PNNL-11557-21

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

# First Quarter Hanford Seismic Report for Fiscal Year 2003

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

February 2003

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

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

PNNL-11557-21

# First Quarter Hanford Seismic Report for Fiscal Year 2003

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

February 2003

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

Pacific Northwest National Laboratory
Richland, Washington 99352

# Summary

Hanford Seismic Monitoring provides an uninterrupted collection of high-quality raw and processed seismic data from the Hanford Seismic Network 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 344 triggers during the first quarter of fiscal year 2003. Of these triggers, 171 were earthquakes.

Twenty-nine earthquakes were located in the Hanford Seismic Network area. Stratigraphically 6 occurred in the Columbia River basalt, 4 were earthquakes in the pre-basalt sediments, and 19 were earthquakes in the crystalline basement. Geographically, 6 earthquakes occurred in swarm areas, 1 earthquake was associated with a major structure, and 22 were random events.

The Denali, Alaska earthquake on November 3, 2002, triggered the Strong Motion Accelerometers at 100K and 200E. Accelerations of 0.12% to 0.14% g were recorded on the east-west component, barely above the trigger threshold of 0.10% g.

# 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 |

# Contents

# Figures



# Tables

# 1.0 Introduction

This report covers seismic activity on and near the Hanford Site for the first quarter of fiscal year (FY) 2003. The report includes earthquake activity that occurred between October 1, 2002 and December 31, 2002 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 insure 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 Applied Geology and Geochemistry Group, Environmental Technology Division.

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

## 1.3 Documentation and Reports

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

(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.

The HSN and the EWRN consist of 41 sensor sites. Most sites are in remote locations and require solar panels and batteries for power. The HSN uses 21 sites (Table 2.1 and Figure 2.1) and the EWRN uses

**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 |
| 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.

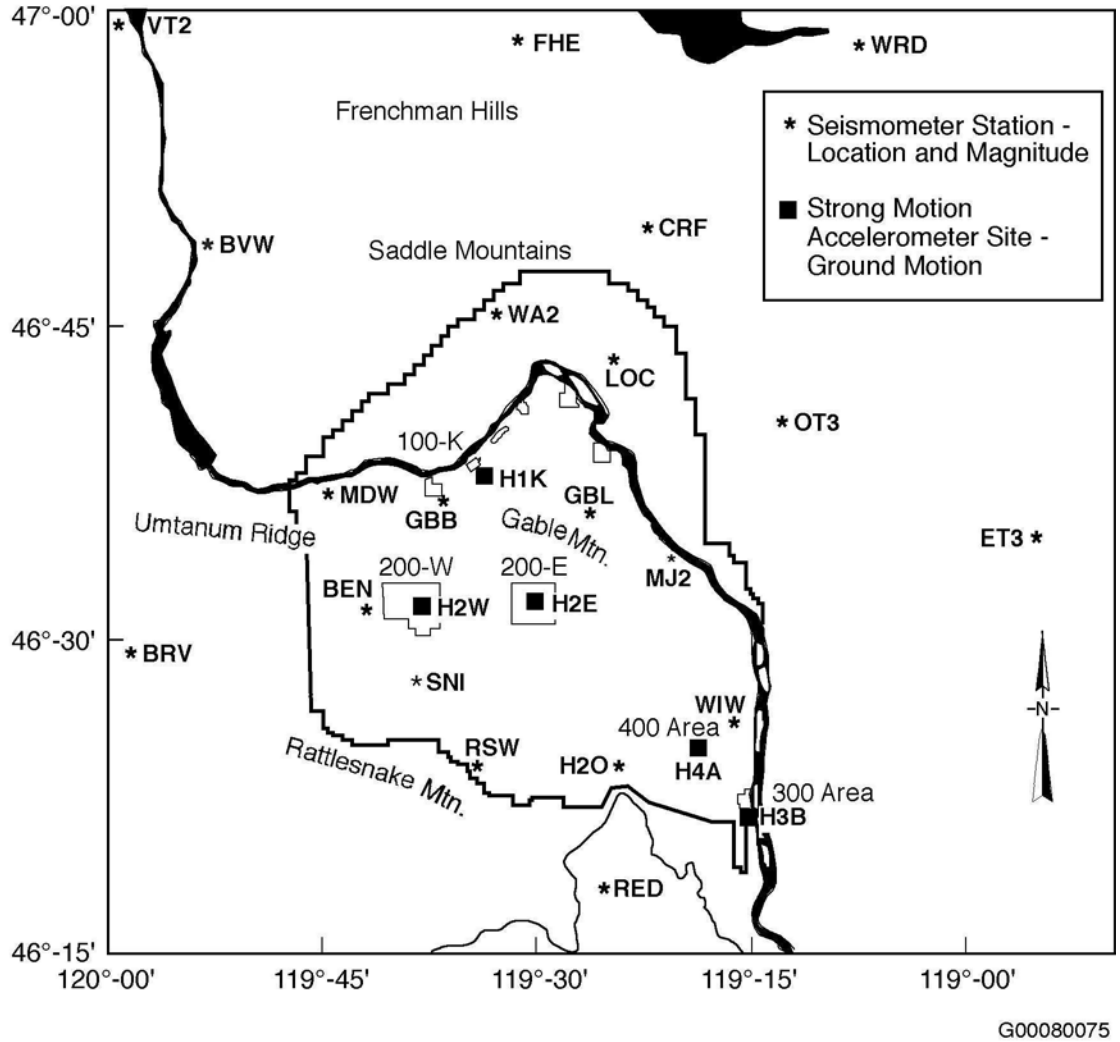


**Figure 2.1.** **Locations of Seismograph Stations and Strong Motion Accelerometer Sites in the Hanford Seismic Network (see Table 2.1 for description of locations). Locations for Prosser (PRO) and Yellepit (YPT) are not shown. See Figure 2.2 for the locations of those sites.**

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.

### 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.

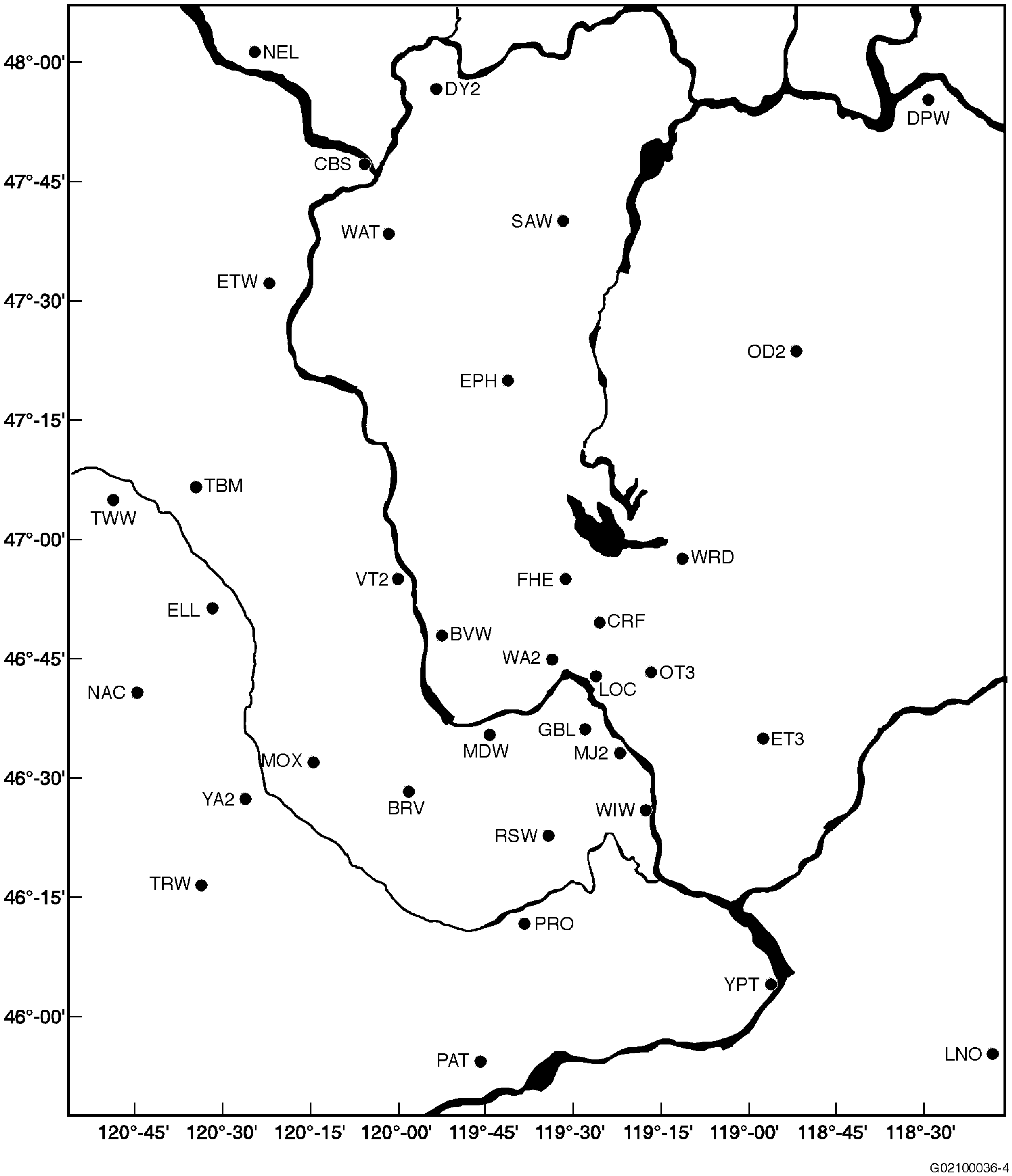


**Figure 2.2.** **Locations of Seismograph Stations in the Eastern Washington Regional Network (see Table 2.2 for location descriptions).**

### 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 in FY 2003 by the seismic acquisition system are summarized in Table 2.3.

## 2.2 Strong Motion Accelerometer Sites

### 2.2.1 Location

The Hanford SMA network consists of five free-field SMA sites (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.

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. The 100-K Area contains the K Basins where spent fuel rods from the N

**Table 2.3. Acquisition System Recorded Triggers**

| Event Type | First Quarter | Second Quarter | Third Quarter | Fourth Quarter | Total | Description |
|---|---|---|---|---|---|---|
| South-Central Washington | 46 | - | - | - | 46 | Seismic events in south-central Washington and north-central Oregon that triggered the HSN. |
| Regional | 44 | - | - | - | 44 | Seismic events in the Western United States and Canada. |
| Teleseism | 81 | - | - | - | 81 | Seismic events at farther distances from around the world. |
| Total Earthquake Events | 171 | - | - | - | 171 | Total number of earthquake triggers. |
| Total Triggers on Primary System | 342 | - | - | - | 342 | Total number of triggers examined. Includes all sources of triggers. |
| Local Explosions | 2 | - | - | - | 2 | Quarry blasts, typically, within the 46-47 degrees north latitude and 119-120 degrees west longitude. |
| Local Earthquakes | 29 | - | - | - | 29 | Seismic events within the 46-47 degrees north latitude and 119-120 degrees west longitude. |

**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’<br>119° 35.53’<br>152 m |
| 200 East Area | H2E | East of B Plant; north of 7th Street and east of Baltimore Avenue. | 46° 33.58’<br>119° 32.00’<br>210 m |
| 200 West Area | H2W | Northeast of Plutonium Finishing Plant (PFP); north of 19th street and east of Camden Avenue. | 46° 33.23’<br>119° 37.51’<br>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’<br>119° 16.55’<br>119 m |
| 400 Area | H4A | 500 feet from fence line on east side of facility and north of parking area). | 46° 26.13’<br>119° 21.30’<br>171 m |

Reactor are stored prior to encapsulation. The Cold Vacuum Drying Facility, located in the 100-K Area, is used to encapsulate spent fuel rods from the K Basins prior to shipment to the Canister Storage Building in 200 East Area.

### 2.2.2 Site Design

All free-field SMA sites consist of 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 the AT&T internet service. This CDPD system along with the solar 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 in the drums and outside 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 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.

**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 | 0.01% - 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.<br>(b) See Section 2.2.4 for discussion of trigger thresholds. | |

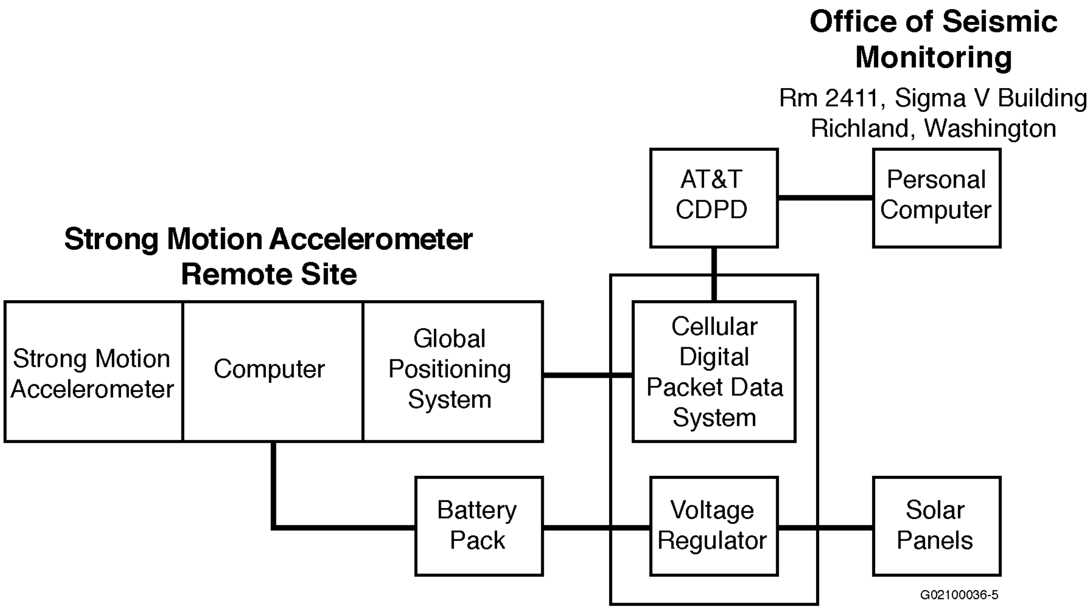


**Figure 2.3. Schematic Diagram of a Strong Motion Accelerometer Installation**

The CDPD system provides the internet address connection to access the system. Stations can be monitored from any computer, 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.

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 Monitoring Team.

### 2.2.4 Strong Motion Operational Characteristics

The signals from the three-accelerometer channels at each site are digitized with a 24-bit digitizer and temporarily stored in a memory buffer. The sampling rate of the digitizer is set to 200 samples/second. The three channels are monitored for signals that equal or exceed a programmable trigger threshold. When one accelerometer channel is triggered, the other channels automatically record. The nominal threshold used is 0.05% of the full-scale range of 2.0 g (g is the acceleration of gravity, 9.8 $m/s^2$ or

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

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.

# 3.0 Earthquake Catalog Description

Earthquake locations and magnitudes are determined by Seismic Monitoring Staff using an interactive program XPED developed at the University of Washington. 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 (46°-47° N, 119° -120° 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.

Coda-length magnitude

## 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, 2002 to December 31, 2002

| Event ID | Type | Date | Time | Latitude | Longitude | Depth | Mag | NS/NP | Gap | DMIN | RMS | Q | Location |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01101700254 | | 01/10/17 | 00:26:02.61 | 46N21.97 | 119W37.05 | 4.50 | 0.3 | 7/08 | 138 | 3 | 0.29 | BC | 21.2 km NNE of Prosser |
| 02100619012 | | 02/10/06 | 19:01:46.23 | 46N06.92 | 119W26.70 | 9.16 | 0.7 | 12/15 | 193 | 20 | 0.11 | AD | 22.1 km SSW of Richland |
| 02100619322 | | 02/10/06 | 19:32:42.27 | 46N07.43 | 119W26.63 | 7.55 | 0.6 | 7/11 | 316 | 19 | 0.10 | BD | 21.3 km SSW of Richland |
| 02100803071 | | 02/10/08 | 03:07:41.10 | 46N18.67 | 119W32.30 | 7.98 | 0.7 | 14/14 | 124 | 7 | 0.09 | AB | 19.3 km W of Richland |
| 02101205244 | | 02/10/12 | 05:25:06.45 | 46N50.60 | 119W44.22 | 3.49 | 1.5 | 20/21 | 70 | 11 | 0.13 | AC | 22.7 km SE of Vantage |
| 02102210321 | | 02/10/22 | 10:32:33.39 | 46N50.71 | 119W47.35 | 2.42 | 2.7 | 39/40 | 43 | 8 | 0.17 | BB | 19.4 km SE of Vantage |
| 02102806211 | | 02/10/28 | 06:21:41.82 | 46N23.02 | 119W35.24 | 18.17 | 0.4 | 14/14 | 196 | 1 | 0.07 | AD | 18.5 km WSW of 400 Area |
| 02103013381 | | 02/10/30 | 13:38:36.14 | 46N36.49 | 119W46.90 | 8.45 | 0.0 | 14/16 | 111 | 1 | 0.09 | AB | 12.4 km WNW of 200 West |
| 02103101295 | | 02/10/31 | 01:30:16.57 | 46N50.28 | 119W19.78 | 2.65 | 0.5 | 16/16 | 90 | 4 | 0.07 | AA | 12.5 km W of Othello |
| 02103120351 | | 02/10/31 | 20:35:41.98 | 46N43.69 | 119W31.04 | 0.02 | -0.1 | 9/10 | 73 | 4 | 0.13 | AA | 11.4 km NNE of 100-K Area |
| 02110323592 | | 02/11/03 | 23:59:49.84 | 46N47.34 | 119W10.63 | 14.87 | 1.3 | 30/41 | 113 | 14 | 0.13 | AB | 4.3 km S of Othello |
| 02110403334 | | 02/11/04 | 03:34:02.26 | 46N14.69 | 119W01.00 | 12.69 | 0.3 | 12/17 | 159 | 22 | 0.17 | BC | 6.3 km E of Pasco |
| 02110407344 | | 02/11/04 | 07:35:06.62 | 46N27.32 | 119W34.89 | 15.86 | -0.1 | 10/14 | 92 | 6 | 0.05 | AB | 12.2 km SSW of 200 East |
| 02110413204 | | 02/11/04 | 13:21:08.05 | 46N40.55 | 119W34.98 | 13.20 | 0.4 | 13/16 | 65 | 8 | 0.08 | AA | 3.9 km NNE of 100-K Area |
| 02110504052 | | 02/11/05 | 04:05:53.58 | 46N27.17 | 119W36.81 | 15.00 | 0.6 | 13/15 | 111 | 3 | 0.06 | AB | 11.8 km S of 200 West |
| 02110612274 | | 02/11/06 | 12:28:05.14 | 46N33.04 | 119W13.83 | 16.23 | 0.3 | 13/18 | 150 | 9 | 0.08 | AC | 16.2 km NE of 400 Area |
| 02110800555 | | 02/11/08 | 00:56:19.55 | 46N40.73 | 119W38.26 | 15.84 | -0.2 | 16/20 | 61 | 7 | 0.11 | AA | 5.1 km NW of 100-K Area |
| 02110920575 | | 02/11/09 | 20:58:11.00 | 46N33.75 | 119W35.26 | 24.08 | 0.3 | 14/18 | 65 | 5 | 0.07 | AA | 3.9 km E of 200 West |
| 02111001232 | | 02/11/10 | 01:23:44.41 | 46N50.06 | 119W33.54 | 14.68 | 0.2 | 11/14 | 130 | 8 | 0.11 | AB | 21.6 km N of 100-K Area |
| 02111023574 | | 02/11/10 | 23:58:05.92 | 46N51.91 | 119W25.36 | 18.98 | 0.4 | 14/16 | 107 | 5 | 0.14 | AB | 20.0 km WNW of Othello |
| 02111609344 | | 02/11/16 | 09:35:06.62 | 46N50.24 | 119W33.07 | 15.94 | 1.4 | 32/36 | 31 | 9 | 0.13 | AA | 22.0 km N of 100-K Area |
| 02112004435 | | 02/11/20 | 04:44:22.18 | 46N36.66 | 119W46.10 | 16.08 | 0.1 | 6/11 | 269 | 0 | 0.06 | AD | 11.6 km WNW of 200 West |
| 02112004482 | | 02/11/20 | 04:48:43.71 | 46N36.91 | 119W46.32 | 17.06 | 0.0 | 7/10 | 180 | 0 | 0.06 | AC | 12.1 km WNW of 200 West |
| 02120205272 | | 02/12/02 | 05:27:49.61 | 46N34.67 | 119W42.44 | 14.37 | -0.2 | 3/05 | 127 | 5 | 0.04 | AD | 5.8 km WNW of 200 West |
| 02120622321 | X | 02/12/06 | 22:32:38.39 | 46N10.11 | 119W28.62 | 0.63 | | 9/09 | 260 | 14 | 0.11 | BD | 19.2 km SW of Richland |

**Table 3.2 (contd.)**

| Event ID | Type | Date | Time | Latitude | Longitude | Depth | Mag | NS/NP | Gap | DMIN | RMS | Q | Location |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 02121417035 | | 02/12/14 | 17:04:20.95 | 46N20.29 | 119W32.89 | 16.58 | 0.6 | 15/16 | 99 | 6 | 0.07 | AB | 18.2 km SW of 400 Area |
| 02122206575 | | 02/12/22 | 06:58:16.19 | 46N22.93 | 119W02.73 | 4.85 | 0.3 | 6/09 | 149 | 19 | 0.17 | BC | 16.8 km NNE of Pasco |
| 02122211403 | | 02/12/22 | 11:40:50.99 | 46N19.32 | 119W30.02 | 4.09 | 0.6 | 8/10 | 110 | 5 | 0.76 | DB | 16.6 km WNW of Richland |
| 02122211412 | | 02/12/22 | 11:41:28.31 | 46N16.17 | 119W28.04 | 10.95 | 0.6 | 10/16 | 287 | 3 | 0.14 | AD | 13.6 km W of Richland |
| 02122211542 | | 02/12/22 | 11:54:39.64 | 46N15.72 | 119W28.27 | 10.60 | 0.3 | 8/13 | 289 | 4 | 0.04 | AD | 14.0 km W of Richland |
| 02122911410 | | 02/12/29 | 11:41:22.66 | 46N43.48 | 119W04.92 | 10.83 | 1.3 | 8/19 | 124 | 13 | 0.08 | AB | 13.1 km SSE of Othello |
| 02123022330 | X | 02/12/30 | 22:33:31.16 | 46N16.10 | 119W23.66 | 0.02 | | 13/13 | 229 | 4 | 0.10 | AD | 8.1 km WSW of Richland |

**Explanation of Table 3.2**

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

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

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

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

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

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

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

**Mag:** The magnitude is expressed as Coda-Length magnitude $M_c$, an estimate of local magnitude $M_L$ (Richter 1958). If magnitude is blank 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 and east-west 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 2 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

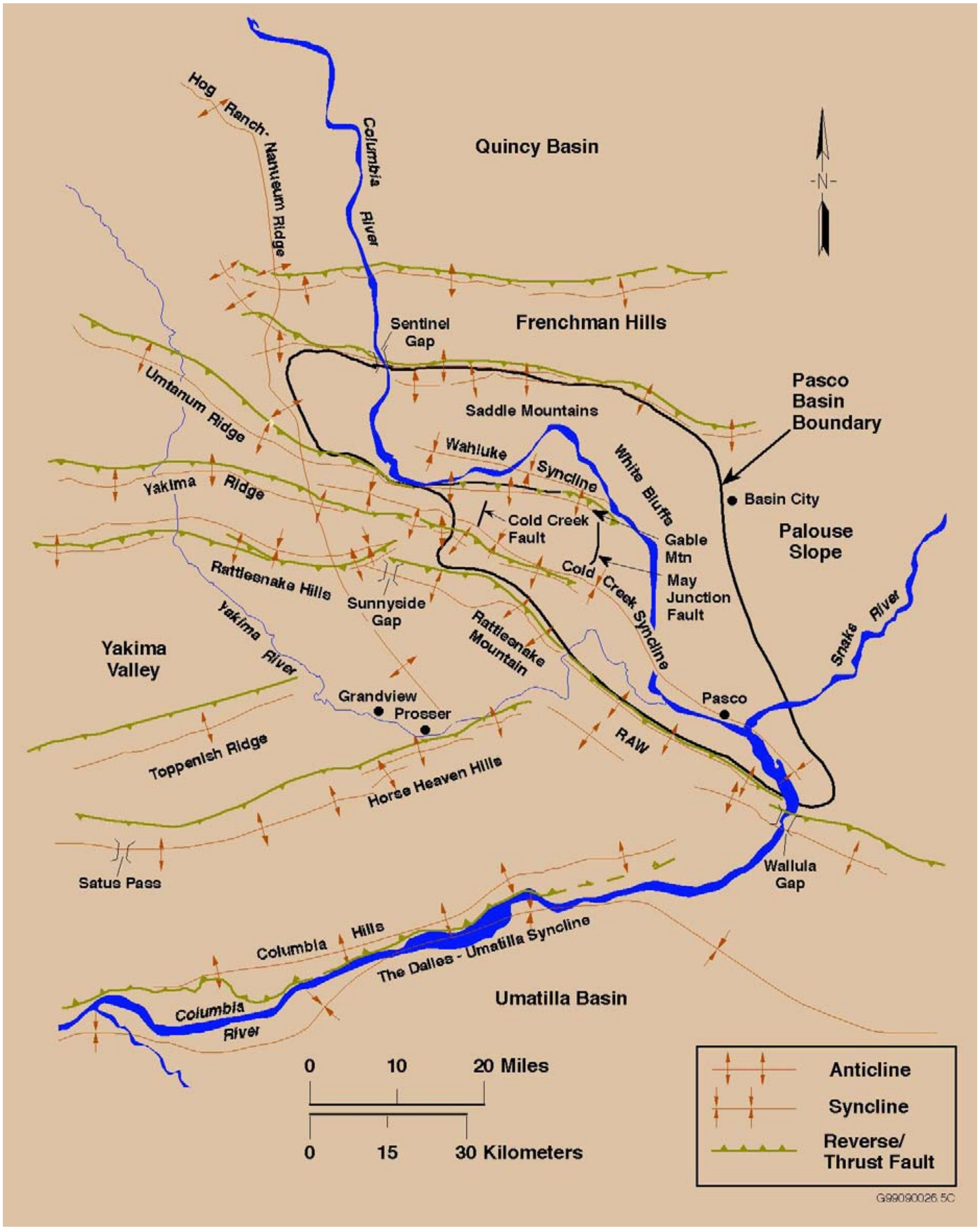


**Figure 4.1. Tectonic Map of Columbia Basin Showing Major Seismic Source Structures**

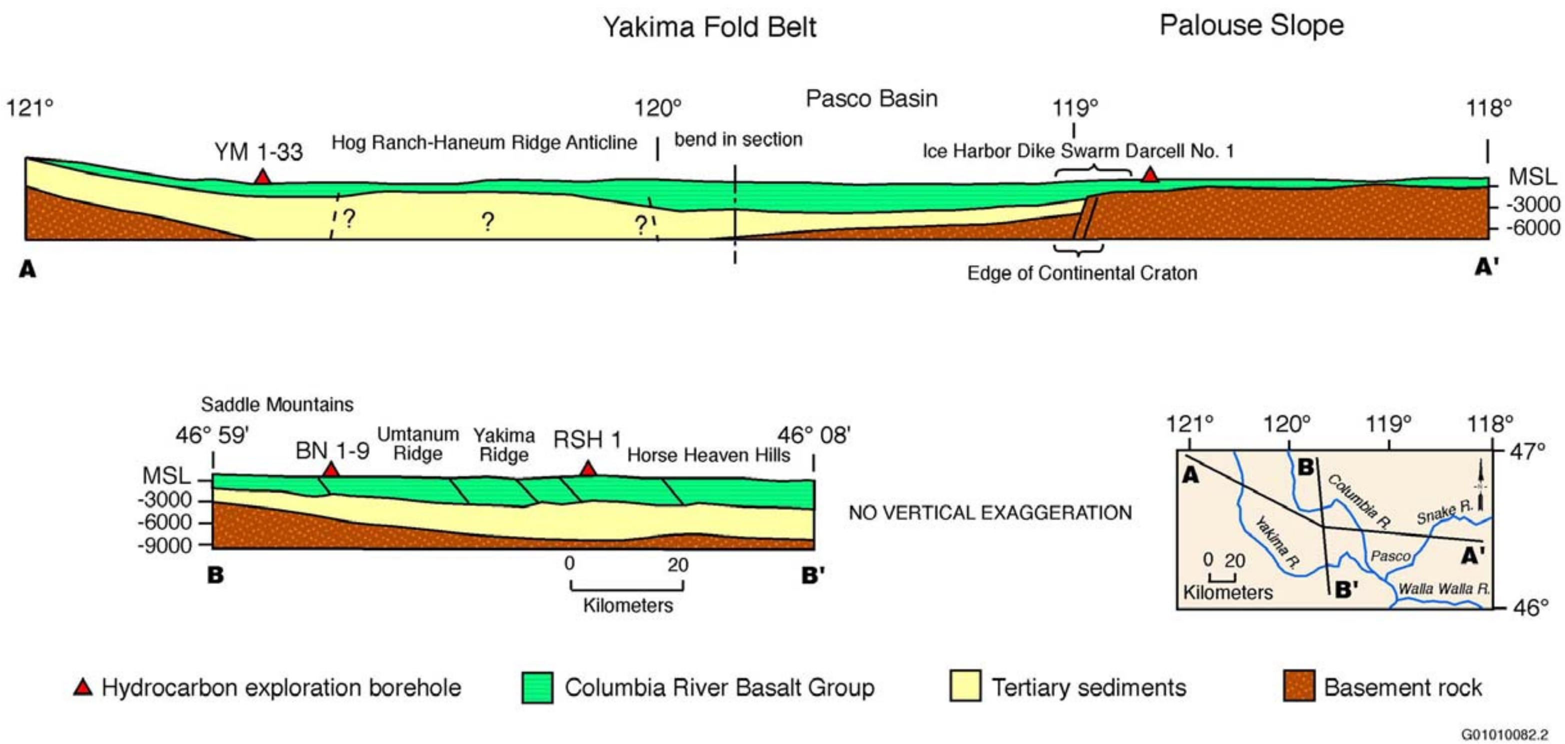


**Figure 4.2. Geologic Cross Sections Through the Columbia Basin (Reidel et al. 1994)**

**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 |

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 Figure 4.2 and was developed for the geologic interpretation in this report. The thicknesses of these units are variable across the monitored area. Table 4.1 summarizes the approximate thickness at the borders of the monitored area.

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

## 4.3 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 and small faults 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 Columbia River Basalt Group. 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 we recognize in the monitoring area (Figure 4.3) but this list will be updated as new swarm areas develop. The Saddle Mountains Swarm Area, Wooded Island Swarm Area, Coyote Rapids 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.

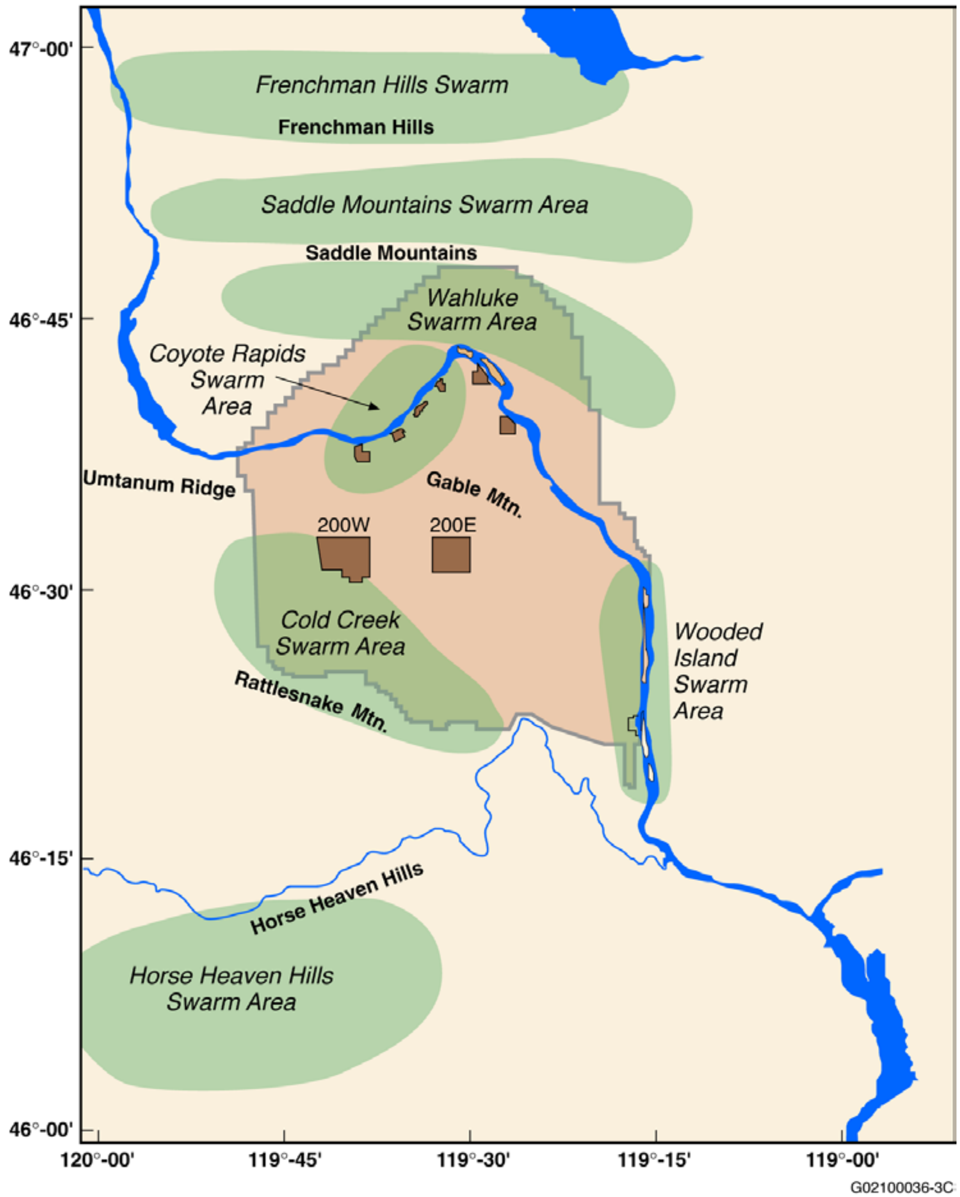


**Figure 4.3. Locations of Known Earthquake Swarm Areas in the Hanford Monitoring Network Area**

- **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 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 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 quarter of FY 2003 are listed in Table 4.2.

## 4.5 Tectonic Activity

### 4.5.1 First Quarter Summary

Twenty-nine earthquakes occurred in the Hanford monitoring area during the first quarter of FY 2003 (October 1, 2002 through December 2003) (Table 4.3) (Figure 4.4). This section summarizes the earthquake activity for the first quarter of the fiscal year. 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 2002 |
|---|---|---|---|---|---|
| Basalt | 6 | - | - | - | 6 (20.7%) |
| Pre-basalt Sediments | 4 | - | - | - | 4 (13.8%) |
| Crystalline Basement | 19 | - | - | - | 19 (65.5%) |
| Total | 29 | - | - | - | 29 |

**Table 4.3. Summary of Earthquake Locations for FY 2002**

| Seismic Sources | | First Quarter 10/01- 12/30 | Second Quarter 1/01 - 3/31 | Third Quarter 4/01 - 6/30 | Fourth Quarter 7/01 - 9/30 | FY 2002 |
|---|---|---|---|---|---|---|
| Geologic Structure | | 1 | - | - | - | 1 (3.4%) |
| Swarm Areas | Saddle Mountains/ Royal Slope | 3 | - | - | - | 3 (10.4%) |
| | Coyote Rapids | 1 | - | - | - | 1 (3.4%) |
| | Wooded Island | 0 | - | - | - | 0 |
| | Wahluke Slope | 0 | - | - | - | 0 |
| | Cold Creek | 0 | - | - | - | 0 |
| | Horse Heaven Hills | 2 | - | - | - | 2 (7.0%) |
| | Total for swarms | 6 | - | - | - | 6 (20.8%) |
| Random Events | | 22 | - | - | - | 22 (75.8%) |
| Total for all earthquakes | | 29 | - | - | - | 29 |

#### 4.5.1.1 Depth of Earthquakes

During the first quarter of FY 2003, 21% of the earthquakes occurred in the Columbia River Basalt Group, 14% of the earthquakes occurred in the underlying pre-basalt sediments, and 65% of the earthquakes occurred in the crystalline basement. Typically, more earthquakes occur in the basalt but earthquakes in the crystalline basement dominated this quarter.

#### 4.5.1.2 Location of Earthquakes

During the first quarter of FY 2003, six events (21% of the earthquakes) were classified as swarm events. The Saddle Mountains, Coyote Rapids and Horse Heaven Hills swarm areas were active.

Only one event was classified as having some association with major geologic structure. This earthquake occurred in the basalt along the Rattlesnake-Wallula structural trend (RAW Figure 4.1).

Twenty-two events (76% of the earthquakes) were classified as random events. 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. During the first quarter, nineteen random events occurred in the crystalline basement. One random event occurred in the basalt and two random events occurred in the pre-basalt sediments.

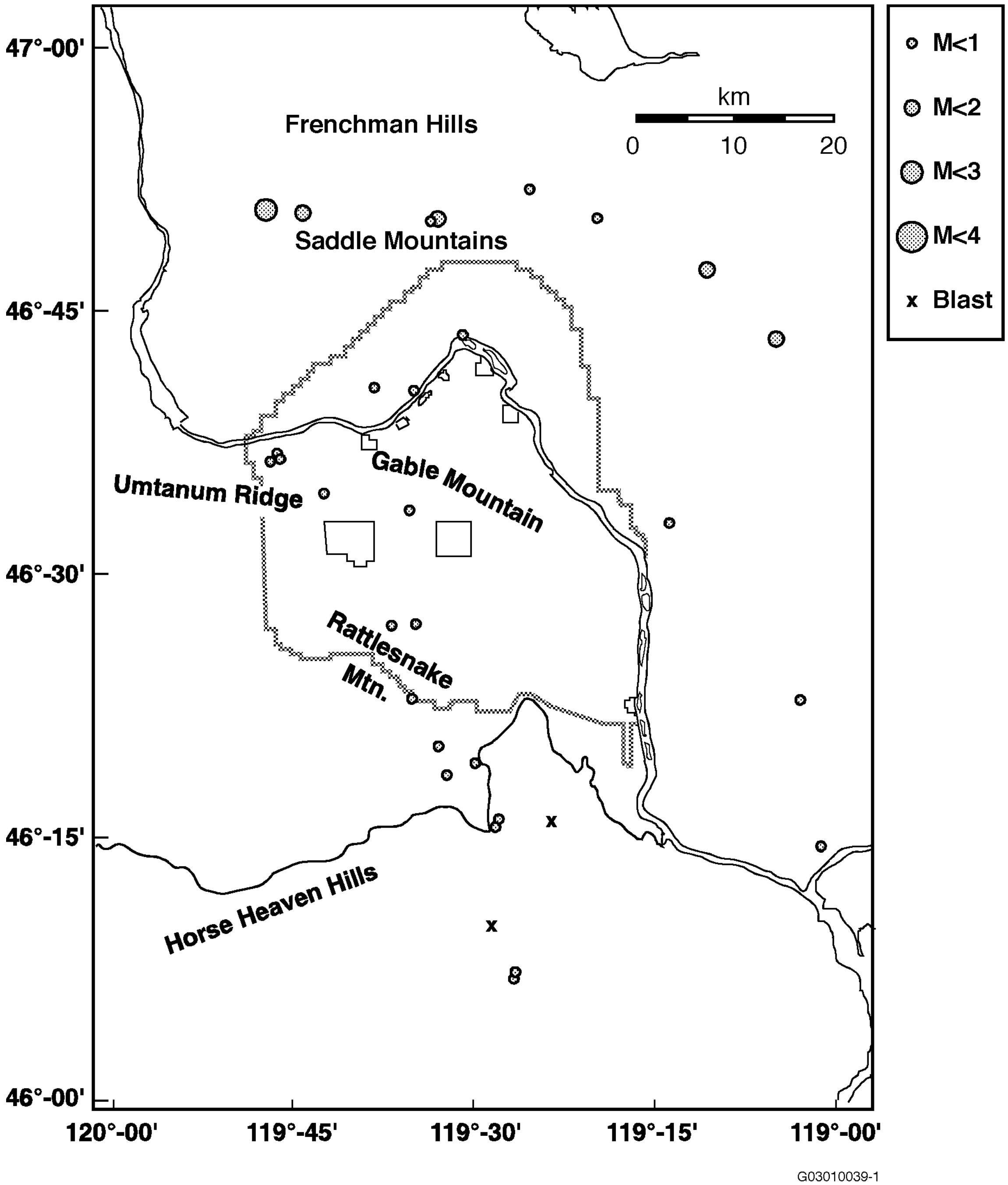


**Figure 4.4. All Earthquakes Recorded in the Hanford Monitoring Area Between October 1, 2002 and December 31, 2002 (Coda Length Magnitude ($M_c$) scale is shown at the side of the map)**

## 4.5.2 First Quarter Earthquakes of FY 2002

### 4.5.2.1 Major Anticlinal Ridges

During the first quarter of FY 2003, we interpret one seismic event to have occurred on a major geologic structure. On December 22nd, a small (>1.0 $M_c$), shallow earthquake occurred along the Rattlesnake-Wallula structural trend (RAW Figure 4.1) between Red Mountain and Rattlesnake Mountain. This event occurred in the CRBG and was near the plunging nose of the Rattlesnake Mountain anticline

### 4.5.2.2 Earthquake Swarm Areas

During the first quarter of FY 2003, we interpret 6 seismic events to have occurred in swarm areas (Figure 4.4). The Saddle Mountains, Coyote Rapids and Horse heaven Hills swarm areas were active. The other swarm areas were not active.

#### 4.5.2.2.1 Saddle Mountains Swarm Area

During the first quarter of FY 2003, three events occurred in the Saddle Mountains swarm area (Figure 4.4). Two of the events occurred on the north side of the Saddle Mountains just east of the Columbia River in the Sentinel Bluffs segment. One event occurred on October 12th and had a magnitude of 1.6 $M_c$. The second event occurred on October 22nd and had a magnitude of 2.7 $M_c$. A 1.6 $M_c$ event occurred at the same location in FY 2002. The third event was small (0.5 $M_c$) and occurred 12 km west of Othello. All events occurred in the basalt.

#### 4.5.2.2.2 Coyote Rapids Swarm Area

One event occurred in the northern part of the Coyote Rapids swarm near the horn of the Columbia River. This event was small (0 $M_c$) and occurred in the basalt.

#### 4.5.2.2.3 Horse Heaven Hills Swarm Area

Two small (>1.0 $M_c$) events occurred at the east end of the Horse Heaven Hills swarm area south of Benton City. Both events occurred on October 6th and were in the pre-basalt sediments. This area experienced earthquakes at the same location and at the same depths in FY 2002.

### 4.5.2.3 Random or Floating Events

During the first quarter of FY 2003, we interpret twenty-two random events to have occurred. One was in the basalt, two were in pre-basalt sediments and nineteen were in the crystalline basement. Events that occurred in the pre-basalt sediments and in the crystalline basement are typically classified as random events 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 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 (4.5.2.1.).

The first random event for FY 2003 (October 8th) occurred on the south slope of Rattlesnake Mountain in the pre-basalt sediments. It was a small event (0.7 $M_c$) that occurred 1 km south of the anticlinal crest. On October 28th another small event (0.4 $M_c$) occurred about 8 km northwest of the first event along the same structural trend. This event, however, was in the crystalline basement (18 km).

Three very small (approximately 0.0 $M_c$) random events occurred west of the Hanford Site in a tight cluster below the crest of Umtanum Ridge. The first event occurred on October 30th and the other two events occurred on November 20th. The October 30th event was in the pre-basalt sediments and the last two were in the crystalline basement. If in the future additional events occur at this location, this area could be classified as a new swarm area.

Three random events occurred in the crystalline basement north of the Saddle Mountains. The events occurred on November 3rd (1.3 $M_c$), November 10th (0.4 $M_c$), and December 22nd (1.3 $M_c$). All events occurred about 4-5 km north of the main Saddle Mountains fault.

On November 4th, a random event having a magnitude 0.3 Mc occurred on the eastern edge of the Hanford monitoring area near the confluence of the Snake and Columbia rivers. This event occurred in the crystalline basement and is not near any known geologic structure. It did occur near the feeder dike system for the 8.5 Ma Ice Harbor Member of the Columbia River Basalt Group. These feeder dikes erupted along fracture systems in the bedrock.

On November 4th and November 5th respectively, two small (>1 $M_c$) events occurred beneath the Benson Ranch syncline north of Rattlesnake Mountain. Both events were in the crystalline basement.

On November 4th and on November 8th respectively, two small events (>0.5 $M_c$) occurred in the crystalline basement below the Coyote Rapids earthquake swarm area. These are considered to be random events because of their great depth.

A small earthquake (0.3 $M_c$) occurred in the crystalline basement near the mouth of Ringold Coulee. This event occurred near the northern end of the Wooded Island swarm area but because of its great depth, it is classified as a random event.

On November 9th a small (0.3 $M_c$) event occurred in the crystalline basement between the 200-East area and 200-West area. This was a very deep earthquake (24 km) and is classified as a random event because no known geologic structure has been identified there.

Two events occurred at the same location north of the Smyrna Bench segment of the Saddle Mountains within five days of each other. Both events were in the crystalline basement. The first was small (0.2 $M_c$) event on November 11th and the second event was November 16th and had a magnitude of 1.4 $M_c$. This same small area has had repeated events of the past several years that have occurred below the basalt. Events occurred here on April 18, 1999 (0.9 $M_c$; 15.6 km), May 27, 1999 (1.5 $M_c$; 7.8 km), February 8, 2002 (0.0 $M_c$; 15.1 km), and August 22, 2002 (0.0 $M_c$; 14.3 km). This area lies within the Saddle Mountains swarm area, however, most of the earthquakes in that swarm are in the basalt.

The first event for the month of December occurred on the 2nd and was located just northwest of the 200-West Area. It occurred in the crystalline basement and was very small (0.0 $M_c$).

On December 6th a random event occurred in the crystalline basement on the south slope of Rattlesnake Mountain near the random event of October 28th and near the small basalt earthquake along Rattlesnake Mountain structure that occurred on December 22nd. Like the random event of October 28th, this earthquake was small (0.6 $M_c$) and occurred in the crystalline basement.

Five earthquakes occurred on December 22nd; four were random and one occurred along Rattlesnake Mountain structure (Section 4.5.2.1). The first random event was shallow (4.8 km) and occurred 17 km northeast of Pasco in the Palouse Slope subprovince of the Columbia Basin. The event was small (0.3 $M_c$) and even though the earthquake occurred in the basalt it is classified as random because it is not near any known geologic structure. The next random event was small (0.6 $M_c$) and occurred in the crystalline basement on the south flank of Red Mountain, the next anticlinal ridge southeast of the Rattlesnake Mountain structure. The next earthquake occurred 2 km southwest of the previous one and was also in the crystalline basement. This event was small (0.3 $M_c$) and located near the bend in the Yakima River at Benton City. The last event of December 22nd was also the last event of the quarter. It occurred in the crystalline basement beneath the eastern most segment of the Saddle Mountains, the Eagle Lakes segment. This event was in the crystalline basement and had a magnitude of 1.4 $M_c$.

# 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 Quarter of FY 2003 Triggers of the Hanford SMA Network

A large earthquake in central Alaska triggered the SMA at 100K and 200E on November 3, 2002. Our sensors at the Hanford Site first detected the initial motions at 14:17:49, and the strong motion accelerometers triggered at 14:25:27.4 (100K area) and 14:25:30.5 (200E area). The trigger was the result of low-frequency, east-west, motion with a peak acceleration of 0.12% to 0.14% g. These two accelerometers are set to trigger on any single channel if the motion exceeds 0.10% g. The motion was dominantly 2-3 cycles of an east-west long-period (15 second period) motion from surface waves. The Denali earthquake had a magnitude of 7.9, was located at 63.52 N, 147.53W at a depth of 5.0 km.

# 6.0 Capabilities in the Event of a Significant Earthquake

The SMA network was designed to provide ground motion in areas at the Hanford Site that have high densities of people and/or 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 buildings 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 typically 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.

# 7.0 References

Campbell, N. P. 1989. "Structural and stratigraphic interpretation of rocks under the Yakima fold belt, Columbia Basin, based on recent surface mapping and well data." In S. P. Reidel and P. R. Hooper (eds.), *Volcanism and Tectonism in the Columbia River Flood-Basalt Province Geological Society of America Special Paper 239*, pp. 209-222.

Crosson, R. S. 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*. Report DOE/RW-0164, Vol. 1, U.S. Department of Energy, Washington, D.C.

Fenneman, N. M. 1931. *Physiography of western United States*. McGraw-Hill, 534 p.

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 S. P. Reidel. 1996. *Hanford Site Seismic Monitoring Instrumentation Plan*. WHC-SD-GN-ER-30036, Westinghouse Hanford Company, Richland, Washington.

Reidel, S. P. and K. R. Fecht. 1994a. *Geologic Map of the Richland 1:100,000 Quadrangle, Washington*. Washington Division of Geology and Earth Resources Open File Report 94-8, 21 p., 1 plate.

Reidel, S. P. and K. R. Fecht. 1994b. *Geologic Map of the Priest Rapids 1:100,000 Quadrangle, Washington*. Washington Division of Geology and Earth Resources Open File Report 94-13, 22 p., 1 plate.

Reidel, S. P. and P. R. Hooper (eds.). 1989. *Volcanism and Tectonism in the Columbia River Flood-Basalt Province Geological Society of America Special Paper 239*, 386 p.

Reidel, S. P., N. P. Campbell, K. R. Fecht, and K. A. Lindsey. 1994. "Late Cenozoic Structure and Stratigraphy of South-Central Washington." In E. Cheney and R. Lasmanis (eds.), *Regional Geology of Washington State, Washington Division of Geology and Earth Resources Bulletin 80*, pp. 159-180, Olympia, Washington.

Reidel, S. P., K. R. Fecht, M. C. Hagood, and T. L. Tolan. 1989. "Geologic Development of the Central Columbia Plateau." In S. P. Reidel and P. R. Hooper (eds.), *Volcanism and Tectonism in the Columbia River Flood-Basalt Province Geological Society of America Special Paper 239*, pp. 247-264.

Richter, C. F. 1958. *Elementary Seismology*, W. H. Freeman and Company, p. 768.

Rohay, A. C., D. W. Glover, and S. D. Malone. 1985. *Time-Term Analysis of Upper Crustal Structure in the Columbia Basin, Washington*. RHO-BW-SA-435 P, Rockwell Hanford Operations, Richland, Washington.

# Distribution

**No. of**
**Copies**

**OFFSITE**

G. Crawford
Earthquake Program Manager
Washington Emergency Management Division
Building 20, M/S: TA-20
Camp Murray, WA 98430-5122

Jeffery Kimball
NA-53/Germantown Building
U.S. Department of Energy
1000 Independence Ave. SW
Washington, D.C. 20585-1290

S. Lilligren
Nez Perce Tribe
P.O. Box 365
Lapwai, ID 83540

J. Litehiser
Bechtel National, Inc.
P.O. Box 193965
San Francisco, CA 94119-3965

T. L. Nielsen
Kennewick General Hospital
P.O. Box 6128
Kennewick, WA 99336

Paul Rizzo
105 Mall Boulevard
Monroeville, PA 15146

**No. of**
**Copies**

3 Oregon Department of Geology and Mineral Industries
Suite 965, 800 NE Oregon Street #28
Portland, OR 97232
ATTN: J. Beaulieu
Library
I. Madin

N. Rasmussen
3140 Ravenshoe Drive
Las Vegas, NV 89134

W. Riggsby
1216 W. Kennewick Avenue
Kennewick, WA 99336

M. Stickney
Montana Tech University
Earthquake Studies Office
Butte, MT 59701

A. Tallman
1940 Quail Court
West Richland, WA 99353

5 University of Washington
Geophysics Program
P.O. Box 351650
Seattle, WA 98195-1650
ATTN: R. Crosson
R. Ludwin
S. Malone
A. Qamar
R. Steele

| No. of Copies | |
|---|---|
| 2 | University of Washington<br>U.S. Geological Survey<br>P.O. Box 351650<br>Seattle, WA 98195<br>ATTN: C. Weaver<br>T. Yelin |
| 2 | U.S. Geological Survey<br>Mail Stop 977<br>345 Middlefield Road<br>Menlo Park, CA 94025<br>ATTN: H. Stenner<br>T. Brocher |
| | U.S. Fish and Wildlife Service<br>3250 Port of Benton Boulevard<br>Richland, WA 99352 |
| 4 | Washington Division of Geology and Earth Resources<br>P.O. Box 47007<br>Olympia, WA 98504-7007<br>ATTN: R. F. Teissere<br>C. Manson<br>S. Palmer<br>T. Walsh |
| | Washington State University<br>Department of Geology<br>P.O. Box 643420<br>Pullman, WA 99164-2812 |
| | I. G. Wong<br>Woodward-Clyde Federal Services<br>500-12th Street, Suite 200<br>Oakland, CA 94607-4010 |
| | J. Zollweg<br>Boise State University<br>Department of Geosciences<br>Boise, ID 83725 |

| No. of Copies | | |
|---|---|---|
| | **ONSITE** | |
| 8 | **DOE Richland Operations Office** | |
| | K. L. Flynn | A6-35 |
| | M. J. Furman | A6-38 |
| | R. D. Hildebrand | A6-38 |
| | L.F. Miller | H6-60 |
| | M. R. Moreno | A5-55 |
| | J. G. Morse | A6-38 |
| | M. L. Talbot | A6-35 |
| | K. M. Thompson | A6-38 |
| 3 | **Bechtel Hanford, Inc.** | |
| | V. J. Cueno | H0-18 |
| | K. R. Fecht | H0-02 |
| | P. J. Mackey | H0-13 |
| 8 | **CH2M HILL Hanford Group, Inc.** | |
| | D. D. Bachland | S7-86 |
| | S. M. Faulk | S7-86 |
| | J. R. Freeman-Pollard | S0-11 |
| | D. T. Heimberger | R2-11 |
| | A. J. Knepp | E6-35 |
| | F. M. Mann | E6-35 |
| | R. R. Thompson | H6-22 |
| | J. J. Zach | R1-49 |
| | **Duratek Federal Services Hanford** | |
| | R. T. Wilde | E6-35 |

| No. of Copies | | |
|---|---|---|
| 8 | **Fluor Hanford, Inc.** | |
| | D. A. Arrigoni | N2-40 |
| | B. R. Bowman | N2-56 |
| | M. E. Brown | A3-05 |
| | J. T. Curtis | B3-15 |
| | S. A. Fargo | H8-60 |
| | T. P. Morales | A3-05 |
| | R. Whitehurst II | X3-78 |
| | M. I. Wood | H8-44 |
| | **Stoller** | |
| | S. Sobczyk | B2-62 |
| | **Numatec Hanford Corporation** | |
| | T. J. Conrads | R3-73 |
| 2 | **Waste Management Federal Services of Hanford, Inc.** | |
| | D. A. Conners | T3-28 |
| | M. T. York | T3-06 |

| No. of Copies | | |
|---|---|---|
| | **Washington State Department of Ecology** | |
| | J. Caggiano | B5-18 |
| 12 | **Pacific Northwest National Laboratory** | |
| | M. V. Berriochoa | K9-56 |
| | J. S. Fruchter | K6-96 |
| | D. C. Hartshorn | K6-81 |
| | D. G. Horton | K6-81 |
| | W. J. Martin | K6-81 |
| | B. D. Moon | K9-55 |
| | P. E. Moore | P7-63 |
| | S. P. Reidel | K6-81 |
| | A. C. Rohay | K6-81 |
| | M. M. Valenta | K6-81 |
| | Hanford Technical Library (2) | P8-55 |