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Pacific Northwest National Laboratory
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First and Second Quarters Hanford Seismic Report for Fiscal Year 2005

Pacific Northwest National Laboratory Hanford Seismic Assessment Team

June 2005

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

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Pacific Northwest National Laboratory Hanford Seismic Assessment Team

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Richland, Washington 99352

Summary

Hanford Seismic Monitoring provides an uninterrupted collection of high-quality raw and processed seismic data from the Hanford Seismic Network 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 Hanford Seismic Network and the Eastern Washington Regional Network consist of 41 individual sensor sites and 15 radio relay sites maintained by the Hanford Seismic Monitoring staff.

For the Hanford Seismic Network, there were 690 triggers during the first quarter of fiscal year 2005 and 378 triggers during the second quarter of fiscal year 2005. Of these triggers for the first and second quarters, 45 were earthquakes within the Hanford Seismic Network.

Twenty-nine earthquakes occurred in the Hanford Seismic Network area during the first quarter and 16 earthquakes occurred during the second quarter. The largest earthquake in the first quarter was a magnitude 1.7 event in the Horse Heaven Hills swarm area on December 19, 2004; the largest in the second quarter was a magnitude 1.6 event on January 21, 2005, also in the Horse Heaven Hills swarm area. During the first quarter, stratigraphically four events occurred in the Columbia River basalt (approximately 0-5 km), four in the pre-basalt sediments (approximately 5-10 km), and 21 in the crystalline basement (approximately 10-25 km). During the second quarter, there were seven events in basalt, one in the pre-basalt sediment, and eight in the crystalline basement. During the first quarter, geographically nineteen earthquakes occurred in swarm areas, three earthquakes were associated with a major geologic structure, and seven were classified as random events. During the second quarter, four earthquakes were in swarm areas, four on major structure, and eight were random. A new sensor site, Bickelton, is currently being installed to provide coverage in order to better locate earthquakes on the southern part of the Hanford Monitoring Network.

Acronyms

BWIP	Basalt Waste Isolation Project
CDPD	Cellular Digital Packet Data
CRBG	Columbia River Basalt Group
DOE	U.S. Department of Energy
ETNA	strong motion accelerometer manufactured by Kinemetrics
EWRN	Eastern Washington Regional Network
FY	fiscal year
GPS	Global Positioning System
HSN	Hanford Seismic Network
M_c	Coda Length Magnitude
M_L	Local Magnitude
M_w	Moment Magnitude
PNNL	Pacific Northwest National Laboratory
RAW	Rattlesnake Mountain-Wallula Alignment
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 covers seismic activity on and near the Hanford Site for the first and second quarter of fiscal year (FY) 2005. The report includes earthquake activity that occurred between October 1, 2004 and March 31, 2005 and the geologic interpretation of the sources of the earthquakes.

1.1 Mission

The principal mission of Hanford Seismic Monitoring at the Hanford Site is to ensure compliance with DOE Order 420.1, "Facility Safety" and DOE Order G 420.1-1, Section 4.7, "Emergency Preparedness and Emergency Communications." DOE Order 420.1 establishes facility safety requirements related to nuclear safety design, criticality safety, fire protection, and natural phenomena hazards mitigation. For seismic monitoring, this 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.*

The Seismic Monitoring Project supports Hanford Site emergency services organizations in complying with DOE Order G 420.1-1, Section 4.7, "Emergency Preparedness and Emergency Communications," by providing assistance in the event of an earthquake on the Hanford Site.

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 the Eastern Washington Regional Network (EWRN). This report 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 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. These seismic data are used to support Hanford Site contractors for waste management activities, Natural Phenomena Hazards assessments, and engineering design and construction.

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 also were 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).[a] Seismic monitoring is part of PNNL's Natural Resources Department.

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, 1998 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.

(a) 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 and will be discussed in Section 2.2.

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 22 sites (Table 2.1 and Figure 2.1) and the EWRN uses 35 sites (Table 2.2 and Figure 2.2); both networks share 16 sites. The networks have 45 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.

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. 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
VT2	46N58.04	120W58.95	1,270	Vantage Two
WA2	46N45.32	119W33.94	244	Wahluke Slope
WIW	46N25.76	119W17.26	128	Wooded Island
WRD	46N58.20	119W08.69	375	Warden
YPT	46N02.93	118W57.73	325	Yellepit

* Three-component station.

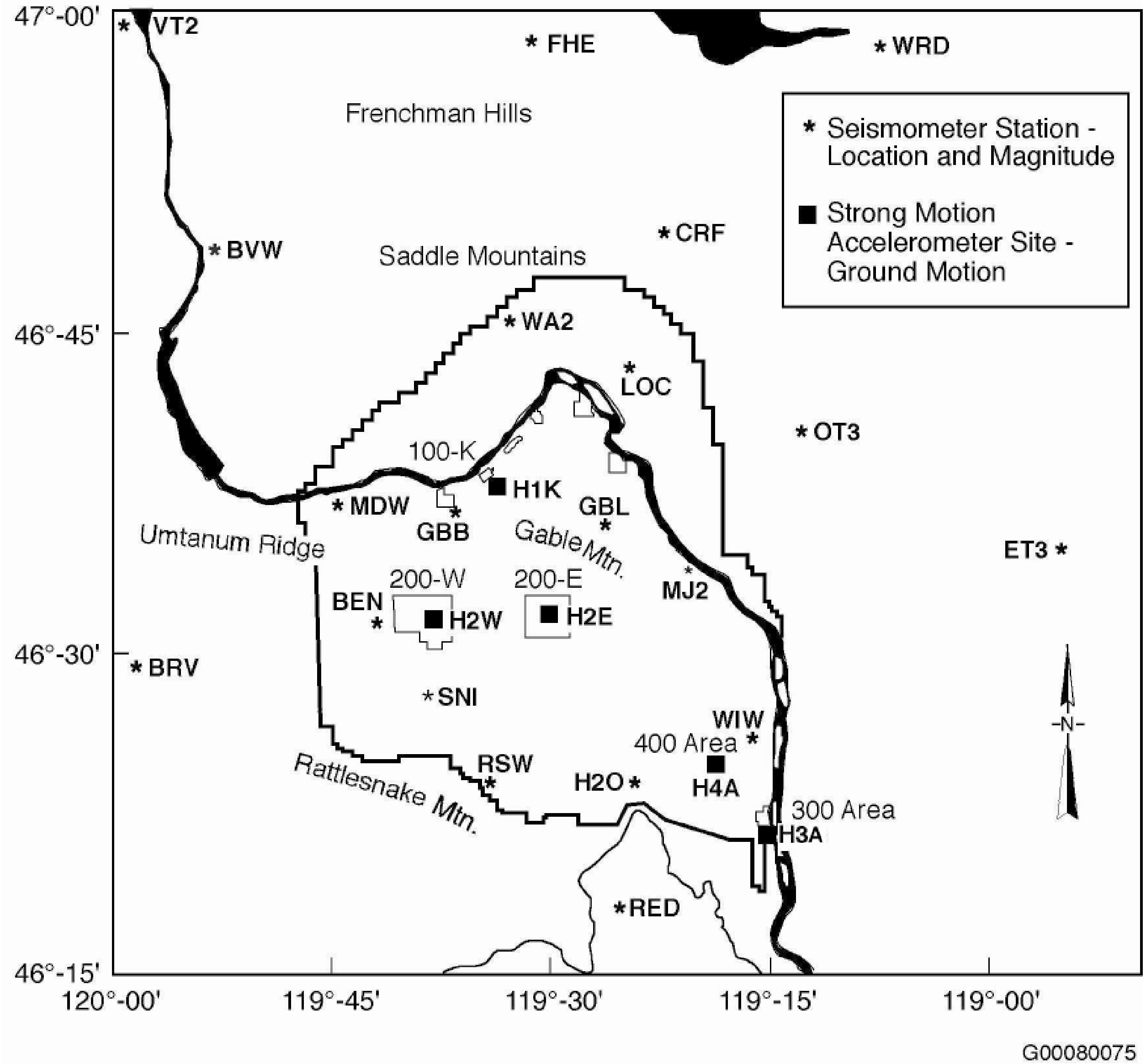

Figure 2.1. **Locations of Seismograph Stations and Strong Motion Accelerometer Sites in the Hanford Seismic Network (see Tables 2.1 and 2.4 for description of locations)**

2.1.1 Station Maintenance

The HSN's maintenance records for the seismic sensor and relay sites are on file in the Hanford Seismic Monitoring office, Sigma V Building, Richland, Washington.

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. 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
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
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	46N02.93	118W57.73	325	Yellepit

* Three-component station.

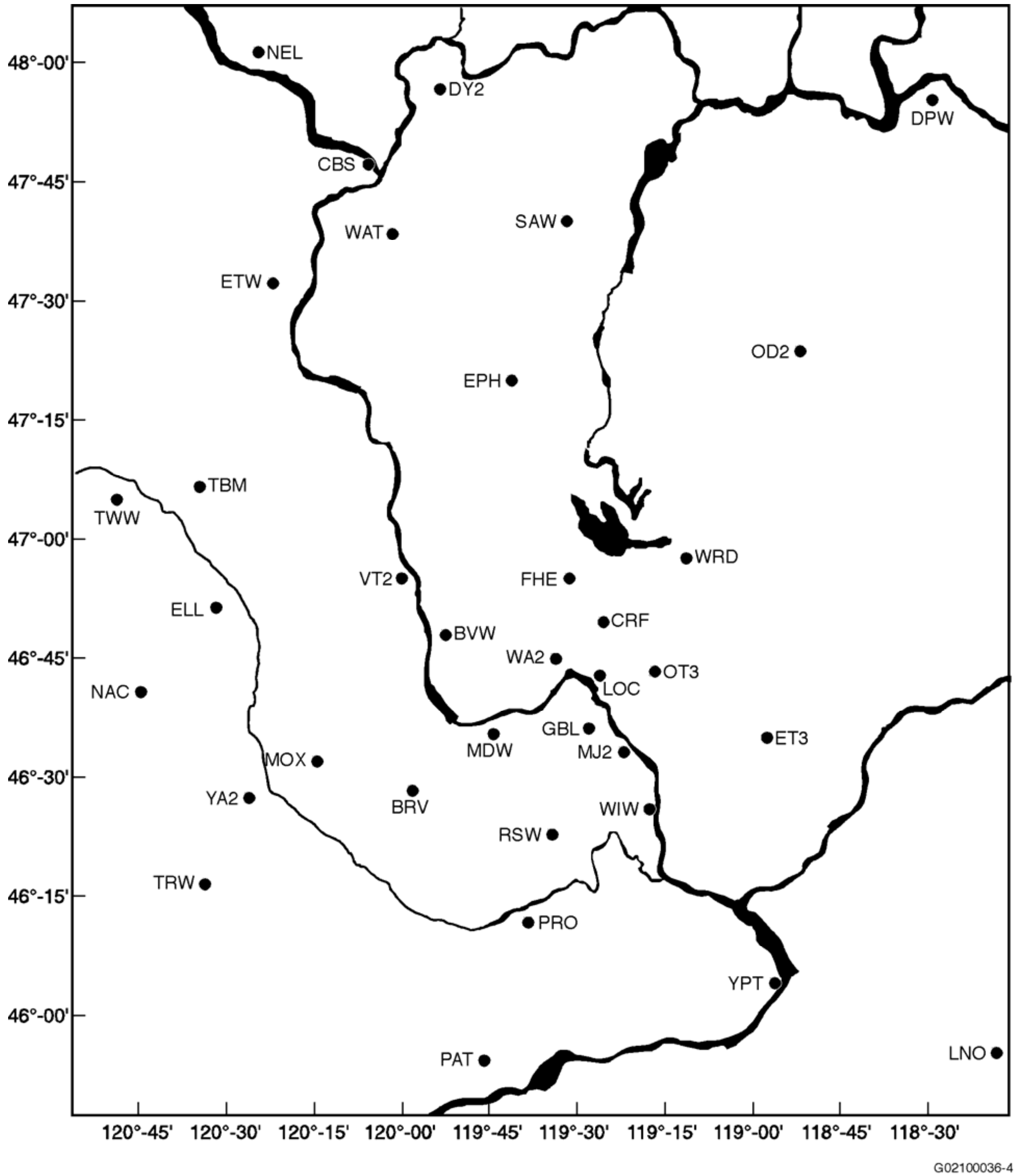

Figure 2.2. **Locations of Seismograph Stations in the Eastern Washington Regional Network (see Table 2.2 for location descriptions)**

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 local (south-central Washington near the Hanford Site), regional (Western U.S. and Canada), and teleseisms (from farther distances around the world). Local and regional events are usually earthquakes, but quarry and mining explosions are also recorded. Quarry and mining explosions 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 (Earthworm system) adapted from a USGS program and the UW system was implemented at Hanford during FY 1999. One system has been in continuous operation since January 6, 1999. A second, backup PC system was installed in mid-March 1999, and both systems have been running in parallel since that time. The hardware and software have been periodically upgraded. Data from triggers are collected on a SUN™ (registered trademark of Sun Microsystems, Santa Clara, California) workstation that is used to determine earthquake locations and magnitudes (Section 3). Although the two systems are practically identical, there is enough granularity (signal-to-noise) 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 during the first and second quarters of FY 2005 by the seismic acquisition system are summarized in Table 2.3.

Table 2.3. Acquisition System Recorded Triggers

Event Type	First Quarter	Second Quarter	Third Quarter	Fourth Quarter	Total	Description
South-Central Washington	40	37	-	-	77	Seismic events in south-central Washington and north-central Oregon that triggered the HSN.
Regional	43	50	-	-	93	Seismic events in the Western United States and Canada.
Teleseism	75	55	-	-	130	Seismic events at farther distances from around the world.
Total Earthquake Events	158	142	-	-	300	Total number of earthquake triggers.
Local Explosions	3	10	-	-	13	Quarry blasts, typically, within the 46-47 degrees north latitude and 119-120 degrees west longitude.
Local Earthquakes	29	16	-	-	45	Seismic events within the 46-47 degrees north latitude and 119-120 degrees west longitude.
Total Triggers	690	378			1,068	Total number of times the recording mechanism was activated.

2.2 Strong Motion Accelerometer Sites

2.2.1 Location

The Hanford SMA network consists of five free-field SMA sites (see 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. With the termination of the Fast Flux Test Reactor and draining of the liquid sodium coolant taking place now, plans have been made to terminate this site and move the instrument to a new location.

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 high-level radioactive waste from past processing of fuel rods is stored in single-shell and double-shell tanks. In addition, the Canister Storage Facility that holds encapsulated spent fuel rods is in 200-East Area and the new vitrification plant is being constructed in 200-East Area. The 100-K Area contains the K Basins where 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 2.4. 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

2.2.2 Site Design

All free-field SMA sites consist of a four-panel solar array and two 30-gallon galvanized drums. Each panel has a maximum 42-watt output. The two 30-gallon drums are set in the ground such that the base of the drum is about 1 m below the surface. One drum houses only the SMA; the other drum, which is connected via a sealed conduit to the SMA drum, contains the batteries. Communication is through a Cellular Digital Packet Data (CDPD) system, which provides a continuous radio data-link with an internet service provider. This CDPD system along with the solar power regulator is housed in a small enclosure mounted at the rear of the solar array. The enclosure serves as a junction box for all cabling between equipment inside and outside of the drums through conduit. The antenna for the CDPD is mounted on top of the enclosure. The enclosure permits quick access to check battery conditions and a connection directly to the RS-232 port of the SMA without removing the drum lids. The CDPD system is scheduled to be replaced with a new system in FY 2005.

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., Pasadena, California). Instrument specifications are summarized in Table 2.5. In addition to the three-component SMAs, each ETNA SMA unit contains a computer, Global Positioning System (GPS) receiver (Figure 2.3). These systems are housed in a watertight box.

The CDPD system provides the internet address connection to access the system. Stations can be monitored from any computer with appropriate access, and data can be downloaded to a dedicated computer in the seismic monitoring laboratory. The data can also be downloaded directly at each site via a built in cable connection at the enclosure in case of communication failure.

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	0.10%–0.20% g [(b)]
Alarm (call-out) Threshold	Not activated
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.

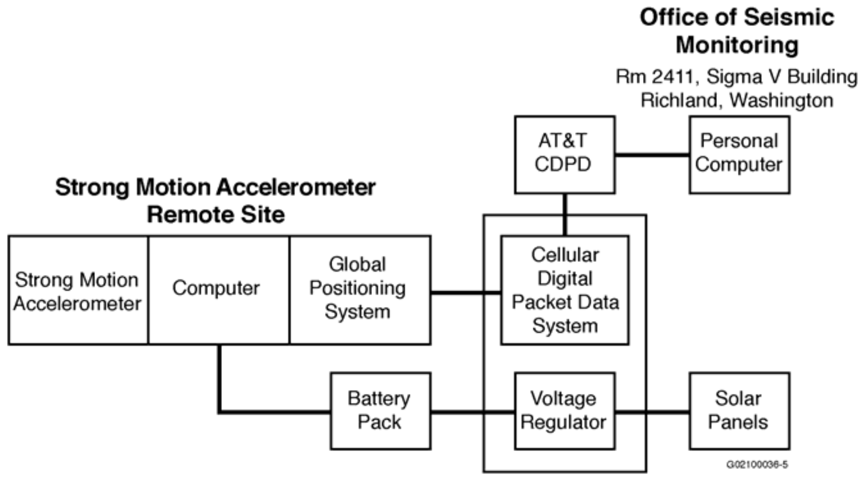

Figure 2.3. Schematic Diagram of a Strong Motion Accelerometer Installation

The SMAs have an internal GPS receiver used principally to link it to the National Bureau of Standards timing system.[(a)] 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 Assessment 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 samples/second. The three channels are monitored for signals that equal to 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.

(a) The GPS antenna is mounted on the enclosure at the rear of the solar array.

3.0 Earthquake Catalog Description

Seismic Monitoring staff uses an interactive program XPED developed at the University of Washington to determine earthquake locations and magnitudes. This program operates on the sections of time saved in files by the trigger algorithm of the Earthworm system. It provides the user with the ability to measure the arrival times and durations of seismic waves from earthquakes and determine the locations and magnitudes of the events. Locations of teleseismic and regional earthquakes are interpreted and saved for operational and quality review and documentation, and are not reported here. Local earthquakes near the Hanford Site (46º-47º N, 119º -120º W) are reported in this report (Table 3.2). Other earthquakes in southeast Washington are kept on file.

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).

This relationship is:

$$M_c = 2.82 \log (D) – 2.46,$$

where D is the duration of the observed signal.

3.2 Velocity Model

The program XPED uses the velocities and layer depths given in Table 3.1. This model does not include a surficial layer for the Hanford or Ringold sediments because most stations are located on basalt. Time corrections, which account for elevation, or local differences in the velocity model (i.e., stations on sedimentary layers), are determined empirically from sets of accurately-located earthquakes and explosions in the region.

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 Seismic Data, October 1, 2004 to March 31, 2005

Event ID	Type	Date	Time	Latitude	Longitude	Depth	Mag	NS/NP	Gap	Dmin	RMS	Q	Location
04100403562		04/10/04	03:56:47.86	46N35.67	119W13.14	16.31	-0.2	13/20	79	8	0.09	AA	20.7 km NNE of 400 Area
04100623285	P	04/10/06	23:29:03.74	46N18.56	119W25.46	0.24		6/06	179	1	0.38	CC	10.6 km WNW of Richland
04101201585		04/10/12	01:59:16.61	46N26.58	119W37.37	16.61	-0.5	9/10	153	3	0.06	AC	12.8 km S of 200 West
04102719461	P	04/10/27	19:46:35.76	46N16.03	119W23.44	3.66		8/08	231	4	0.05	AD	7.8 km WSW of Richland
04103106015		04/10/31	06:02:21.33	46N29.11	119W21.19	0.03	0.5	7/09	144	8	0.06	AC	5.6 km N of 400 Area
04110504280		04/11/05	04:29:25.15	46N27.28	119W00.51	11.82	0.4	12/16	220	14	0.09	AD	23.4 km ENE of 300 Area
04111418541		04/11/14	18:54:30.17	46N51.80	119W23.90	20.53	-0.4	13/13	107	4	0.07	AB	18.1 km WNW of Othello
04111419182		04/11/14	19:18:48.36	46N51.53	119W23.36	19.31	-0.1	11/15	94	3	0.08	AB	17.4 km WNW of Othello
04111519010		04/11/15	19:01:29.23	46N32.47	119W49.85	7.44	0.4	4/05	270	9	0.14	CD	14.9 km W of 200 West
04112221550		04/11/22	21:55:22.83	46N31.93	119W53.42	7.87	0.3	5/07	284	13	0.34	CD	19.6 km W of 200 West
04112319555		04/11/23	19:56:20.07	46N32.63	119W52.83	5.38	0.4	5/06	292	11	0.15	BD	18.7 km W of 200 West
04112510441		04/11/25	10:44:31.69	46N00.19	119W41.97	17.49	1.0	26/29	163	14	0.16	BC	23.3 km SSE of Prosser
04120808135		04/12/08	08:14:21.33	46N21.96	119W01.90	3.22	0.7	15/18	239	20	0.12	AD	15.4 km NNE of Pasco
04121019225		04/12/10	19:23:20.09	46N32.23	119W51.01	0.02	0.3	4/06	279	10	0.15	BD	16.4 km W of 200 West
04121301095		04/12/13	01:10:15.92	46N22.56	119W02.47	4.84	0.1	7/09	150	19	0.22	BC	16.3 km NNE of Pasco
04121410020		04/12/14	10:02:29.72	46N27.48	119W38.40	17.90	-0.7	7/08	162	1	0.04	AC	11.1 km S of 200 West
04121903234		04/12/19	03:23:59.85	46N03.83	119W44.67	12.26	0.9	8/13	180	17	0.21	BC	16.0 km S of Prosser
04121903245		04/12/19	03:24:52.01	46N03.32	119W46.23	12.68	0.7	12/17	151	18	0.16	BC	16.9 km S of Prosser
04121903261		04/12/19	03:26:12.44	46N03.35	119W45.19	13.09	1.0	11/18	146	18	0.11	AC	16.9 km S of Prosser
04121903270	S	04/12/19	03:27:03.71	46N07.21	119W45.02	14.97	0.4	3/04	319	11	0.00	AD	9.8 km S of Prosser
04121903272	S	04/12/19	03:27:23.07	46N02.40	119W26.34	19.00	-0.4	4/06	244	27	0.21	DD	29.4 km SSW of Richland
04121903275		04/12/19	03:28:13.46	46N03.49	119W44.34	13.33	0.7	6/12	184	17	0.13	AD	16.7 km S of Prosser
04121903284	S	04/12/19	03:29:03.03	46N07.38	119W33.42	76.70	-0.5	7/07	184	14	0.47	DD	18.8 km ESE of Prosser
04121903285		04/12/19	03:29:20.52	46N02.70	119W43.26	19.94	0.4	5/08	179	18	0.09	BD	18.4 km SSE of Prosser
04121903292		04/12/19	03:29:44.65	46N03.71	119W43.66	11.44	0.9	9/10	175	17	0.28	CC	16.4 km S of Prosser
04121903294		04/12/19	03:30:23.49	46N03.69	119W45.40	11.72	0.7	9/11	184	17	0.26	BD	2 km S of Prosser

Table 3.2. (contd)

Event ID	Type	Date	Time	Latitude	Longitude	Depth	Mag	NS/NP	Gap	Dmin	RMS	Q	Location
04121903313	S	04/12/19	03:31:31.00	46N07.63	119W43.98	14.52	0.6	6/07	185	10	0.25	BD	9.3 km SSE of Prosser
04121903315		04/12/19	03:32:14.44	46N04.10	119W46.72	11.27	1.0	10/12	186	17	0.12	AD	15.4 km S of Prosser
04121907090		04/12/19	07:09:24.31	46N03.78	119W44.42	11.84	1.7	27/28	109	17	0.12	AD	16.2 km S of Prosser
04121907100		04/12/19	07:10:05.41	46N04.14	119W43.88	12.04	1.4	18/24	280	16	0.22	BD	15.6 km S of Prosser
04121907125		04/12/19	07:13:13.45	46N03.71	119W45.52	12.97	0.8	12/16	185	17	0.16	BD	16.2 km S of Prosser
04122022513	P	04/12/20	22:51:54.07	46N56.37	119W36.05	0.04		13/14	84	8	0.27	BB	29.2 km E of Vantage
05010301145		05/01/03	01:15:17.72	46N27.47	119W00.28	3.54	0.1	7/11	220	14	0.14	AD	23.8 km ENE of 300 Area
05010310394		05/01/03	10:40:05.26	46N27.03	119W00.22	3.43	-0.1	6/09	243	14	0.13	AD	23.5 km ENE of 300 Area
05011223151		05/01/12	23:15:29.63	46N57.64	119W34.05	17.48	0.0	5/06	259	5	0.16	BD	28.4 km SW of Moses Lake
05011400405	P	05/01/14	00:41:09.04	46N59.07	119W38.38	17.72		6/06	289	11	0.40	DD	26.3 km E of Vantage
05011501234		05/01/15	01:24:06.85	46N31.42	119W41.56	10.45	-1.1	5/07	131	1	0.08	AD	5.7 km SW of 200 West
05011501235		05/01/15	01:24:15.84	46N31.07	119W41.07	11.19	-1.1	4/06	139	2	0.12	BD	5.7 km SW of 200 West
05011723035	P	05/01/17	23:04:19.10	46N54.21	119W37.53	0.02		14/14	78	11	0.38	CC	27.9 km ESE of Vantage
05012000162	P	05/01/20	00:38:23.46	46N52.91	119W36.90	2.15		14/14	71	11	0.08	AC	26.7 km N of 100-K Area
05012100572	P	05/01/21	00:57:47.20	46N52.90	119W37.64	0.04		14/14	88	12	0.10	AC	26.8 km N of 100-K Area
05012108211		05/01/21	08:21:38.29	46N09.38	119W30.92	10.33	1.6	17/19	265	14	0.09	AD	20.3 km ESE of Prosser
05012113043		05/01/21	13:05:02.12	46N09.80	119W31.23	8.41	0.5	6/08	270	13	0.04	AD	19.7 km ESE of Prosser
05013012361		05/01/30	12:36:36.83	46N27.89	119W43.59	15.24	-0.4	6/09	259	5	0.05	AD	12.4 km SSW of 200 West
05013113580		05/01/31	13:58:31.46	46N34.86	119W48.39	6.06	-0.2	4/06	265	5	0.05	AD	13.2 km WNW of 200 West
05020120332	X	05/02/01	20:33:53.17	46N16.81	119W32.97	0.44		10/10	156	8	0.06	AC	18.7 km ENE of Prosser
05020300411	P	05/02/03	00:41:36.88	46N52.09	119W33.88	0.40		6/06	192	10	0.03	AD	25.3 km N of 100-K Area
05020300554	P	05/02/03	00:55:52.16	46N53.70	119W36.26	2.09		8/08	166	10	0.36	CC	28.1 km N of 100-K Area
05020323510	P	05/02/03	23:51:17.79	46N53.86	119W36.85	6.95		8/08	116	10	0.09	AB	28.5 km N of 100-K Area
05020514073		05/02/05	14:07:53.48	46N23.09	119W41.18	20.47	-0.2	7/10	193	7	0.06	AD	19.6 km S of 200 West
05020518431		05/02/05	18:43:33.75	46N04.90	119W21.38	7.27	0.9	8/11	269	24	0.07	AD	22.5 km SW of Kennewick
05020900032		05/02/09	00:03:49.61	46N34.74	119W48.42	3.78	0.0	6/09	208	5	0.12	AD	13.2 km W of 200 West

Table 3.2. (contd)

Event ID	Type	Date	Time	Latitude	Longitude	Depth	Mag	NS/NP	Gap	Dmin	RMS	Q	Location
05021506241		05/02/15	06:24:35.54	46N34.92	119W48.64	5.97	-0.3	4/07	269	5	0.04	AD	13.5 km WNW of 200 West
05022520025	P	05/02/25	20:03:15.09	46N14.99	119W42.68	0.27		7/07	166	4	0.15	BC	6.5 km NE of Prosser
05031108282		05/03/11	08:28:49.25	46N49.74	119W18.72	0.03	0.5	15/18	122	5	0.13	AB	11.1 km W of Othello
05031216163		05/03/12	16:17:03.07	46N27.08	119W37.90	16.75	0.3	9/11	149	2	0.05	AC	11.9 km S of 200 West
05031417034		05/03/14	17:03:59.42	46N58.43	119W57.53	1.92	1.4	27/27	61	3	0.14	AA	2.5 km NE of Vantage
05031821400	P	05/03/18	21:40:25.52	46N10.47	119W16.10	0.04		13/13	108	18	0.13	AC	11.7 km WSW of Kennewick

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 an 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 a determination was not 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.

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**.

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 et al. 1989, 1994; 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 et al. 1989, 1994).

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) (Reidel and Fecht 1994a, 1994b). 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 (B-B') and east-west (A-A') cross sections through the Columbia Basin based on surface mapping (Reidel and Fecht 1994a, 1994b), deep boreholes (Reidel et al. 1994), geophysical data (Rohay et al. 1985; DOE 1988), 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 seismic activity 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 Columbia River Basalt Group (CRBG)
- Pre-basalt sediments of Paleocene, Eocene, and Oligocene age
- The crystalline basement consisting of two layers composed of 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. 1989, 1994), 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 4.1 is derived from Reidel et al. (1994) 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.

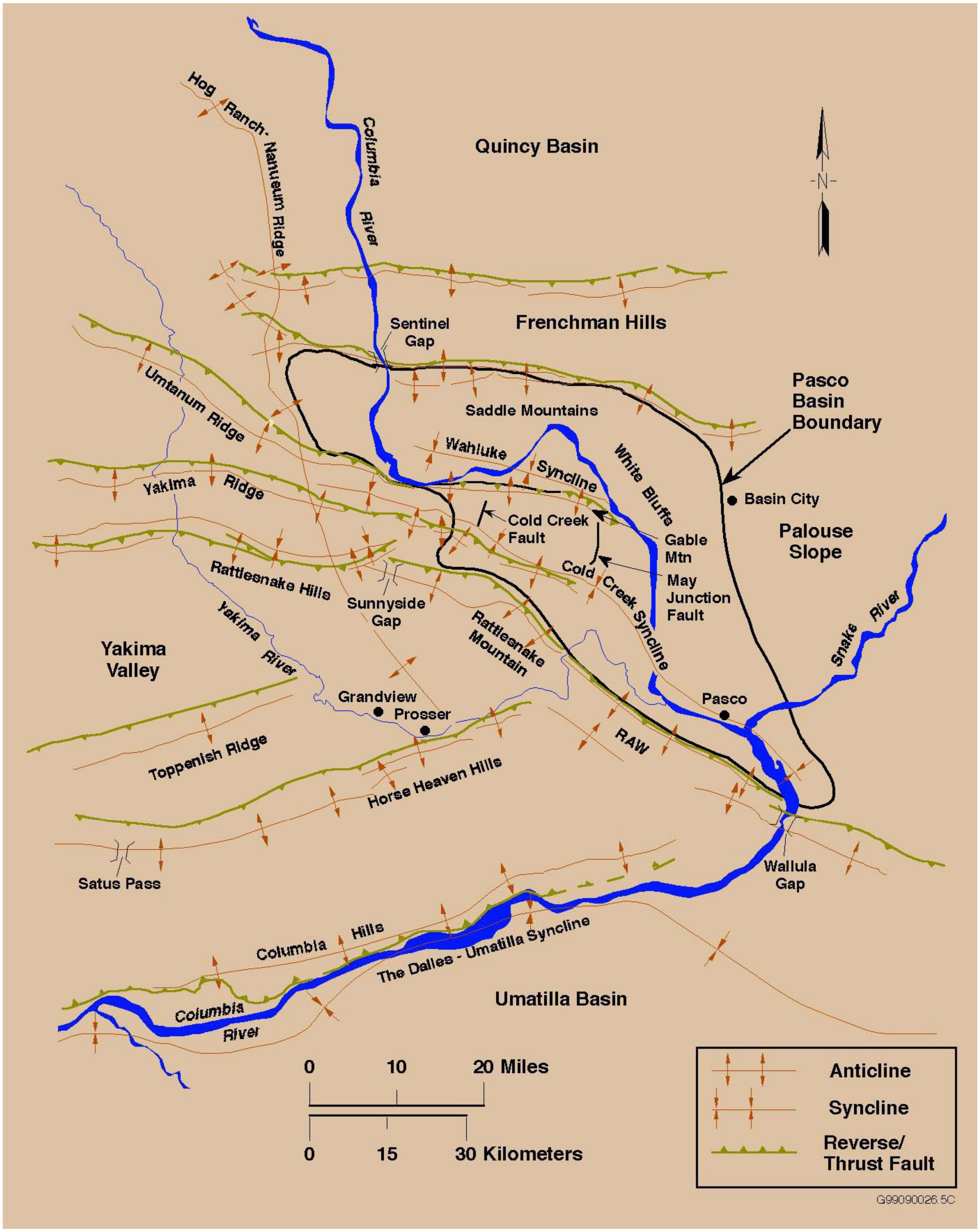

Figure 4.1. **Tectonic Map of Columbia Basin Showing Major Seismic Source Structures**

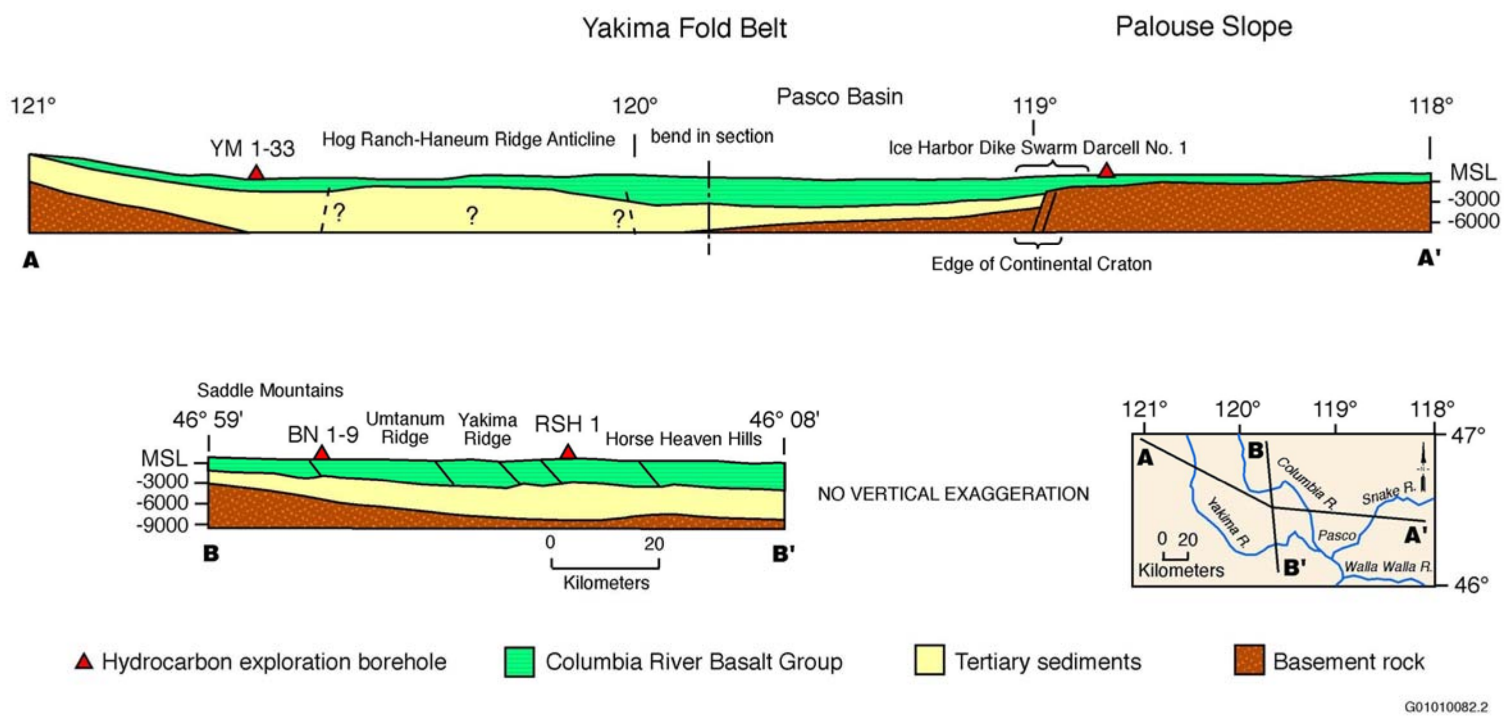

Figure 4.2. Geologic Cross Sections Through the Columbia Basin (Reidel et al. 1994)

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 (Reidel et al. 1994). The stratigraphy on the craton consists of CRBG overlying crystalline basement; the crystalline basement is continental crustal rock that underlies much of the western North America. The stratigraphy west of the craton consists of 4 to 5 km of CRBG overlying at least 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 Historic Tectonic Pattern

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

- **Major Geologic Structures**. 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 faults are typically smaller (1–20 km) than the main reverse/thrust faults that occur along the major anticlinal ridges (up to 100 km). Secondary faults can be segment boundaries (tear faults) and small faults of any orientation that formed along with the main structure.

- **Swarm areas**. Small geographic areas not known to contain any geologic structures 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. In the past, swarms were thought to occur only in the CRBG. Most swarm areas are in the basalt but swarm events also appear to occur in all geologic layers. However, typically a swarm event at a specific time is usually restricted to one layer. There are seven earthquake swarm areas that are recognized in the Hanford Monitoring Network area (Figure 4.3) but this list will be updated as new swarm areas develop. The Saddle Mountains swarm area, Wooded Island swarm area, Wahluke swarm area, Coyote Rapids swarm area, and Horse Heaven Hills swarm area are typically active at one time or another during the year. The other earthquake swarm areas are active less frequently.

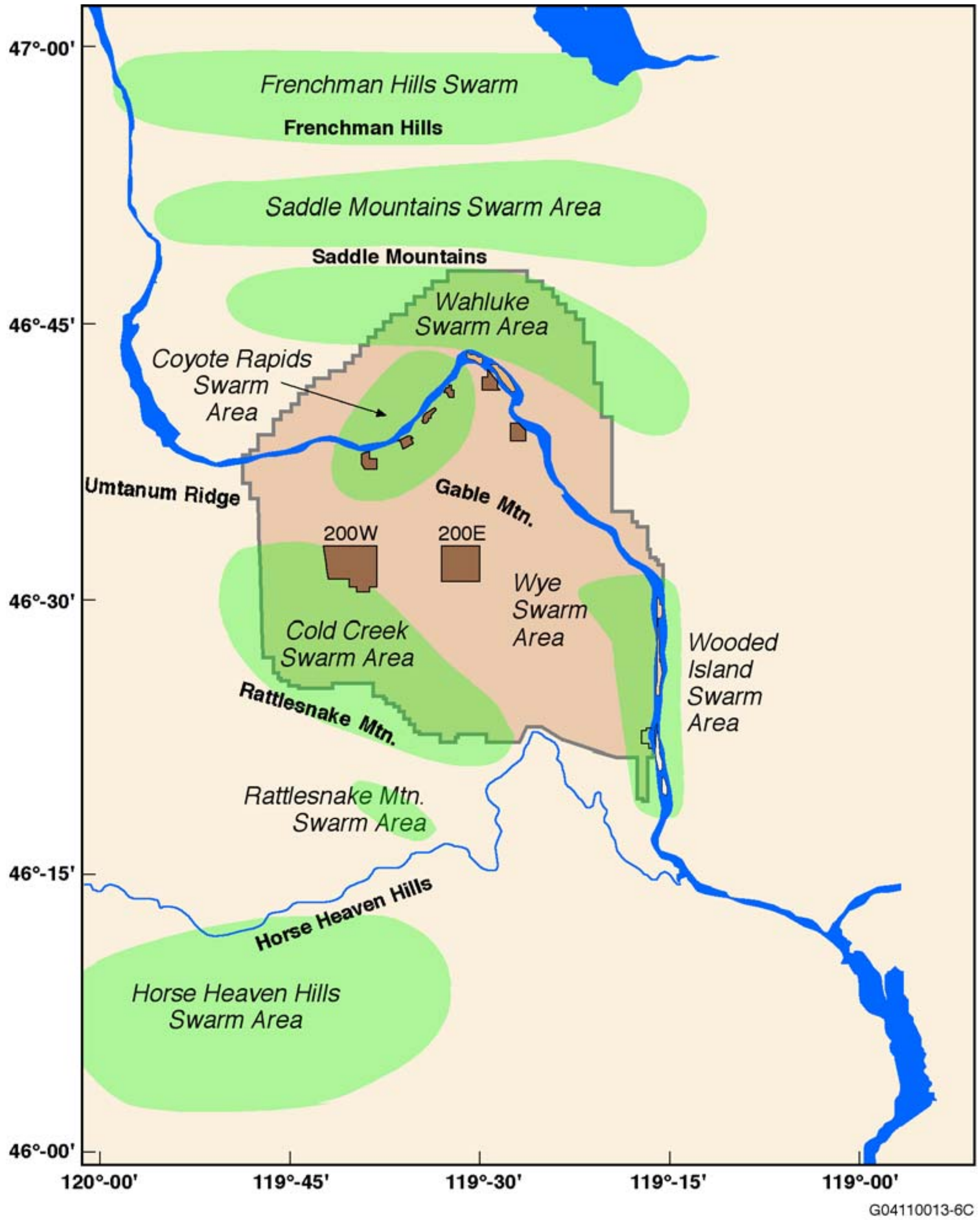

Figure 4.3. **Locations of Recognized Earthquake Swarm Areas in the Hanford Monitoring Network Area**

- **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.

- **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 or can be felt like the February 2001 Nisqually earthquake, UW monitors and reports on this earthquake source for the DOE. Ground motion from any moderate or larger Cascadia Subduction Zone earthquake is detected by Hanford SMAs and reported (see Section 5.0).

4.4 Historic Pattern of 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 of earthquakes followed by the pre-basalt sediments. The stratigraphic units for local earthquakes recorded during the first and second quarters of FY 2005 are listed in Table 4.2.

4.5 Tectonic Activity

4.5.1 First and Second Quarters Summary

Twenty-nine earthquakes occurred in the Hanford area during the first quarter of FY 2005 (October 1, 2004 through December 31, 2004 [Figure 4.4]) and sixteen earthquakes occurred during the second quarter of FY 2005 (January 1, 2005 through March 31, 2005 [Figure 4.4]) (Table 4.3). This section summarizes the earthquake activity for those periods of time. More detailed descriptions of this activity are given below.

Table 4.2. Number of Local Earthquakes Occurring in Stratigraphic Units

Unit	First Quarter	Second Quarter	Third Quarter	Fourth Quarter	FY 2004
Basalt	4	7	-	-	11 (24.5%)
Pre-Basalt Sediments	4	1	-	-	5 (11%)
Crystalline Basement	21	8	-	-	29 (64.5%)
Total	29	16	-	-	45

Table 4.3. Summary of Earthquake Locations for FY 2005

Seismic Sources		First Quarter 10/01- 12/31	Second Quarter 1/01 - 3/31	Third Quarter 4/01 - 6/30	Fourth Quarter 7/01 - 9/30	FY 2005
Geologic Structure		3	4	-	-	7 (15.6 %)
Swarm Areas	Frenchman Hills	-		-	-	
	Saddle Mountains/ Royal Slope	2	1	-	-	3 (6.7%)
	Wahluke Slope	-	-	-	-	
	Coyote Rapids	-		-	-	
	Wye	1	-	-	-	1 (2.1%)
	Wooded Island	-	-	-	-	
	Cold Creek	-	-	-	-	
	Rattlesnake Mt.	-	-	-		
	Horse Heaven Hills	16	3	-	-	19 (42%)
	Total for swarms	19	4	-	-	23 (50.8%)
Random Events		7	8	-	-	15 (33.6%)
Total for all earthquakes		29	16	-	-	45

4.5.1.1 Depth of Earthquakes

During the first quarter of FY 2005, four (14%) of the earthquakes occurred in the CRBG, four (14%) earthquakes occurred in the underlying pre-basalt sediments, and 21 (72%) earthquakes occurred in the crystalline basement. During the second quarter, seven (43.8%) events occurred in the basalt, one (6.2%) in the pre-basalt sediment, and eight (50%) in the crystalline basement.

4.5.1.2 Location of Earthquakes

During the first quarter of FY 2005, 19 (65.5%) events occurred in swarm areas. During the second quarter, four (25%) events occurred in the swarm areas.

Three (10%) events were classified as having some association with major geologic structures during the first quarter and four (25%) during the second quarter.

Seven events (24%) were classified as random during the first quarter and eight (50%) events were classified as random during the second quarter. Earthquakes typically are classified as random if they occur below the Columbia River Basalt Group. Very little is known about geologic structures in the pre-basalt sediments and crystalline basement so any interpretations are speculative at this time. An earthquake also can be classified as a random event if it occurs in the basalt but is not located near any known geologic structure.

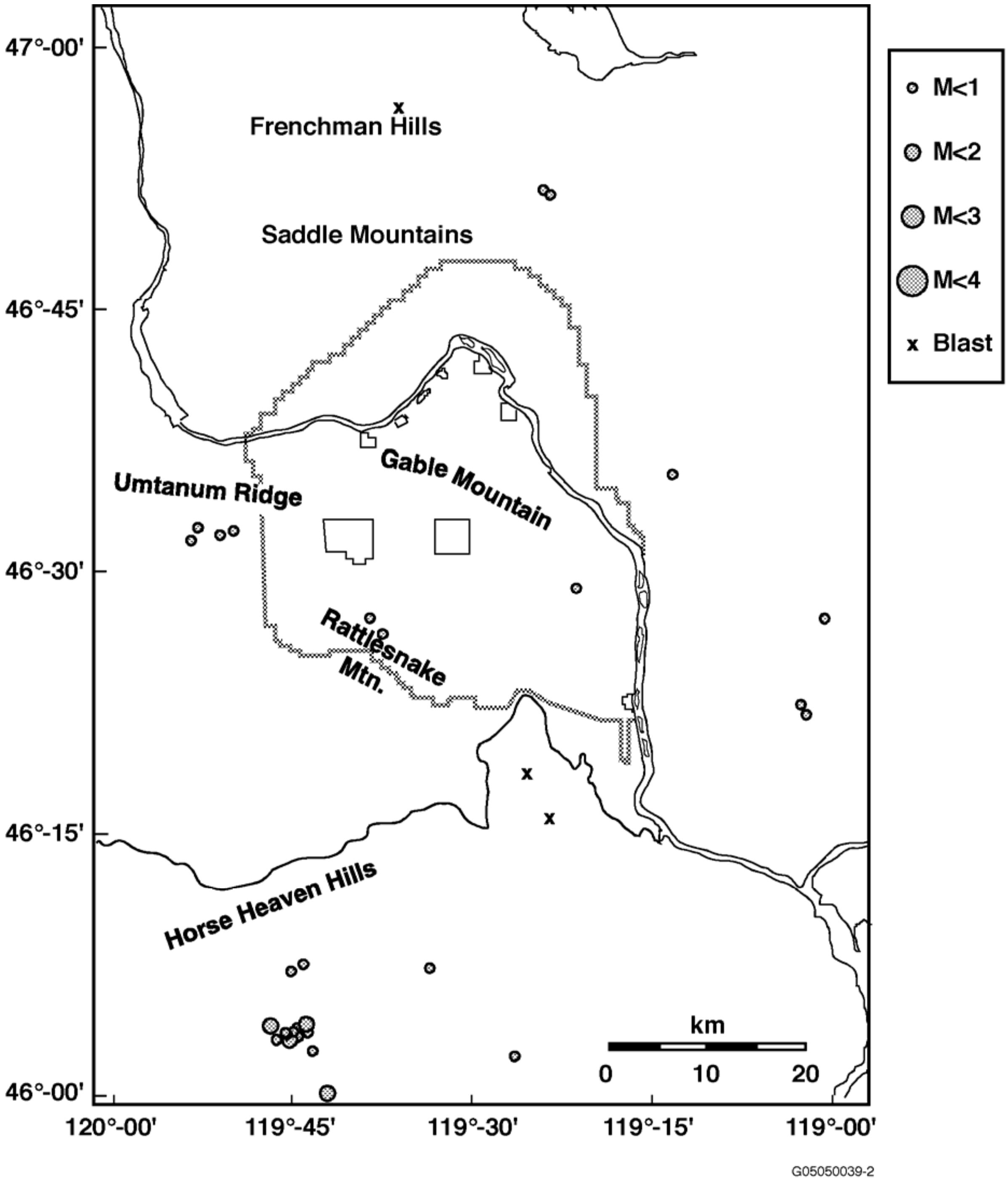

Figure 4.4. **All Earthquakes Recorded During the First Quarter of FY 2005 in the Hanford Monitoring Area Between October 1, 2004 and December 31, 2004 (Coda Length Magnitude [M_c] scale is shown at the side of the map)**

4.5.2 First-Quarter Earthquakes of FY 2005

4.5.2.1 Major Anticlinal Ridges

During the first quarter of FY 2005, we interpret three seismic events to have occurred on major geologic structures. On November 22 and 23, two small (>0.5 M_c) events occurred near the base of the basalt along a structure feature, the Rattlesnake Hills "extension," between the Rattlesnake Hills and Yakima Ridge. These events are approximately where the proposed Black Rock Valley dam site is located. On December 10, a small earthquake (0.3 M_c) occurred in the basalt along Yakima Ridge.

4.5.2.2 Earthquake Swarm Areas

4.5.2.2.1 Saddle Mountains Swarm Area

Two earthquakes occurred in the Saddle Mountains swarm area on November 14. Both events were approximately 0 M_c and both occurred below the basalt.

4.5.2.2.2 Wye Swarm Area

On October 31, we interpret one small (0.5 M_c) seismic event to have occurred in the Wye swarm area west of the Wooded Island swarm area (Figure 4.5). This event was in the basalt and occurred where similar events previously occurred on April 5, 2004, April 30, 2004, May 9, 2004, August 8, 2004, and August 12, 2004.

4.5.2.2.3 Horse Heaven Hills Swarm Area

Between November 25, and December 19, 2004, 16 earthquakes occurred in the Horse Heaven Hills swarm area. The first event was on November 25 and the remainder occurred on December 19. All events were within the crystalline basement and all were small (>0 M_c) except for the last three events. The final events were, respectively, 1.0 M_c, 1.7 M_c, and 1.4 M_c.

This area has been active over the past several years with earthquakes occurring at depths from the shallow basalt to deeper crystalline basement. The scatter in Figure 4.4 is a result of the absence of network coverage on the south side of the swarm area; this is shown by the number of stations that recorded these earthquakes (Table 3.1) and the quality factor for them. A new sensor site, Bickelton, is currently being installed to provide coverage in order to better locate earthquakes on the southern part of the Hanford Monitoring Network.

4.5.2.3 Random or Floating Events

During the first quarter of FY 2005, we interpret seven random events to have occurred in the monitoring area. Events that occurred in the pre-basalt sediments and in the crystalline basement are typically classified as random events. This is because there are no known geologic structures that have been identified in the rocks that occur below the Columbia River Basalt Group. However, we now recognize

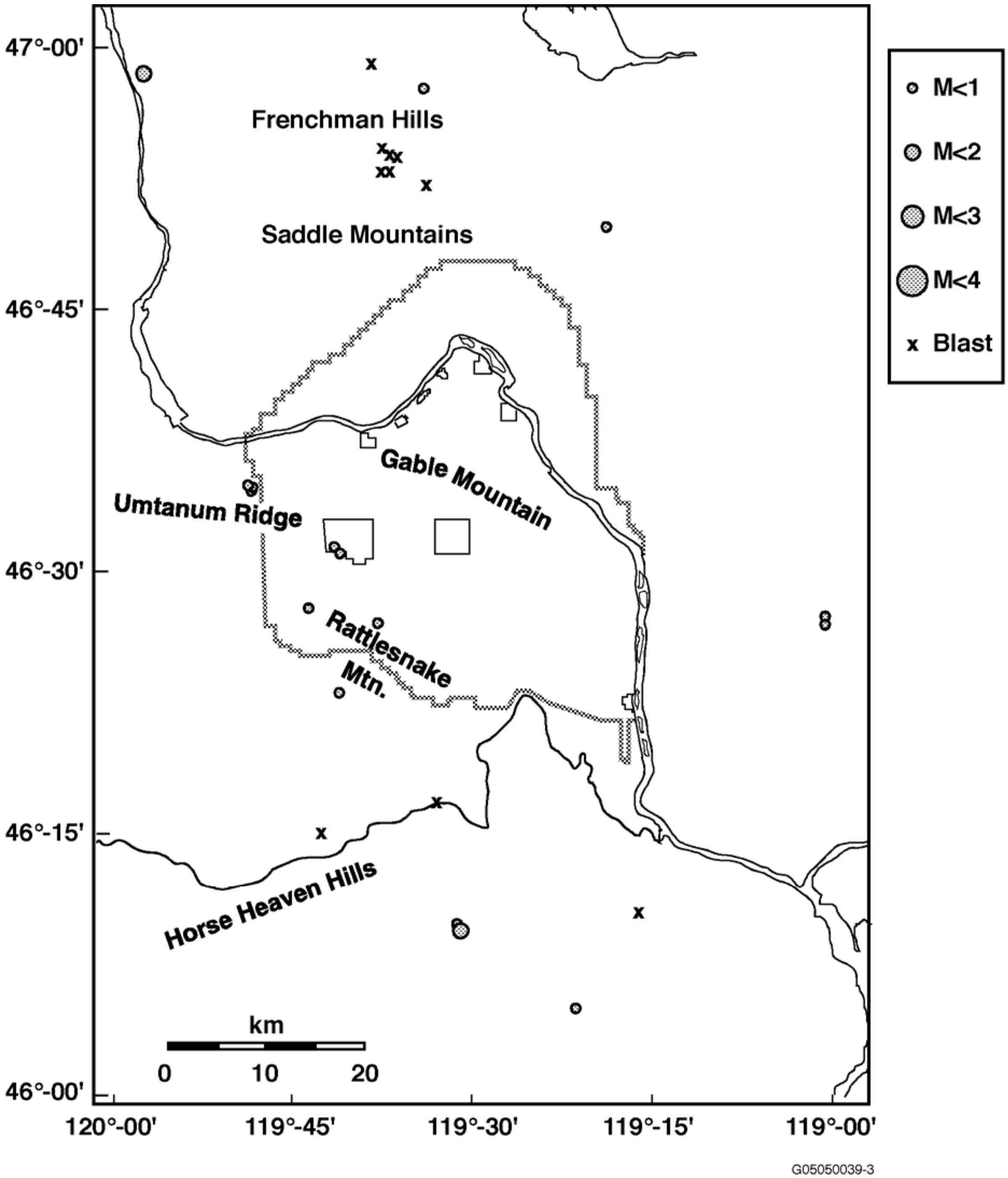

Figure 4.5. **All Earthquakes Recorded During the Second Quarter of FY 2005 in the Hanford Monitoring Area Between January 1, 2005 and March 31, 2005 (Coda Length Magnitude [M_c] scale is shown at the side of the map)**

that some events that occur at depths that places them in the pre-basalt sediments and crystalline basement occur in patterns that fit our definition of earthquake swarms (Section 4.4). Those events are now reported in the appropriate sections on earthquake swarms.

The first random event occurred on October 4, 2004 near Ringold Coulee on the eastern side of the Hanford Site. This was a very small event (approximately 0.0 M_c) that occurred in the crystalline basement. There is no history of earthquakes occurring in that area.

Two small (0.0 M_c) random event occurred on October 12 and December 14 in the Benson Ranch syncline between Rattlesnake Mountain and Yakima Ridge. Both were deep events (>16 km).

On November 5, a small (0.4 Mc) earthquake occurred in the crystalline basement (>11 km) on the eastern edge of the monitoring area near Eltopia in Esquatzel Coulee.

A small (0.4 Mc) random earthquake occurred in the pre-basalt sediment beneath Yakima Ridge on November 15.

Two small earthquakes occurred along the eastern boundary of the monitoring area south of the Eltopia event of November 5. These two events occurred on December 8 and December 13, 2004. Both were in the basalt. The first event was magnitude 0.7 and the second was 0.1. Over the past 5 years there have been several events in this area (e.g., March 23, 1998, May 4, 1998, September 1, 1999, December 22, 2002, and February 4, 2003).

4.5.3 Second-Quarter Earthquakes of FY 2005

4.5.3.1 Major Anticlinal Ridges

During the second quarter of FY 2005, we interpret four seismic events to have occurred on a major geologic structure in the monitoring area.

On March 14, a 1.4 Mc earthquake occurred in the Columbia River Basalt Group on the Frenchman Hills near Vantage, Washington. The earthquake was centered along the Columbia River on the south flank of the anticline.

Three small earthquakes (all approximately 0.0 M_c) occurred on the Umtanum Ridge anticline about 2 miles northwest of the Yakima Barricade at Hanford (intersection of SR 24 and SR 240). The first event occurred on January 31, the second event was on February 9, and the third event was on February 15. All were located at the same location with depths in or at the base of the basalt.

4.5.3.2 Earthquake Swarm Areas

During the second quarter of FY 2005, we interpret four seismic events to have occurred in swarm areas (Figure 4.5). The Saddle Mountains and Horse Heaven Hills swarm areas were the active swarm areas.

4.5.2.2.1 Saddle Mountains Swarm Area

On March 11, a 0.5 Mc earthquake occurred in the western part of the Saddle Mountains swarm area. This earthquake was in the basalt and was approximately four miles from the two earthquakes that occurred in the Saddle Mountains swarm area during the first quarter.

4.5.2.2.2 Horse Heaven Hills Swarm Area

The swarm in the Horse Heaven Hills continued into the second quarter. Three earthquakes were located. The first two occurred on January 21 and both were located in the pre-basalt sediment to crystalline basement. They were in the northern part of the swarm south of the intersection of the northwest and northeast trends of the Horse Heaven Hills. The third occurred on February 5 and was in the pre-basalt sediments. It was located farther east, however, due to the poor sensor station coverage on the south, the locations of these three earthquakes are poor and we consider them to be part of the main swarm.

4.5.3.3 Random or Floating Events

There were eight earthquakes recorded during the second quarter of FY 2005 that we classify as random events.

On January 3, two random events occurred in Esquatzel Coulee along the eastern margin of the network area. Both events were small (approximately 0.0 M_c) and was located in the basalt. These occurred at the same location as the earthquake of November 5; however, that event occurred below the basalt.

A deep (17.5 km) event occurred beneath the anticlinal axis of the Frenchman Hills on January 12. This earthquake was small (0.0 M_c).

On January 15, two deep (>10 km) events occurred in the Cold Creek Depression along the Cold Creek syncline. The Cold Creek Depression is southwest of 200-West Area. Both events were approximately 0.0 M_c.

On January 30, a deep (>15 km) earthquake occurred about five miles south of the two earthquakes in the Cold Creek depression. This event was also approximately 0.0 Mc and centered along the northern boundary of Snively Basin.

On February 5, a deep (>20 km) earthquake occurred three miles south of the anticlinal axis for the Rattlesnake Mountain-Snively Basin anticline. This event was approximately 0.0 Mc.

The final random event for the second quarter occurred on March 12, about one mile north of Rattlesnake Mountain where two events from the first quarter, October 12 and December 14, had occurred. All three events were deep (>16 km) and small (>0.4). The event of March 16 was the largest (0.3 M_c).

5.0 Strong Motion Accelerometer Operations

The Hanford SMA network has been in continuous operation since November 20, 1998. The nominal threshold used in the SMA network is 0.001 g in order to provide ground motion 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).

5.1 First and Second Quarters of FY 2005 Triggers of the Hanford SMA Network

The Hanford strong motion accelerometer network was not triggered by any seismic event during the first and second quarters of FY 2005.

6.0 Capabilities in the Event of a Significant Earthquake

The SMA network was designed to provide ground motion data in areas at the Hanford Site that have high densities of people and/or facilities containing hazardous materials in order to insure the Hanford Site is in compliance with DOE Order 420.1, "Facility Safety." The network also allows Hanford Seismic Monitoring to support Hanford Site emergency services organizations in complying with DOE Order G 420.1-1, Section 4.7, "Emergency Preparedness and Emergency Communications," by providing area ground motion data in the event of an earthquake on the Hanford Site. 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 also contain hazardous materials (Moore and Reidel 1996).

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" in a facility on the Hanford Site, 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 significant damage to a building but, without adequate characterization of the ground motion, initial determination of the building's possibility of having damage may be impossible.

In the event of an earthquake such as the 2001 Nisqually 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. This is done through the Hanford Site Emergency Services Organization. Normal hours of operation for the PNNL Seismic Monitoring Project are between 6 a.m. and 4:30 p.m., Monday through Friday. If a SMA is triggered, the Seismic Monitoring Team will download events that were recorded and determine the peak ground accelerations. This information is then passed on to Hanford Emergency Services personnel where the facility engineers can use the data 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 re-occupy 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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