PNNL-18134

U.S. DEPARTMENT OF ENERGY

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

Annual Hanford Seismic Report for Fiscal Year 2008

Pacific Northwest National Laboratory
Hanford Seismic Assessment Team
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December 2008

Pacific Northwest
NATIONAL LABORATORY

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operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC05-76RL01830

Printed in the United States of America

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Pacific Northwest National Laboratory
Richland, Washington 99352

Summary

The Hanford Seismic Assessment Program (HSAP) 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. The HSAP is responsible for locating and identifying sources of seismic activity and monitoring 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 HSAP 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 44 individual sensor sites and 15 radio relay sites maintained by the Hanford Seismic Assessment Team. This includes three recently acquired Transportable Array stations located at Cold Creek, Didier Farms, and Phinney Hill.

During fiscal year 2008, the Hanford Seismic Network recorded 1431 triggers on the seismometer system, which included 112 seismic events in the southeast Washington area and an additional 422 regional and teleseismic events. There were 74 events determined to be local earthquakes relevant to the Hanford Site. The highest-magnitude event (3.7 M_c) occurred on May 18, 2008, and was located approximately 17 km east of Prosser at a depth of 20.5 km. With regard to the depth distribution, 13 earthquakes were located at shallow depths (less than 4 km, most likely in the Columbia River basalts), 45 earthquakes were located at intermediate depths (between 4 and 9 km, most likely in the pre-basalt sediments), and 16 earthquakes were located at depths greater than 9 km, within the crystalline basement. Geographically, 54 earthquakes were located in swarm areas and 20 earthquakes were classified as random events.

The May 18 earthquake was the highest magnitude event recorded since 1975 in the vicinity of the Hanford Site (between 46-47° north latitude and 119-120° west longitude). The event was not reported as being felt on the Hanford Site or causing any damage and was communicated to the Pacific Northwest National Laboratory Operations Center per HSAP communications procedures. The event is not considered to be significant with regard to site safety and not unprecedented given the site's seismic history.

The Hanford strong motion accelerometer (SMA) stations at the 200 East Area, 300 Area, and 400 Area were triggered by the May 18 event. The maximum acceleration recorded at the SMA stations (0.17% at the 300 Area) was 12 times smaller than the reportable action level (2% g) for Hanford Site facilities.

Abbreviations and Acronyms

BWIP	Basalt Waste Isolation Project
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
GPRS	General Packet Radio Service
GPS	Global Positioning System
HSAP	Hanford Seismic Assessment Program
HSN	Hanford Seismic Network
M_c	coda-length magnitude
M_L	local magnitude
PNNL	Pacific Northwest National Laboratory
SMA	strong motion accelerometer
USGS	U.S. Geological Survey
UTC	Coordinated Universal Time
UW	University of Washington
WHC	Westinghouse Hanford Company

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1.0 Introduction

This annual report documents the locations, magnitudes, and seismic interpretations of earthquakes recorded for the Hanford monitoring region of south-central Washington during fiscal year (FY) 2008 (October 2007 through September 2008). The report provides summaries of seismic events recorded during the first three quarters of FY 2008 and a more comprehensive discussion of seismic events for the fourth quarter of FY 2008. Comprehensive discussions of seismic events recorded during the first three quarters of FY 2008 may be found in previously published quarterly reports (Rohay et al. 2008a, 2008b, 2008c).

1.1 Mission

The principal mission of the Hanford Seismic Assessment Program (HSAP) is to maintain the seismometer and strong motion accelerometer (SMA) sites, report data from measured events, and provide assistance in the event of an earthquake. This mission supports the U.S. Department of Energy (DOE) and the other Hanford Site contractors in their compliance with DOE Order 420.1B, Chapter IV, Section 3.d "Seismic Detection" and DOE Order G 420.1-1, Section 4.7, "Emergency Preparedness and Emergency Communications." DOE Order 420.1B requires facilities or sites with hazardous materials to maintain instrumentation or other means to detect and record the occurrence and severity of the seismic event. The HSAP maintains the seismic network located on and around the Hanford Site. The data collected from the seismic network can be used to support facility or site operations to protect the public, workers, and the environment from the impact of seismic events.

In addition, the HSAP provides an uninterrupted collection of high-quality raw seismic data from the Hanford Seismic Network (HSN) and the Eastern Washington Regional Network (EWRN) and provides interpretations of seismic events from the Hanford Site and the vicinity. The program locates and identifies sources of seismic activity, monitors changes in the historical pattern of seismic activity, 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 46-47° north latitude and between 119-120° west longitude. Data from the EWRN and other seismic networks in the northwest provide the HSAP 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 Monitoring Seismic Activity at Hanford

Assessing seismic activity at the Hanford Site was initiated in 1969 by the U.S. 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; the seismic program (including the UW contract) was transferred to the WHC Environmental Division. Maintenance responsibilities for the EWRN also were assigned to WHC, who made major upgrades to EWRN sites. Effective October 1, 1996, all seismic assessment activities were transferred to the Pacific Northwest National Laboratory (PNNL).[1]

The Hanford SMA network was constructed during 1997, becoming operational in May 1997. It was shut down in FY 1998 due to lack of funding but became operational again in FY 1999 and has operated continuously since that time.

1.3 Documentation and Reports

The HSAP issues quarterly reports of local activity, an annual catalog of earthquake activity in southeastern Washington, and special-interest bulletins on local seismic events. This includes information and special reports as requested by DOE and Hanford Site contractors. Earthquake information provided in these reports is subject to revision as new information becomes available. In addition, an archive of all seismic data from the HSAP is maintained by PNNL on computer servers.

[1] Pacific Northwest National Laboratory is operated by Battelle for the U.S. Department of Energy under Contract DE-AC05-76RL01830.

2.0 Network Operations

2.1 Seismometer Stations

The seismic network consists of two types of earthquake sensors—seismometers and strong motion accelerometers (SMAs). Seismometers are designed primarily to detect micro earthquakes near Hanford recording seismograms that are used to determine the magnitudes and locations of seismic events. SMA stations are designed to measure ground motion and are discussed in Section 2.2.

The HSN and the EWRN consist of 44 seismometer stations. This includes three recently acquired Transportable Array (TA) stations located at Cold Creek (CCRK), Didier Farms (DDRF), and Phinney Hill (PHIN). The TA stations are tri-axial, broad-band seismometers with full digital telemetry capabilities. Most stations reside in remote locations and require solar panels and batteries for power. The HSN includes 26 stations (Table 2.1 and Figure 2.1), and the EWRN consists of 39 stations (Table 2.2 and Figure 2.2). Twenty-one stations are shared by both networks. Note that the Bickelton (BLT) and Phinney Hill (PHIN) stations are shown on Figure 2.2.

The EWRN is used by the HSAP for two major reasons. A large earthquake located in the Pacific Northwest outside of Hanford could produce significant ground motion and damage at the Hanford Site. For example, the magnitude 7.0 event that occurred in 1872 near Chelan/Entiat or other events located in the region (e.g., eastern Cascade mountain range) could have such an effect. The EWRN would provide valuable information to help determine the impacts of such an event. Additionally, the characterization of seismicity throughout the surrounding areas, as required for the Probabilistic Seismic Hazard Analysis, supports facility safety assessments at the Hanford Site. Both the HSN and the EWRN are fully integrated within the Pacific Northwest Seismic Network managed by the University of Washington.

Table 2.1. Seismometer Stations in the Hanford Seismic Network

Station[a]	Latitude Deg. Min. N	Longitude Deg. Min. W	Elevation (m)	Station Name
BEN	46N31.13	119W43.02	340	Benson Ranch
BLT	45N54.91	120W10.55	659	Bicklelton
BRV	46N29.12	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
CCRK[b]	46N55.85	119W85.49	560	Cold Creek
DDRF[b]	46N49.12	119W05.96	270	Didier Farms
FHE[b]	46N57.11	119W29.82	455	Frenchman Hills East
PHIN[b]	45N89.52	119W92.78	270	Phinney Hill
GBB[b]	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	119W58.95	387	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

(a) The first column is the alphanumeric 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 all are in Washington; locations were derived from the Global Positioning System (GPS).
(b) Three-component station.

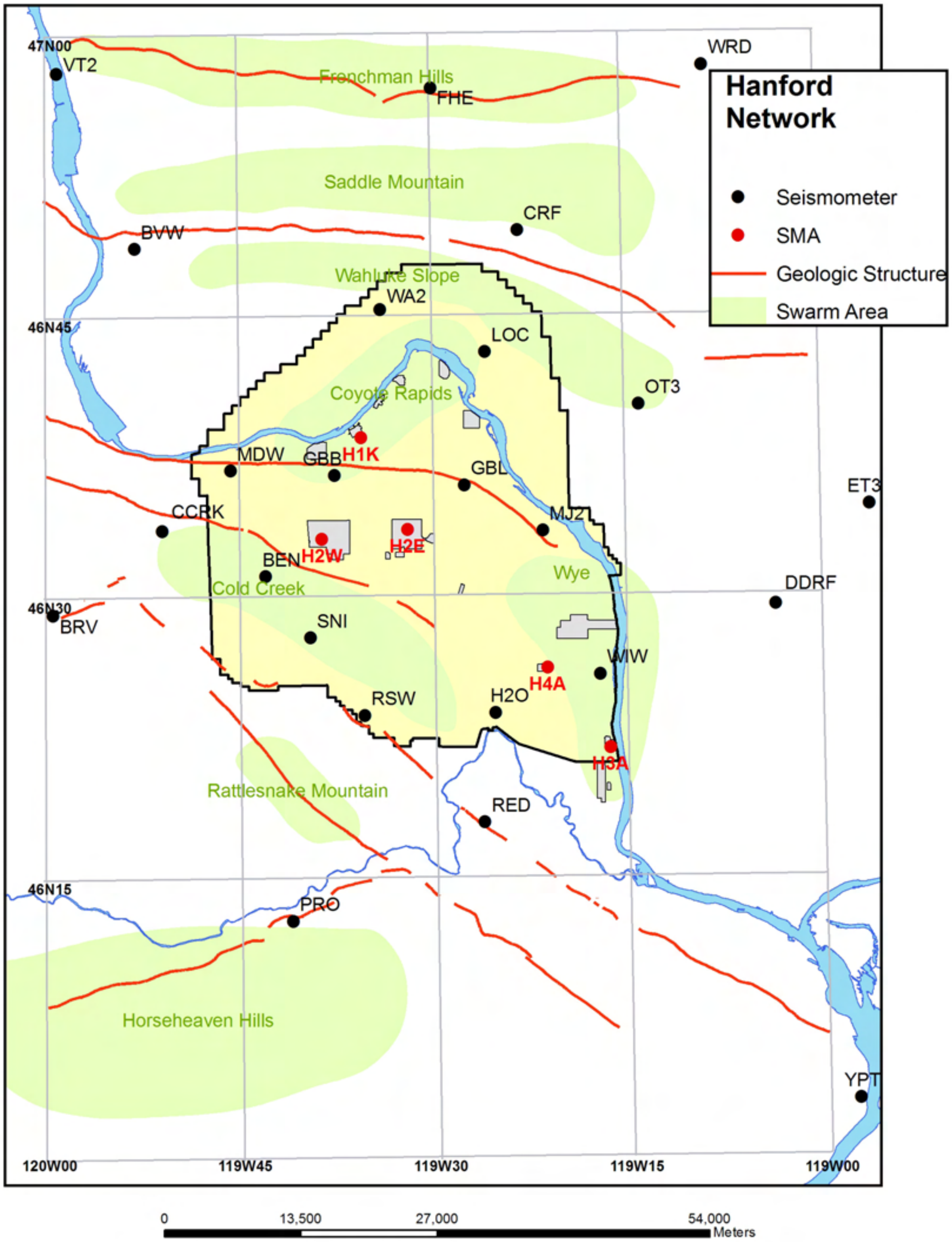


Figure 2.1. Seismometer and Strong Motion Accelerometer Stations in the Hanford Seismic Network

Table 2.2. Seismometer Stations in the Eastern Washington Regional Network

Station[a]	Latitude Deg. Min. N.	Longitude Deg. Min. W.	Elevation (m)	Station Name
BLT	45N54.91	120W10.55	659	Bickleton
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
CCRK[b]	46N55.85	119W85.49	560	Cold Creek
DDRF[b]	46N49.12	119W05.96	270	Didier Farms
FHE[b]	46N57.11	119W29.82	455	Frenchman Hills East
PHIN[b]	45N89.52	119W92.78	270	Phinney Hill
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
PAT2	45N53.03	119W45.40	259	Paterson Two
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	387	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

(a) The first column is the alphanumeric 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 all are in Washington unless otherwise indicated; locations were determined from the Global Positioning System (GPS).
(b) Three-component station.

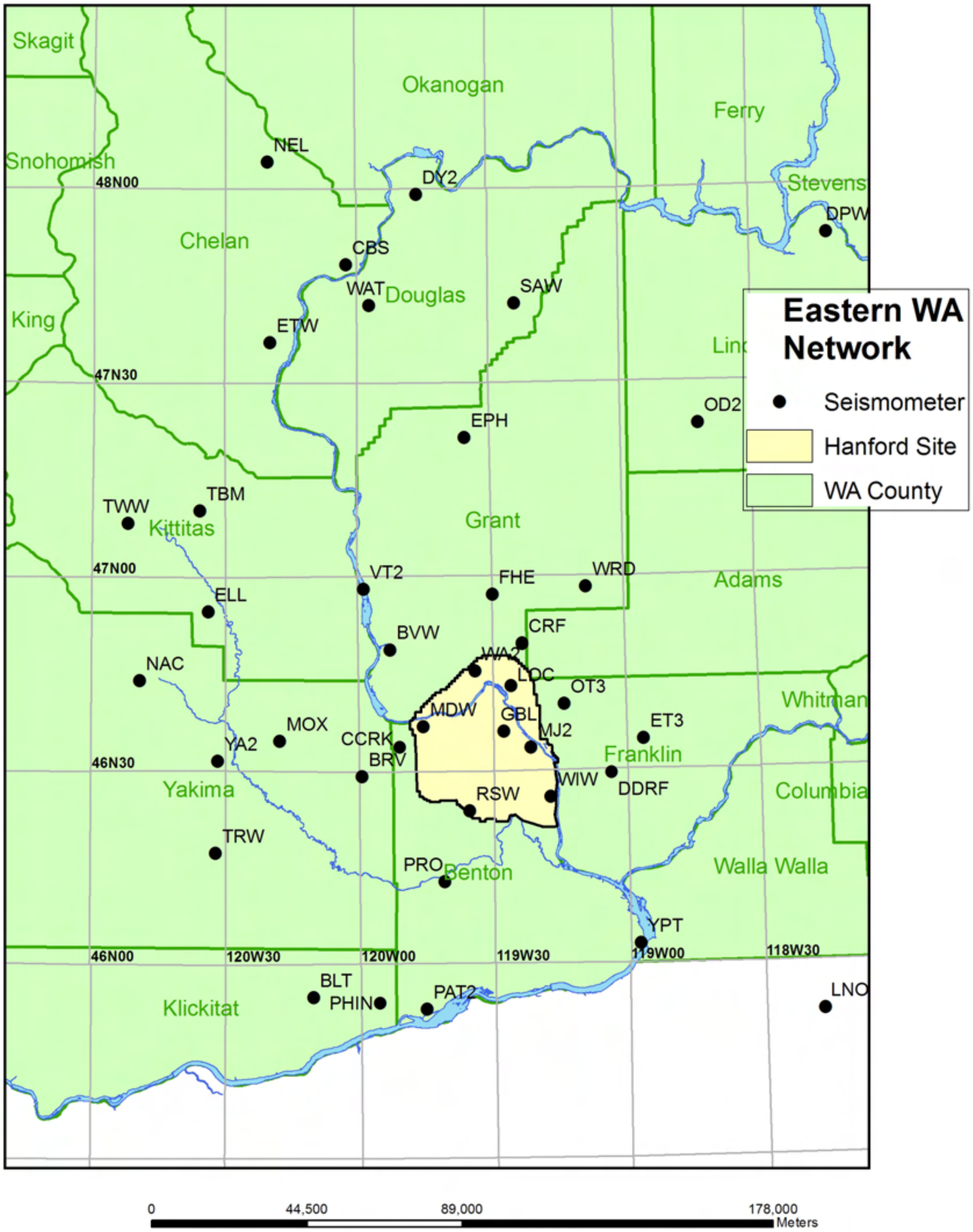


Figure 2.2. Seismometer Stations in the Eastern Washington Regional Network

The HSN and EWRN networks have 54 combined data channels because the three-component sites (Gable Butte, Frenchman Hills East, Cold Creek, Didier Farms, and Phinney Hill) require 4 additional data channels per station. The tri-axial stations record motion in the vertical, north-south horizontal, and east-west horizontal directions. The other 39 stations are single vertical component seismometers. Fifteen radio telemetry relay sites are used by both networks to continuously transmit seismogram data to the Seismic Assessment Laboratory in the Sigma V building, Richland, Washington, for processing and archiving.

2.1.1 Station Maintenance

The fourth quarter of FY 2008 was a typical period of warm sunny days with excellent sunlight. The remote location of the seismic monitoring sites (Figure 2.3) necessitates total dependency on solar power generation. Generally, the long summer days are conducive to optimal solar panel energy production and peak battery recharge. Site maintenance was minimal.

Continued efforts were made to improve the data transmission of the three newly acquired Transportable Array stations located at Cold Creek (CCRK), Didier Farms (DDRF), and Phinney Hill (PHIN). This involved reorienting the site antennas as the cell phone carriers improve their local area coverage with new cell towers and hardware upgrades. New Raven X modems were installed to replace the older Raven Edge equipment. This required a change in modem settings and vault cable design to accommodate the faster Ethernet function.

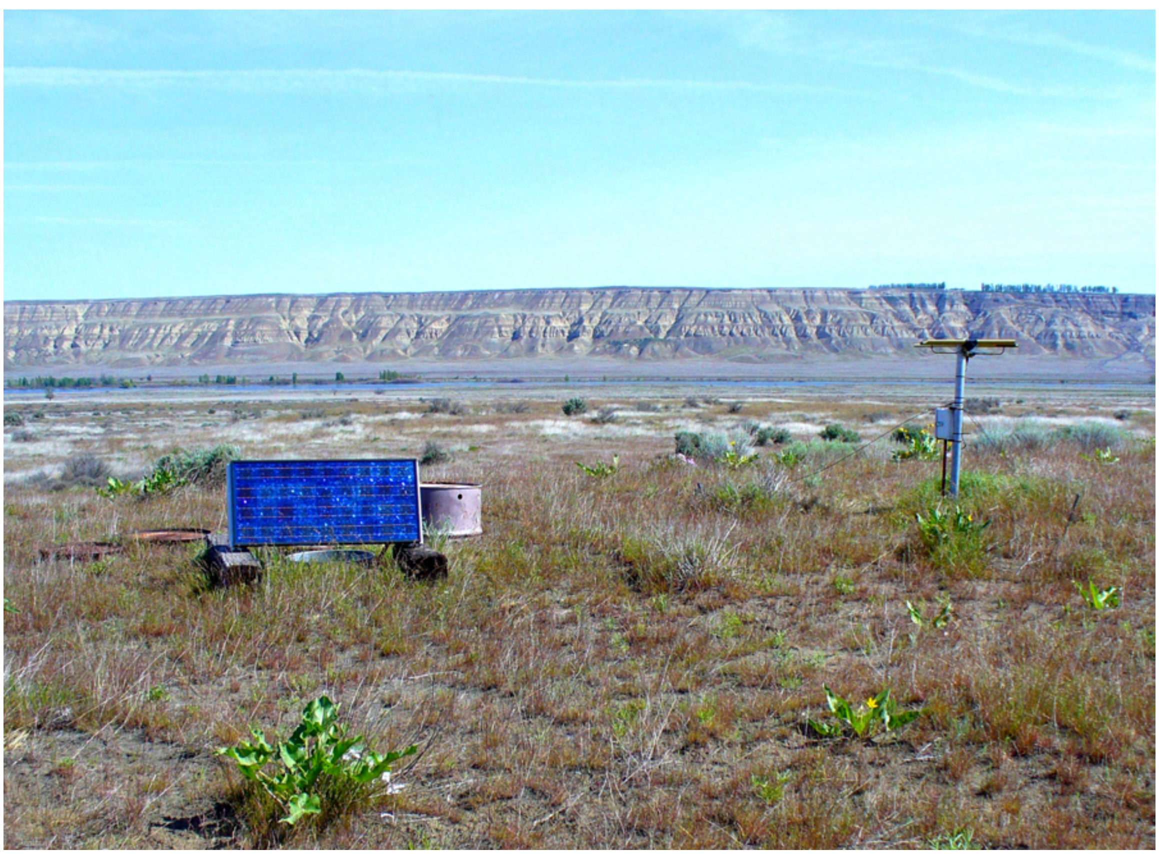


Figure 2.3. White Bluffs behind May Junction site (MJ2)

During FY 2007, the HSAP began upgrading the Hanford seismometer network with the ultimate goal of replacing analog radio telemetry with digital, Internet-based telemetry. The upgrade will help eliminate the reliance on aging radio receiving and multiplexing equipment currently located in the Seismic Assessment Laboratory in the Sigma V building. The first upgrade is planned for the Gable Butte seismometer station (GBB) to be equipped with tri-axial broad-band seismometers with built-in digitizing and telemetry equipment.

Work progressed on upgrading GBB. Communications were established that allowed data transmissions between the tri-axial, broad-band seismometers, the Quanterra Q330 data recorder, and the internet. Earthworm version 7.2 was installed on PNNL servers so that digital data transmissions are received at the HSAP laboratory. The GBB equipment is scheduled to be installed in the field in the first quarter of FY 2009.

2.1.2 Data Acquisition

The signals from the seismometer stations 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 United States and Canada), and teleseisms (from farther distances around the world). Local and regional events are usually earthquakes, but quarry and mining explosions also are recorded. Quarry and mining explosions usually can be identified from wave characteristics and the time of occurrence and may be confirmed with local government agencies and industries. Frequently, military exercises at the U.S. Army Yakima Training Center produce a series of acoustic shocks that trigger the recording system. Sonic booms and thunder also produce acoustic signals that may trigger the recording system.

The HSAP uses Earthworm, a PC-based system developed by the USGS and used by the Pacific Northwest Seismic Network at the UW, to record triggered events. One Earthworm system has been in continuous operation since January 6, 1999. A second system was installed in mid-March 1999. Both systems have been running in parallel since that time, with periodic hardware and software upgrades performed. Seismogram data from triggered events are collected on a SUN workstation (Sun Microsystems, Santa Clara, California) for assessment by HSAP staff. This information is evaluated to determine if the event is “false” (for example, due to a sonic boom) or is an earthquake or ground-surface or underground blast. Earthquake events are evaluated to determine epicenter locations, focal depths, and magnitudes (Section 4).

Although the two Earthworm systems are practically identical, slight differences in the trigger algorithms, combined with the granularity of the signal-measurement time windows, sometimes result in triggered events from one Earthworm system but not the other. These different or *exclusive* events are generally “false” triggers resulting from acoustical sources and not earthquakes or quarry blasts. Sometimes these exclusive events correspond to barely detectable, distant regional, or teleseismic earthquakes.

2.2 Strong Motion Accelerometer Stations

2.2.1 Location

The Hanford SMA network consists of five free-field SMA stations (see Figure 2.1; Table 2.3). SMAs are located in the 200 East and 200 West Areas, in the 100-K Area adjacent to the K Basins, in the 400 Area near the former Fast Flux Test Facility, and at the south end of the 300 Area.

The locations of SMA stations were chosen based on two criteria: 1) density of workers and 2) siting of hazardous facilities (Moore and Reidel 1996). The 200 East and 200 West Areas contain single-shell and double-shell tanks in which high-level radioactive wastes from past processing of fuel rods are stored. In addition, the Canister Storage Facility (holding encapsulated spent fuel rods) and the new Waste Treatment and Immobilization Plant being constructed are both located in the 200 East Area. The 100-K Area contains the K Basins, where spent fuel rods from the N Reactor were stored prior to encapsulation.

Table 2.3. 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	46º 38.51’ 119º 35.53’ 152 m
200 East Area	H2E	East of B Plant; northwest of Waste Treatment and Immobilization Plant; north of 7th Street and east of Baltimore Avenue	46º 33.58’ 119º 32.00’ 210 m
200 West Area	H2W	West of Plutonium Finishing Plant (PFP) and 200 West Area tree barrier	46º 33.11’ 119º 38.64’ 201 m
300 Area	H3A	South end of 300 Area inside fence lines (NE 1/4, SW 1/4, Sec. 11, T10N, R28E)	46º 21.83’ 119º 16.55’ 119 m
400 Area	H4A	500 ft from fence line on east side of facility and north of parking area)	46º 26.13’ 119º 21.30’ 171 m

The Cold Vacuum Drying Facility, also 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 the 200 East Area. The 400 Area is the site of construction activities.

2.2.2 Station Design

All free-field SMA stations consist of a four-panel solar array and two 30-gal galvanized drums that contain equipment. Each panel has a maximum 42-W output. The two 30-gal drums are set in the ground such that the base of each drum is about 1 m below the ground surface. One drum houses only the SMA; the other drum, which is connected via a sealed conduit to the SMA drum, contains the batteries. Data communication is provided by a General Packet Radio Service (GPRS) system, a continuous radio data-link to an Internet service provider. The GPRS 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 the drums through conduit. The antenna for the GPRS 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 SMA stations are three-component units consisting of vertical, north-south horizontal, and east-west horizontal seismometers manufactured by Kinemetrics, Inc., Pasadena, California, and known as the ETNA system (specifications summarized in Table 2.4). Each ETNA unit contains a digital recorder, a data storage unit, and a Global Positioning System (GPS) receiver (Figure 2.4). These components are housed in a watertight box.

Table 2.4. Instrument Parameters for the Kinemetrics ETNA System in the Hanford SMA Network

Parameter	Value or Range
Sensor	
Type	Triaxial EpiSensor Accelerometer
Full-scale	±2 g[(a)]
Frequency range	0–80 Hz
Damping	Approximately 70% critical[(a)]
Data Acquisition	
Number of channels	3
Sample rate	200 samples/sec
Resolution	18 bits
Digital output	Real-time, RS-232 output stream
Seismic Trigger	
Filter	0.1–12.5 Hz
Trigger level	0.02% g[(b)]
Alarm (call-out) threshold	Not activated
Pre-event memory	10 s
Post-event time	40 s

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

The GPRS 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 Assessment Laboratory. The data also can be downloaded directly at each site via a built-in cable connection at the enclosure in case of communication failure.

The GPS receiver is used principally to access the National Bureau of Standards timing system. The GPS receiver antenna is mounted on the enclosure at the rear of the solar array. The GPS receiver is activated internally approximately every 4 hr and checks the “location of the instrument” and the time.

Any differences between the internal clock and the GPS time are recorded by the SMA. Any corrections to the internal timing are made automatically. Typically, the greatest correction recorded is approximately 4 milliseconds (ms).

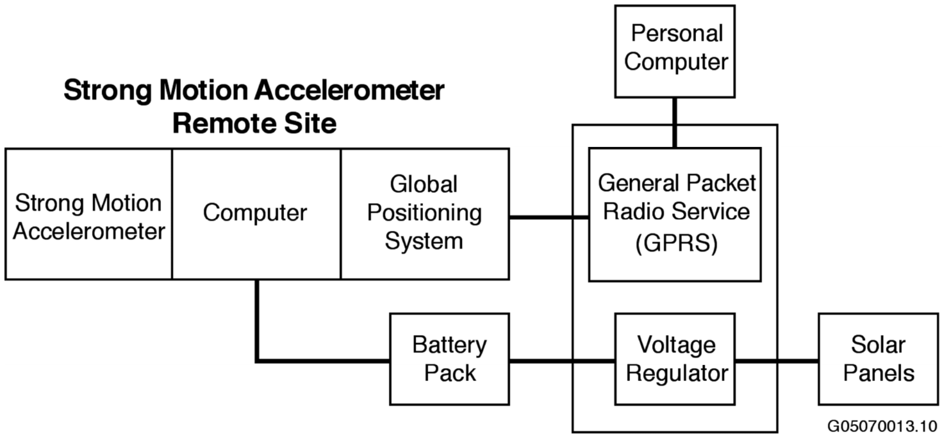


Figure 2.4. Schematic Diagram of a Strong Motion Accelerometer Installation

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 HSAP.

2.2.4 Strong Motion Operational Characteristics

Signals from the three accelerometer channels use an 18-bit digitizer with data temporarily stored in a memory buffer. The digital sampling rate is 200 samples/s. The three channels are monitored for signals that exceed a programmable trigger threshold. When one accelerometer channel is triggered, the other channels automatically record. The nominal threshold used from 1998 to 2006 was 0.1% g (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). Threshold trigger levels are set to trigger infrequently on noise sources (e.g., vehicles, sonic booms) near each site. In 2006, larger data storage capacities were installed that allowed the trigger thresholds to be reduced to 0.02% g (see Section 6). This permits the recording of ground motion data for smaller, non-damaging earthquakes that can be useful in estimating impacts of larger earthquakes. It also helps confirm the correct operation of the instruments by analyzing the smaller-amplitude triggers.

When one of the accelerometer channels exceeds the trigger threshold, the recorders save information within the data buffers. Data recording begins 10 s before the actual trigger time, continues until the trigger threshold is no longer exceeded, and ends with an additional 40 s of data. The saved files created by a triggered event are stored on memory cards to be retrieved and examined by HSAP staff.

3.0 Geology and Tectonic Analysis

The Hanford Site lies within the Columbia Basin, an intermontane basin between the Cascade Range and the Rocky Mountains 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 et al. 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 typically along the northern flanks (Figure 3.1) (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-wave-length folds on an otherwise gently westward dipping paleoslope. Figure 3.2 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).

3.1 Earthquake Stratigraphy

Seismic studies at the Hanford Site have shown that the earthquake activity is related to crustal stratigraphy (large groupings of rock types) (Rohay et al. 1985; DOE 1988). The main geologic units important to earthquakes at the Hanford Site and the surrounding area are

- the Miocene CRBG
- pre-basalt sediments of Paleocene, Eocene, Oligocene, and Early Miocene age
- the crystalline basement composed of Precambrian and Paleozoic craton/continental margin
- Mesozoic accreted terranes.

3.2 Geologic Structure Beneath the Monitored Area

Between the late 1950s and the mid 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. Table 3.1, derived from Reidel et al. (1994), was developed for the geologic interpretation in this report. The thicknesses of these units are variable across the monitored area. Table 3.1 summarizes the approximate thickness at the borders of the monitored area.

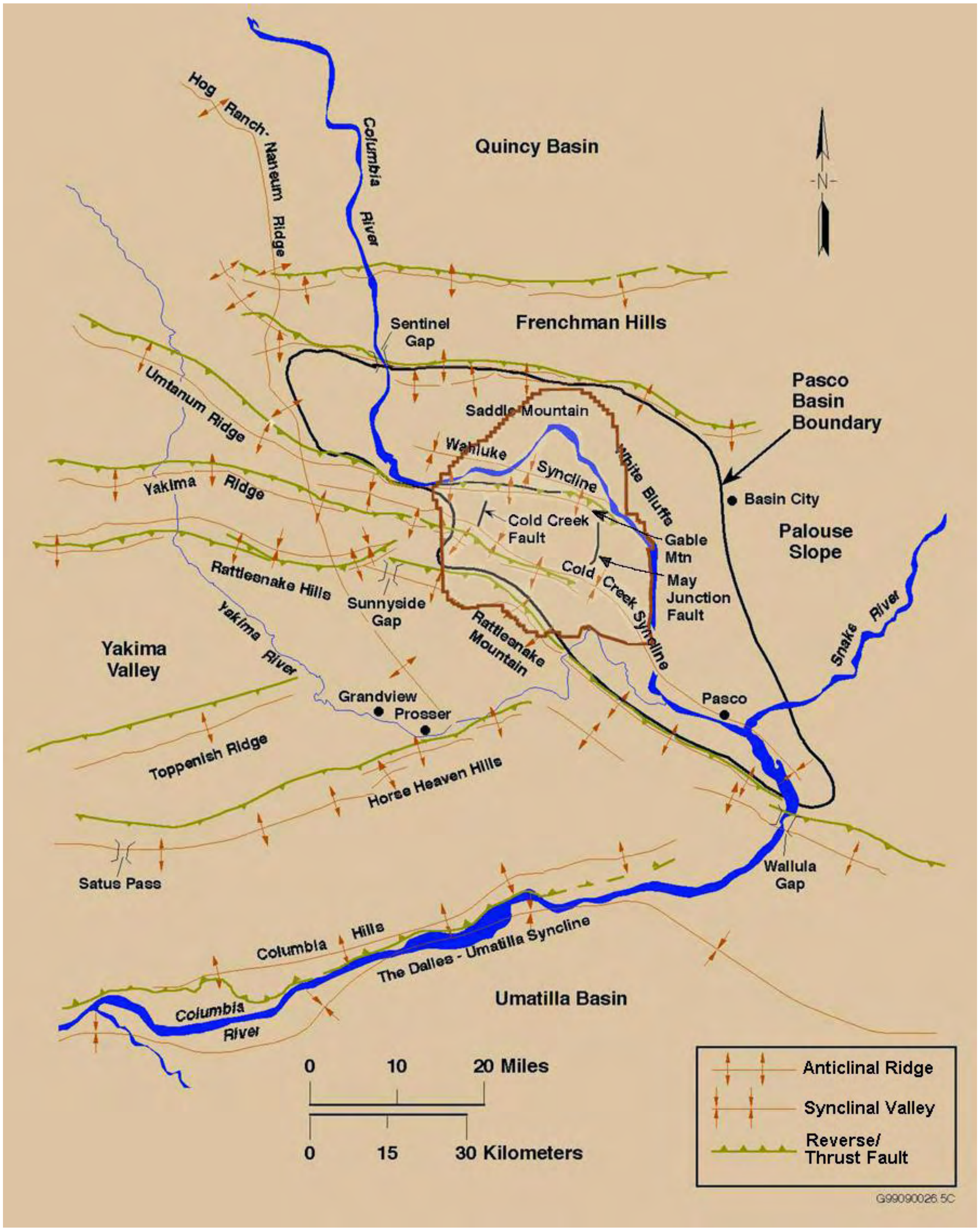


Figure 3.1. Physical and Structural Geology of the Hanford Site, Washington

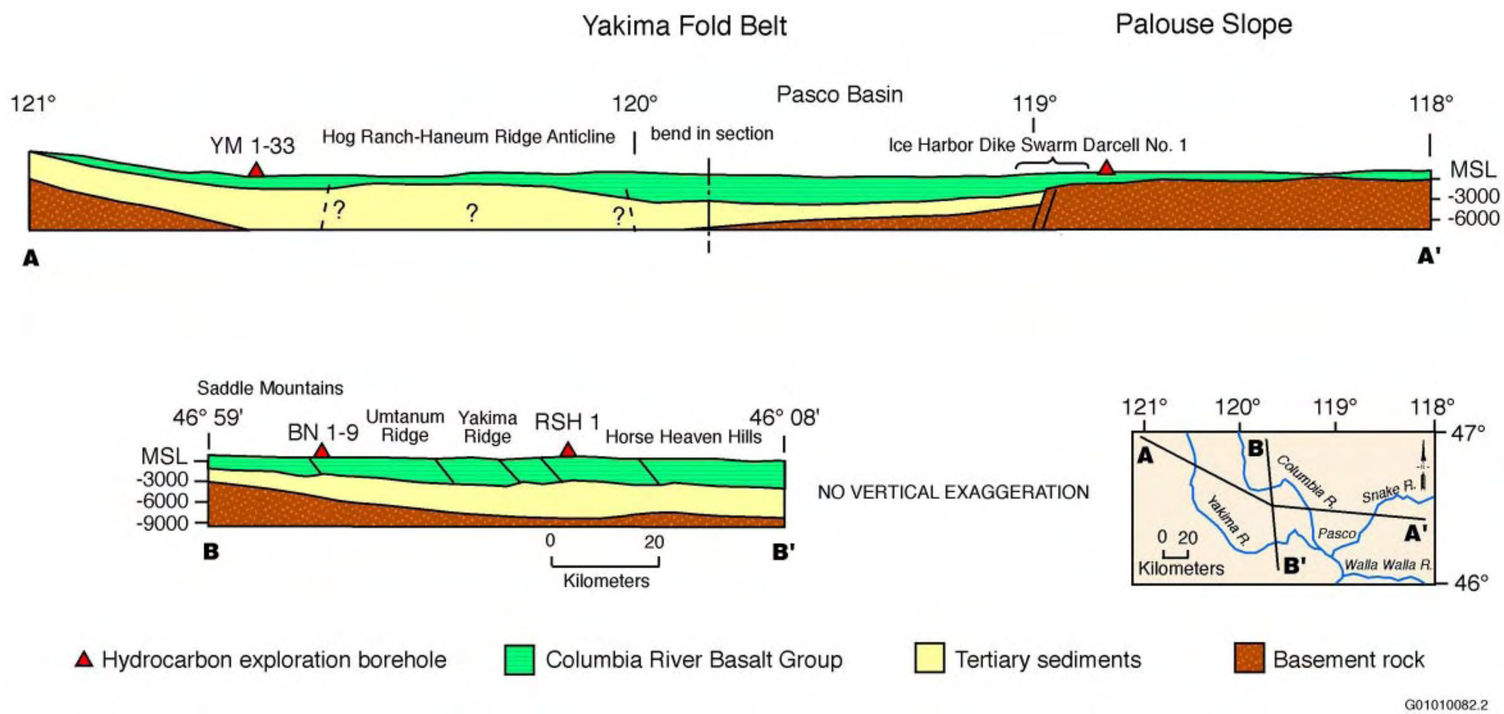


Figure 3.2. Geologic Cross Sections through the Columbia Basin (Reidel et al. 1994)

Table 3.1. Thicknesses of Stratigraphic Units in the Monitoring Area (from Reidel et al. 1994)

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 up to 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).

3.3 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 to 20 km in length) than the main reverse/thrust faults that occur along the major anticlinal ridges (up to 100 km in length). 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 located 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. Seven earthquake swarm areas are recognized in the HSN area, but this list will be updated as new swarm areas develop. The Saddle Mountains, Wooded Island, Wahluke, Coyote Rapids, and Horse Heaven Hills swarm areas are typically active at one time or another during the year (see Figure 5.2 for a map of these swarm areas). The other earthquake swarm areas are active less frequently.
- **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 interpretation 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.
- **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).

4.0 Earthquake Catalog Description

An interactive program called XPED, developed at the University of Washington, is used to determine earthquake locations and magnitudes. This program reads seismogram data recorded by the Earthworm system and lets the user measure arrival times and durations from earthquakes. Arrival and duration times are used as input to the hypocenter routine within XPED to estimate locations and magnitudes of the seismic events. XPED results for local earthquakes (46-47° north latitude, 119-120° west longitude) are reported in Table 4.1. Other seismic events located in southeastern Washington, the Pacific Northwest, or outside the region also are evaluated, with results stored on the computer system; these results are not reported in this document. These other results sometimes are used as a check to confirm that the HSN is functioning properly (e.g., quality checks on data recording).

4.1 Coda-Length Magnitude

Coda-length magnitude (M_c), an estimate of local magnitude (M_L) (Richter 1958), is calculated using a relationship developed for Washington State by Crosson (1972):

$$M_c = 2.82 \log (D) - 2.46$$

where D is the duration of the observed event. Many of the earthquakes have magnitude determinations that are very small ($M_c < 0$) and highly uncertain. In Section 4, we define earthquakes as “minor” with magnitudes (M_c) smaller than 1.0. Coda-length magnitudes for events classified as explosions are not reported because they are biased by a prominent surface wave that extends the apparent duration in a way inconsistent with coda-length measurement.

4.2 Velocity Model

XPED uses the crustal velocity model for eastern Washington given in Table 4.2. The model does not include a surficial layer for the Hanford or Ringold formations because most seismometer stations are sited on basalt. The crustal velocity model extends 38 km deep (to the mantle) and consists of six layers, each with uniform seismic velocity. The crustal velocity model was developed using available geologic information and calibrated from seismic data recorded from accurately located earthquake and blast events in eastern Washington. Time corrections (delays) are incorporated into the velocity model to account for significant deviations in station elevations or stations situated on sedimentary layers. Station delays also are determined empirically from accurately located earthquakes and blast events in the region.

Table 4.1. Local Seismic Data, October 1, 2007 – September 30, 2008

Event ID	Type	Date	Time	Latitude	Longitude	Depth	Mag	NS/NP	Gap	Dmin	RMS	Q	Location
07100311561		07/10/03	11:56:36.38	46N18.41	119W32.94	7.31	1.4	26/34	77	9	0.15	AB	20 km W of Richland
07100311573		07/10/03	11:57:59.95	46N18.44	119W32.77	7.20	0.3	11/18	169	9	0.05	AC	20 km W of Richland
07101900462		07/10/19	00:46:45.49	46N51.32	119W37.16	16.46	0.5	21/26	88	11	0.11	AA	24 km N of 100-K Area
07102313040		07/10/23	13:04:27.13	46N43.37	119W28.81	4.36	-0.1	6/08	161	3	0.09	AC	13 km NE of 100-K Area
07102620501		07/10/26	20:50:34.15	46N43.38	119W29.81	2.44	-0.7	5/10	153	5	0.10	AD	12 km NE of 100-K Area
07110915255		07/11/09	15:26:18.62	46N38.81	119W28.04	16.41	0.5	21/26	47	5	0.12	AA	10 km E of 100-K Area
07111014464		07/11/10	14:47:11.31	46N28.40	119W15.46	0.43	-0.4	4/04	244	5	0.02	AD	9 km ENE of 400 Area
07111812431		07/11/18	12:43:31.85	46N20.24	119W40.52	7.89	0.1	7/10	167	9	0.04	AC	16 km NNE of Prosser
07111813064		07/11/18	13:07:08.23	46N20.28	119W40.79	6.13	0.5	9/12	166	9	0.07	AC	16 km NNE of Prosser
07111813072		07/11/18	13:07:37.64	46N20.24	119W40.47	7.43	-0.2	3/06	303	9	0.03	AD	16 km NNE of Prosser
07111813135		07/11/18	13:14:15.15	46N20.23	119W40.72	5.49	0.1	8/11	169	9	0.04	AC	16 km NNE of Prosser
07111900542		07/11/19	00:54:48.71	46N20.27	119W40.81	4.56	1.2	16/19	122	9	0.08	AB	16 km NNE of Prosser
07111909522		07/11/19	09:52:53.38	46N20.31	119W40.73	5.75	0.9	17/20	122	9	0.11	AB	16 km NNE of Prosser
07111910122		07/11/19	10:12:43.79	46N20.30	119W40.67	6.13	0.3	7/10	169	9	0.04	AC	16 km NNE of Prosser
07111919565		07/11/19	19:57:16.99	46N20.29	119W40.81	5.62	0.5	8/11	170	9	0.06	AC	16 km NNE of Prosser
07112111375		07/11/21	11:38:15.28	46N20.22	119W40.29	6.58	0.3	10/14	162	8	0.07	AC	16 km NNE of Prosser
07112112022		07/11/21	12:02:49.56	46N20.34	119W40.66	5.45	0.1	9/12	165	9	0.06	AC	16 km NNE of Prosser
07112112260		07/11/21	12:26:22.87	46N20.90	119W39.24	7.64	-0.3	3/06	295	7	0.02	AD	18 km NNE of Prosser
07112117554		07/11/21	17:56:10.16	46N20.25	119W40.67	4.75	0.6	13/16	165	9	0.06	AC	16 km NNE of Prosser
07112402092		07/11/24	02:09:51.48	46N20.25	119W40.46	5.92	0.4	10/14	164	8	0.05	AC	16 km NNE of Prosser
07112406452		07/11/24	06:45:47.19	46N13.74	119W33.92	8.18	0.2	8/09	206	9	0.06	AD	16 km E of Prosser
07112407361		07/11/24	07:36:39.69	46N20.20	119W40.03	6.46	0.3	11/14	117	8	0.14	AB	16 km NNE of Prosser
07112408452		07/11/24	08:45:45.96	46N20.26	119W40.74	5.32	0.2	9/12	166	9	0.07	AC	16 km NNE of Prosser
07112409163		07/11/24	09:16:59.48	46N20.35	119W40.58	5.88	0.4	10/13	165	8	0.05	AC	16 km NNE of Prosser
07112409190		07/11/24	09:19:00.34	46N20.29	119W40.63	6.43	0.2	6/09	182	9	0.07	AD	16 km NNE of Prosser
07112506091		07/11/25	06:09:35.85	46N20.18	119W40.49	4.97	0.3	7/10	164	9	0.07	AC	16 km NNE of Prosser
07112511584		07/11/25	11:59:11.97	46N20.40	119W40.81	4.33	1.5	17/20	122	9	0.08	AB	16 km NNE of Prosser
07112617244		07/11/26	17:25:06.24	46N19.69	119W41.72	3.45	0.6	7/11	255	10	0.08	BD	15 km NNE of Prosser
07112801200		07/11/28	01:20:30.32	46N20.23	119W40.61	5.50	0.7	11/15	165	9	0.07	AC	16 km NNE of Prosser
07112810484		07/11/28	10:49:03.63	46N20.24	119W40.50	6.10	0.4	7/11	164	9	0.05	AC	16 km NNE of Prosser

Table 4.1. Local Seismic Data, October 1, 2007 – September 30, 2008 (contd)

Event ID	Type	Date	Time	Latitude	Longitude	Depth	Mag	NS/NP	Gap	Dmin	RMS	Q	Location
07112810492		07/11/28	10:49:29.04	46N20.32	119W40.79	6.35	0.5	6/09	166	9	0.05	AC	16 km NNE of Prosser
07112819432		07/11/28	19:43:50.98	46N20.28	119W40.53	5.47	1.0	14/17	120	9	0.07	AB	16 km NNE of Prosser
07112822041		07/11/28	22:04:34.42	46N20.44	119W40.19	7.74	0.4	4/07	258	8	0.02	AD	16 km NNE of Prosser
07112905245		07/11/29	05:25:18.60	46N20.30	119W40.25	6.29	0.5	11/15	162	8	0.05	AC	16 km NNE of Prosser
07112905260		07/11/29	05:24:35.88	46N20.26	119W40.17	5.35	0.6	9/13	161	8	0.06	AC	16 km NNE of Prosser
07112913350		07/11/29	13:35:25.76	46N20.44	119W40.97	6.14	0.4	7/10	167	9	0.05	AC	16 km NNE of Prosser
07112918015		07/11/29	18:02:12.06	46N20.22	119W40.95	6.05	0.1	6/08	167	9	0.05	AC	16 km NNE of Prosser
07113009394		07/11/30	09:40:04.55	46N20.33	119W40.93	6.35	0.4	10/13	167	9	0.06	AC	16 km NNE of Prosser
07120619443	X	07/12/06	19:44:55.85	46N07.64	119W01.05	0.03		15/15	122	9	0.12	AB	12 km SE of Kennewick
07120806063		07/12/08	06:07:02.13	46N20.20	119W40.27	6.20	0.4	10/13	162	8	0.04	AC	16 km NNE of Prosser
07121114304		07/12/11	14:31:08.71	46N40.40	119W29.43	17.96	0.6	17/21	98	6	0.08	AB	9 km ENE of 100-K Area
07121301044		07/12/13	01:05:07.39	46N42.08	119W30.52	4.94	-0.8	4/05	109	6	0.06	AD	10 km NE of 100-K Area
07121818025		07/12/18	18:03:14.25	46N43.05	119W29.66	0.02	0.0	7/08	86	4	0.09	AB	12 km NE of 100-K Area
07122011101		07/12/20	11:10:36.06	46N32.42	119W37.12	24.02	1.1	20/20	54	7	0.09	AA	3 km SE of 200 West
07122522022		07/12/25	22:02:50.48	46N23.24	119W33.61	16.26	0.0	12/12	81	2	0.08	AA	16 km WSW of 400 Area
08010723430		08/01/07	23:43:29.21	46N51.54	119W24.12	18.85	1.2	25/028	90	3	0.10	AA	18 km WNW of Othello
08011822511		08/01/18	22:51:41.44	46N28.77	119W22.42	8.36	0.0	11/014	122	8	0.07	AB	5 km NNW of 400 Area
08012904402		08/01/29	04:40:49.21	46N20.08	119W40.59	4.09	0.2	10/013	121	9	0.11	BB	16 km NNE of Prosser
08013001161		08/01/30	01:1630.76	46N20.61	119W42.50	8.47	-0.5	7/008	158	10	0.26	BC	16 km NNE of Prosser
08020300453		08/02/03	00:45:53.02	46N04.22	119W50.83	0.04	1.5	15/016	109	20	0.13	AC	16 km SSW of Prosser
08020323354		08/02/03	23:35:04.38	46N32.77	119W10.81	22.46	2.3	33/033	76	13	0.18	BA	18 km NE of 400 Area
08020517393	X	08/02/05	17:39:52.71	46N07.41	119W02.04	0.02		7/007	173	9	0.15	AC	11 km SE of Kennewick
08020519241	P	08/02/05	19:24:41.19	46N15.59	119W22.46	0.29		8/008	238	6	0.28	CD	7 km WSW of Richland
08020821563	P	08/02/08	21:56:04.10	46N15.78	119W22.79	2.29		11/011	235	5	0.11	BD	7 km WSW of Richland
08021422295	P	08/02/14	22:29:21.22	46N56.90	119W27.66	1.48		12/012	97	2	0.08	AB	24 km SW of Moses Lake
08022000225		08/02/20	00:22:20.07	46N53.32	119W53.96	0.45	1.8	30/030	53	8	0.17	BB	10 km SE of Vantage
08040521511		08/04/05	21:51:41.92	46N20.22	119W31.01	10.07	-0.4	4/06	192	6	0.06	AD	16 km SW of 400 Area
08040720360		08/04/07	20:36:33.29	46N32.15	119W51.83	0.75	1.9	16/16	124	11	0.18	BC	18 km W of 200 West
08042805175		08/04/28	05:18:15.09	46N43.21	119W30.28	0.47	-0.2	7/10	92	5	0.13	AB	11 km NE of 100-K Area
08042808021		08/04/28	08:02:31.71	46N07.91	119W27.90	7.23	0.4	9/11	275	18	0.13	AD	22 km SW of Richland
08050122153		08/05/01	22:15:57.19	46N33.79	119W49.53	7.06	0.6	8/11	165	7	0.12	AC	14 km W of 200 West
08050312140		08/05/03	12:14:25.18	46N10.86	119W44.95	10.89	0.5	9/10	130	6	0.09	AB	3 km SSE of Prosser

Table 4.1. Local Seismic Data, October 1, 2007 – September 30, 2008 (contd)

Event ID	Type	Date	Time	Latitude	Longitude	Depth	Mag	NS/NP	Gap	Dmin	RMS	Q	Location
08051520104		08/05/15	20:11:03.34	46N33.37	119W52.53	0.56	0.4	5/11	284	10	0.12	AD	18 km W of 200 West
08051520150		08/05/15	20:15:24.88	46N33.58	119W51.40	4.85	0.1	6/09	278	9	0.05	AD	17 km W of 200 West
08051822193		08/05/18	22:19:54.98	46N09.95	119W33.34	20.53	3.7	34/34	87	11	0.19	BA	17 km ESE of Prosser
08052122032		08/05/21	22:03:43.00	46N33.53	119W48.86	7.41	0.2	8/08	155	7	0.24	BC	14 km W of 200 West
08052220314		08/05/22	20:32:05.19	46N32.70	119W53.59	0.02	0.2	8/10	132	10	0.24	BC	20 km W of 200 West
08052823021		08/05/28	23:02:42.36	46N32.88	119W49.84	3.42	0.6	13/13	107	8	0.10	AB	15 km W of 200 West
08053109533		08/05/31	09:54:03.66	46N36.24	119W51.19	6.73	0.1	9/14	135	7	0.13	AB	17 km WNW of 200 West
08061819150	P	08/06/18	19:15:30.20	46N07.07	119W27.53	0.41		8/08	280	20	0.31	DD	23 km SW of Richland
08062117355	X	08/06/21	17:36:12.33	46N39.89	119W33.05	0.38		5/05	103	8	0.02	AD	4 km NE of 100-K Area
08062922254		08/06/29	22:26:03.94	46N20.11	119W40.43	4.97	-0.2	8/10	163	9	0.08	AC	16 km NNE of Prosser
08072207055		08/07/22	07:06:21.47	46N33.83	119W42.75	3.09	-0.2	6/08	142	5	0.07	AC	6 km W of 200 West
08072910002		08/07/29	10:00:40.68	46N52.55	119W34.01	14.20	-0.1	15/21	135	9	0.10	AB	26 km N of 100-K Area
08080613003		08/08/06	13:00:55.35	46N37.31	119W17.96	15.14	0.4	20/24	57	7	0.09	AA	19 km ENE of 200 East
08081814264		08/08/18	14:26:59.76	46N18.39	119W23.78	6.98	-0.3	4/08	220	3	0.06	AD	9 km WNW of Richland
08082821224		08/08/28	21:22:59.91	46N48.42	119W23.97	0.03	-0.3	7/08	126	2	0.10	AB	18 km W of Othello
08090607253		08/09/06	07:25:59.44	46N42.19	119W18.87	27.26	0.2	22/23	84	9	0.08	AA	18 km SW of Othello
08090704351		08/09/07	04:35:38.75	46N22.81	119W34.62	15.10	-0.1	7/09	194	1	0.05	AD	18 km WSW of 400 Area
08091815345		08/09/18	15:35:18.66	46N51.70	119W18.02	15.28	0.0	14/18	94	7	0.16	BB	11 km WNW of Othello
08092920390	P	08/09/29	20:39:29.23	46N25.17	119W00.49	4.26		6/06	230	18	0.17	CD	22 km NNE of Pasco
08093019093		08/09/30	19:09:55.64	46N09.56	119W22.24	11.44	0.9	15/19	113	16	0.14	AB	15 km SSW of Richland

Explanation of Table 4.1	
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; blank is local earthquake.
Date:	The year and date in Universal Time Coordinated (UTC). UTC is used throughout this report unless otherwise indicated.
Time:	The origin time of the earthquake given in Coordinated Universal Time (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 useful as a measure of quality of the solution only 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 s.
Q:	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."

4.3 Quality Factors (Q)

XPED assigns a two-letter **Quality factor** (Table 4.1) 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 arrival time residuals. For example: Quality **A** requires a root-mean-square residual (**RMS**) less than 0.15 s, while a **RMS** of 0.5 s 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 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**.

Uncertainties associated with estimated depths depend upon the number of stations and number of phase measurements (**NS/NP**) utilized in the XPED calculation. Generally speaking, if the number of phases exceeds 10 measurements, the depth estimate is considered to be reliable. In this case the second letter in the quality evaluation is either "A" or "B" (cf. Table 4.1). For example, the number of phase measurements from earthquakes ultimately classified as "deep" events typically falls within the

10-20 measurement range; these depth estimates are considered reliable. However, the number of phase measurements from earthquakes classified as "shallow" or "intermediate" may be less than 10 readings; in this case the depth estimate is less certain and the event could be classified as occurring in the CRBG or pre-basalt layers.

Table 4.2. Crustal Velocity Model for Eastern Washington (from Rohay et al. 1985)

Depth to Top of Velocity Layer (km)	Layer	Velocity (km/s)
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

5.0 Seismic Activity – FY 2008

5.1 Summary

During FY 2008, the Hanford Seismic Network recorded 1431 triggers on the seismometer system, which included 112 seismic events in the southeast Washington area and an additional 422 regional and teleseismic events. There were 74 events determined to be local earthquakes relevant to the Hanford Site (Table 4.1; Figure 5.1). The highest-magnitude event (3.7 M_c) occurred on May 18, 2008, and was located approximately 17 km east of Prosser at a depth of 20.5 km. A total of 31 micro earthquakes were recorded within the Rattlesnake Mountain swarm area at depths in the 4-8 km range during the first quarter of FY 2008. The depth distribution and geographic pattern of the 74 earthquakes that occurred in the Hanford area are classified in Table 5.1 and Table 5.2.

With regard to the depth distribution, 13 earthquakes were located at shallow depths (less than 4 km, most likely in the Columbia River basalts), 45 earthquakes were located at intermediate depths (between 4 and 9 km, most likely in the pre-basalt sediments), and 16 earthquakes were located at depths greater than 9 km, within the crystalline basement. Geographically, 54 earthquakes were located in swarm areas and 20 earthquakes were classified as random events.

Table 5.1. Depth Distribution of Earthquakes for FY08

Category	First Quarter	Second Quarter	Third Quarter	Fourth Quarter	FY 2008
Shallow (0-4 km deep)	4	2	5	2	13 (18%)
Intermediate (4-9 km deep)	35	3	6	1	45 (61%)
Deep (greater than 9 km deep)	5	2	3	6	16 (21%)
Total	44	7	14	9	74 (100%)

Table 5.2. Earthquake Locations for FY 2008

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 2008
Geologic Structure			-	-	-	
Swarm Areas	Frenchman Hills					
	Saddle Mountains/ Royal Slope	1	1		2	4
	Wahluke Slope				1	1
	Coyote Rapids	5		1		6
	Wye	1	1			2
	Cold Creek			4		4
	Rattlesnake Mountain.	31	2	1		34
	Horse Heaven Hills		1	2		3
	Total for swarm areas	38	5	8	3	54 (73%)
Random Events		6	2	6	6	20 (27%)
Total for all earthquakes		44	7	14	9	74

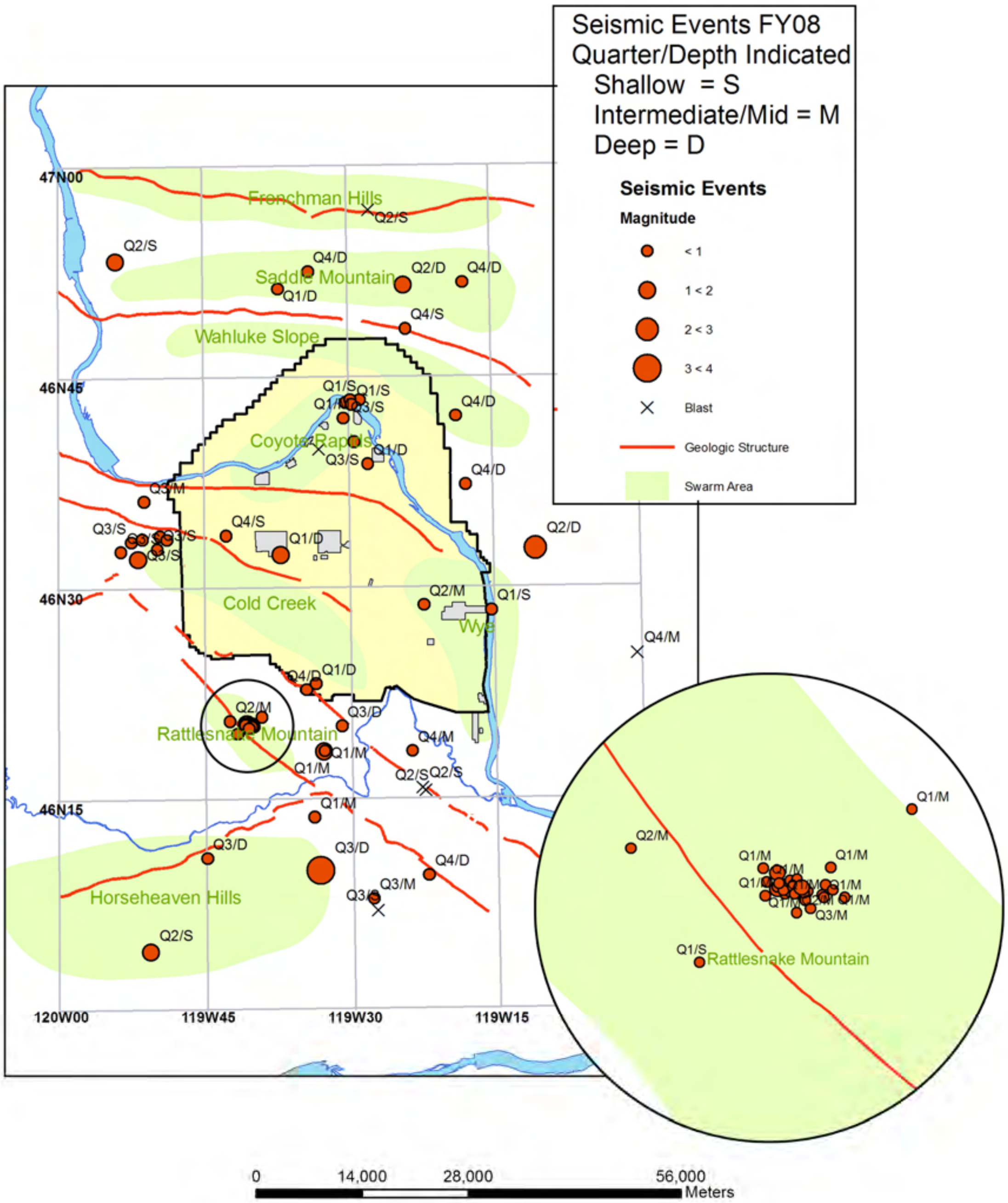


Figure 5.1. FY 2008 Earthquakes Recorded Within the Hanford Monitoring Area (October 2007 through September 2008)

5.2 First Quarter FY 2008 Earthquakes

For the Hanford Seismic Network, 44 local earthquakes and 1 blast event were recorded during the first quarter of FY 2008. A total of 31 micro earthquakes were recorded within the Rattlesnake Mountain swarm area at depths in the 4-8 km range, most likely within the pre-basalt sediments. In the following discussions, *minor earthquakes* refer to seismic events for which the magnitude is less than 1.0 M_c.

5.2.1 Location and Depth of Earthquakes

With regard to the depth distribution, 4 earthquakes occurred at shallow depths (less than 4 km, most likely in the Columbia River Basalt Group -CRBG), 35 earthquakes at intermediate depths (between 4 and 9 km, most likely in the pre-basalt sediments), and 5 earthquakes were located at depths greater than 9 km, within the crystalline basement. Geographically, 38 earthquakes occurred in swarm areas and 6 earthquakes were classified as random events.

In the past, swarms were thought to occur only at relatively shallow depths within the CRBG. During the last several years deeper based swarm events have been recorded, for example, the 31 micro earthquakes within the Rattlesnake Mountain swarm area during this quarter.

Four of the 44 recorded events with magnitude greater than 1.0 M_c are discussed below.

5.2.2 Major Anticlinal Ridges

No earthquakes were associated with the major geologic structures in the area surrounding the Hanford Site for the first quarter of FY 2008.

5.2.3 Earthquake Swarm Areas

Thirty-eight earthquakes were characterized as swarm events in the first quarter of FY 2008.

Rattlesnake Mountain Swarm Area

During the quarter, 31 micro earthquakes were recorded in the Rattlesnake Mountain swarm area at a range of depths 3.5-8.2 km. The proximity of epicenters (Figure 5.2) suggests that these earthquakes have a common source with the most reliable depth estimates between 4.3 and 5.5 km. For this reason, the swarm events are considered to have occurred within the pre-basalt sediments, deeper than the known geologic structure expressed at the surface. On November 19 and November 25, events measuring 1.2 and 1.5 M_c were recorded within this swarm area.

5.2.4 Random or Floating Events

Two events (October 3 and December 20) measuring 1.4 and 1.1 M_c were recorded and classified as random events. The October 3 event was located east of Rattlesnake Mountain with estimated depth 7.3 km, most likely within the pre-basalt sediments. The December 20 event was located within the crystalline basement at depth 24.0 km beneath the 200 West Area.

5.3 Second Quarter FY 2008 Earthquakes

For the Hanford Seismic Network, seven local earthquakes and four blast events were recorded during the second quarter of FY 2008.

5.3.1 Location and Depth of Earthquakes

With regard to the depth distribution, two earthquakes occurred at shallow depths (less than 4 km, most likely in the Columbia River basalts), three earthquakes at intermediate depths (between 4 and 9 km, most likely in the pre-basalt sediments), and two earthquakes were located at depths greater than 9 km, within the crystalline basement. Geographically, five earthquakes occurred in swarm areas and two earthquakes were classified as random events.

Four of the seven recorded events with magnitude greater than 1.0 M_c are discussed below.

5.3.2 Major Anticlinal Ridges

No earthquakes were associated with the major geologic structures in the area surrounding the Hanford Site for the second quarter of FY 2008.

5.3.3 Earthquake Swarm Areas

Five earthquakes were characterized as swarm events in the second quarter of FY 2008.

Saddle Mountains Swarm Area

On January 7, an earthquake measuring 1.2 M_c was recorded at depth approximately 18.9 km within the crystalline basement.

Horse Heavens Hills Swarm Area

On February 3, an earthquake measuring 1.5 M_c was recorded at depth approximately 0.04 km and considered to be within the CRBG.

5.3.4 Random or Floating Events

The largest event recorded by the network during the second quarter (February 3 - magnitude 2.3 M_c) was located northeast of Richland in Franklin County at a depth of 22.5 km. This event occurred within the crystalline basement. On February 20, a 1.8 M_c event was recorded at depth 0.5 km and located near the Columbia River west of the Saddle Mountain swarm area. This event occurred within the CRBG.

5.4 Third Quarter FY 2008 Earthquakes

For the Hanford Seismic Network (HSN), 14 local earthquakes and 2 blast events were recorded during the third quarter of FY 2008. The largest event recorded by the network during the third quarter occurred on May 18 (magnitude 3.7 M_c) and was located approximately 17 km east of Prosser at a depth of 20.5 km within the crystalline basement. This earthquake was the highest magnitude event recorded since 1975 in the vicinity of the Hanford Site (between 46-47° north latitude and between 119-120° west longitude). The event, not reported as being felt on the Hanford Site or causing any damage, was communicated to the PNNL Operations Center per HSAP communications procedures. The event is not considered to be significant with regard to site safety and not unprecedented given the site’s seismic history.

Two of the fourteen recorded events with magnitude greater than 1.0 M_c are discussed below.

5.4.1 Location and Depth of Earthquakes

With regard to the depth distribution, five earthquakes were located at shallow depths (less than 4 km, most likely in the Columbia River basalts), six earthquakes were located at intermediate depths (between 4 and 9 km, most likely in the pre-basalt sediments), and three earthquakes were located at depths greater than 9 km, within the crystalline basement. Geographically, eight earthquakes were located in swarm areas and six earthquakes were classified as random events.

5.4.2 Major Anticlinal Ridges

No earthquakes were associated with the major geologic structures in the area surrounding the Hanford Site for the third quarter of FY 2008.

5.4.3 Earthquake Swarm Areas

Eight earthquakes were characterized as swarm events in the third quarter of FY 2008.

Cold Creek Swarm Area

A 1.9 M_c magnitude event was recorded on April 7 at depth approximately 0.8 km within the CRBG.

Horse Heavens Hills Swarm Area

The largest magnitude event recorded since 1975 occurred on May 18 (magnitude 3.7 M_c) and located approximately 17 km east of Prosser at a depth of 20.5 km within the crystalline basement. The Hanford SMA network was triggered by this event and the SMA recordings are discussed in Section 6.0.

The Pacific Northwest Seismic Center classifies this event as minor since the magnitude did not exceed 4.0 M_c. Other notable events recorded by the HSN include 1) a 4.4 M_c event in 1973 at depth 3.3 km with epicenter in the Saddle Mountain swarm area, 2) a 3.8 M_c event in 1971 at depth 4.0 km with epicenter in the Coyote Rapids swarm area, and 3) a 3.8 M_c event in 1975 at depth 11.0 km with epicenter in the Horse Heavens Hills swarm area. Other events with magnitude greater than 3.0 M_c with epicenters within the Horse Heaven Hills swarm (depths between 9.3 and 21.3 km) occurred in 1979 (3.6 M_c), 1975 (3.3 M_c), and twice in 1995 (3.1 M_c both times).

5.4.4 Random or Floating Events

Six minor events were recorded during the third quarter of FY 2008.

5.5 Fourth Quarter FY 2008 Earthquakes

During the fourth quarter of FY 2008, the HSN recorded 304 triggers, which included 17 events located in the southeast Washington area and an additional 104 regional and teleseismic events. Ten events were located in the Hanford vicinity for this report and included one blast event (Table 4.1).

5.5.1 Location and Depth of Earthquakes

The depth distribution and geographic pattern of the nine earthquakes that occurred in the Hanford area are classified in Table 5.1 and Table 5.2. Epicenters of these events are shown in Figure 5.2. The depth distribution of these events is shown in Figure 5.3 with the events projected onto the 119W30 Longitude cross section.

With regard to the depth distribution, two earthquakes were located at shallow depths (less than 4 km, most likely in the Columbia River basalts), one earthquake was located at intermediate depths (between 4 and 9 km, most likely in the pre-basalt sediments), and six earthquakes were located at depths greater than 9 km, within the crystalline basement. Geographically, three earthquakes were located in swarm areas and six earthquakes were classified as random events.

In the following discussion, *minor earthquakes* refer to seismic events for which the magnitude is less than 1.0 $M_{c.}$

5.5.2 Major Anticlinal Ridges

No earthquakes were associated with the major geologic structures in the area surrounding the Hanford Site for the fourth quarter of FY 2008.

5.5.3 Earthquake Swarm Areas

Three earthquakes were characterized as swarm events in the fourth quarter of FY 2008.

Saddle Mountains Swarm Area

Two minor events were recorded on July 29 and September 18 and located at depths 14.2 and 15.3 km within the crystalline basement.

Wahluke Slope Swarm Area

A minor event was recorded on September 6 and located at depth 27.3 km within the crystalline basement.

5.5.4 Random or Floating Events

Six minor events were recorded during the fourth quarter of FY 2008. A minor event with epicenter located approximately 6 km west of the 200 West Area at depth 3.1 km (CRBG) was recorded on July 22. A minor event with epicenter located 19 km northeast of the 200 East Area (Franklin County) at depth 15.1 km (crystalline basement) was recorded on August 6. A minor event with epicenter located approximately 9 km west of Richland at depth 7.0 km (pre-basalt sediments) was recorded on August 18. A minor event with epicenter located 18 km west of Othello and north of the Hanford site at depth 0.03 km (CRBG) was recorded on August 28; this event is considered to be located well above the Saddle Mountain fault. A minor event with epicenter located approximately 18 km southwest of the 400 Area south of the Hanford Site at depth 15.1 km (crystalline basement) was recorded on September 7; this event is considered to be located substantially below known fault structure. A minor event with epicenter located approximately 15 km south of Richland at depth 11.4 km (crystalline basement) was recorded on September 30.

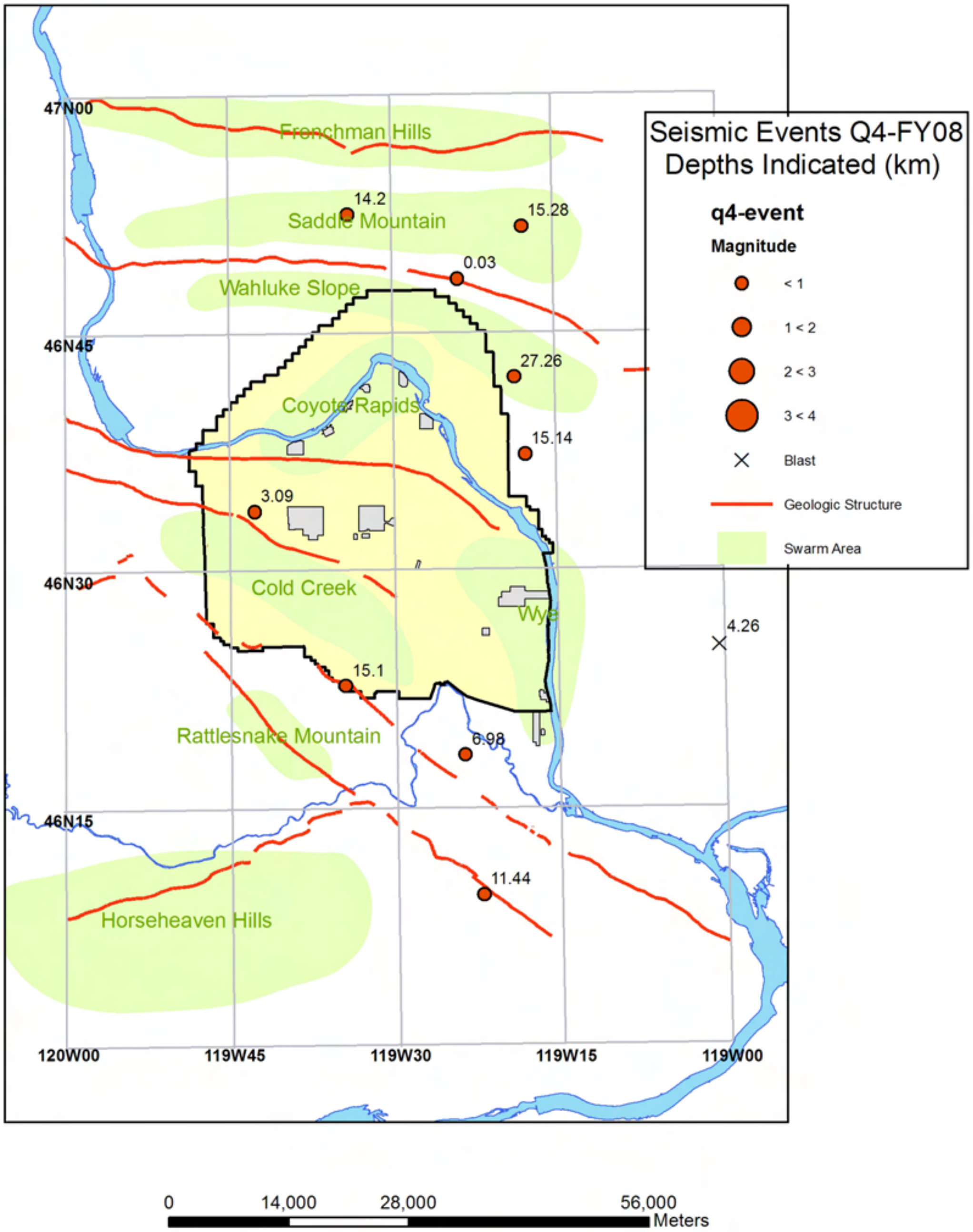


Figure 5.2. Earthquakes Occurring in the Hanford Monitoring Area Between July 1, 2008 and September 30, 2008 (fourth quarter)

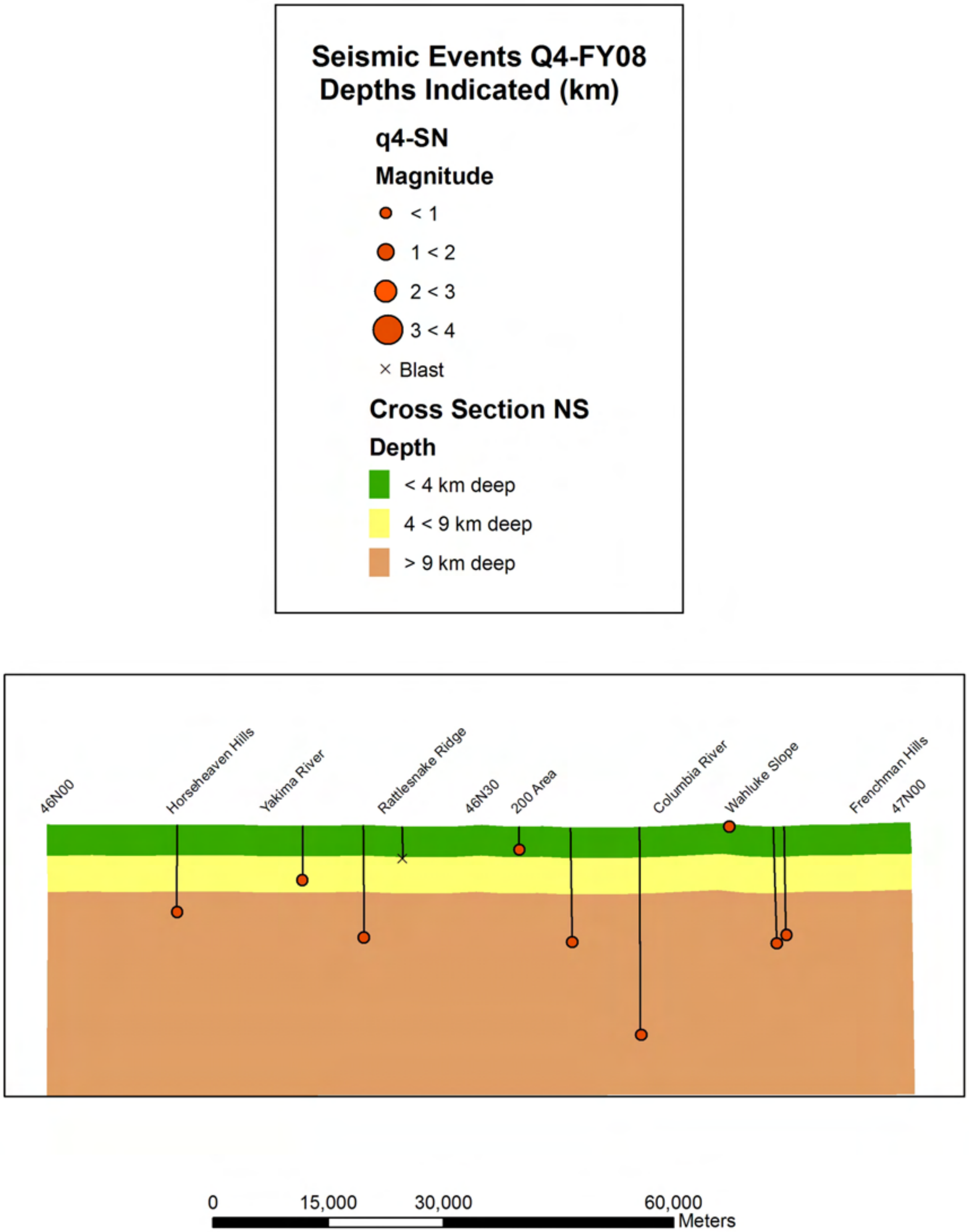


Figure 5.3. Cross-Sectional Depiction (along 119W30 longitude) of Earthquakes Occurring in the Hanford Monitoring Area between July 1, 2008 and September 30, 2008 (fourth quarter)

6.0 Strong Motion Accelerometer Operations

The Hanford SMA network has been in continuous operation since November 20, 1998. Initially, the threshold used in the SMA network was 0.1% g. In 2006, the trigger threshold was reduced to 0.02% g when new instruments with greater storage capacity were installed. The lower trigger threshold saves the ground motion recordings 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).

6.1 Fourth Quarter FY 2008 Triggers of the Hanford SMA Network

The Hanford SMA network was triggered by a 4.2 M_c seismic event that occurred on July 14, 2008, with epicenter located approximately 11.5 km southeast of Maupin, Oregon, at depth 17.4 km within the crystalline basement. This event, located outside of the Hanford monitoring window, showed a peak horizontal acceleration of 0.023% g (recorded at the 400 Area SMA, Figure 6.1), approximately 90 times lower that the reportable action level for Hanford facilities (2% g). No action was required.

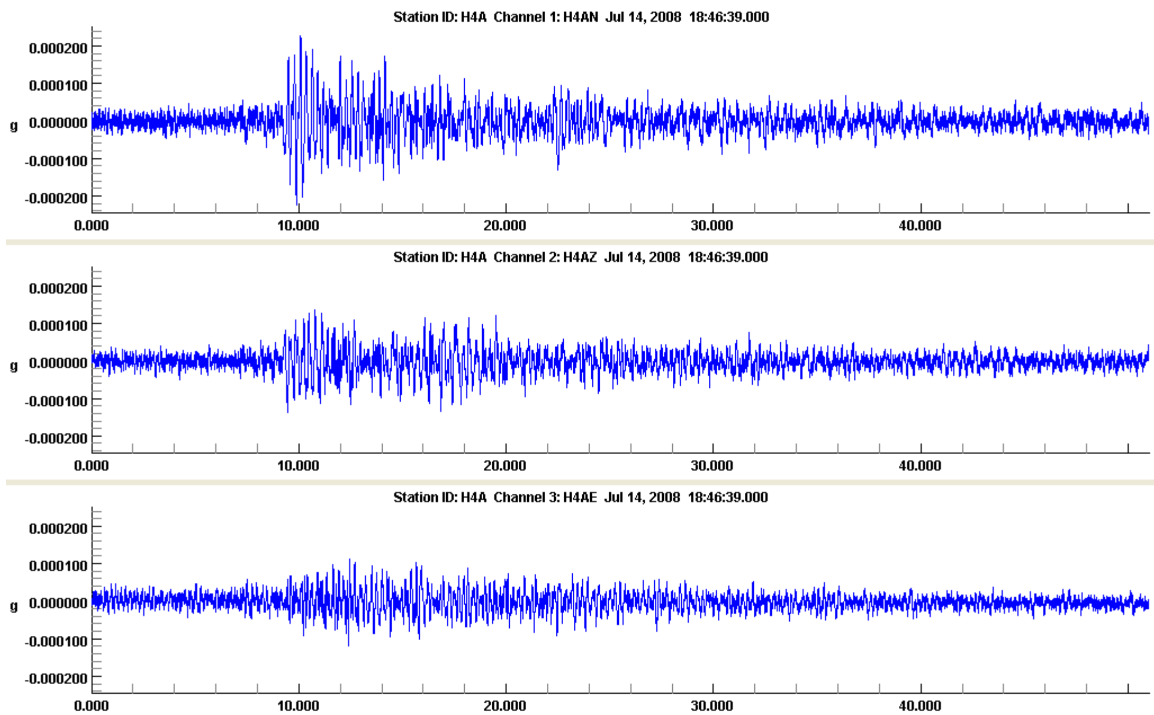


Figure 6.1. July 14, 2008 Acceleration Time Histories at 400 Area SMA from Maupin, Oregon, Earthquake

6.2 FY 2008 Triggers of the Hanford SMA Network

The Hanford SMA network was triggered by the 2.3 M_c seismic event that occurred on February 3, 2008. That event was recorded on the 300 Area and the 400 Area SMA units. At the 400 Area SMA station, which is located approximately 18 km from the epicenter of the event, the maximum horizontal and vertical accelerations were measured at 0.026% g (Figure 6.2). The reportable action level of 2% g for Hanford facilities is approximately 80 times larger than the peak accelerations observed at the 300 and 400 Areas and no action was required.

The Hanford SMA network was triggered by the 3.7 M_c seismic event that occurred on May 18, 2008. That event was recorded on the 200 East Area, 300 Area, and 400 Area SMA units. Data shown in Figure 6.3 was plotted from event files downloaded from the 300 Area SMA unit. The maximum acceleration recorded at the SMA stations (0.17% at 300 Area) was 12 times smaller than the reportable action level (2% g) for Hanford Site facilities. The Pacific Northwest Seismic Center produced a shake map for the May 18, 2008 event (Figure 6.4) that predicted "light" shaking and no damage on the Hanford Site. No reports of ground shaking or facility damage were received from Hanford Site personnel.

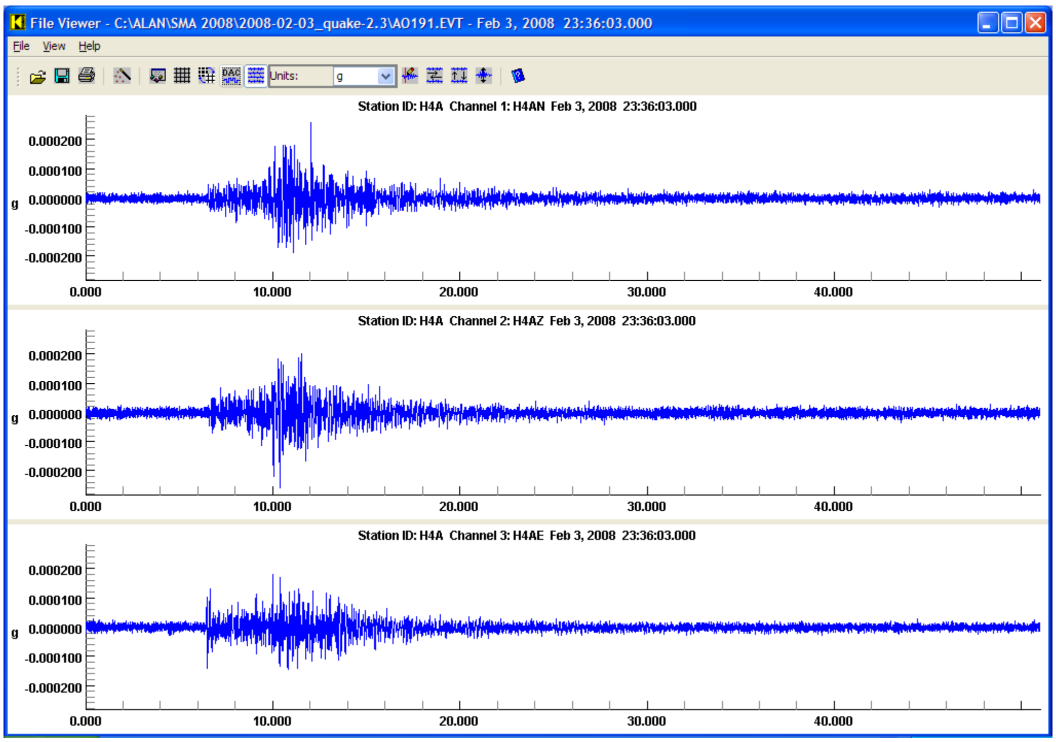


Figure 6.2. February 3, 2008 Micro Earthquake Acceleration Time Histories at 400 Area SMA

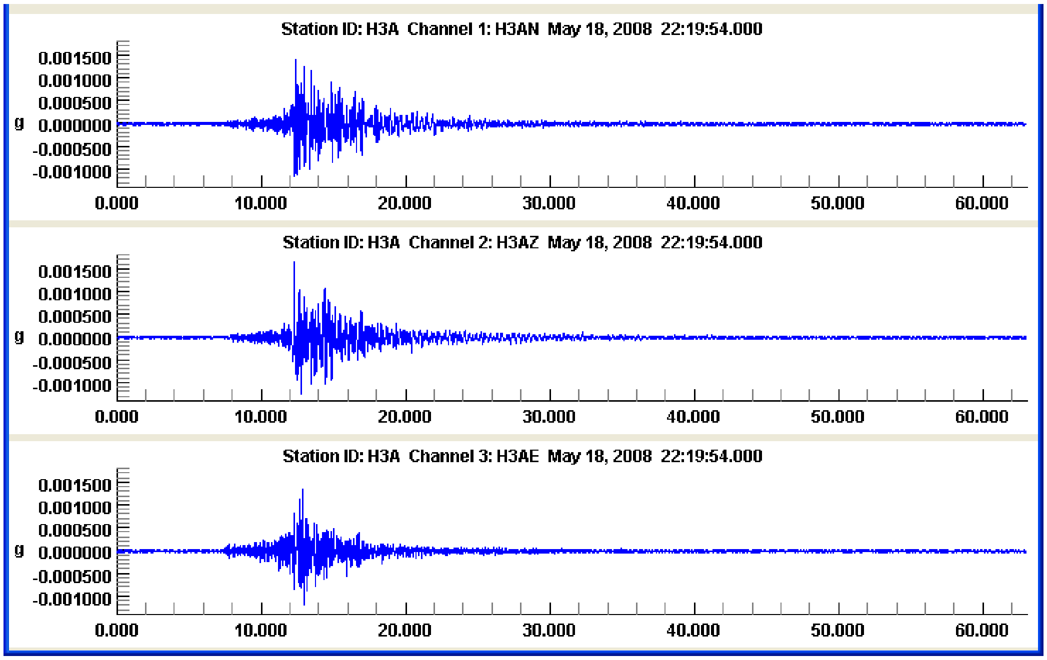
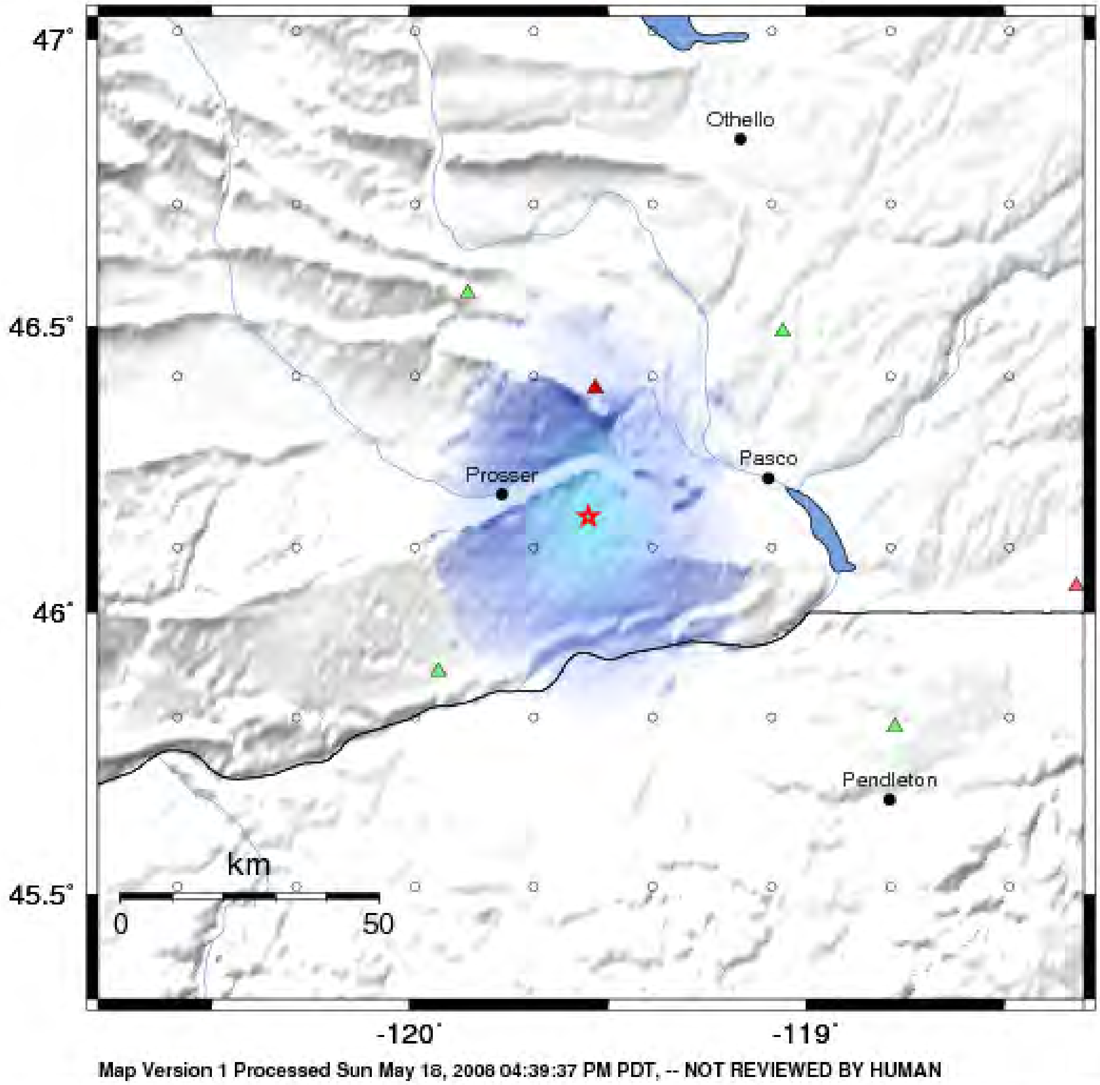


Figure 6.3. May 18, 2008 Micro Earthquake Acceleration Time Histories at 300 Area SMA



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Figure 6.4. Shake Map of May 18, 2008 Event (courtesy of Pacific Northwest Seismic Center)

7.0 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, to ensure that the Hanford Site is in compliance with DOE Order 420.1B, Chapter IV, Section 3.d, “Seismic Detection.” The network also allows the HSAP 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 HSAP in the event of an earthquake at Hanford.

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 current 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, and 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 requalification. 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 a major regional earthquake such as the 2001 Nisqually event, building managers, emergency directors, and engineers can obtain ground motion data recorded by the SMA network from the HSAP in the Sigma V Building. This is done through the Hanford Site Emergency Services organization. Normal hours of operation for the HSAP are between 6 a.m. and 4:30 p.m., Monday through Friday. If a SMA is triggered, the HSAP will download events that were recorded and determine the peak ground accelerations. This information is then passed on to Hanford Site 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.

8.0 References

Campbell NP. 1989. "Structural and Stratigraphic Interpretation of Rocks under the Yakima Fold Belt, Columbia Basin, Based on Recent Surface Mapping and Well Data." In *Volcanism and Tectonism in the Columbia River Flood-Basalt Province*, SP Reidel and PR Hooper (eds.), Special Paper 239, pp. 209–222. Geological Society of America, Boulder, Colorado.

Crosson RS. 1972. "Small Earthquakes, Structure and Tectonics of the Puget Sound Region." *Bulletin of the Seismological Society of America* 62(5):1133–1171.

DOE. 1988. *Site Characterization Plan for the Reference Location, Hanford, Washington – Consultation Draft*. DOE/RW-0164, Vol. 1, U.S. Department of Energy, Washington, D.C.

DOE Order 420.1B, Chapter IV, Section 3.d. "Seismic Detection." U.S. Department of Energy, Washington, D.C.

DOE Order G 420.1-1, Section 4.7. "Emergency Preparedness and Emergency Communications." U.S. Department of Energy, Washington, D.C.

Fenneman NM. 1931. *Physiography of Western United States*. McGraw-Hill Book Company, Inc., New York.

Geomatrix. 1996. *Probabilistic Seismic Hazard Analysis, DOE Hanford Site, Washington*. WHC-SD-W236A-TI-002, Rev. 1, Westinghouse Hanford Company, Richland, Washington.

Moore C and SP Reidel. 1996. *Hanford Site Seismic Monitoring Instrumentation Plan*. WHC-SD-GN-ER-30036, Westinghouse Hanford Company, Richland, Washington.

Reidel SP and KR Fecht. 1994a. *Geologic Map of the Richland 1:100,000 Quadrangle, Washington*. Open File Report 94-8, Division of Geology and Earth Resources, Washington State Department of Natural Resources, Olympia.

Reidel SP and KR Fecht. 1994b. *Geologic Map of the Priest Rapids 1:100,000 Quadrangle, Washington*. Open File Report 94-13, Division of Geology and Earth Resources, Washington State Department of Natural Resources, Olympia.

Reidel SP, NP Campbell, KR Fecht, and KA Lindsey. 1994. "Late Cenozoic Structure and Stratigraphy of South-Central Washington." In *Regional Geology of Washington State*, E Cheney and R Lasmanis (eds.), Bulletin 80, pp. 159-180. Division of Geology and Earth Resources, Washington State Department of Natural Resources, Olympia.

Reidel SP, KR Fecht, MC Hagood, and TL Tolan. 1989. "Geologic Development of the Central Columbia Plateau." In *Volcanism and Tectonism in the Columbia River Flood-Basalt Province*, SP Reidel and PR Hooper (eds.), Special Paper 239, pp. 247-264. Geological Society of America, Boulder, Colorado.

Richter CF. 1958. *Elementary Seismology*. W. H. Freeman & Company, San Francisco, California.

Rohay AC, DW Glover, and SD Malone. 1985. *Time-Term Analysis of Upper Crustal Structure in the Columbia Basin, Washington*. RHO-BW-SA-435 P, Rockwell Hanford Operations, Richland, Washington.

Rohay AC, MD Sweeney, DC Hartshorn, RE Clayton, and JL Devary. 2008a. *First Quarter Seismic Report for Fiscal Year 2008*. PNNL-17412, Pacific Northwest National Laboratory, Richland, Washington.

Rohay AC, MD Sweeney, DC Hartshorn, RE Clayton, and JL Devary. 2008b. *Second Quarter Seismic Report for Fiscal Year 2008*. PNNL-17654, Pacific Northwest National Laboratory, Richland, Washington.

Rohay AC, MD Sweeney, DC Hartshorn, RE Clayton, and JL Devary. 2008c. *Third Quarter Seismic Report for Fiscal Year 2008*. PNNL-17830, Pacific Northwest National Laboratory, Richland, Washington.

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