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**Pacific Northwest  
National Laboratory**

Operated by Battelle for the  
U.S. Department of Energy

# Annual Hanford Seismic Report for Fiscal Year 2003

Pacific Northwest National Laboratory Seismic Monitoring Team

December 2003



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

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## **Annual Hanford Seismic Report for Fiscal Year 2003**

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December 2003

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## Summary

Hanford Seismic Monitoring provides an uninterrupted collection of high-quality raw and processed seismic data from the Hanford Seismic Network 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 1,336 triggers during fiscal year 2003. Of these triggers, 590 were earthquakes.

One hundred and one earthquakes of the 590 earthquakes were located in the Hanford Seismic Network area. Stratigraphically 35 (34.6%) occurred in the Columbia River basalt, 29 (28.7%) were earthquakes in the pre-basalt sediments, and 37 (36.7%) were earthquakes in the crystalline basement. Geographically, 48 (47%) earthquakes occurred in swarm areas, 4 (4%) earthquakes were associated with a major geologic structure, and 49 (49%) were classified as random events.

During the third and fourth quarters, an earthquake swarm consisting of 27 earthquakes occurred on the south limb of Rattlesnake Mountain. The earthquakes are centered over the northwest extension of the Horse Heaven Hills anticline and probably occur near the interface of the Columbia River Basalt Group and pre-basalt sediments.

## 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 Kinometrics
EWRN	Eastern Washington Regional Network
FY	fiscal year
GPS	Global Positioning System
HSN	Hanford Seismic Network
$M_c$	Coda Length Magnitude
$M_L$	Local Magnitude
$M_w$	Moment Magnitude
PNNL	Pacific Northwest National Laboratory
RAW	Rattlesnake Mountain-Wallula Alignment
SMA	strong motion accelerometer
USGS	United States Geological Survey
UTC	Universal Time, Coordinated
UW	University of Washington
WHC	Westinghouse Hanford Company

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# **1.0 Introduction**

This report covers seismic activity on and near the Hanford Site for fiscal year (FY) 2003. The report includes earthquake activity that occurred between October 1, 2002 and September 30, 2003 and the geologic interpretation of the sources of the earthquakes.

## **1.1 Mission**

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

4.4.5 Natural Phenomena Detection.

*Facilities or sites with hazardous materials shall have instrumentation or other means to detect and record the occurrence and severity of seismic events.*

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

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

## **1.2 History of Seismic Monitoring at Hanford**

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



responsibility for the UW contract were then transferred to WHC's Environmental Division. Maintenance responsibilities for the EWRN also were assigned to WHC who made major upgrades to EWRN sites.

Effective October 1, 1996, seismic monitoring was transferred to the Pacific Northwest National Laboratory (PNNL)<sup>(a)</sup>. Seismic monitoring is part of PNNL's Hanford Groundwater Performance Assessment Project.

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.

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## 2.0 Network Operations

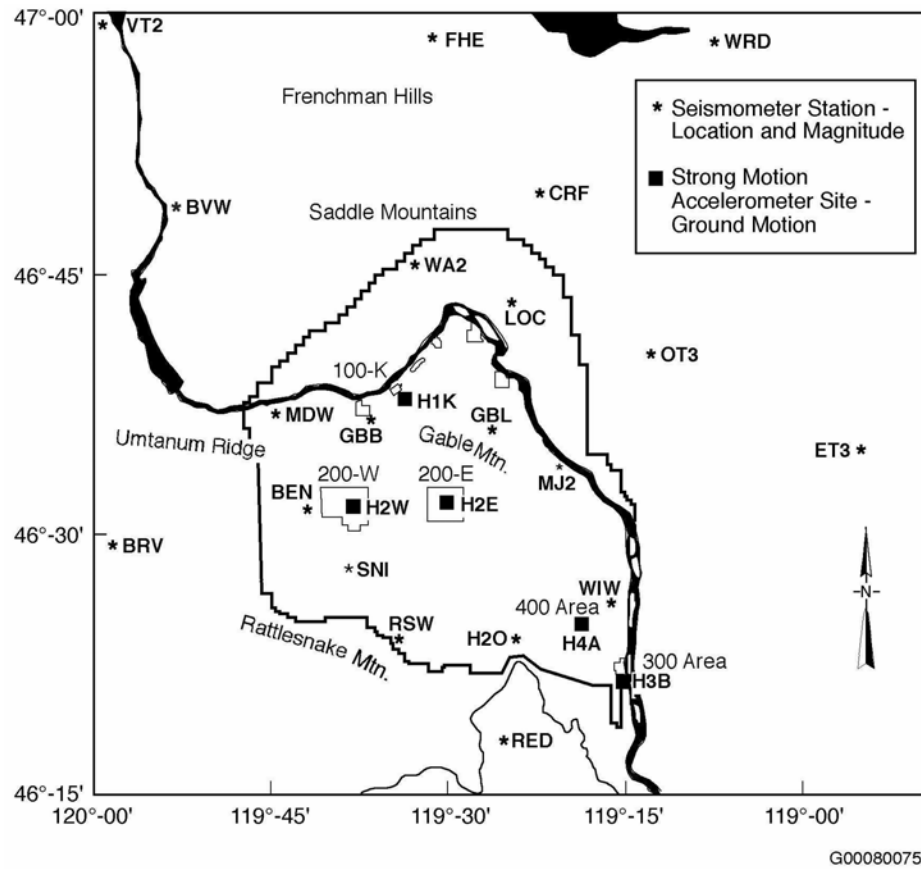
### 2.1 Seismometer Sites

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 35 sites (Table 2.2 and Figure 2.2); both networks share 16 sites. The networks have 45 combined data channels because Gable Butte and Frenchman Hills East are three-component sites, each consisting of one vertical, one north-south horizontal, and one east-west horizontal data channel. Both networks use 15 additional telemetry relay sites. Data from all sites or relays are transmitted to the Sigma V building, Richland, Washington.

**Table 2.1. Seismic Stations in the Hanford Seismic Network**

The first column is the three-letter seismic station designator. The latitude and longitude, elevation above sea level in meters, and the full station name follow this. The locations of the stations are all in Washington; locations were derived from a Global Positioning System (GPS).				
Station	Latitude Deg. Min. N	Longitude Deg. Min. W	Elevation (m)	Station Name
BEN	46N31.13	119W43.02	340	Benson Ranch
BRV	46N49.12	119W59.47	920	Black Rock Valley
BVW	46N48.66	119W52.99	670	Beverly
CRF	46N49.50	119W23.22	189	Corfu
ET3	46N34.64	118W56.25	286	Eltopia Three
*FHE	46N57.11	119W29.82	455	Frenchman Hills East
*GBB	46N36.49	119W37.62	177	Gable Butte
GBL	46N35.92	119W27.58	330	Gable Mountain
H2O	46N23.75	119W25.38	158	Water
LOC	46N43.02	119W25.85	210	Locke Island
MDW	46N36.79	119W45.66	330	Midway
MJ2	46N33.45	119W21.54	146	May Junction Two
OT3	46N40.14	119W13.98	322	Othello Three
PRO	46N12.73	119W41.15	550	Prosser
RED	46N17.92	119W26.30	366	Red Mountain
RSW	46N23.67	119W35.48	1,045	Rattlesnake Mountain
SNI	46N27.85	119W39.60	312	Snively Ranch
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.**

### 2.1.1 Station Maintenance

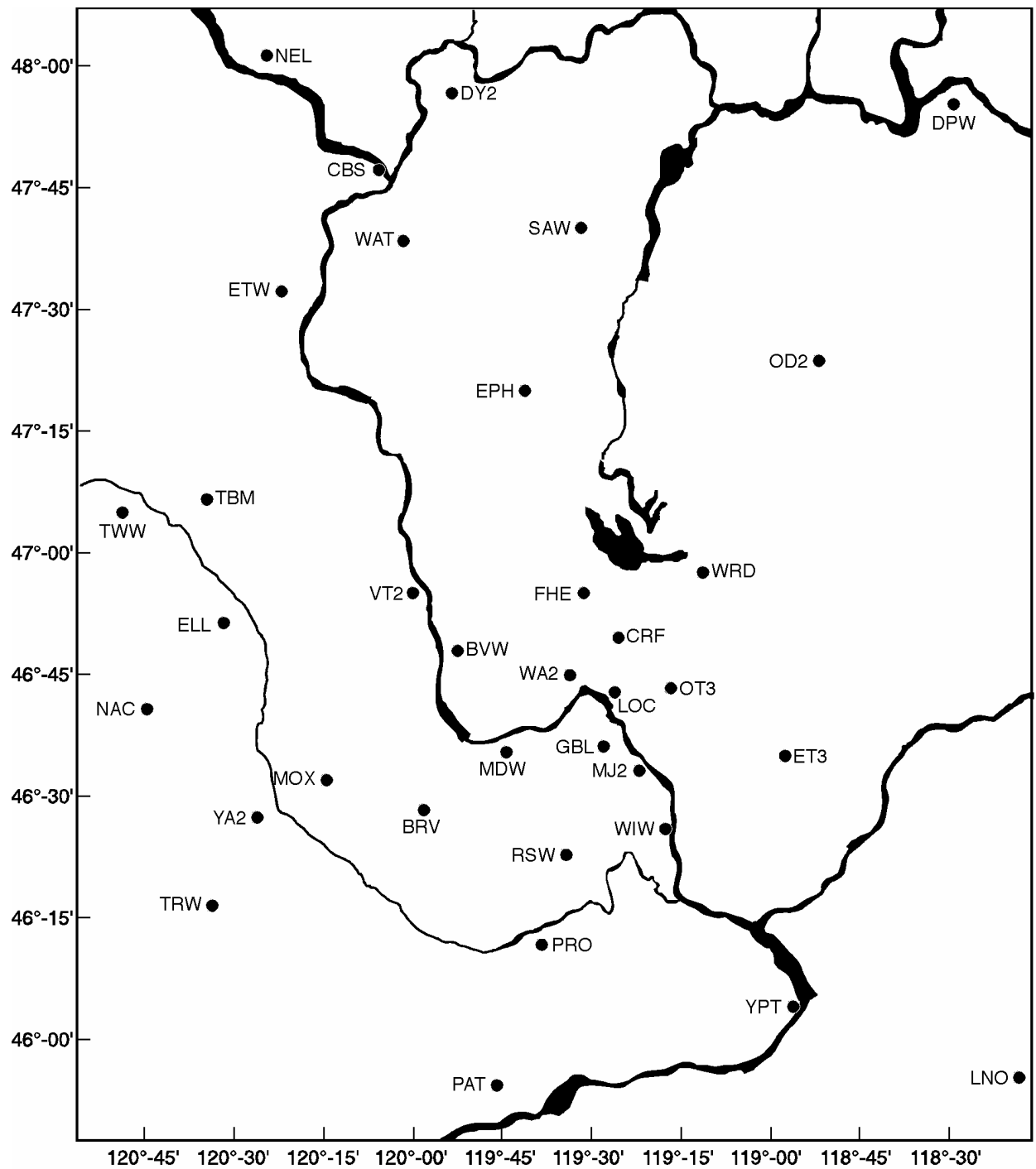
The HSN's maintenance records for the seismic sensor and relay sites are on file in the Hanford Seismic Monitoring office, Sigma V Building, Richland Washington.

### 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,

**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	Linton 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	385	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.				



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

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<sup>TM</sup> (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.

**Table 2.3. Acquisition System Recorded Triggers**

Event Type	First Quarter	Second Quarter	Third Quarter	Fourth Quarter	Total	Description
South-Central Washington	46	40	49	25	160	Seismic events in south-central Washington and north-central Oregon that triggered the HSN.
Regional	44	47	31	39	161	Seismic events in the Western United States and Canada.
Teleseism	81	54	61	71	267	Seismic events at farther distances from around the world.
Total Earthquake Events	171	141	141	135	588	Total number of earthquake triggers.
Total Triggers on Primary System	342	271	356	367	1336	Total number of triggers examined. Includes all sources of triggers.
Local Explosions	2	5	7	3	17	Quarry blasts, typically, within the 46-47 degrees north latitude and 119-120 degrees west longitude.
Local Earthquakes	29	20	34	18	101	Seismic events within the 46-47 degrees north latitude and 119-120 degrees west longitude.

## 2.2 Strong Motion Accelerometer Sites

### 2.2.1 Location

The Hanford SMA network consists of five free-field SMA sites (see Figure 2.1) (Table 2.4). There is one free-field SMA located in each of the 200 Separations Areas, one adjacent to the K Basins in the 100-K Area, one adjacent to the 400 Area where the Fast Flux Test Reactor is located, and one at the south end of the 300 Area. With the termination of the Fast Flux Test Reactor and draining of the liquid sodium coolant taking place now, we are making plans to terminate this site and move the instrument to a new location.

The instrumentation locations were chosen based on two criteria (Moore and Reidel 1996): 1) instruments should be located in areas having the highest densities of people and 2) instruments should be located in areas having hazardous facilities. Some of the highest concentrations of employees at Hanford are 200 East and West Areas, 100-K Area, the Fast Flux Test Facility (400 Area), and the 300 Areas. The 200 Areas are where high-level radioactive waste from past processing of fuel rods is stored in single-shell and double-shell tanks. In addition, the Canister Storage Facility that holds encapsulated spent fuel rods is in 200 East Area and the new vitrification plant is being constructed in 200 East Area. The 100-K Area contains the K Basins where spent fuel rods from the N Reactor are stored prior to encapsulation. The Cold Vacuum Drying Facility, located in the 100-K Area, is used to encapsulate spent fuel rods from the K Basins prior to shipment to the Canister Storage Building in 200 East Area.

**Table 2.4. Free-Field Strong Motion Accelerometer Sites**

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

### 2.2.2 Site Design

All free-field SMA sites consist of a four-panel solar array and two 30-gallon galvanized drums. Each panel has a maximum 42-watt output. The two 30-gallon drums are set in the ground such that the base of the drum is about 1 m below the surface. One drum houses only the SMA; the other drum, which is connected via a sealed conduit to the SMA drum, contains the batteries. Communication is through a Cellular Digital Packet Data (CDPD) system, which provides a continuous radio data-link with 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 CDPD system is scheduled to be terminated by AT&T and replaced with a new system in January 2004.

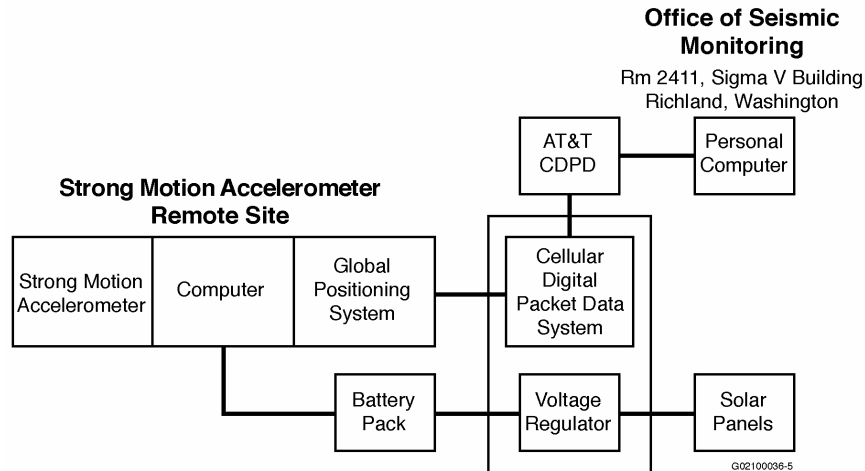
The SMA instruments are three-component units consisting of one vertical, one north-south horizontal, and one east-west horizontal data channel. The instruments in use are the ETNA™ system (registered trademark of Kinemetrics, Inc., Pasadena, California). Instrument specifications are summarized in Table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

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

**Table 2.5. Instrument Parameters for the Kinemetrics ETNA™ System in the Hanford SMA Network**

Parameter	Value or Range
<b>Sensor</b>	
Type	Tri-axial Force Balance Accelerometer orthogonally oriented with internal standard
Full-Scale	$\pm 2 \text{ g}^{(a)}$
Frequency Range	0-50 Hz
Damping	Approximately 70% critical <sup>(a)</sup>
<b>Data Acquisition</b>	
Number of Channels	3
Sample Rate	18-bit resolution @ 200 samples/second
Digital Output	Real-time, RS-232 Output Stream
<b>Seismic Trigger</b>	
Filter	0.1 - 12.5 Hz
Trigger level	0.10% - 0.20% $\text{g}^{(b)}$
Alarm (call-out) Threshold	Not activated
Pre-event Memory	10 sec
Post-event Time	40 sec
(a) Setting is dependent on instrument calibration.	
(b) See Section 2.2.4 for discussion of trigger thresholds.	





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

The SMAs have an internal GPS receiver used principally to link it to the National Bureau of Standards timing system.<sup>(a)</sup> 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<sup>2</sup> or 32 ft/s<sup>2</sup>) 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.

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

### 3.0 Earthquake Catalog Description

Seismic Monitoring staff uses an interactive program XPED developed at the University of Washington to determine earthquake locations and magnitudes. This program operates on the sections of time saved in files by the trigger algorithm of the Earthworm system. It provides the user with the ability to measure the arrival times and durations of seismic waves from earthquakes and determine the locations and magnitudes of the events. Locations of teleseismic and regional earthquakes are interpreted and saved for operational and quality review and documentation, and are not reported here. Local earthquakes near the Hanford Site (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.

#### 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 September 30, 2003**

Event ID	Type	Date	Time	Latitude	Longitude	Depth	Mag	NS/NP	Gap	Dmin	RMS	Q	Location
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
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
0212206575		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
03011421583	X	03/01/14	21:58:59.57	46N15.82	119W23.58	0.07		13/13	232	5	0.13	AD	8.1 km WSW of Richland
03012400230	P	03/01/24	00:23:29.86	46N15.94	119W23.48	3.12		12/12	129	5	0.09	AB	7.9 km WSW of Richland
03012611344		03/01/26	11:35:09.10	46N29.40	119W20.58	0.35	1.0	8/08	124	7	0.08	AB	6.2 km N of 400 Area

**Table 3.2. (Contd.)**

Event ID	Type	Date	Time	Latitude	Longitude	Depth	Mag	MS/NP	Gap	Dmin	RMS	Q	Location
03012821092	X	03/01/28	21:09:50.34	46N08.73	119W11.82	0.05		15/15	188	21	0.18	BD	8.6 km SW of Kennewick
03020416331		03/02/04	16:33:39.63	46N27.62	119W01.21	15.76	1.7	21/21	113	14	0.14	AB	22.9 km ENE of 300 Area
03021202012		03/02/12	02:01:47.14	46N36.18	119W45.14	16.56	0.8	15/18	165	1	0.07	AC	10.1 km WNW of 200 West
03021222082	X	03/02/12	22:08:42.73	46N08.74	119W11.13	0.84		14/14	158	20	0.13	BC	8.0 km SW of Kennewick
03021417463		03/02/14	17:46:54.14	46N36.21	119W51.58	6.54	0.3	8/09	217	7	0.06	AD	17.7 km WNW of 200 West
03021621242		03/02/16	21:24:44.95	46N33.92	119W53.34	8.15	0.1	3/06	310	11	0.09	BD	19.3 km W of 200 West
03021807232		03/02/18	07:23:42.64	46N27.18	119W37.09	17.21	-0.1	8/11	128	3	0.07	AB	11.8 km S of 200 West
03021822404	P	03/02/18	22:41:10.59	46N59.69	119W12.89	0.84		8/08	153	6	0.07	AC	15.6 km SSE of Moses Lake
03030910315		03/03/09	10:32:20.29	46N44.93	119W22.18	3.15	0.7	13/14	95	5	0.06	AB	17.8 km WSW of Othello
03031305552		03/03/13	05:55:39.58	46N57.15	119W07.57	3.88	0.5	6/08	161	2	0.14	BC	14.3 km NNE of Othello
03031411402		03/03/14	11:40:45.59	46N24.24	119W23.15	16.58	0.6	16/19	129	2	0.12	AB	4.1 km SSW of 400 Area
03031801175		03/03/18	01:18:22.69	46N50.82	119W44.10	2.36	1.8	26/28	66	11	0.11	AC	22.6 km ESE of Vantage
03031903190		03/03/19	03:19:14.81	46N46.24	119W55.48	0.04	0.8	6/06	109	5	0.09	AC	21.3 km SSE of Vantage
03031904385		03/03/19	04:39:20.17	46N39.59	119W39.25	16.10	0.0	12/15	120	6	0.07	AB	4.8 km WNW of 100-K Area
03032011414		03/03/20	11:42:07.13	46N28.92	119W35.84	12.46	-0.1	7/10	114	5	0.08	AB	9.0 km SSE of 200 West
03032115185		03/03/21	15:19:20.34	46N29.06	119W35.80	10.66	-0.1	7/08	90	5	0.03	AB	8.8 km SSE of 200 West
03032115193		03/03/21	15:19:33.94	46N29.28	119W35.53	9.05	-0.3	7/09	88	5	0.04	AB	8.5 km SSE of 200 West
03032323322		03/03/23	23:32:44.39	46N39.72	119W36.75	0.25	0.0	6/06	134	6	0.10	AC	2.5 km NNW of 100-K Area
03032323323		03/03/23	23:32:46.72	46N39.81	119W36.93	0.03	1.9	18/19	89	6	0.07	AB	2.8 km NNW of 100-K Area
03032401584		03/03/24	01:57:22.21	46N46.75	119W57.69	0.02	0.2	8/09	190	6	0.18	BD	20.0 km S of Vantage
03032419435		03/03/24	19:44:19.75	46N39.73	119W36.79	1.69	1.6	16/17	64	6	0.05	AB	2.6 km NNW of 100-K Area
03033014200		03/03/30	14:20:28.50	46N35.17	119W20.77	14.09	-0.4	10/15	115	3	0.09	AB	14.8 km ENE of 200 East
03040306580		03/04/03	06:58:21.64	46N49.35	119W45.41	0.49	0.3	11/14	102	9	0.22	BB	22.9 km SE of Vantage
03040812335		03/04/08	12:34:14.38	46N51.49	119W34.52	2.51	1.4	24/26	66	11	0.10	AC	24.1 km N of 100-K Area
03042420445	P	03/04/24	20:45:17.10	46N13.06	119W25.69	6.02		6/08	243	8	0.15	BD	12.8 km SW of Richland
03042621195		03/04/26	21:20:12.02	46N33.63	119W49.26	6.94	-0.2	7/10	160	7	0.15	AC	14.0 km W of 200 West
03042701130		03/04/27	01:13:26.16	46N33.28	119W50.97	5.65	0.9	13/14	130	9	0.08	AB	16.2 km W of 200 West
03042716233		03/04/27	16:24:00.01	46N33.40	119W50.19	0.02	0.3	4/05	288	8	0.06	AD	15.2 km W of 200 West
03043023323	P	03/04/30	23:32:59.23	46N14.69	119W27.65	3.81		8/08	225	6	0.06	AD	13.7 km WSW of Richland
03043023370	P	03/04/30	23:37:33.45	46N14.90	119W27.67	3.67		11/11	223	5	0.09	AD	13.6 km WSW of Richland
03050507013		03/05/05	07:01:55.31	46N44.68	119W21.83	0.02	-0.6	6/08	141	5	0.11	AC	17.6 km WSW of Othello
03050507290		03/05/05	07:29:30.23	46N44.84	119W21.78	3.69	0.5	16/19	86	6	0.08	AB	17.4 km WSW of Othello
03050507300		03/05/05	07:28:30.18	46N44.52	119W22.42	2.47	-0.2	8/10	133	5	0.15	AB	18.4 km WSW of Othello
03050602484		03/05/06	02:49:10.27	46N16.40	119W36.59	6.60	0.9	13/14	142	8	0.05	AC	14.3 km ENE of Prosser

**Table 3.2. (Contd.)**

Event ID	Type	Date	Time	Latitude	Longitude	Depth	Mag	MS/NP	Gap	Dmin	RMS	Q	Location
03050723025	P	03/05/07	23:03:21.28	46N15.15	119W27.76	3.45		7/07	221	5	0.03	AD	13.6 km WSW of Richland
03051122571		03/05/11	22:57:31.91	46N29.02	119W29.25	15.21	-0.5	9/12	61	10	0.04	AA	9.2 km SSE of 200 East
03051222515	P	03/05/12	22:52:19.33	46N13.43	119W25.51	6.96		3/05	332	8	0.03	BD	12.2 km WSW of Richland
03051404592		03/05/14	04:59:43.65	46N07.00	119W47.70	22.38	1.7	25/27	126	13	0.09	AB	10.3 km SSW of Prosser
03051422413	P	03/05/14	22:41:46.81	46N16.37	119W27.49	2.83		4/04	285	3	0.00	AD	12.9 km W of Richland
03052309465		03/05/23	09:47:13.57	46N21.60	119W39.92	8.70	0.1	5/07	176	6	0.03	AD	18.8 km NNE of Prosser
03052400584		03/05/24	00:59:12.40	46N20.16	119W41.10	4.40	0.3	11/13	169	9	0.12	AC	15.7 km NNE of Prosser
03052502524		03/05/25	02:52:57.28	46N33.07	119W11.52	0.78	-0.4	5/06	289	21	0.28	BD	18.2 km NE of 400 Area
03052521244		03/05/25	21:25:08.00	46N44.73	119W21.77	4.05	0.4	16/19	96	6	0.09	AB	17.5 km WSW of Othello
03052914484		03/05/29	14:49:11.62	46N09.47	119W41.87	8.61	1.1	15/15	166	6	0.07	AC	7.7 km SE of Prosser
03060404453		03/06/04	04:45:51.85	46N04.24	119W14.16	12.42	0.5	9/09	219	21	0.06	AD	17.1 km SSW of Kennewick
03060623154	P	03/06/06	23:16:07.18	46N14.18	119W27.13	3.52		9/10	231	6	0.11	AD	13.4 km WSW of Richland
03060801020		03/06/08	01:02:27.86	46N20.09	119W41.68	2.93	0.6	11/15	173	10	0.10	BC	15.3 km NNE of Prosser
03061310095		03/06/13	10:10:15.17	46N18.83	119W39.57	6.47	-0.4	6/09	298	10	0.19	CD	14.5 km NE of Prosser
03061310103		03/06/13	10:10:55.36	46N20.19	119W40.41	4.63	0.4	12/15	120	9	0.17	BB	16.1 km NNE of Prosser
03061422131		03/06/14	22:13:32.82	46N20.19	119W41.47	3.82	0.2	7/08	171	10	0.07	AC	15.6 km NNE of Prosser
03061815363		03/06/18	15:36:59.79	46N20.30	119W40.59	6.27	0.1	4/06	286	9	0.09	BD	16.2 km NNE of Prosser
03061815384		03/06/18	15:39:06.34	46N18.77	119W43.08	6.31	0.0	6/08	265	13	0.14	CD	12.4 km NNE of Prosser
03061917520		03/06/19	17:52:22.79	46N19.54	119W41.17	5.84	0.0	5/07	254	10	0.11	BD	14.6 km NNE of Prosser
03062314213		03/06/23	14:21:58.47	46N20.21	119W41.37	4.04	0.8	8/08	171	9	0.11	BC	15.7 km NNE of Prosser
03062319242		03/06/23	19:24:42.71	46N19.97	119W41.10	2.16	0.2	9/12	169	9	0.08	BC	15.4 km NNE of Prosser
03062320515		03/06/23	20:52:17.88	46N22.97	119W19.08	15.69	-0.4	6/06	199	5	0.11	BD	4.1 km NW of 300 Area
03062423172		03/06/24	23:17:46.90	46N26.69	119W35.83	15.14	0.2	13/15	99	5	0.06	AB	13.0 km SSE of 200 West
03062423575		03/06/24	23:58:19.70	46N20.17	119W40.89	6.22	0.0	6/07	167	9	0.13	BC	15.8 km NNE of Prosser
03062500251		03/06/25	00:25:35.03	46N20.09	119W40.62	6.05	1.4	25/27	121	9	0.14	AB	15.9 km NNE of Prosser
03062509421		03/06/25	09:42:33.06	46N20.86	119W32.84	14.25	0.0	9/09	202	5	0.03	AD	17.5 km WSW of 400 Area
03062622340		03/06/26	22:34:25.16	46N20.17	119W40.52	7.10	-0.1	3/06	304	9	0.06	BD	16.0 km NNE of Prosser
03062809530		03/06/28	09:53:21.46	46N19.98	119W40.37	5.37	0.5	7/07	163	9	0.08	AC	15.8 km NNE of Prosser
03063003194		03/06/30	03:19:38.96	46N07.68	119W07.62	0.04	1.0	5/07	103	52	0.57	DD	8.4 km S of Kennewick
03070201131	P	03/07/02	01:13:41.05	46N13.90	119W27.50	2.52		12/12	232	7	0.14	BD	14.1 km WSW of Richland
03071115054		03/07/11	15:05:64.36	46N27.68	119W26.77	14.32	2.3	6/41	36	7	0.15	AA	7.4 km WNW of 400 Area
03071218584	P	03/07/12	18:58:65.78	46N15.01	119W27.66	3.62		9/09	222	5	0.05	AD	13.6 km WSW of Richland
03071306252		03/07/13	06:25:37.94	46N58.62	119W19.39	14.76	0.5	10/14	147	13	0.09	AC	16.9 km S of Moses Lake
03071502355		03/07/15	02:35:80.03	46N20.18	119W41.69	1.44	0.7	12/14	173	10	0.07	BC	15.5 km NNE of Prosser

**Table 3.2. (Contd.)**

Event ID	Type	Date	Time	Latitude	Longitude	Depth	Mag	MS/NP	Gap	Dmin	RMS	Q	Location
03071903351		03/07/19	03:35:33.73	46N36.92	119W46.09	15.13	-0.2	9/12	178	0	0.07	AC	11.8 km WNW of 200 West
03072307252		03/07/23	07:25:47.70	46N33.66	119W52.39	6.05	0.0	9/12	131	10	0.14	AB	18.0 km W of 200 West
03080115591	P	03/08/01	15:59:35.48	46N25.31	119W00.68	4.05		10/10	156	18	0.10	AC	21.7 km ENE of 300 Area
03080701191		03/08/07	01:19:28.41	46N06.13	119W27.18	2.74	1.0	8/08	239	21	0.14	BD	23.7 km SSW of Richland
03082205585		03/08/22	05:58:82.42	46N50.64	119W33.09	2.32	1.7	23/23	49	9	0.14	AB	22.7 km N of 100-K Area
03082718521		03/08/27	18:51:93.59	46N43.56	119W33.41	0.04	0.9	13/13	117	3	0.13	AB	9.8 km NNE of 100-K Area
03090907450		03/09/09	07:45:30.30	46N19.97	119W41.06	5.06	0.5	13/17	168	9	0.08	AC	15.4 km NNE of Prosser
03090910543		03/09/09	10:54:59.72	46N20.26	119W41.66	3.95	0.5	9/13	173	10	0.12	BC	15.6 km NNE of Prosser
03091000485		03/09/10	00:48:82.94	46N20.20	119W40.42	5.91	1.3	15/18	120	9	0.13	AB	16.2 km NNE of Prosser
03091010292		03/09/10	10:29:50.30	46N20.21	119W41.01	4.98	0.8	11/13	160	9	0.07	AC	15.8 km NNE of Prosser
03091401010		03/09/14	01:00:80.88	46N20.47	119W39.29	6.46	-0.2	4/05	287	7	0.10	BD	17.3 km NNE of Prosser
03091423383		03/09/14	23:38:59.57	46N19.64	119W40.89	7.75	0.1	3/04	308	10	0.00	AD	15.0 km NNE of Prosser
03091500402		03/09/15	00:40:52.33	46N20.05	119W39.82	6.84	1.0	14/17	116	8	0.14	AB	16.3 km NNE of Prosser
03092115294		03/09/21	15:29:66.19	46N17.94	119W36.01	6.47	0.0	7/10	249	10	0.07	AD	16.5 km NE of Prosser
03092610143		03/09/26	10:14:58.80	46N20.19	119W40.79	6.55	0.1	7/11	170	9	0.07	AC	15.9 km NNE of Prosser
03092906380		03/09/29	06:37:85.84	46N15.46	119W33.34	7.62	0.3	13/13	179	10	0.07	AC	17.3 km ENE of Prosser

### Explanation of Table 3.2

<b>Event ID:</b>	The Earthworm Recording System creates the identification number. XPED uses the year, month, day and time to create a unique number for each event.
<b>Type:</b>	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.
<b>Date:</b>	The year and day of the year in Universal Time Coordinated (UTC). UTC is used throughout this report unless otherwise indicated.
<b>Time:</b>	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.
<b>Latitude:</b>	North latitude, in degrees and minutes, of the earthquake epicenter.
<b>Longitude:</b>	West longitude, in degrees and minutes, of the earthquake epicenter.
<b>Depth:</b>	The depth of the earthquake in kilometers (km).
<b>Mag:</b>	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.
<b>NS/NP:</b>	Number of stations/number of phases used in the solutions.
<b>Gap:</b>	Azimuthal gap. The largest angle (relative to the epicenter) containing no stations.
<b>DMIN:</b>	The distance from the earthquake epicenter to the closest station
<b>RMS:</b>	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.
<b>Q:</b>	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 underlying 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).

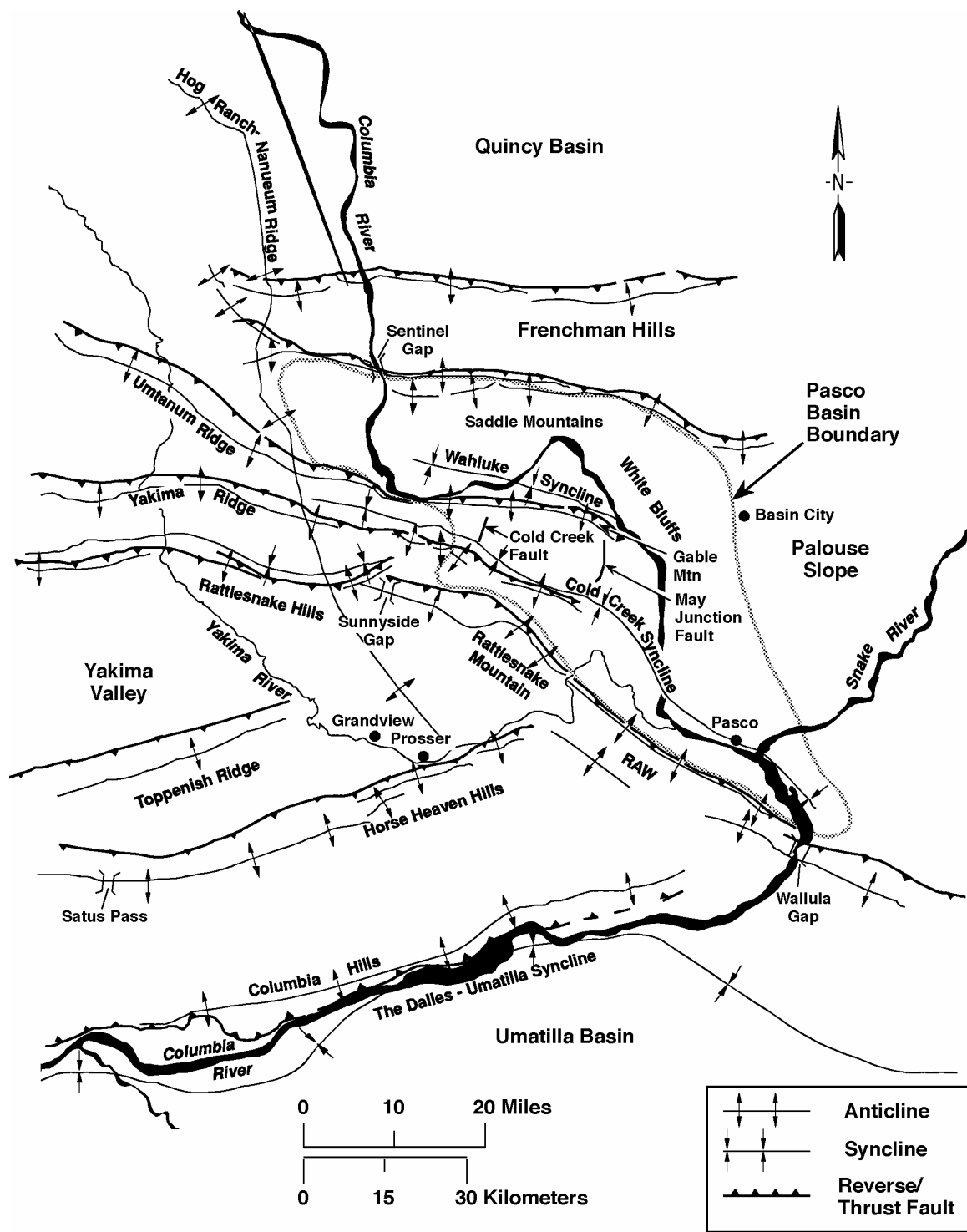
### **4.1 Earthquake Stratigraphy**

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.

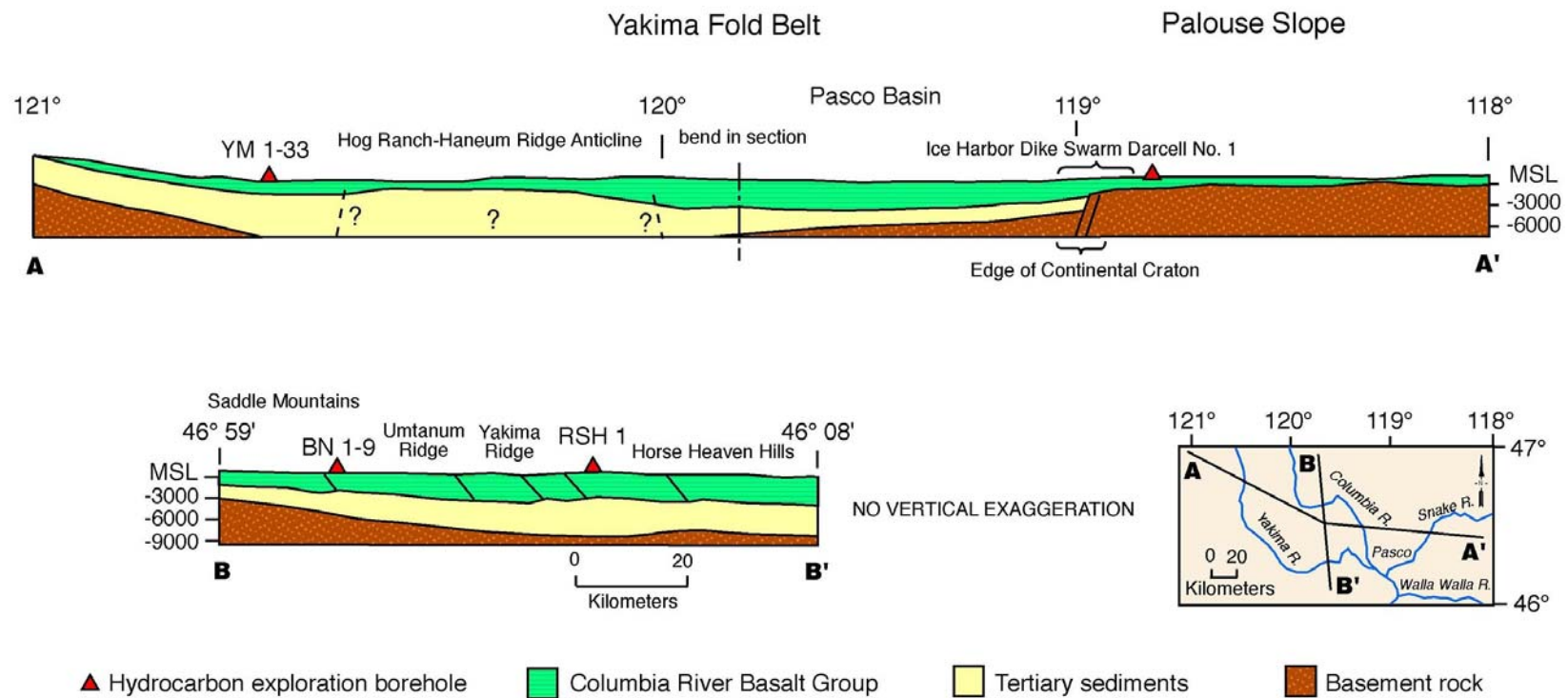
### **4.2 Geologic Structure Beneath the Monitored Area**

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 thicknesses listed in Table 4.1 and the thicknesses of the crustal layers in the velocity model in Table 3.1 reflect data specific to the crustal velocity model for eastern Washington. Table 4.1 is derived from Reidel et al. (1994) and was developed for the geologic interpretation in this report. The thicknesses of these units are variable across the monitored area. Table 4.1 summarizes the approximate thickness at the borders of the monitored area.



G99090026.5

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



G01010082.2

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

**Table 4.1. Thicknesses of Stratigraphic Units in the Monitoring Area**

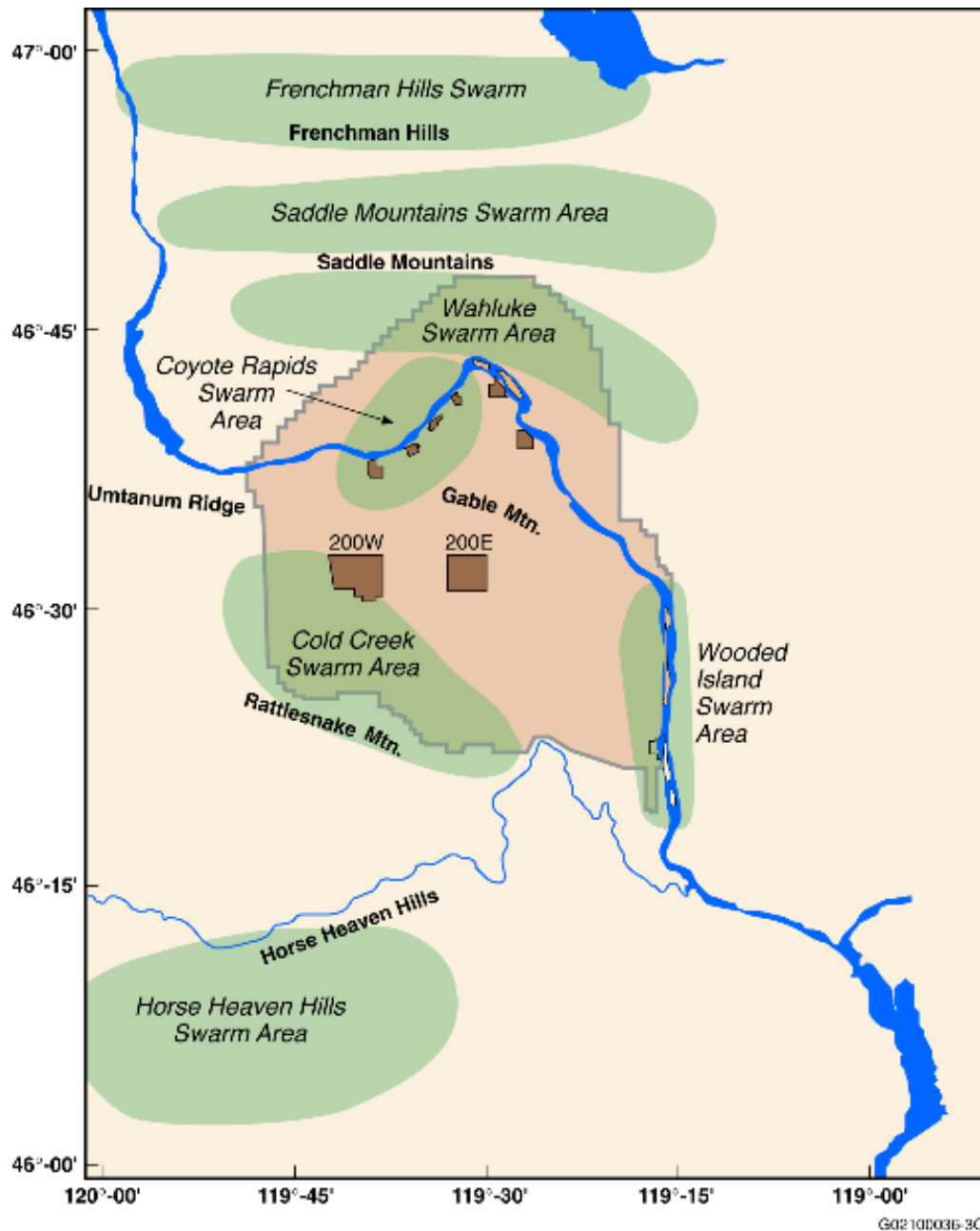
Stratigraphy	North	South	East	West
Columbia River Basalt Group (includes suprabasalt sediments)	3.0 km	4.5 km	2.2 km	4.2 km
Pre-basalt Sediments	3.0 km	>4.5 km	0	>6.0 km

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

### 4.3 Tectonic Pattern

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

- **Major Geologic Structures.** Reverse/thrust faults in the CRBG associated with major anticlinal ridges such as Rattlesnake Mountain, Yakima Ridge, and Umtanum Ridge could produce some of the largest earthquakes.
- **Secondary faults.** These faults are typically smaller (1-20 km) than the main reverse/thrust faults that occur along the major anticlinal ridges (up to 100 km). Secondary faults can be segment boundaries (tear faults) and small faults of any orientation that formed along with the main structure.
- **Swarm areas.** Small geographic areas not known to contain any geologic structures produce clusters of events (swarms), usually in the CRBG in synclinal valleys. These clusters consist of a series of small shocks with no outstanding principal event. Swarms occur over a period of days or months and the events may number into the hundreds and then quit, only to start again at a later date. This differs from the sequence of foreshocks, mainshock, and trailing-off aftershocks that have the same epicenter or are associated with the same fault system. In the past, swarms were thought to occur only in the 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, Wahluke swarm area, Coyote Rapids swarm area, and Horse Heaven Hills swarm area are typically active at one time or another during the year. The other earthquake swarm areas are active less frequently.



**Figure 4.3. Locations of 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 the DOE. Ground motion from any moderate or larger Cascadia Subduction Zone earthquake is detected by Hanford SMAs and reported (see Section 5.0).

## 4.4 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, second and third quarters of FY 2003 are listed in Table 4.2.

## 4.5 Tectonic Activity

### 4.5.1 Annual Summary

This section summarizes the earthquake activity for that period of time (Figure 4.4). More detailed descriptions of this activity are given below. During Fiscal year 2003 one hundred and one earthquakes of the 588 earthquakes were located in the Hanford Seismic Network area. Stratigraphically, 35 (34.6%) occurred in the Columbia River basalt, 29 (28.7%) were earthquakes in the pre-basalt sediments, and 37 (36.7%) were earthquakes in the crystalline basement. Geographically, 48 (47%) earthquakes occurred in swarm areas, 4 (4%) earthquakes were associated with a major geologic structure, and 49 (49%) were classified as random events.

**Table 4.2. Number of Local Earthquakes Occurring in Stratigraphic Units**

Unit	First Quarter	Second Quarter	Third Quarter	Fourth Quarter	FY 2003
Basalt	6	9	15	5	35 (34.6%)
Pre-basalt Sediments	4	2	13	10	29 (28.7%)
Crystalline Basement	19	9	6	3	37 (36.7%)
Total	29	20	34	18	101

**Table 4.3. Summary of Earthquake Locations for FY 2003**

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 2003
Geologic Structure		1	2	1	0	4 (4%)
Swarm Areas	Frenchman Hills	0	1	0	0	1 (1%)
	Saddle Mountains/ Royal Slope	3	1	2	1	7 (6.8%)
	Coyote Rapids	1	3	0	1	5 (4.9%)
	Wahluke Slope	0	1	4	0	5 (4.9%)
	Wooded Island	0	0	1	0	1 (1%)
	Cold Creek	0	0	0	0	0
	Rattlesnake Mt.	0	0	16	11	27 (26.7%)
	Horse Heaven Hills	2	0	0	0	2 (2%)
	Total for swarms	6	6	23	13	48 (47%)
Random Events		22	12	10	5	49 (49%)
Total for all earthquakes		29	20	34	20	101

During the third and fourth quarters, an earthquake swarm consisting of 27 earthquakes occurred on the south limb of Rattlesnake Mountain. The earthquakes are centered over the northwest extension of the Horse Heaven Hills anticline and probably occur near the interface of the Columbia River Basalt Group and pre-basalt sediments.

## **4.5.2 First Quarter Earthquakes**

### **4.5.2.1 Major Anticlinal Ridges**

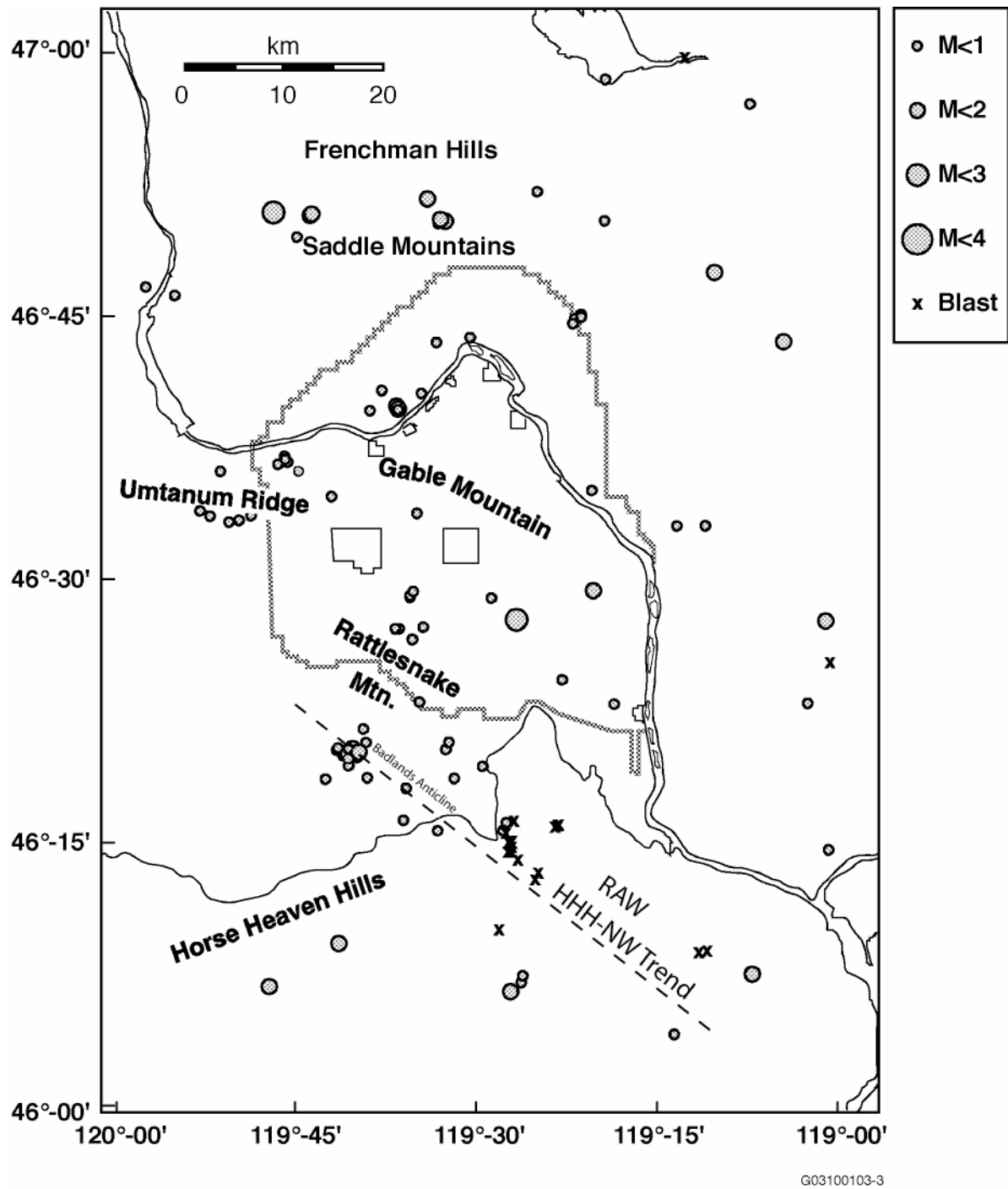
During the first quarter of FY 2003, we interpret one seismic event to have occurred on a major geologic structure (Figure 4.5). On December 22<sup>nd</sup> (11:40 UTM), a small ( $>1.0 M_c$ ), shallow earthquake occurred along the Rattlesnake-Wallula structural trend (RAW Figure 4.1) between Red Mountain 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 4.5). The Saddle Mountains, Coyote Rapids and Horse heaven Hills swarm areas were active. The other swarm areas were not active.

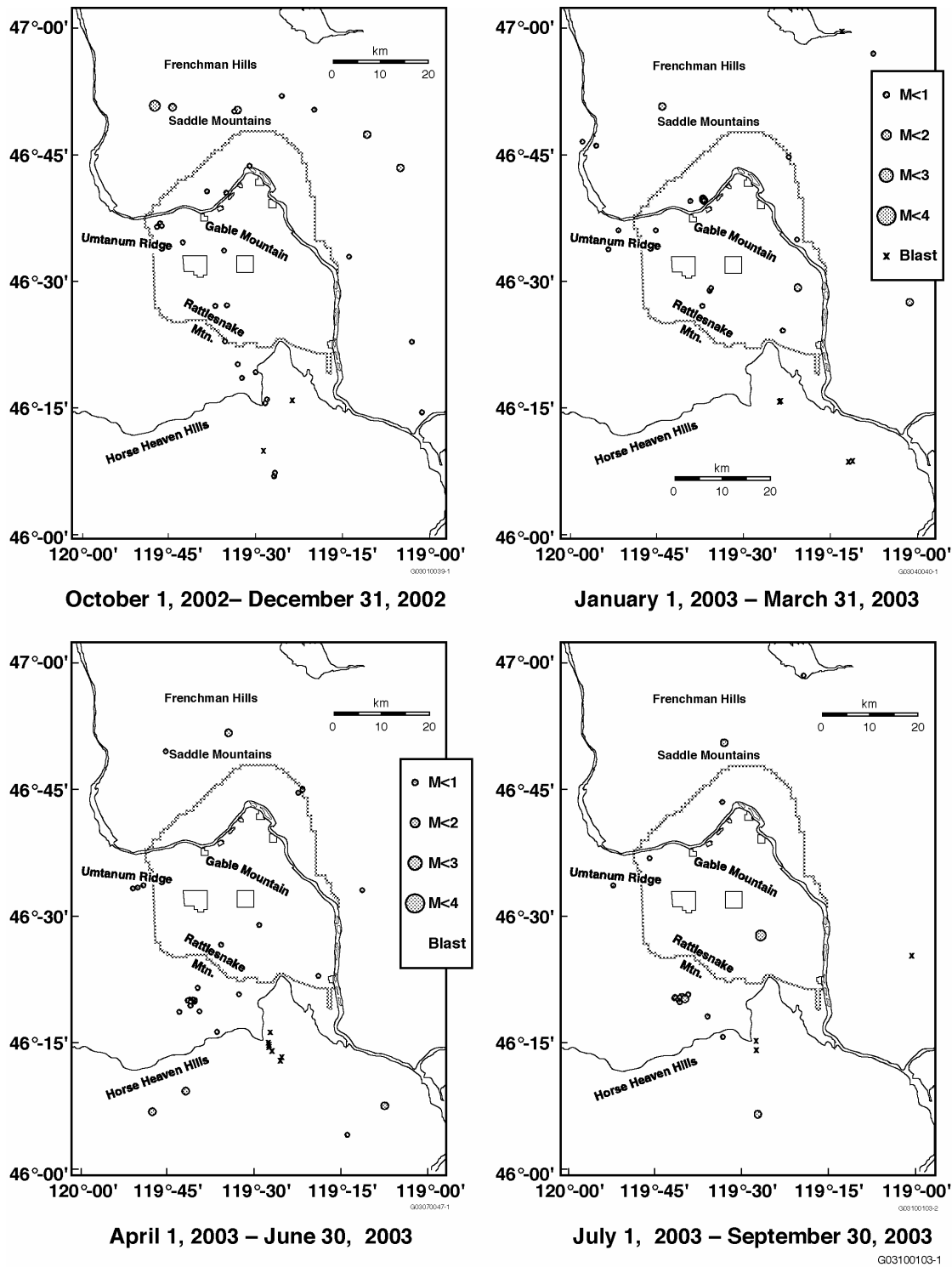
#### **4.5.2.2.1 Saddle Mountains Swarm Area**

During the first quarter of FY 2003, three events occurred in the Saddle Mountains swarm area (Figure 4.5). 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 12<sup>th</sup> and had a magnitude of  $1.5 M_c$ . The second event occurred on October 22<sup>nd</sup> 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.



**Figure 4.4.** All Earthquakes Recorded in the Hanford Monitoring Area Between October 1, 2002 and September 30, 2003 (Coda Length Magnitude ( $M_c$ ) scale is shown at the side of the map)





**Figure 4.5.** All Earthquakes Recorded in the Hanford Monitoring Area Between October 1, 2002 and September 30, 2003 as shown by Quarter (Coda Length Magnitude [ $M_c$ ] scale is shown on map).

#### **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 6<sup>th</sup> and were in the pre-basalt sediments. This area experienced earthquakes at the same location and at the same depths in 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.

The first random event occurred on October 8<sup>th</sup> along 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 28<sup>th</sup> 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 30<sup>th</sup> and the other two events occurred on November 20<sup>th</sup>. The October 30<sup>th</sup> event was in the pre-basalt sediments and the last two were in the crystalline basement.

Three random events occurred in the crystalline basement north of the Saddle Mountains. The events occurred on November 3<sup>rd</sup> (1.3  $M_c$ ), November 10<sup>th</sup> (0.4  $M_c$ ), and December 29<sup>nd</sup> (1.3  $M_c$ ). All events occurred about 4-5 km north of the main Saddle Mountains fault.

On November 4<sup>th</sup>, a random event having a magnitude 0.3  $M_c$  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 4<sup>th</sup> and November 5<sup>th</sup> 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 4<sup>th</sup> and on November 8<sup>th</sup> 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 on November 6<sup>th</sup> 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 9<sup>th</sup> a small ( $0.3 M_c$ ) event occurred in the crystalline basement between the 200-East area and 200-West area (The locations of these areas are shown in Figure 2.1). 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 10<sup>th</sup> and the second event was November 16<sup>th</sup> 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 2<sup>nd</sup> 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 6<sup>th</sup> a random event occurred in the crystalline basement on the south slope of Rattlesnake Mountain near the random event of October 28<sup>th</sup> and near the small basalt earthquake along Rattlesnake Mountain structure that occurred on December 22<sup>nd</sup>. Like the random event of October 28<sup>th</sup>, this earthquake was small ( $0.6 M_c$ ) and occurred in the crystalline basement.

Five earthquakes occurred on December 22<sup>nd</sup>; four were random and one occurred along Rattlesnake Mountain structure (see 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 22<sup>nd</sup> 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  $1.3 M_c$ .

### **4.5.3 Second Quarter Earthquakes**

#### **4.5.3.1 Major Anticlinal Ridges**

During the second quarter of FY 2003, we interpret two seismic events to have occurred on a major geologic structure (Figure 4.5). On March 18<sup>th</sup>, a small (1.8 M<sub>c</sub>), shallow earthquake occurred at Sentinel Gap in the Saddle Mountains (Figure 4.1). A second event also occurred near there on March 24<sup>th</sup> and had a magnitude of 1.9 M<sub>c</sub>. These events were located in the CRBG and are interpreted to be associated with the Saddle Mountains anticline and possibly a small tear fault that is present in Sentinel Gap (Reidel 1984, 1988).

#### **4.5.3.2 Earthquake Swarm Areas**

During the second quarter of FY 2003, we interpret 6 seismic events to have occurred in swarm areas. The Frenchman Hills, Saddle Mountains, Coyote Rapids and Wahluke Slope swarm areas were active (Figure 4.3).

##### **4.5.3.2.1 Frenchman Hills Swarm Area**

One earthquake (Figure 4.5) occurred at the eastern end of the Frenchman Hills swarm area on March 13<sup>th</sup>. The earthquake was small (0.5 M<sub>c</sub>) and was in the basalt.

##### **4.5.3.2.2 Saddle Mountains Swarm Area**

During the second quarter of FY 2003, one event occurred in the Saddle Mountains swarm area (Figure 4.5). The event occurred on March 18<sup>th</sup> and had a magnitude of 1.8 M<sub>c</sub>. The event occurred in the basalt and was at the same location where previous earthquakes had occurred on October 12, 2002 and October 22, 2002.

##### **4.5.3.2.3 Coyote Rapids Swarm Area**

Three small events (<2.0 M<sub>c</sub>) occurred in the Coyote Rapids earthquake swarm during the second quarter of FY 2003. The first two events occurred on March 23<sup>rd</sup> and the third event occurred the following day. All three events occurred in the basalt and in an area that had been active in the past. Another event occurred there on March 19<sup>th</sup> but this event was in the crystalline basement and is classified as a random event because of its depth. However, we have noticed that activity in a swarm area may not be confined to just one layer. If a consistent pattern of earthquakes occurring in several stratigraphic layers can be established here, this deep event may be reclassified as a swarm event in the future.

##### **4.5.3.2.4 Wahluke Slope Swarm Area**

One event occurred in the Wahluke Slope swarm area on March 9<sup>th</sup>. The event was small (0.7 M<sub>c</sub>) and occurred in the basalt along the eastern edge of an area where earthquakes have occurred in the past several fiscal years. Four events occurred there in FY 2002 and 13 events occurred there in FY 2001.

#### 4.5.3.3 Random or Floating Events

During the second quarter of FY 2003, we interpret twelve random events to have occurred in the monitoring area. One was in the basalt, two were in pre-basalt sediments and nine were in the crystalline basement.

The first random event for the second quarter of FY 2003 was on January 26<sup>th</sup> and occurred in the basalt on the east side of Hanford in the Cold Creek syncline. It was a small earthquake (1.0 M<sub>c</sub>) that was located east of the May Junction fault (This feature is shown on Figure 4.1) in one of the larger basins that developed along the Cold Creek syncline.

A small earthquake (1.7 M<sub>c</sub>) occurred on February 4<sup>th</sup> in Esquatzel coulee near the town of Eltopia. This event was on the Palouse Slope and was located in the crystalline basement. It is classified as random because of its depth and the absence of any known geologic structures in the area.

On February 12<sup>th</sup> a small event (0.8 M<sub>c</sub>) occurred in the crystalline basement beneath Umtanum Ridge. This event is classified as random because it was in the crystalline basement. However, during the first quarter of FY 2003, three events occurred at the same location. Two were also in the crystalline basement and the third was in the prebasalt sediments. Two events also occurred at this location during FY2002. One event was in the crystalline basement and one was in the pre-basalt sediments. Another small event (0.3 M<sub>c</sub>) occurred on February 14<sup>th</sup> about 4 km west of the February 12<sup>th</sup> event. It was located in the pre-basalt sediments and therefore is classified as a random event.

On February 16<sup>th</sup> a small event (0.1 M<sub>c</sub>) occurred on Yakima Ridge south of the February 12<sup>th</sup> and 14<sup>th</sup> events on Umtanum Ridge. This earthquake occurred in the prebasalt sediments.

On February 18<sup>th</sup> a small event (approximately 0 M<sub>c</sub>) occurred in the Benson Ranch syncline north of the Rattlesnake Mountain structure and south of Yakima Ridge. Two events occurred nearby during the first quarter; all earthquakes were in the crystalline basement.

The next random event occurred on March 14<sup>th</sup> in the Cold Creek syncline near the ‘horn’ of the Yakima River (the abrupt bend at it’s northern most point on Figure 4.1). This event was deep and is not near any known geologic structure.

A small event (approximately 0 M<sub>c</sub>) occurred on March 19<sup>th</sup> in the crystalline basement beneath the three Coyote Rapids swarm area events that occurred this quarter (Section 4.5.3.2.3). Other deep earthquakes have occurred here in the past. If this pattern continues, this earthquake may be reclassified as a swarm event in the future.

Three small events (approximately 0 M<sub>c</sub>) occurred under Yakima Ridge in the crystalline basement. The first one occurred on March 20<sup>th</sup> and the next two occurred on March 21<sup>st</sup>. No previous events have been recorded here in the past.

The final random event for the second quarter occurred on March 30<sup>th</sup> near Ringold Coulee, which is east of Gable Mountain. This event was very small (approximately 0  $M_c$ ) and was located in the crystalline basement.

#### **4.5.4 Third Quarter Earthquakes**

##### **4.5.4.1 Major Anticlinal Ridges**

During the third quarter of FY 2003, we interpret one seismic event to have occurred on a major geologic structure. On June 30<sup>th</sup>, a small (1.0  $M_c$ ), earthquake occurred in the basalt on a small doubly plunging anticline along the Rattlesnake Alignment -Wallula (RAW on Figure 4.1) south of Kennewick, Washington.

##### **4.5.4.2 Earthquake Swarm Areas**

During the third quarter of FY 2003, we interpret six seismic events to have occurred in swarm areas (Figure 4.3). The Saddle Mountains, Coyote Rapids, Wahluke Slope, Wooded Island and Rattlesnake Mountain swarm areas were active.

###### **4.5.4.2.1 Saddle Mountains Swarm Area**

During the third quarter of FY 2003, two events occurred in the Saddle Mountains swarm area (Figure 4.5). The first event occurred on April 3<sup>rd</sup> and had a magnitude of 0.3  $M_c$ . It occurred in the basalt and was at the same location where previous earthquakes had occurred on March 18<sup>th</sup>, 2003, October 12, 2002 and October 22, 2002. The second event occurred on April 8<sup>th</sup> and had a magnitude ( $M_c$ ) of 1.4. This event occurred in the basalt near Smyrna Bench, which is east of the April 3<sup>rd</sup> earthquake.

###### **4.5.4.2.2 Wahluke Slope Swarm Area**

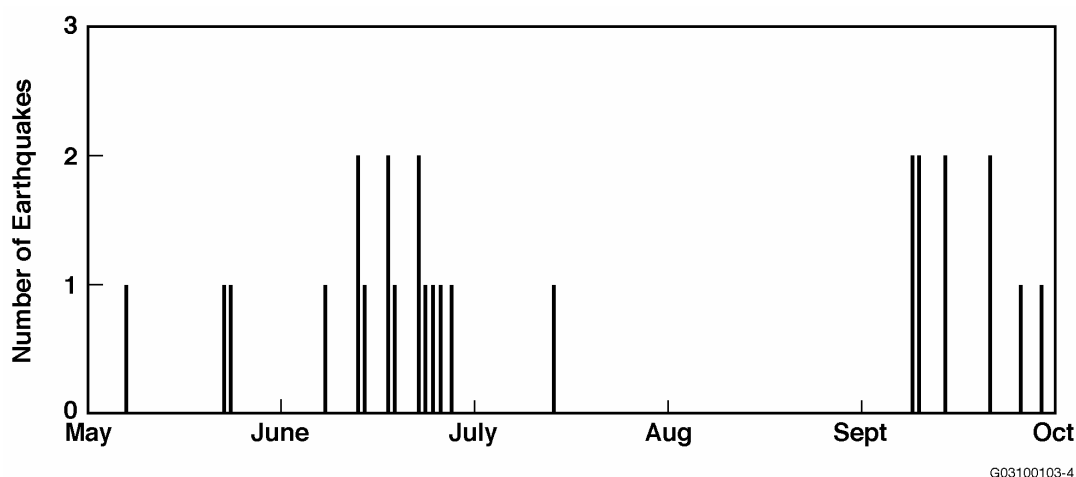
Four small ( $M_c < 1$ ) events occurred in the basalt in the Wahluke Slope swarm area during the third quarter. Three events occurred on May 5<sup>th</sup>. The fourth event occurred on May 25<sup>th</sup>. These earthquakes occurred along the eastern edge of an area where earthquakes have occurred in the past several years. One event occurred there on March 9<sup>th</sup>, 2003; 17 events occurred there in 2001; and one event occurred there in 2002.

###### **4.5.4.2.3 Wooded Island Swarm Area**

One small ( $M_c < 1$ ) earthquake occurred in the Wooded Island swarm area on May 25<sup>th</sup>. The earthquake was in the basalt and on the northeast part of the swarm area in Ringold Coulee.

###### **4.5.4.2.4 Rattlesnake Mountain**

Between May 6<sup>th</sup> and June 28<sup>th</sup> (Figure 4.6), 16 small (all but 1  $M_c < 1$ ) events occurred on the south slope of Rattlesnake Mountain approximately 11 km from the crest of the anticline. These events occurred near the interface between the basalt and the pre-basalt sediments. The average depth was



**Figure 4.6. Plot Showing the Date and the Number of Earthquakes That Occurred in the Rattlesnake Mountain Swarm Area Between May and October 2003**

approximately 5 km, which places them at the estimated base of the basalt. The swarm was centered over the northwest extension of the Horse Heaven Hills-NW anticline, locally called the ‘badlands’ anticline (Figure 4.5) that is manifested at the surface as a low amplitude anticline. However, to the southeast, this structure forms the main NW portion of the Horse Heaven Hills anticline and thrust fault. The location of the swarm is also marked by the intersection of a small anticline with this portion of the Horse Heaven Hills-NW structural trend. This secondary anticline is thought to be confined to the upper layers of the basalt. The May 6<sup>th</sup> event that was originally classified as a random event is now reclassified as part of this swarm.

#### 4.5.4.3 Random or Floating Events

During the third quarter of FY 2003, we interpret ten random events to have occurred in the monitoring area (The May 6<sup>th</sup> reclassified event changed this from eleven in the report for the third quarter). One was in the basalt, three were in pre-basalt sediments and six were in the crystalline basement.

From April 26<sup>th</sup> through April 27<sup>th</sup>, three small ( $M_c < 1$ ) earthquakes occurred along the Yakima Ridge trend west of the Hanford Site. The first two events were in the pre-basalt sediments and the last event was in the basalt. These events occurred about 3 km east of a similar type event from the second quarter of FY 2003 (February 16, 2003).

An event occurred on May 6<sup>th</sup> and was small ( $M_c$  0.9). It occurred along the badlands anticline (Figure 4.4) near the base of the basalt. This is the same geologic feature that the 15 Rattlesnake Mountain swarm events occurred on beginning on May 6<sup>th</sup>. The swarm events occurred approximately 4 km northwest of this event. This event is plotted on Figure 4.6 with the swarm events; we now have reclassified this event as part of the swarm and not as a random event as it was classified in the third quarter report.

On May 11 and small ( $M_c$  approximately 0) event occurred in the crystalline basement east of the 200 Areas on Hanford.

Two earthquakes occurred near south of Prosser, Washington in May. The May 14<sup>th</sup> event was in the crystalline basement and had a magnitude ( $M_c$ ) of 1.7. The May 29<sup>th</sup> event was in the pre-basalt sediments and had a magnitude ( $M_c$ ) of 1.1. Although both events occurred in the Horse Heaven Hills swarm area, because they were single events and below the basalt, they are classified as random events.

On June 4<sup>th</sup> a small ( $M_c < 1.0$ ) random event occurred in the crystalline basement in the portion of the Horse Heaven Hills (HHH-NW, Figure 4.5) south of Kennewick, Washington. No other events in the past several years have occurred near there.

A very small ( $M_c$  approximately 0) random event occurred in the crystalline basement beneath the Cold Creek syncline on June 23<sup>rd</sup>.

On June 24<sup>th</sup>, a small ( $M_c < 1.0$ ) event occurred in the crystalline basement south of the 200 Areas. This earthquake occurred near two events in the same area on November 4<sup>th</sup> and 5<sup>th</sup>, 2002. All events were in the crystalline basement at about 15 km depth.

The final random event for the third quarter occurred on June 25<sup>th</sup> in the crystalline basement. This event was very small ( $M_c$  approximately 0) and occurred beneath the southeast extension of Rattlesnake Mountain. Three events, October 8, and 28, and December 14, 2002, from the first quarter of FY 2003 occurred near this event. Two were in the crystalline basement and one in the pre-basalt sediments.

#### **4.5.5 Fourth Quarter Earthquakes**

##### **4.5.5.1 Major Anticlinal Ridges**

There were no earthquakes that occurred on major anticlinal ridges during the fourth quarter of fiscal year 2003.

##### **4.5.5.2 Earthquake Swarm Areas**

###### **4.5.5.2.1 Saddle Mountains Swarm Area**

On August 22<sup>nd</sup> a 1.7  $M_c$  earthquake occurred in the basalt north of the Saddle Mountains (Figure 4.5). This earthquake occurred at the same location that earthquakes occurred on October 12, 2002 (1.7  $M_c$ ), October 22, 2002 (2.7  $M_c$ ), March 18, 2003 (1.8  $M_c$ ) and April 3, 2003 (0.3  $M_c$ ).

###### **4.5.5.2.2 Coyote Rapids Swarm Area**

A small (0.9  $M_c$ ) event occurred on August 27<sup>th</sup> in the basalt in the Coyote Rapids swarm area. This event occurred near an event that occurred on October 31, 2002 ( $M_c$  approximately 0).



#### **4.5.5.2.3 Rattlesnake Mountain Swarm Area**

Eleven earthquakes occurred between July 15<sup>th</sup> and September 29<sup>th</sup> in the newly defined Rattlesnake Mountain swarm area (Figure 4.3). The Rattlesnake Mountain swarm area is centered over the northwest extension of the Horse Heaven Hills-NW anticline, locally called the ‘badlands’ anticline (Figure 4.5) that is manifested at the surface as a low amplitude anticline.

These Rattlesnake Mountain swarm events occurred in the same area as previous earthquakes had occurred in the third quarter beginning on May 6<sup>th</sup>. The earthquakes cluster at two general times (Figure 4.6); one cluster occurs in the mid to late June timeframe and the second cluster is in September.

The last event of the quarter (September 29) is actually centered at the intersection of the Badlands anticline, the northwest trending portion of the Horse Heaven Hills and the northeast trending portion of the Horse Heaven Hills. This event is included in with the swarm although it actually occurs several miles southeast of the main swarm events. This brings the total number of earthquakes in the newly defined Rattlesnake Mountain swarm area for FY04 to 27 (this includes the reclassification of the May 6<sup>th</sup> event).

#### **4.5.6 Random Events**

During the fourth quarter of FY 2003, we interpret five events to be random earthquakes. Three random events occurred in the basalt, one occurred in the pre-basalt sediments and three events occurred in the crystalline basement.

The first random event occurred on July 11 near the Hanford 400 Area. An event also occurred here on May 11, 2003 ( $M_c$  approximately 0). This event occurred in the crystalline basement and is not near any known geologic structure.

A random event occurred on July 13<sup>th</sup> in the crystalline basement near the Potholes Reservoir. This event was small (0.5  $M_c$ ) and not near any known geologic structure.

The third random event of the quarter occurred on July 19<sup>th</sup> and was in the crystalline basement. This event was small ( $M_c$  approximately 0) and occurred near events that occurred on October 30, 2002 (approx 0  $M_c$ ), November 20, 2002 (two events, 0.1 and approx 0.0  $M_c$ ), and February 12, 2003 (0.8  $M_c$ ). All events were in the crystalline basement.

The next random event was small ( $M_c$  approximately 0) and occurred on July 23<sup>rd</sup>. It was in the pre-basalt sediments beneath Yakima Ridge where a previous event occurred on February 16, 2003 (0.1  $M_c$ ) in the pre-basalt sediments.

The final random event for the quarter occurred on August 7<sup>th</sup> on the south flank of the Horse Heaven Hills. This event was in the basalt and had a magnitude of 1.0  $M_c$ . Two previous events occurred there on October 6, 2002 (0.7 and 0.6  $M_c$ ). Both earthquakes were in the pre-basalt sediment.

## **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 FY 2003 Triggers of the Hanford SMA Network**

The Hanford strong motion accelerometer network was triggered by the large Alaska earthquake of 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 data in areas at the Hanford Site that have high densities of people and/or facilities containing hazardous materials in order to insure the Hanford Site is in compliance with DOE Order 420.1, "Facility Safety." The network also allows Hanford Seismic Monitoring to support Hanford Site emergency services organizations in complying with DOE Order G 420.1-1, Section 4.7, "Emergency Preparedness and Emergency Communications," by providing area ground motion data in the event of an earthquake on the Hanford Site. This section summarizes the capabilities of the Seismic Monitoring Team in the event of an earthquake at Hanford.

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

Historically, only a few facilities at the Hanford Site had instruments to provide data on peak ground accelerations or any type of ground motion. The present SMA instruments were located so that if an earthquake occurred, ground motion data would be readily available to assess the damage at the 100-K Area, the 200 East and West Areas, the 300 and 400 Area facilities, which have the greatest concentration of people and also contain hazardous materials (Moore and Reidel 1996).

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

In the event of an earthquake such as the 2001 Nisqually earthquake, building managers, emergency directors, and engineers can obtain ground motion data recorded by the SMA network from the Seismic Monitoring Team in the Sigma V Building. This is done through the Hanford Site Emergency Services Organization. Normal hours of operation for the PNNL Seismic Monitoring Project are between 6 a.m. and 4:30 p.m., Monday through Friday. If a SMA is triggered, the Seismic Monitoring Team will download events that were recorded and determine the peak ground accelerations. This information is then passed on to Hanford Emergency Services personnel where the facility engineers can use the data to determine if the ground motion exceeded, is equal to, or is less than the building design. This, along with assessments from trained engineers, allows the facility manager to make a rapid and cost-effective determination on whether a building is safe to re-occupy or should not be used until it has been inspected in more detail. Buildings that have designs exceeding the recorded ground motion could be put back into service very quickly; buildings with designs that are very close to or less than measured ground motion could be given priority for onsite damage inspections.

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