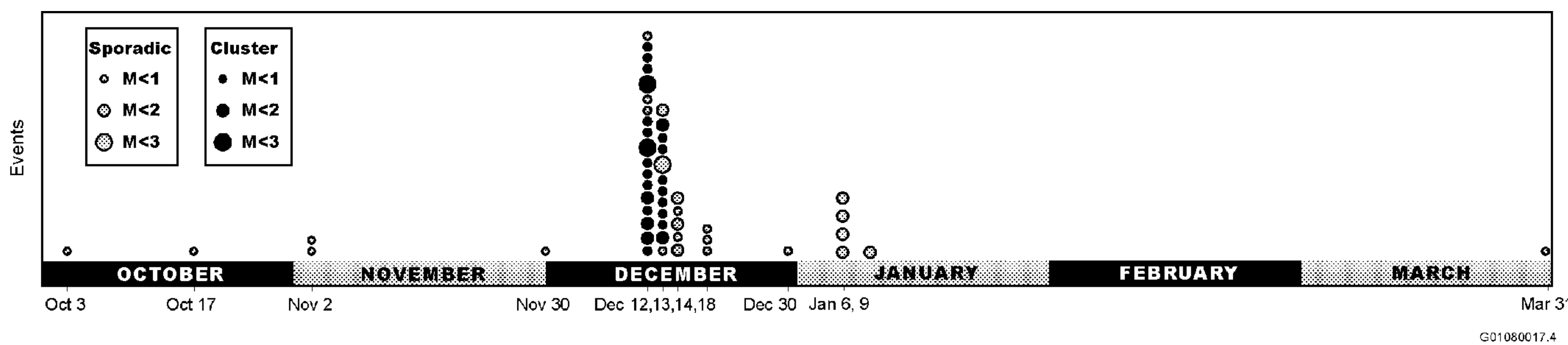

Figure 4.4. Time Sequence for the Second and Third Quarters, Horse Heaven Hills Earthquake Swarm Cluster

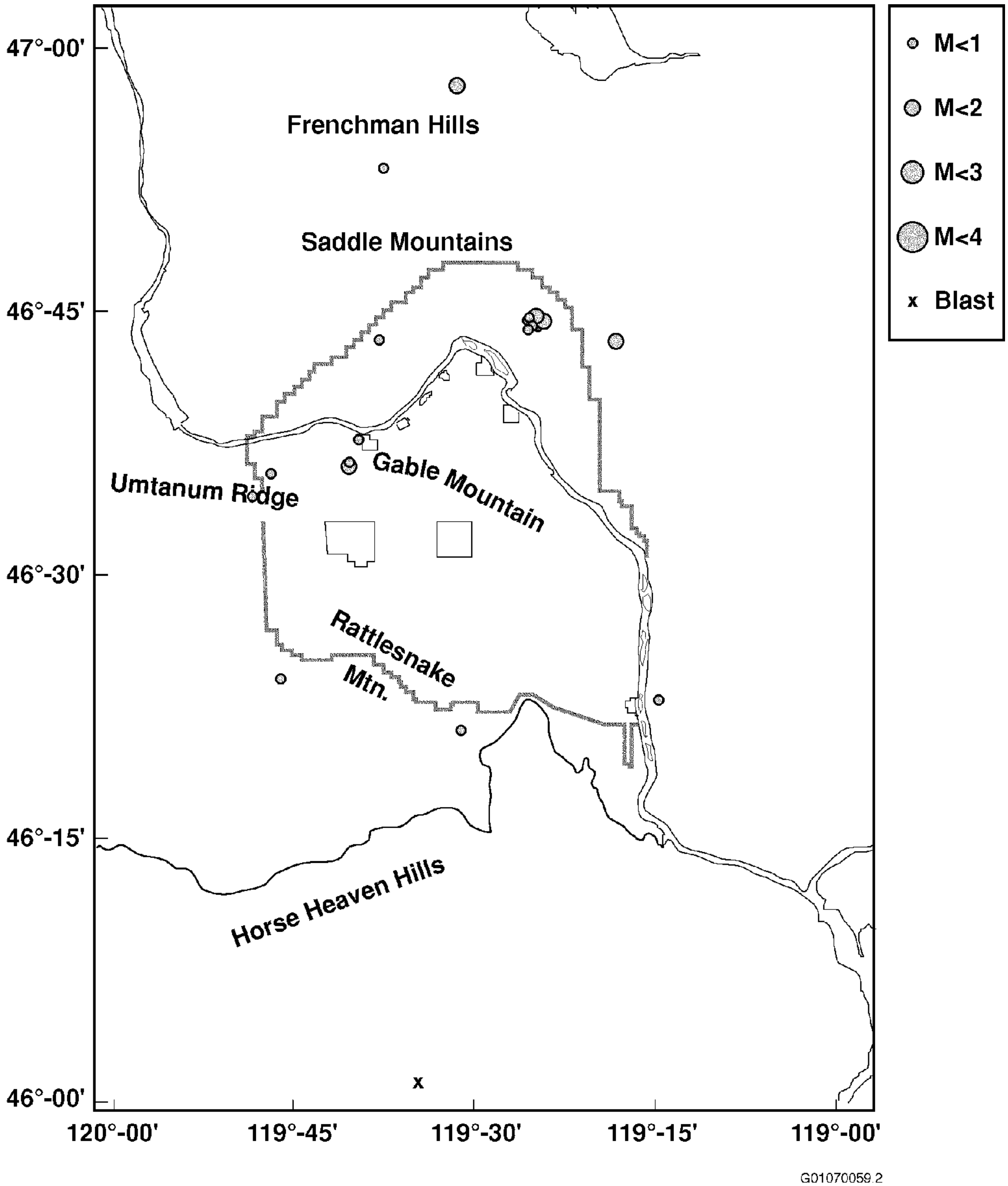

Figure 4.5. Locations of All Events Between April 1, 2001 and June 30, 2001 (Coda Length Magnitude (M_c) scale is shown at the side of the map)

Vernita Bridge. This event was shallow (0.02 km) and occurred in the CRBG. On June 9th, a smaller (0.0 M_c), shallow event occurred on Umtanum Ridge anticline at the same locality as the June 8th event. A third small earthquake (<1 M_c) on June 25th occurred about 1 km north of the previous two events and at a greater depth (3 km) in the CRBG. The locations and depths are consistent with this earthquake occurring in the Umtanum Ridge fault zone.

On June 24th, a small (0.1 M_c) earthquake occurred on Rattlesnake Mountain in the CRBG (near surface). This event occurred within 1 km of the Rattlesnake Mountain fault zone. Because of its proximity, we interpret it to be associated with the Rattlesnake Mountain structure.

4.5.2.2 Earthquake Swarm Areas

Eight earthquakes occurred in swarm areas during the third quarter of FY 2001. Of those eight, all but one was in the Wahluke Slope swarm area. The seven events on the Wahluke Slope took place in the same region that was active during the second quarter (see Figure 4.3). The Horse Heaven Hills swarm area that was active during the first and second quarters was not active during the third quarter. This pattern is typical of most earthquake swarms in the Columbia Basin.

4.5.2.2.1 Wahluke Slope Swarm Area. All seven earthquakes were shallow (near surface) and occurred in the CRBG. These events ranged in magnitude from 0.1 to 1.1 M_c. They occurred between April 3rd and May 9th and appear to be sporadic with only two occurring on the same day.

4.5.2.2.2 Wooded Island Swarm Area. One earthquake occurred on April 7th within the Wooded Island swarm area east of Johnson Island. This event was small (<1 M_c) and was in the CRBG.

4.5.2.3 Random or Floating Events

During the third quarter, six events were classified as random because they occurred in the crystalline basement. Events in the crystalline basement are considered random because no known geologic structure is identified beneath the CRBG.

On April 5th, a small (0.7 M_c) event occurred was just north of the Saddle Mountains. Although this event's location is within the Saddle Mountains, it is considered a random event because it is in the crystalline basement (15 km) where no geologic structure has been identified. The second random event occurred south of Snively Basin where Rattlesnake Mountain and the Rattlesnake Hills intersect. This event was small (0.2 M_c) and 14 km deep. On April 30th, a small earthquake (0.5 M_c) occurred beneath Umtanum Ridge. We do not classify this earthquake as controlled by the Umtanum Ridge structure because it occurs within the crystalline basement (17 km). On June 3rd, a 1.6 M_c earthquake occurred east of the Wahluke Slope swarm area at a depth of 14 km. The next event was on June 7th in the Frenchman Hills and was the largest (2.3 M_c) and deepest (20 km) earthquake of the third quarter. The last random event was on June 12th. It occurred west of the 100-N Area at a depth of 12 km and had a magnitude of 0.2 (M_c).

5.0 Strong Motion Accelerometer Operations

The Hanford SMA network has been in continuous operation since November 20, 1998 after a 1-year hiatus. The SMA network had numerous triggers resulting from noise. The number of triggers resulting from noise and normal human activity is routinely monitored to adjust the optimal settings for the triggering system. Our objective is to obtain an optimum balance between having minimal triggers caused by noise and detection of the smallest possible earthquake. The nominal threshold used in the SMA network is 0.001 g in order to provide ground motion data for smaller, non-damaging earthquakes that can be useful in estimating the ground motion expected from larger earthquakes, and to confirm correct operation of the instruments by analyzing the smaller-amplitude triggers (see Section 2.2). All the accelerometers triggered and recorded the nisqually earthquake in Western Washington (Section 5.1).

5.1 Nisqually Earthquake

At 10:54:32 am (18:54:32.78 UTC) on February 28, 2001, a 6.8 magnitude (M_w) earthquake occurred 57 km southwest of Seattle, Washington. This earthquake triggered the Hanford SMA network.

The raw data obtained from the Hanford SMAs, Caltech broadband instrument at LIGO, and the U.S. Geological Survey broadband instrument (HAWA) on Rattlesnake Mountain are given in Table 5.1. The data in Table 5.1 has been baseline corrected to remove the small DC offset in the center line of the accelerometers and a filter has been introduced to reduce low-frequency noise from the instrument, which does not affect the frequency range of interest. In addition, several of the recorders are not oriented exactly north-south and east-west; the horizontal components have been rotated to represent true north and east directions. The maximum positive and negative peaks are not necessarily equal and may not even occur at the same exact time. Table 5.2 shows the average absolute value of the maximum and minimum peak accelerations.

For the five Hanford SMAs, the highest accelerations were recorded at the 100K and 200E locations (northern portion of the Hanford Site) , and the lowest were recorded at the 400 Area and 300 Area locations (southern portion of the Hanford Site). The overall lowest accelerations were recorded on a bedrock site west of Hanford (HAWA). However, the accelerations at the Caltech LIGO site, which is closest to HAWA and the 400 Area sites, were nearly as high as at the northern sites. We are attempting to determine the causes of this variation in terms of the geologic structure beneath these locations.

In summary: Hanford Area locations experienced approximately

0.002-0.003 g or maximum of 0.3% g vertical peak ground acceleration
0.002-0.005 g or maximum of 0.5% g horizontal peak ground acceleration

Table 5.1. Hanford Strong Motion Accelerometer Raw Data

Nisqually Earthquake 2001/02/28 18:54			
Site	Acceleration in % g's Rotated		
	Vertical	North-South	East-West
100-K Area	+0.290 -0.255	+0.513 -0.548	+0.468 -0.463
200 East Area	+0.264 -0.350	+0.568 -0.461	+0.481 -0.502
200 West Area	+0.261 -0.269	+0.325 -0.411	+0.351 -0.319
400 Area (FFTF)	+0.264 -0.285	+0.294 -0.372	+0.409 -0.274
300 Area	+0.151 -0.198	+0.221 -0.238	+0.183 -0.205
LIGO (Caltech) Episensor Broadband	+0.285 -0.343 +0.280 -0.341	+0.399 -0.446 +0.397 -0.444	+0.487 -0.554 +0.480 -0.552
HAWA (USGS) Episensor Broadband (Base of Rattlesnake Mountain)	+0.131 -0.161 +0.131 -0.163	+0.219 -0.185 +0.175 -0.149	+0.153 -0.160

Table 5.2. Hanford Strong Motion Accelerometer Data as 1/2 Peak-to-Peak

Nisqually Earthquake 2001/02/28 18:54			
Site	Acceleration in % g's (1/2 peak-to-peak) Rotated		
	Vertical	North-South	East-West
100-K Area	0.272	0.530	0.466
200 East Area	0.307	0.510	0.492
200 West Area	0.265	0.368	0.335
400 Area (FFTF)	0.275	0.333	0.342
300 Area	0.175	0.230	0.194
LIGO (Caltech) Episensor	0.314	0.423	0.521
HAWA (USGS) Episensor	0.146	0.202	0.157

6.0 Capabilities in the Event of a Significant Earthquake

The SMA network was designed to provide ground motion in areas at the Hanford Site that have high densities of people and/or have hazardous facilities. This section summarizes the capabilities of the Seismic Monitoring Team in the event of an earthquake at Hanford.

6.1 Use of the SMA Network in the Event of an Earthquake

Historically, only a few facilities at the Hanford Site had instruments to provide data on peak ground accelerations or any type of ground motion. The present SMA instruments were located so that if an earthquake occurred, ground motion data would be readily available to assess the damage at the 100-K Area, the 200 East and West Areas, the 300 and 400 Area facilities, which have the greatest concentration of people, and all the hazardous materials.

Many facilities at the Hanford Site have undergone various degrees of seismic analysis either during design or during re-qualification. Although the seismic design of a building may be known, when an earthquake is felt, a determination must be made as to the extent of damage before it can be reoccupied and the systems restarted. A felt earthquake may not cause any damage to a building but, without adequate characterization of the ground motion, initial determination of damage may be impossible.

In the event of an earthquake such as the Nisqually earthquake, building managers, emergency directors, and engineers can and did obtain ground motion data recorded by the SMA network from the Seismic Monitoring Team in the Sigma V Building. If a SMA is triggered, the Seismic Monitoring Team will download events that were recorded and determine the peak ground accelerations and the spectral response curves. This information can then be used by the facility engineers to determine if the ground motion exceeded, is equal to, or is less than the building design. This, along with assessments from trained engineers, allows the facility manager to make a rapid and cost effective determination on whether a building is safe to reoccupy or should not be used until it has been inspected in more detail. Buildings that have designs exceeding the recorded ground motion could be put back into service very quickly; buildings with designs that are very close to or less than measured ground motion could be given priority for onsite damage inspections.

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