PNNL-11557-16

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

Hanford Seismic Annual Report for Fiscal Year 2000

D. C. Hartshorn
S. P. Reidel
A. C. Rohay
M. M. Valenta

December 2000

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

PACIFIC NORTHWEST NATIONAL LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC06-76RL01830

Printed in the United States of America

Available to DOE and DOE contractors from the
Office of Scientific and Technical Information, P.O. Box 62, Oak Ridge, TN 37831;
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Available to the public from the National Technical Information Service,
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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 2,169 triggers during fiscal year (FY) 2000 on the data acquisition system.

For the entire fiscal year, 64 earthquakes were located; 30 were earthquakes in the Columbia River Basalt Group, 7 were earthquakes in the pre-basalt sediments, and 27 were earthquakes in the crystalline basement. Geographically, 25 earthquakes occurred in swarm areas, 7 earthquakes were on major structures, and 32 earthquakes were random occurrences.

No earthquakes triggered the Hanford Strong Motion Accelerometers during FY 2000.

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
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
WHC	Westinghouse Hanford Company

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1.0 Introduction

This report is the annual Hanford seismic activity report for fiscal year 2000. In this report we summarize earthquake activity from the Hanford Site and vicinity that occurred between October 1, 1999 and September 30, 2000 and our geologic interpretation of the sources of the earthquakes. In addition, we report on other studies that have occurred or are ongoing that could have an impact on seismic hazards at the Hanford Site.

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 the 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.

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 consists 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. All sites or relays are transmitted to the Sigma V building, Richland Washington.

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.

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

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
WG4	46N01.85	118W51.34	511	Wallula Gap Four
WIW	46N25.76	119W17.26	128	Wooded Island
WRD	46N58.20	119W08.69	375	Warden
YPT[a]	46N02.93	118W57.73	325	Yellepit

(a) Replacement site for WG4.

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 FY 2000 by the seismic acquisition system are summarized in Table 2.3.

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 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.

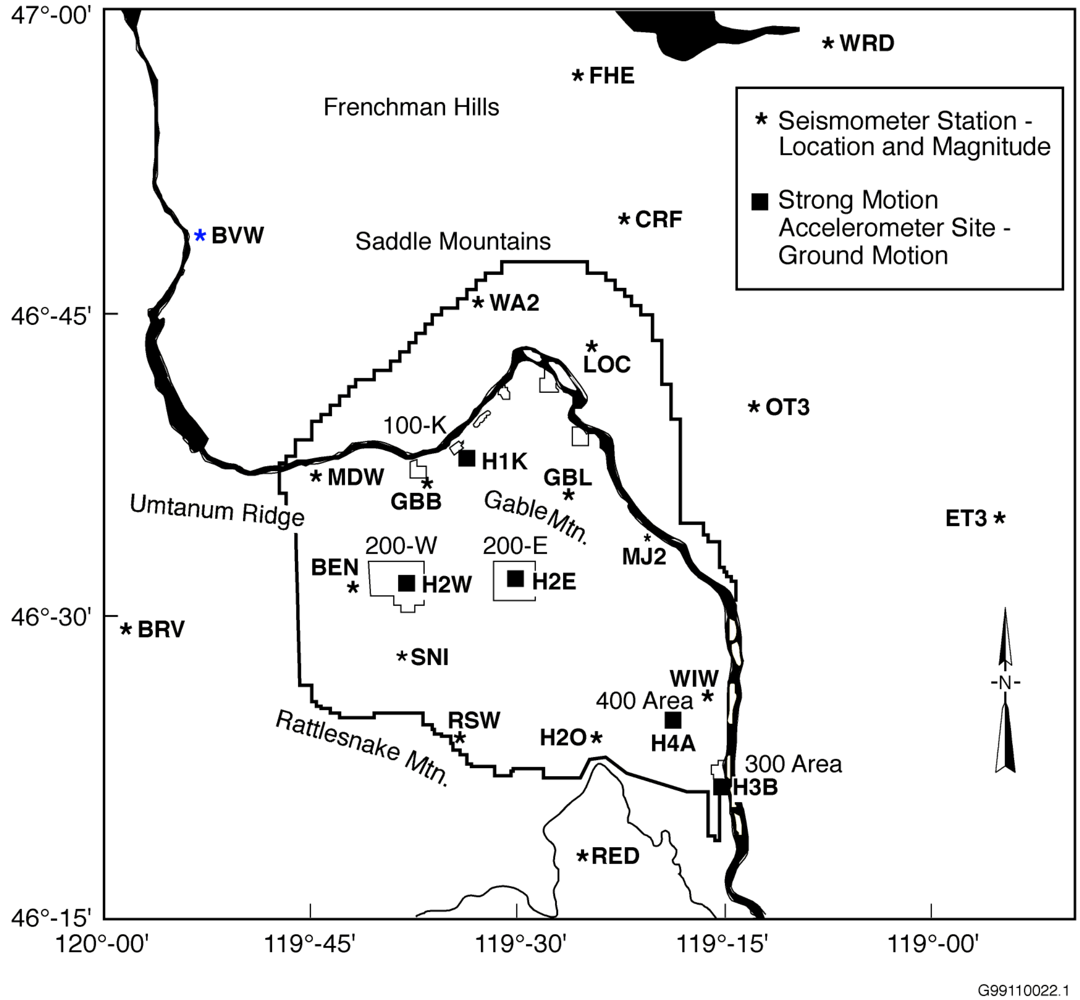


Figure 2.1. Locations of Seismograph Stations and Strong Motion Accelerometer Sites in the Hanford Seismic Network (see Table 2.1 for description of locations). Locations for Prosser (PRO), Wallula Gap (WG4), and Yellepit (YPT) are not shown. See Figure 2.2 for the locations of those sites.

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 being constructed 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.

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
WG4	46N01.85	118W51.34	511	Wallula Gap Four
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 replaces site WG4.

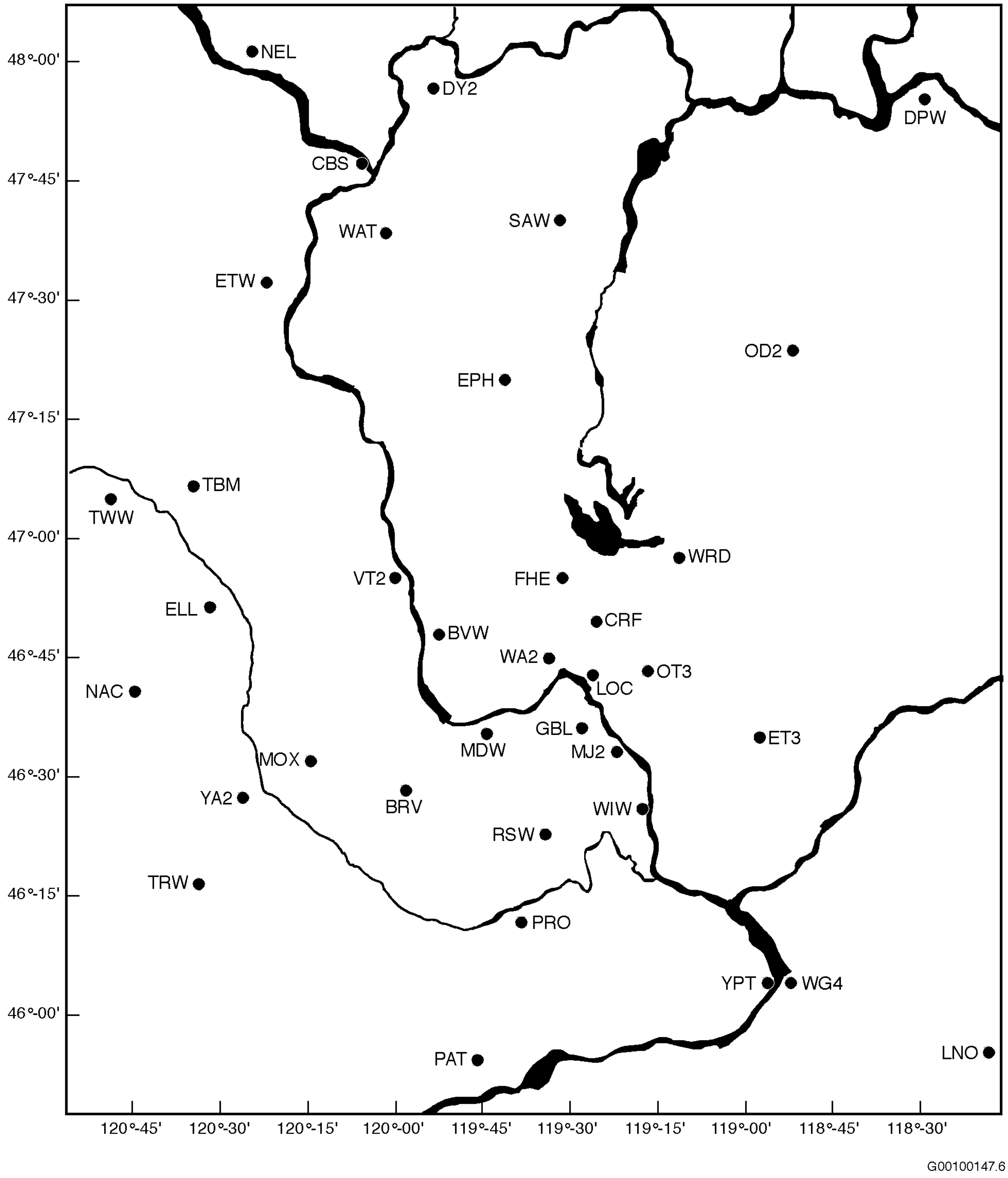


Figure 2.2. Locations of Seismograph Stations in the Eastern Washington Regional Network (see Table 2.2 for location descriptions). YPT replaces site WG4.

Table 2.3. Acquisition System Recorded Triggers

Event Type	First Quarter A	First Quarter B	Second Quarter	Third Quarter	Fourth Quarter	Remarks
Southcentral Washington	20	19	75	19	35	Seismic events in southcentral Washington and northcentral Oregon that triggered the HSN
Regional	26	23	64	59	43	Seismic events in the Western United States and Canada
Teleseism	56	57	134	73	95	Seismic events at farther distances from around the world
Noise	50	60	233	667	361	Triggers caused by data line circuits, lightning, maintenance triggers during system testing, high winds, coincidental noise at multiple sites within a trigger subnet, etc.
Total Triggers	152	159	506	818	534	A total of 311 triggers were examined this quarter.
Local	11		22	13	18	Seismic events within the 46-47 degrees north latitude and 119-120 degrees west longitude
A and B are the two Earthworm triggering systems.						

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 Ave.	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 Ave.	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

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 m (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.

Two 100 amp-hour batteries that are housed in the equipment and communications drum (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.

Table 2.5. Instrument Parameters for the Kinemetrics 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.

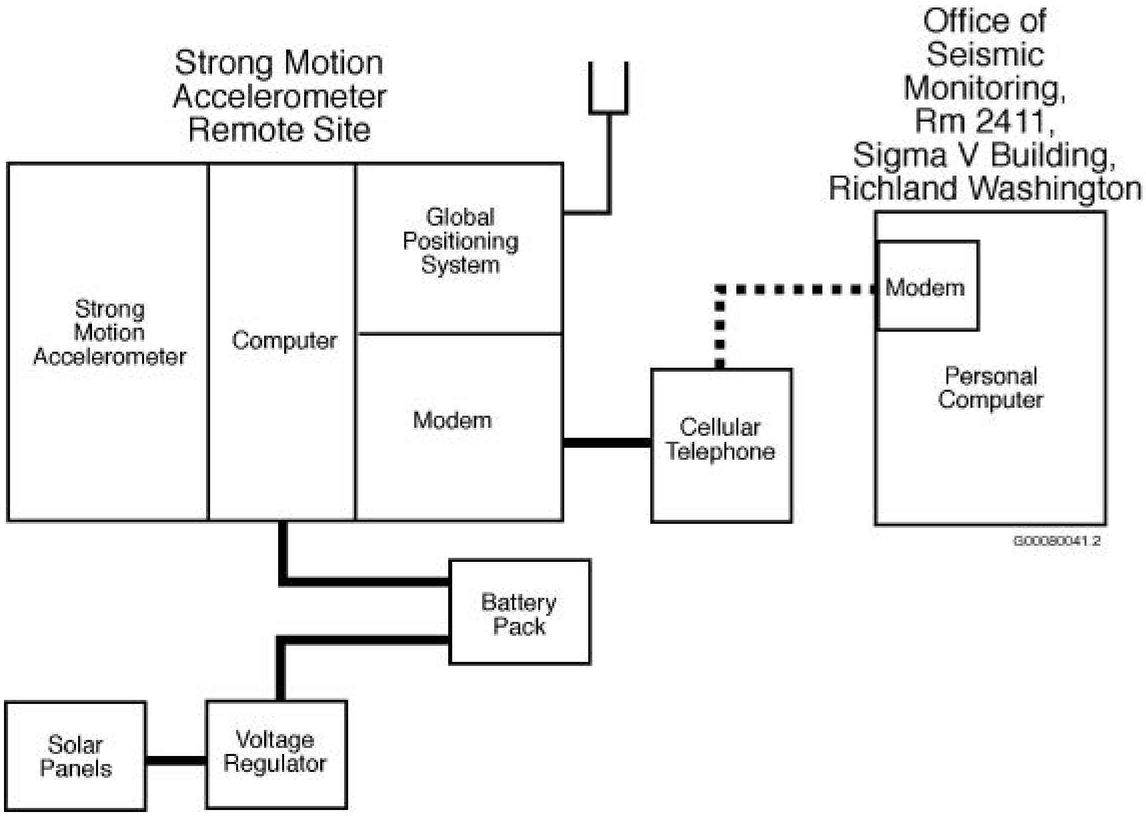


Figure 2.3. Schematic Diagram of a Strong Motion Accelerometer Installation

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 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. The recorders store information for 10 seconds before the trigger threshold is exceeded and for 40 seconds after the trigger ceases to be exceeded.

The SMA network is designed to transmit the data to the Hanford Seismic Recording Center at the Sigma V building or to be remotely accessed with a PC and modem. In addition, all SMAs can be accessed in the field where the data can be downloaded and interpreted.

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 the 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^o, and **DMIN** <5 km (or the hypocenter depth if it is greater than 5 km). If **NP** $\leq$5, **GAP** >180^o, 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, 1999 to September 30, 2000

Event ID	Type	Date	Time	Latitude	Longitude	Depth	Mag	NS/NP	Gap	DMIN	RMS	Q	Location
9910172141		99/10/17	21:42:18.75	46N19.47	119W47.17	6.69	1.4	6/09	215	14	0.14	BD	13.1 km N of Prosser
9910182316	P	99/10/18	23:17:17.80	46N16.85	119W25.09	0.05	2.3	12/12	178	2	0.26	BC	9.8 km W of Richland
9910271006		99/10/27	10:06:48.41	46N26.73	119W38.38	18.64	0.6	8/12	176	2	0.09	AC	12.5 km S of 200 West
9910311934*		99/10/31	19:34:27.01	46N28.73	119W42.62	18.35	0.8	13/16	136	13	0.17	BC	10.4 km SSW of 200 West
9911080404		99/11/08	04:05:10.20	46N34.47	119W19.40	14.69	0.2	11/16	136	10	0.09	AC	15.7 km N of 400 Area
9911122219		99/11/12	22:19:37.90	46N09.82	119W13.56	0.04	0.8	10/12	287	22	0.15	BD	9.1 km WSW of Kennewick
9911130323		99/11/13	03:23:48.06	46N41.71	119W29.47	12.03	0.1	12/17	73	8	0.08	AA	10.0 km NE of 100-K Area
9911211323		99/11/21	13:23:40.03	46N35.25	119W39.18	18.22	1.6	23/30	76	3	0.15	AA	3.5 km NNW of 200 West
9911211324		99/11/21	13:24:43.25	46N34.84	119W39.16	16.90	1.0	17/22	77	3	0.08	AA	2.8 km NNW of 200 West
9912012011		99/12/01	20:12:12.14	46N58.91	119W17.57	5.39	-0.4	6/06	235	11	0.16	CD	16.1 km S of Moses Lake
9912110707		99/12/11	07:07:59.94	46N36.67	119W56.97	6.51	0.3	3/06	280	14	0.09	AD	24.6 km WNW of 200 West
9912220933		99/12/22	09:33:31.66	46N36.34	119W47.60	7.88	1.1	13/16	114	2	0.13	AB	13.0 km WNW of 200 West
200001012342		00/01/01	23:43:05.44	46N08.78	119W46.33	21.87	0.6	14/19	296	9	0.05	AD	6.8 km S of Prosser
200001201753		00/01/20	17:53:43.97	46N49.65	119W45.10	0.02	0.8	7/08	152	10	0.07	AC	22.9 km SE of Vantage
200001231243		00/01/23	12:44:20.12	46N20.80	119W41.67	0.04	-0.1	5/08	244	9	0.09	AD	16.5 km NNE of Prosser
200001240949		00/01/24	09:49:31.48	46N43.57	119W14.42	2.91	0.5	6/10	220	6	0.09	AD	12.5 km SSW of Othello
200001280656		00/01/28	06:57:17.73	46N23.06	119W35.45	18.09	-0.4	5/07	303	1	0.05	AD	18.8 km WSW of 400 Area
200002020525		00/02/02	05:25:42.00	46N36.49	119W53.15	6.36	0.3	5/11	310	9	0.05	AD	19.8 km WNW of 200 West
200002030124	P	00/02/03	01:25:03.24	46N58.57	119W01.24	2.34	0.9	11/12	299	9	0.06	AD	20.0 km NE of Othello
200002041228		00/02/04	12:29:05.15	46N49.05	119W21.11	0.02	0.6	8/13	115	2	0.09	AB	W of Othello
200002072013		00/02/07	20:14:05.90	46N44.01	119W46.44	2.42	1.5	13/16	140	11	0.15	BC	16.9 km NW of 100-K Area
200002072253		00/02/07	22:54:05.71	46N43.89	119W46.57	3.76	1.7	14/17	142	12	0.09	AC	16.9 km NW of 100-K Area
200002080534		00/02/08	05:35:06.65	46N43.93	119W46.15	0.05	1.6	16/17	137	12	0.10	AC	16.6 km NW of 100-K Area

Table 3.2. (contd)

Event ID	Type	Date	Time	Latitude	Longitude	Depth	Mag	NS/NP	Gap	DMIN	RMS	Q	Location
200002190530		00/02/19	05:30:44.63	46N34.55	119W48.24	18.63	0.8	15/25	200	5	0.11	AD	12.9 km W of 200 West
200002200155		00/02/20	01:56:18.12	46N10.61	119W34.78	17.73	0.6	10/13	256	9	0.07	AD	14.9 km ESE of Prosser
200002200956		00/02/20	09:56:58.89	46N23.88	119W56.79	20.66	0.4	8/13	255	21	0.10	AD	25.3 km NNW of Prosser
200002221906*		00/02/22	19:06:43.44	46N33.64	119W38.86	3.14	0.6	11/13	137	10	0.16		0.8 km WNW of 200 West
200002222312		00/02/22	23:12.51.75	46N34.72	119W56.83	0.03	2.0	13/13	201	14	0.38	CD	23.8 km W of 200 West
200002222341	P	00/02/22	23:41:13.51	46N53.50	119W58.17	0.05	1.5	8/10	189	8	0.12	AD	7.5 km S of Vantage
200002232021	P	00/02/23	20:21:39.31	46N57.04	119W03.89	0.03	0.2	6/06	137	6	0.13	AC	15.8 km NNE of Othello
200003031203		00/03/03	12:03:49.83	46N50.63	119W35.96	0.04	0.5	13/16	83	10	0.14	AC	22.5 km N of 100-K Area
200003062159		00/03/06	21:59:51.00	46N49.34	119W05.27	7.93	-0.2	9/09	214	16	0.37	CD	6.0 km E of Othello
200003271602		00/03/27	16:02:32.71	46N33.55	119W45.62	0.44	0.7	9/10	195	5	0.15	AD	9.4 km W of 200 West
200003280803		00/03/28	08:03:55.47	46N12.81	119W47.54	30.73	0.7	9/13	291	8	0.04	AD	2.0 km WNW of Prosser
200003280812		00/03/28	08:12:20.38	46N13.10	119W46.52	32.28	0.4	8/13	290	24	0.04	AD	1.4 km NNW of Prosser
200003280923		00/03/28	09:23:37.60	46N13.07	119W46.36	32.51	0.7	10/14	290	24	0.05	AD	1.3 km NNW of Prosser
200003281156		00/03/28	11:56:47.62	46N13.87	119W46.10	34.18	0.5	11/16	244	6	0.11	AD	2.7 km N of Prosser
200003282323	P	00/03/28	23:23:49.68	46N58.05	119W02.59	0.03	0.7	6/08	291	7	0.10	AD	18.3 km NNE of Othello
200003301943	P	00/03/30	19:43:44.11	46N19.70	119W51.81	1.10	1.7	7/07	278	18	0.07	AD	15.4 km NNW of Prosser
200004212350		00/04/21	23:51:10.24	46N41.68	119W30.82	3.32	0.0	6/11	107	6	0.14	BC	8.7 km NE of 100-K Area
200004301107		00/04/30	11:07:36.64	46N34.32	119W43.13	18.30	-0.1	8/11	142	5	0.05	AC	6.4 km WNW of 200 West
200005031231		00/05/03	12:31:59.98	46N22.23	119W15.46	0.02	0.7	6/12	259	6	0.09	AD	2.1 km NE of 300 Area
200005041702		00/05/04	17:02:56.01	46N14.76	119W27.51	2.55	1.8	9/09	225	5	0.06	AD	13.5 km WSW of Richland
200005052154		00/05/05	21:54:30.59	46N14.63	119W27.69	0.02	2.1	17/19	211	6	0.21	BD	13.8 km WSW of Richland
200005100924		00/05/10	09:25:07.67	46N39.47	119W24.20	13.98	0.4	15/21	131	6	0.05	AB	14.8 km NE of 200 East
200005111028		00/05/11	10:28:40.64	46N22.84	119W02.15	0.98	0.8	11/11	234	20	0.07	AD	16.9 km NNE of Pasco
200005150948		00/05/15	09:49:19.86	46N27.20	119W35.80	15.71	0.9	16/22	115	5	0.07	AB	12.1 km SSE of 200 West
200005261040		00/05/26	10:40:55.73	46N06.16	119W53.03	0.04	1.1	9/12	212	19	0.12	AD	14.7 km SW of Prosser
200006191236		00/06/19	12:36:39.37	46N36.00	119W51.15	6.97	0.4	9/11	190	7	0.06	AD	17.1 km WNW of 200 West

Table 3.2. (contd)

Event ID	Type	Date	Time	Latitude	Longitude	Depth	Mag	NS/NP	Gap	DMIN	RMS	Q	Location
200006230654		00/06/23	06:55:09.63	46N28.51	119W43.18	15.03	1.0	15/22	173	4	0.08	AC	11.1 km SW of 200 West
200006291848		00/06/29	18:48:59.41	46N01.05	119W54.73	0.04	2.3	19/25	90	19	0.23	BC	23.8 km SSW of Prosser
200006300426		00/06/30	04:26:45.11	46N28.23	119W42.88	14.82	0.1	10/14	215	3	0.06	AD	11.4 km SSW of 200 West
200007122259		00/07/12	22:59:35.80	46N01.66	119W54.90	0.02	1.7	4/6	136	20	0.17	BD	23.0 km SSW of Prosser
200007150119		00/07/15	01:20:22.37	46N38.76	119W38.30	2.63	-0.3	8/11	135	4	0.15	AB	3.2 km W of 100-K Area
200007160913		00/07/16	09:13:44.28	46N42.38	119W16.39	20.15	0.7	10/15	123	17	0.18	BB	15.7 km SSW of Othello
200007251928		00/07/25	19:28:51.09	46N00.47	119W55.65	0.36	1.8	10/15	92	19	0.31	CC	25.4 km SSW of Prosser
200007300916		00/07/30	09:17:13.05	46N16.82	119W32.99	7.29	0.5	10/15	156	8	0.10	AC	18.7 km ENE of Prosser
200008060111		00/08/06	01:11:25.08	46N51.66	119W38.41	12.97	0.9	17/24	61	13	0.08	AB	24.6 km N of 100-K Area
200008172108		00/08/17	21:08:25.53	46N49.74	119W38.78	15.07	1.1	15/20	65	10	0.11	AA	21.1 km N of 100-K Area
200008180711		00/08/18	07:12:13.70	46N23.84	119W14.64	0.02	-0.1	4/8	259	4	0.08	AD	5.1 km NNE of 300 Area
200008181554		00/08/18	15:55:19.68	46N24.36	119W16.51	0.26	-0.1	5/9	246	2	0.32	CD	5.3 km N of 300 Area
200008200559	P	00/08/20	06:00:04.56	46N53.38	119W13.10	2.53	1.3	10/11	113	10	0.15	AC	8.0 km NNW of Othello
200008261934		00/08/26	19:34:42.74	46N07.10	119W17.14	19.76	1.4	17/22	210	23	0.17	BD	15.7 km SW of Kennewick
200008281615		00/08/28	16:15:27.34	46N08.44	119W46.35	22.52	1.0	13/15	151	10	0.07	AC	7.4 km S of Prosser
200009020246		00/09/02	02:47:23.75	46N53.26	119W13.26	1.66	0.7	11/11	115	10	0.17	BC	7.9 km NNW of Othello
200009060341		00/09/06	03:41:25.85	46N52.98	119W12.69	0.02	1.2	9/11	180	10	0.09	AC	7.1 km NNW of Othello
200009190827		00/09/19	08:27:58.53	46N21.16	119W39.74	0.04	0.3	7/9	158	7	0.09	AC	18.1 km NNE of Prosser
200009251527		00/09/25	15:27:26.94	46N51.74	119W17.82	14.91	0.1	10/15	143	8	0.11	AC	10.7 km WNW of Othello
200009251637		00/09/25	16:37:50.50	46N51.89	119W18.40	15.63	0.3	16/19	91	7	0.12	AB	11.5 km WNW of Othello
200009251828		00/09/25	18:28:42.01	46N02.56	119W54.41	0.51	1.1	10/13	186	21	0.33	CD	21.2 SSW of Prosser

*Event 9910311934 was located by the University of Washington. Hanford Seismic Monitoring was being moved from the 337 building to the Sigma V building.
*Event 200002221906 was located by the University of Washington. Hanford Seismic Monitoring experienced a power failure.

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; H is hand picked from helicorder; 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 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 of the anticlines 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, 1998), 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 the 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.

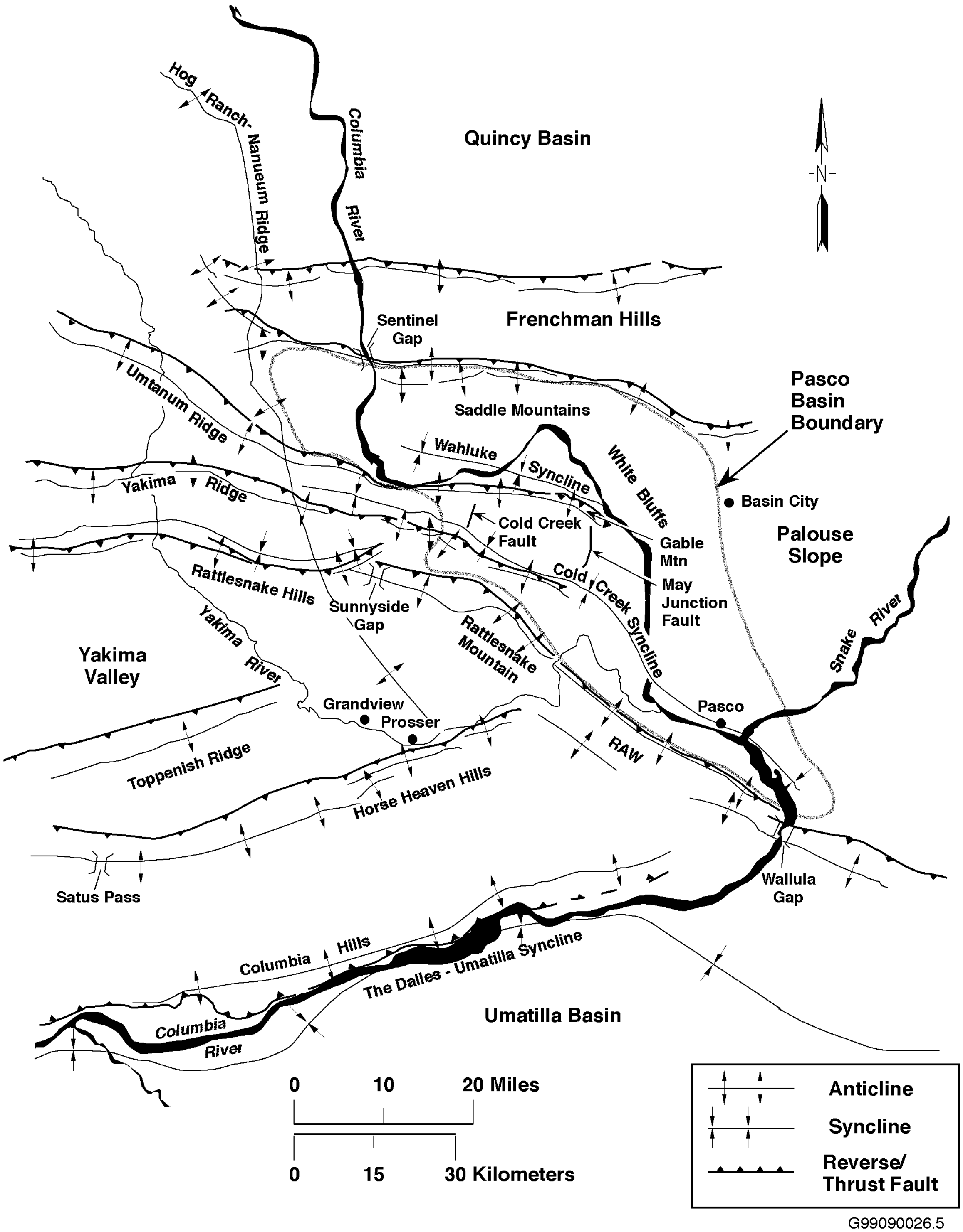


Figure 4.1. Structural and Tectonic Map of Columbia Basin Showing Major Seismic Source Structures

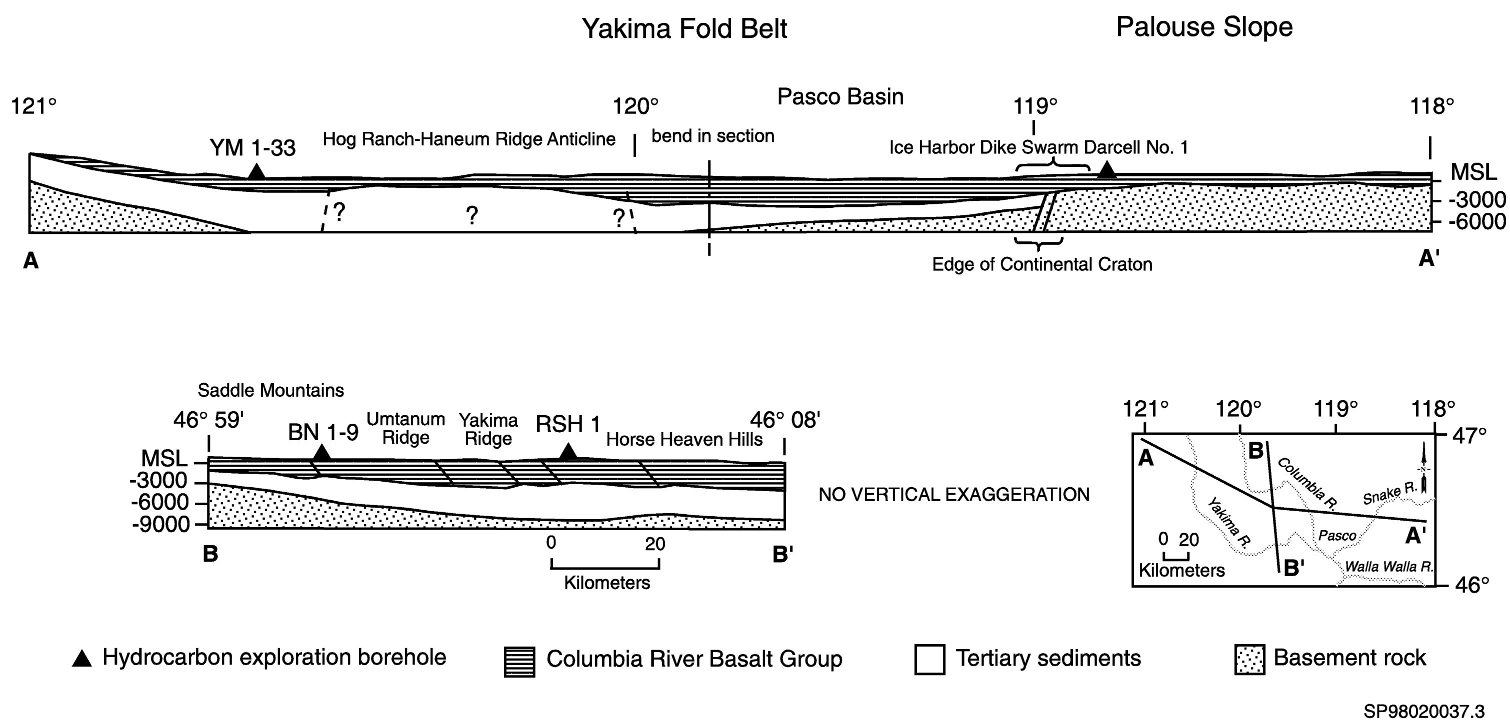


Figure 4.2. Geologic Cross Sections Through the Columbia Basin

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, about 75% of the earthquakes at the Hanford Site have originated in the CRBG layer. The pre-basalt sediments have had about 7% of the events and the crystalline basement has had 18%. The stratigraphic units for local earthquakes recorded for FY 2000 are listed in Table 4.2.

Table 4.2. Number of Local Earthquakes Occurring in Stratigraphic Units

Unit	First Quarter	Second Quarter	Third Quarter	Fourth Quarter	FY 2000
Basalt	2	11	7	10	30 (47%)
Pre-basalt Sediments	3	2	1	1	7 (11%)
Crystalline Basement	6	9	5	7	27 (42%)
Total	11	22	13	17	64

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.

- **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 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 recently 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), the 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

The locations for earthquakes that occurred in FY 2000 are summarized in Tables 4.2 and 4.3. Earthquakes that occurred in the four quarters are described in the following sections. Preliminary descriptions of earthquakes that occurred in the first, second and third quarters are in quarterly reports for FY 2000. Final descriptions of earthquakes for the first three quarters and earthquakes and their descriptions that occurred in the fourth quarter of FY 2000 are reported here.

Table 4.3. Summary of Earthquake Locations

Seismic Sources		First Quarter	Second Quarter	Third Quarter	Fourth Quarter	FY 2000
Geologic Structure		2	3	2	0	7 (11%)
Swarm Areas	Saddle Mountains/ Royal	0	5	0	7	12
	Coyote Rapids	0	3	1	1	5
	Wooded Island	0	0	1	2	3
	Wahluke Slope	0	0	0	0	0
	Horse Heaven Hills	0	4	1	0	5
	Cold Creek	0	0	0	0	0
	Total for swarms	0	12	3	10	25 (39%)
Random Events		9	7	8	8	32 (50%)
Total for all earthquakes		11	22	13	17	64

4.5.1 Annual Summary

The locations of all earthquakes that occurred between October 1, 1999 and September 30, 2000 are shown on Figure 4.3. Figure 4.4 shows these earthquakes separated out by quarter.

For FY 2000 there were a total of sixty four earthquakes (Table 4.3 and Figure 4.3). Forty four percent of all earthquakes occurred in the CRBG; eleven percent occurred in the pre-basalt sediments and forty three percent occurred in the crystalline basement. Seven earthquakes (11%) we interpret to have occurred along geologic structures; twenty-five earthquakes (39%) occurred in known swarm areas and thirty-two earthquakes (50%) are interpreted as random occurrences.

4.5.2 First Quarter of FY 2000

The locations of all mapped earthquakes that occurred between October 1, 1999 and December 30, 1999 are shown on Figure 4.4.

4.5.2.1 Major Anticlinal Ridges

During the first quarter of FY 2000, we interpret two seismic events to have occurred on major ridges. On November 12th, a small (0.8 M_c), shallow earthquake occurred along the Rattlesnake-Wallula alignment of anticlines and faults southwest of Kennewick, Washington. This event was shallow and occurred in the CRBG. Although the location is of poorer quality (BD, Table 3.2) than we would prefer, we place the event on the nearest structure (Badger Mountain) because of its close proximity and because it lies within a series of three closely spaced anticlines.

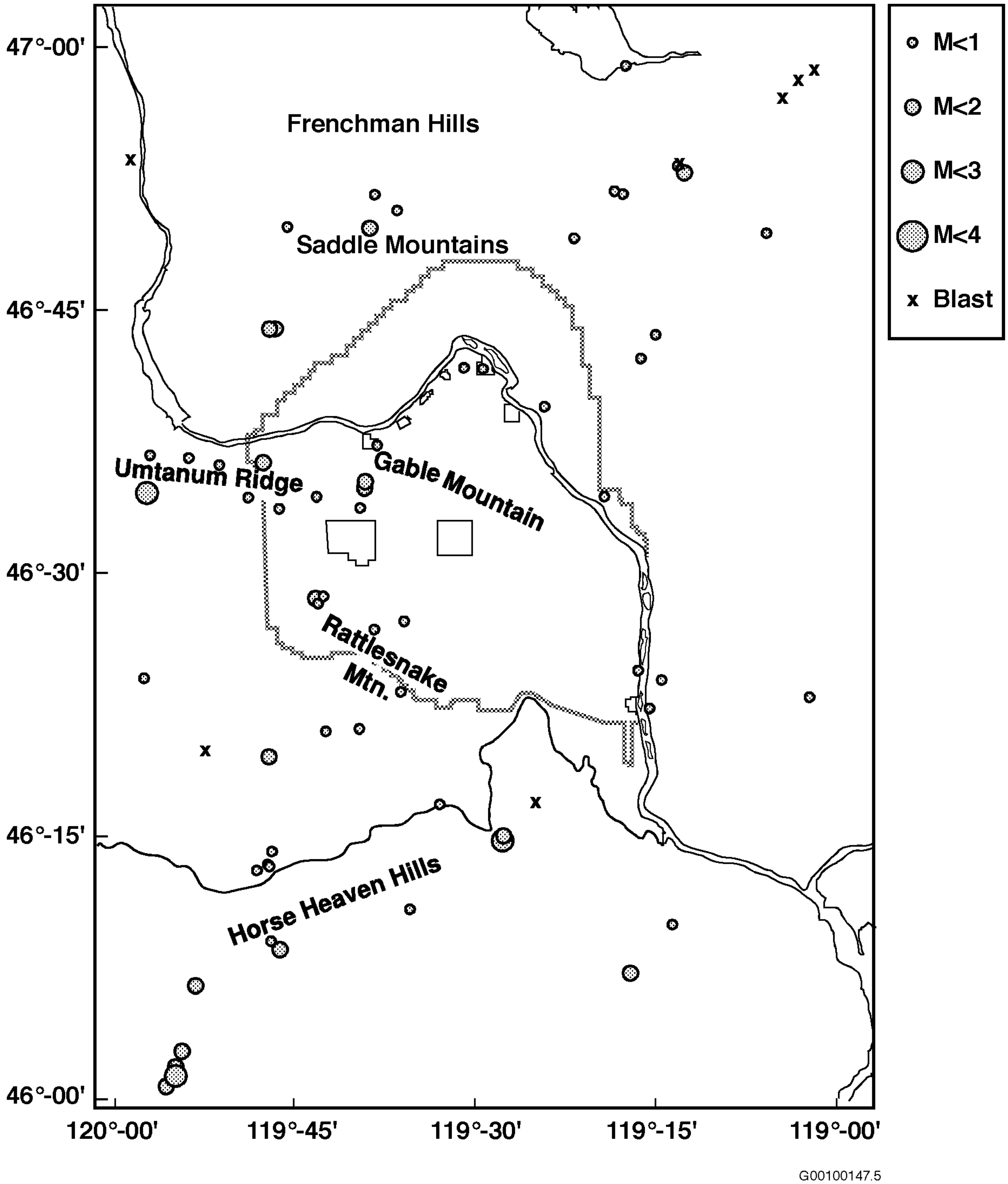
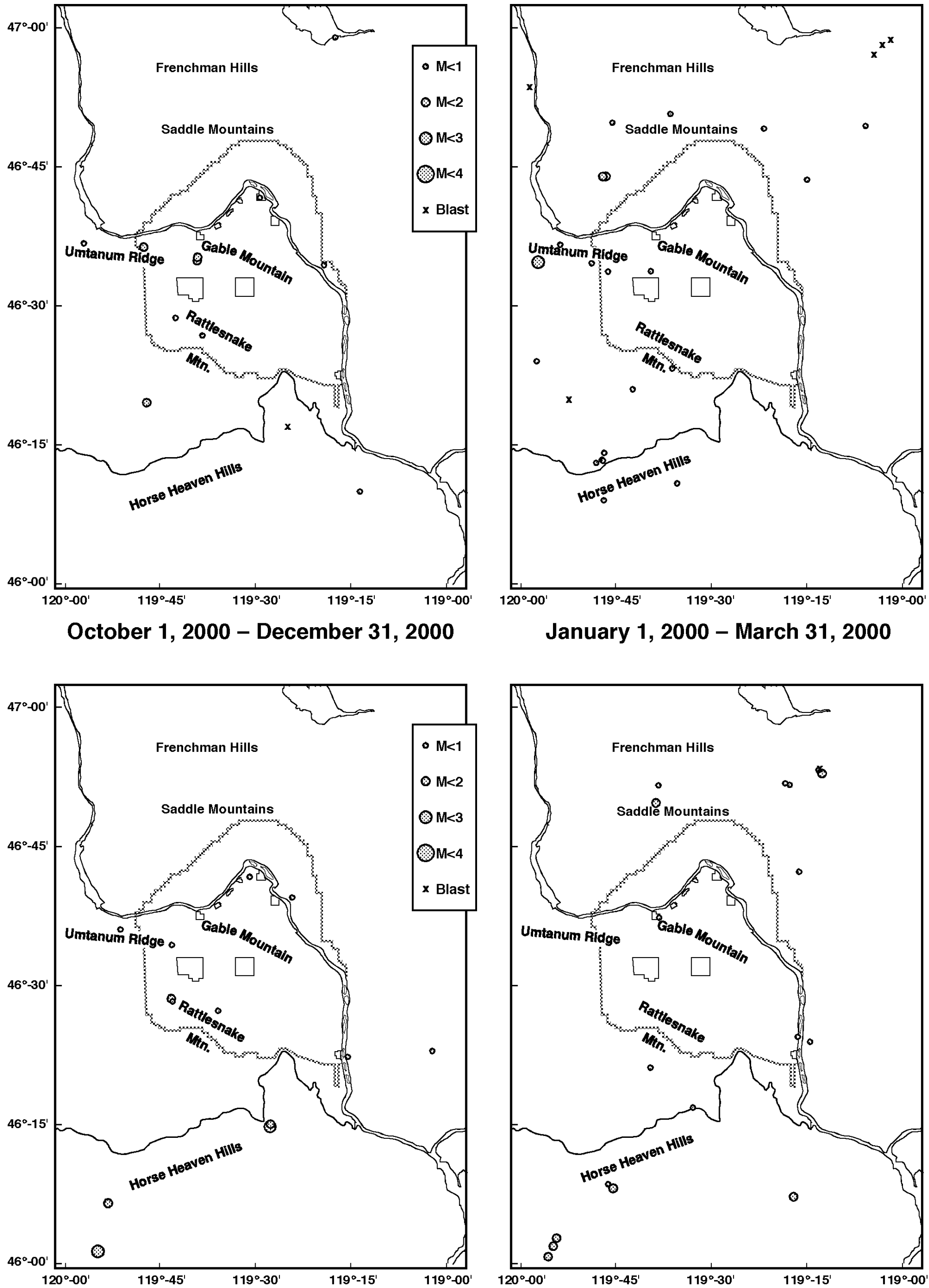


Figure 4.3. Locations of All Events Between October 1, 1999 and September 30, 2000 (Coda Length Magnitude (M_c) scale is shown at the side of the map)



October 1, 2000 – December 31, 2000

January 1, 2000 – March 31, 2000

April 1, 2000 – June 30, 2000

July 1, 2000 – September 30, 2000

G00100147.1-4

Figure 4.4. Locations of All Events Between October 1, 1999 and September 30, 2000 Separated by Quarter (Coda Length Magnitude [M_c] scale is shown at the side of the map)

A small event (approximately 0 M_c) occurred on December 1, 1999 along the north flank of the Frenchman Hills. This earthquake occurred in the basalt, and was centered on O Sullivan Dam. Young faults have been mapped in this area (Geomatrix 1996).

4.5.2.2 Earthquake Swarm Areas

No earthquakes occurred in any of the known swarm areas during the first quarter of FY 2000.

4.5.2.3 Random or Floating Events

There were 9 events classified as random events this quarter because they did not occur in known earthquake swarm areas or along known geologic structures. Three events were in the prebasalt sediments and six events were in the crystalline basement. No faults or folds have been identified below the basalt so events in the prebasalt sediments and crystalline basement are classified as random events.

On October 17th an earthquake occurred in the sediments below the CRBG on the south flank of the Rattlesnake Hills. This earthquake was small (1.4 M_c) and 10 km from the crest of the fold. No known faults occur in this area.

Two events occurred along the Rattlesnake Mountain fault but both were over 18 km deep, which places them in the crystalline basement. The first event was small (0.6 Mc) and occurred on October 27th It was west of Rattlesnake Mountain between sensor sites RSW and SNI (Figure 2.1). The second event was also small (0.8 Mc) and occurred on October 31. It occurred 5 km northwest of the October 27th event very near site SNI (Figure 2.1).

On November 8th, a small (0.2 M_c), isolated event occurred 14 km deep in the crystalline basement near the eastern termination of Umtanum Ridge (Figure 4.1). On November 13th, second small (0.1 Mc) earthquake occurred 18 km farther north along the Columbia River than the November 8th event. It too was in the crystalline basement. There is no known geologic structure near this event.

On November 21st two small events (1.6 and 1.0 M_c, respectively) occurred within a minute of each other in the crystalline basement a few km northwest of the 200-West Area. Neither event is along any known geologic structure.

On December 11th a small (0.3 Mc) event occurred in the pre-basalt sediments under Yakima Ridge in the Cold creek valley. The earthquake was immediately below where the Yakima Ridge fault is exposed at the surface and south of the Umtanum Ridge fault. Because neither of these faults is thought to extend below the basalt, this earthquake is classified as a random event.

The last event for the quarter was a small event (1.1 M_c) that occurred on December 22nd 10 km east of the December 11th event. This earthquake also occurred in the pre-basalt sediments and it too is classified as a random event.

4.5.3 Second Quarter of FY 2000

The locations of all mapped earthquakes that occurred between January 1, 2000 and March 31, 2000 are shown on Figure 4.4.

4.5.3.1 Geologic Structures

During the second quarter of FY 2000, we interpret three seismic events to have occurred on anticlinal ridges.

On January 23rd, a very small event occurred near the surface on the south flank of Rattlesnake Mountain. This event was centered on the continuation of the northwest trend of the Horse heaven Hills. The major relief of the northwest trending segment of the Horse Heaven Hills decreases significantly near Benton City where the northwest and northeast trends intersect. However, the Horse Heaven Hills structural trend continues northwest to a point where it intersects the Rattlesnake Hills west of Snively Basin and east of Sunnyside Gap (Figure 4.1). Because this event is located directly on the structure and it is near surface, we classify this event as related to the northwest extension of the Horse Heaven Hills.

On February 22nd and March 27th, two events occurred along Yakima Ridge west of the Hanford Site that we interpret to be associated with that structure. The February 22nd event was shallow (0.03 km) but had a M_c of 2.0. It was centered on the main ridge and along the continuation of a mapped fault. We interpret this earthquake to be associated with Yakima Ridge. The March 27th event occurred about 10 km farther east along Yakima Ridge and was also shallow (0.4 km). This event was small (M_c 0.7) and near the mapped fault zone for Yakima Ridge.

4.5.3.2 Earthquake Swarm Areas

There were twelve earthquakes that occurred in known swarm areas during the second quarter of FY 2000.

Saddle Mountains/Royal Earthquake Swarm Area

Five events occurred in the Saddle Mountains/Royal swarm area during the second quarter. The events were less than M_c 1 and were spaced along the entire length of the Saddle Mountains (Figure 4.4). Three events occurred in late January (20th and 24th) and early February (4th), and two events occurred in early March (3rd and 6th). All but the March 6th event were located in the basalt; the March 6th event was very small (near M_c 0) and was located in the pre-basalt sediments.

Coyote Rapids Earthquake Swarm Area

Between February 7th and February 8th three small events (M_c 1.5, 1.7, and 1.6) occurred on the Wahluke Slope south of the Saddle Mountains and north of the 100-K Area. We classify this area as part of the Coyote Rapids earthquake swarm area. These events were all in the basalt and clustered at the same location (Figure 4.4). This location has been active in the past but there are no known geologic structures in this area.

Horse Heaven Hills Swarm Area

Four small (M_c<1.0) events occurred on March 28th along the north side of the Horse Heaven Hills. All events occurred in the crystalline basement at a depth of approximately 30 km. This area first became active during FY 1999 and was designated the Horse heaven Hills swarm area. During FY 1999 the swarm started deep in the crystalline basement (approx. 30 km) and then became shallower with time.

4.5.3.3 Random or Floating Events

There were 7 events classified as random this quarter because they did not occur in known earthquake swarm areas or along known geologic structures. One event was in the prebasalt sediments and five events were in the crystalline basement. No faults or folds have been identified below the basalt so events in the prebasalt sediments and crystalline basement are classified as random events.

On January 1, a small (M_c 0.6) event occurred on the south flank of the Horse Heaven Hills south of Prosser, Washington. This event was 21 km deep and in the crystalline basement. No known geologic structures have been identified at that depth. Four events occurred in the crystalline basement north of this locality in March and were considered to be part of the Horse Heaven Hills earthquake swarm area. This event may be related to those events.

A very small earthquake occurred on January 28th in the crystalline basement beneath Rattlesnake Mountain. No faults or folds have been identified beneath the basalt so this event is classified as a random event.

A small event (M_c 0.3) occurred on February 2nd in the prebasalt sediments on the south side of Umtanum Ridge. Another event occurred nearby at a similar depth during the first quarter. These are classified as random events because the faults associated with the major folds in the basalt are interpreted to not extend below the basalt.

On February 19th a small event (M_c 0.8) occurred 6 km east of the February 2nd event on Umtanum Ridge. This event occurred in the crystalline basement and is also interpreted as a random event.

On February 20th, two small events occurred in the southern part of the Pasco Basin. The first event (Mc 0.6) occurred in the crystalline basement on the south flank of the Horse Heaven Hills. The second event occurred north of Prosser on the south flank of the Rattlesnake Hills. It too was small (Mc 0.4) and occurred in the crystalline basement. These events are classified as random events because of their great depth and the absence of any known geologic structure at those locations.

On February 22nd, a small earthquake (M_c 0.6) occurred in the CRBG in the Cold Creek syncline 3 km west of the 200 West Area. No geologic structure has been mapped at that location so it is classified as a random event. This event had not been included in the second quarterly report for FY 2000.

4.5.4 Third Quarter of FY 2000

The locations of all mapped earthquakes that occurred between April 1, 2000 and June 30, 2000 are shown on Figure 4.4.

4.5.4.1 Geologic Structures

During the third quarter of FY 2000, we interpret two seismic events to be related to anticlinal ridges. On May 4th and 5th two events (M_c 1.8 and 2.1, respectively) occurred in the basalt near the mouth of Badger Coulee in the Benton City Area. These events occurred along the southwest end of Goose Hill, a small anticlinal ridge between the Rattlesnake Mountain trend and the Horse Heaven Hills.

4.5.4.2 Earthquake Swarm Areas

There were 3 earthquakes that occurred in known swarm areas during the third quarter of FY 2000.

Coyote Rapids Earthquake Swarm Area

One April 21st, one small (M_c 0.0), shallow event occurred near 100-D K Area. This location saw an event during the first quarter of FY 2000 and has been active in the past. There are no known geologic structures in this area.

Wooded Island Earthquake Swarm Area

On May 3th a small (M_c 0.7) event occurred in the basalt near Johnson Island. This is the first event to occur in the Wooded Island earthquake swarm this FY.

Horse Heaven Hills Swarm Area

A small (M_c 1.1) event occurred on May 26th along the south side of the Horse Heaven Hills about 3 km from the crest of the ridge. The event occurred in the basalt near the surface. This area first became active during FY 1999 and was designated the Horse heaven Hills swarm area.

4.5.4.3 Random or Floating Events

There were eight events classified as random this quarter because they did not occur in known earthquake swarm areas or along known geologic structures. One event was in the prebasalt sediments and five events were in the crystalline basement. The other events occurred in the basalt. No faults or folds have been identified below the basalt so events in the prebasalt sediments and crystalline basement are classified as random events.

A small event (M_c 0.0) occurred on April 30th in the crystalline basement on the south side of Umtanum Ridge; a second event (M_c 0.4) occurred nearby in the prebasalt sediments on June 19th. These events are classified as random events because the faults associated with the major folds in the basalt are interpreted to not extend below the basalt. Other events have occurred along the Umtanum trend during the first two quarters of FY 2000.

On May 10th a small (M_c 0.4) event occurred in the crystalline basement beneath the Columbia River in the vicinity of Locke Island and east of the Coyote Rapids earthquake swarm area. This event is classified as random because it is in the crystalline basement. However, this event occurred in the vicinity of the edge of the North American craton and might be related to one of the many faults interpreted to compose the suture zone between the craton and accreted terranes.

On May 11th a small event (M_c 0.8) occurred in the basalt near the town of Eltopia, Washington on the east side of the Pasco Basin. No geologic structure has been mapped there so this event is interpreted as a random event. However, this event may also be classified as a swarm event because it occurred in the Eltopia swarm area, a swarm area defined by the BWIP in the 1980s.

On May 15th a small (M_c 0.9) event occurred in the crystalline basement north of Rattlesnake Mountain. This event is also classified as a random event because of its great depth.

On June 23rd and June 30th, two events (M_c 1.0 and 0.1, respectively) occurred at the same location in the crystalline basement beneath the Snively Basin area of Rattlesnake Mountain-Rattlesnake Hills (SNI Figure 2.1). Because of their great depths both events are classified as random events.

On June 29th a M_c 2.3 event occurred in the basalt (instrumentally located at a depth of 0.04 km) about 10 km south of the crest of the Horse Heaven Hills. Because this event can not be associated with a known, mapped geologic structure on the Horse heaven Hills, it is classified as a random event.

4.5.5 Fourth Quarter of FY 2000

The locations of all located earthquakes that occurred between July 1 and September 30, 2000 are shown on Figure 4.4.

4.5.5.1 Major Anticlinal Ridges

There were no earthquakes located on major anticlinal ridges during the fourth quarter of FY 2000.

4.5.5.2 Swarm Area Activity

Ten earthquakes occurred in swarm areas during the fourth quarter of FY 2000 (Table 4.4). Seven earthquakes occurred in the Saddle Mountains/Royal swarm area, one occurred in the Coyote Rapids swarm area, and two in the Wooded Island swarm area.

Saddle Mountains/Royal Swarm Area

On August 6th and August 17th, two small earthquakes (Mc 0.9 and 1.1) occurred in the crystalline basement beneath the Smyrna bench segment of the Saddle Mountains. Both earthquakes were well located.

On August 20th, September 2nd, and September 6th, small events (≤Mc1.3) occurred in the basalt at the same location in the Drumheller channels on the northeast portion of the Royal Slope earthquake swarm.

On September 25th, two small earthquakes (M_c 0.1 and 0.3, respectively) occurred in the crystalline basement 3 km west the previously discussed events in the Royal Slope swarm area.

Wooded Island Swarm Area

Two small earthquakes (<M_c 0.1) occurred near Johnson Island on September 25th. Both events were shallow in the CRBG.

Coyote Rapids Swarm Area

One small event (<M_c 0.1) occurred in the Coyote Rapids swarm area on July 15th. The earthquake occurred in the CRBG near the 100-B-C Area.

4.5.5.3 Random or Floating Events

Eight events occurred during the fourth quarter of FY 2000 that we classify as random events, either because they were not near known geologic structures, swarm areas or they were below the CRBG where no geologic structure have been identified.

On July 12th, July 25th, and September 25th, three small earthquakes (M_c 1.7, 1.8 and 1.1, respectively) occurred in the CRBG on the south flank of the Horse Heaven Hills southwest of Prosser, Washington. During the 3rd quarter an event also occurred in this location, as did events in the previous FY. We currently classify these events as random because there is no known geologic structure near this location. The increased activity in this area since last year may indicate the presence of a new earthquake swarm. The closest monitoring site to this area is the Prosser site (Figure 2.1), which is east of the earthquakes. There are currently no monitoring sites on the west side of the area of earthquake activity.

A M_c 0.7 event occurred on the Wahluke Slope on July 16th in the crystalline basement. This event occurred in the Wahluke Slope swarm area but because of its great depth we classify it as a random event.

On July 30th a small earthquake (M_c 0.5) occurred in the pre-basalt sediments near Benton City and the bend in the Horse Heaven Hills. This event is located along the northeast projection of the Horse Heaven Hills but because it is below the basalt and Horse Heaven Hills is thought to be confined to the CRBG, this event is classified as a random event.

On August 26th and August 28th, two events (Mc 1.4 and 1.0, respectively) occurred in the crystalline basement on the south flank of the Horse Heaven Hills. The first earthquake occurred southwest of Kennewick, Washington along the northwest trend of the Horse Heaven Hills. It was located along a mapped fault but because the earthquake was deep (19 km) it is classified as a random event. The second event occurred south of Prosser, Washington where an earthquake occurred on January 1, 2000. Both were deep (approx 20 km) and not on any mapped geologic structure.

The last random event of the quarter occurred on September 19th in the CRBG on the south flank of Rattlesnake Mountain. This event occurred near the northwest extension of the Horse heaven Hills along the “badlands” anticline. It was well located but not on the structure so it is classified as a random event.

5.0 Strong Motion Accelerometer Operations

The Hanford SMA network was restarted November 20, 1998 after a one year hiatus. During the 1 month of operating during the first quarter and the remainder of the fiscal year, there were no earthquake triggers. The SMA network had several triggers resulting from noise. The number of triggers resulting from noise and normal human activity is being monitored to determine 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.

6.0 Seismic Hazard Studies in the Pacific Northwest

This section summarizes seismic hazard investigations and activities in the Pacific Northwest during FY 2000 that can have an impact on seismic hazards at the Hanford Site.

6.1 Pacific Northwest Workshop for New National Earthquake Hazard Map

FEMA and the 2000 International Building Code now use the 1996 U.S. Geological Survey (USGS) hazard maps and their processed products as design maps in the building code provisions. The design values being used are 2/3 the spectral map values having 2% probability of exceedance in 50 years. Because of this small probability value, faults with return times of 1,000 or 2,000 years and longer have a direct effect on design values.

In March 2000, a meeting was held at the University of Washington to discuss new information that will be incorporated into the next generation of seismic hazards maps. The purposes of the meeting were to learn about new research, to get feedback about the input methodology, and to listen to the user communities' concerns and uncertainties.

The USGS meeting organizers indicated that there would be a meeting in 2001 to reexamine the issue of how to go from hazard maps to building code design values. A review panel for the year-2001 maps has been selected and the USGS hopes to release the new maps in 2001. The Hanford Site currently uses design values determined by Geomatrix (1996) which are compatible with the 1996 USGS seismic hazard maps.

Alan Rohay, Steve Reidel (both PNNL), and Newell Campbell (Yakima Valley College) attended the meeting and summarized information on eastern Washington and the Hanford Site. Information presented by them will be incorporated into the new USGS maps.

6.2 FY 2000 National Earthquake Hazards Reduction Program Studies on the Hanford Site

Evaluation of seismic hazards in southeastern Washington is difficult because, although the anticlinal ridges that comprise the Yakima Fold Belt have been growing since the Miocene, there is an apparent scarcity of Holocene faulting and there is no present-day spatial correlation of seismicity with mapped or inferred faults. Geologic studies of the deformation within the Columbia River Basalt Group demonstrate progressive growth of the folds, but little data are available to constrain Pleistocene and Holocene growth rates, particularly on the major frontal thrusts/faults associated with the folds. Areas of documented Pleistocene and Holocene faulting are sparse because of resurfacing and burial of much of the Columbia Basin by the last Pleistocene cataclysmic flood at 13 ka. Only Toppenish Ridge, which was out of the main flood track, shows clear evidence for large Holocene earthquakes. Other folds such as the Saddle Mountains show evidence for Holocene faulting but the size of ruptures and the magnitude of the events cannot be constrained.

The seismicity in the Columbia Basin is consistent with on-going geologic deformation in a north-south compressional stress field, but the observed M<4.5 earthquakes occur more frequently in the broad, relatively undeformed synclinal areas.

The largest of all the anticlines is Rattlesnake Mountain. Rattlesnake Mountain comprises the central portion of the Olympic-Wallowa lineament (OWL), a 500-km alignment of folds and faults stretching across northeast Oregon and Washington. The Rattlesnake-Wallula Alignment (RAW) was explicitly included in the USGS (1996) National Seismic Hazard Maps, which is based primarily on geologic studies in Oregon. Faults within the Rattlesnake Mountain structure show indirect evidence for late Pleistocene-Holocene tectonic activity including sag ponds and photo lineaments.

We have identified areas of possible late Pleistocene-Holocene faulting on Rattlesnake Mountain and the adjacent Rattlesnake Hills on the Hanford Site. The National Earthquake Hazards Reduction Program has funded Rohay and Reidel to investigate these features to assess them for earthquake hazards at the Hanford Site. The data from this study will be incorporated into the new USGS seismic hazards maps and future maps.

The principal objectives of the Hanford Site study are 1) locate areas of late Pleistocene-Holocene faulting on the Rattlesnake Mountain structure; 2) determine the magnitude and recurrence history of fault activity of the Rattlesnake Mountain structure; and 3) use the results of this study to improve estimates of slip rates and maximum magnitudes for future seismic hazard assessments of the region. The results of the study will provide the first data for the late Pleistocene-Holocene fault history of the Rattlesnake Mountain structure.

Ground Penetrating Radar (GPR) profiles will be collected across potential fault locations and nearby sag ponds, followed by auger sampling to map the stratigraphy across the faults and within the sag ponds, and to obtain material for age dating. Based on the results of these activities, trenches will be excavated at two or three of the most promising sites during the second year of the study. Detailed mapping of the strata exposed in the trenches and dating of the strata using volcanic ash chemistry, radiocarbon, and thermo-luminescence methods will be used to determine the history of fault movement.

7.0 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.

7.1 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, building managers, emergency directors, and engineers can 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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