PNNL-14953-1

Pacific Northwest National Laboratory
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U.S. Department of Energy

Annual Hanford Seismic Report for Fiscal Year 2004

Pacific Northwest National Laboratory
Hanford Seismic Assessment Team

December 2004

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

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

Printed in the United States of America

Available to DOE and DOE contractors from the
Office of Scientific and Technical Information, P.O. Box 62, Oak Ridge, TN 37831:
prices available from (615) 576-8401.

Available to the public from the National Technical Information Service,
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Pacific Northwest National Laboratory
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Summary

The Hanford Seismic Assessment Program provides an uninterrupted collection of high-quality raw and processed seismic data from the Hanford Seismic Network for the U.S. Department of Energy and its contractors. The Hanford Seismic Assessment Team 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 Assessment Team.

For the Hanford Seismic Network, there were 1,629 triggers during fiscal year 2004 of which 63 were local earthquakes. The largest earthquake was a magnitude 2.8 on February 28, 2004. This event occurred in the basalt on the south slope of the Horse Heaven Hills anticline near Wallula Gap. Stratigraphically, 25 earthquakes occurred in the Columbia River basalt (approximately 0-5 km), 20 earthquakes were in the pre-basalt sediments (approximately 5-10 km), and 18 earthquakes were in the crystalline basement (approximately 10-25 km). Geographically, 34 earthquakes occurred in swarm areas, 8 earthquakes were on major geologic structures, and 21 earthquakes were classified as random events.

Fourth quarter earthquakes are reported in the annual report. For the Hanford Seismic Network, there were 554 triggers during the fourth quarter, of which 31 were earthquakes. The largest earthquake during the fourth quarter was a magnitude 1.4 event on August 17, 2004; this event occurred in the Horse Heaven Hills earthquake swarm area and was located in the pre-basalt sediments. Stratigraphically, a total of 14 earthquakes occurred in the Columbia River basalt (approximately 0-5 km), 13 earthquakes were in the pre-basalt sediments (approximately 5-10 km), and 4 earthquakes were in the crystalline basement (approximately 10-25 km). Geographically, 17 earthquakes occurred in swarm areas, 7 earthquakes were on major geologic structures, and 7 earthquakes were classified as random events.

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
HSAP	Hanford Seismic Assessment Program
HSAT	Hanford Seismic Assessment Team
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) 2004. The report also includes seismic activity from the fourth quarter (July 1, 2004 to September 30, 2004). This report locates seismicity within the monitored region and provides the geologic interpretations of the earthquakes.

1.1 Mission

The principal mission of the Hanford Seismic Assessment Program (HSAP) 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 assessment, 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 HSAP 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, the HSAP 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. The Hanford Seismic Assessment Team (HSAT) 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 HSAP with necessary regional input for the seismic hazards analysis at the Hanford Site. These seismic data are used to support Hanford Site contractors for waste management activities, Natural Phenomena Hazards assessments, and engineering design and construction.

1.2 History of Monitoring Seismic Activity at Hanford

Assessing seismic activity at the Hanford Site was initiated in 1969 by the 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. Assessment of seismic activity 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, all seismic assessment activities were transferred to the Pacific Northwest National Laboratory (PNNL).[1]

The Hanford Strong Motion Accelerometer (SMA) network was constructed during 1997 and came on-line in May 1997. It operated 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 SMA sites resumed on November 20, 1999, and has operated continuously since that time.

1.3 Documentation and Reports

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

[1] Pacific Northwest National Laboratory is operated by Battelle Memorial Institute for the U.S. Department of Energy.

2.0 Network Operations

2.1 Seismometer Sites

The seismic assessment network consists of two designs of equipment and sites: seismometer sites and SMA sites. Seismometer sites are designed to locate earthquakes and determine their magnitude and hypocenter location. SMA sites are designed to measure ground motion acceleration.

The HSN and the EWRN consist of 41 sensor sites. Most sites are in remote locations and require solar panels and batteries for power. The HSN uses 22 sites (Table 2.1 and Figure 2.1) and the EWRN uses 35 sites (Table 2.2 and Figure 2.2); both networks share 16 sites. The networks have 45 combined data channels because Gable Butte and Frenchman Hills East are three-component sites, each consisting of one vertical, one north-south horizontal, and one east-west horizontal data channel. Both networks use 15 additional telemetry relay sites. Data from all sites or relays are transmitted to the Sigma V Building, Richland, Washington.

Table 2.1. Seismic Stations in the Hanford Seismic Network

The first column is the three-letter seismic station designator. The latitude and longitude, elevation above sea level in meters, and the full station name follow this. The locations of the stations are all in Washington; locations were derived from a Global Positioning System (GPS).

Station	Latitude Deg. Min. N	Longitude Deg. Min. W	Elevation (m)	Station Name
BEN	46N31.13	119W43.02	340	Benson Ranch
BRV	46N49.12	119W59.47	920	Black Rock Valley
BVW	46N48.66	119W52.99	670	Beverly
CRF	46N49.50	119W23.22	189	Corfu
ET3	46N34.64	118W56.25	286	Eltopia Three
*FHE	46N57.11	119W29.82	455	Frenchman Hills East
*GBB	46N36.49	119W37.62	177	Gable Butte
GBL	46N35.92	119W27.58	330	Gable Mountain
H2O	46N23.75	119W25.38	158	Water
LOC	46N43.02	119W25.85	210	Locke Island
MDW	46N36.79	119W45.66	330	Midway
MJ2	46N33.45	119W21.54	146	May Junction Two
OT3	46N40.14	119W13.98	322	Othello Three
PRO	46N12.73	119W41.15	550	Prosser
RED	46N17.92	119W26.30	366	Red Mountain
RSW	46N23.67	119W35.48	1,045	Rattlesnake Mountain
SNI	46N27.85	119W39.60	312	Snively Ranch
VT2	46N58.04	120W58.95	1,270	Vantage Two
WA2	46N45.32	119W33.94	244	Wahluke Slope
WIW	46N25.76	119W17.26	128	Wooded Island
WRD	46N58.20	119W08.69	375	Warden
YPT	46N02.93	118W57.73	325	Yellepit

*Three-component station.

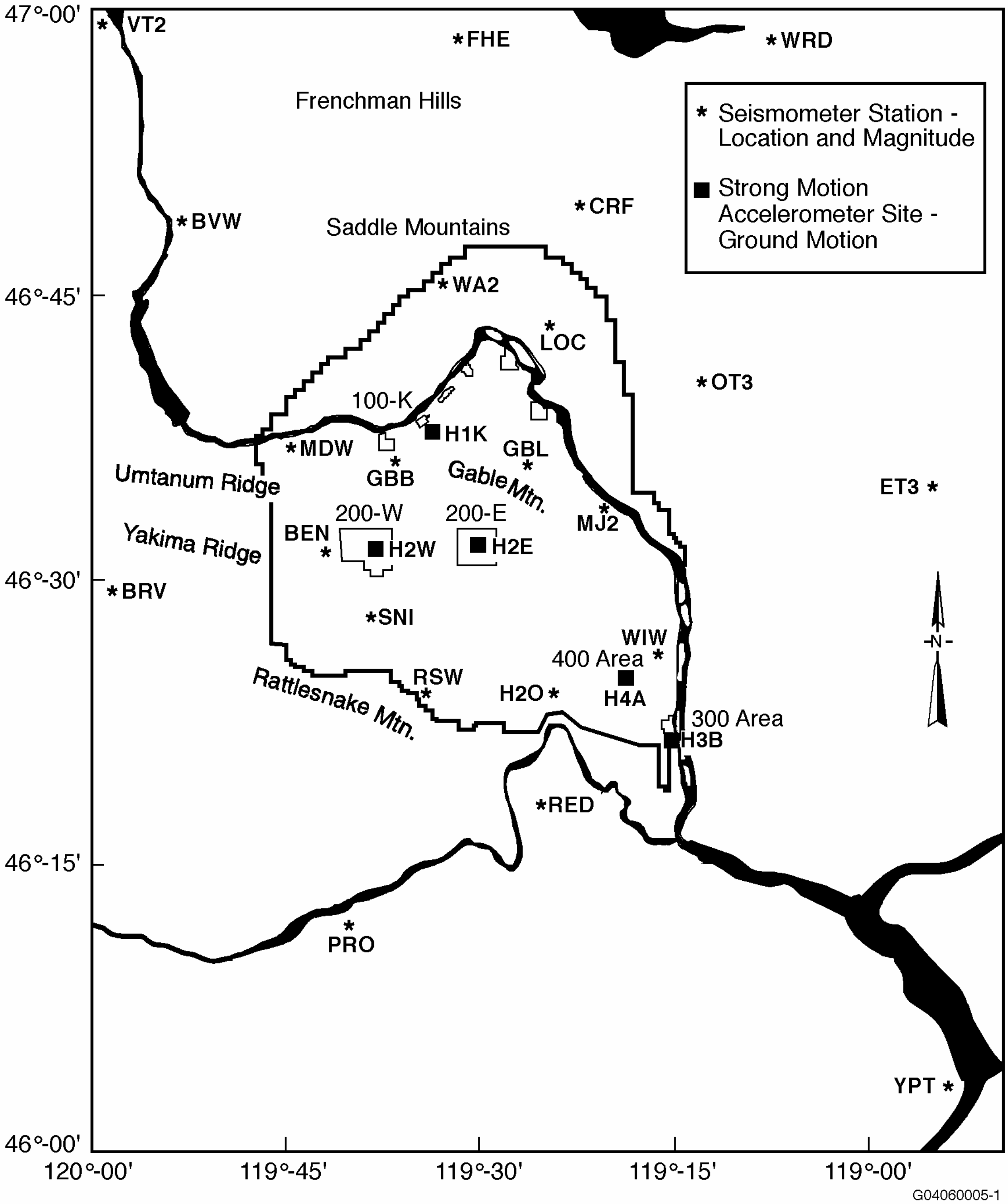

Figure 2.1. Locations of Seismograph Stations and Strong Motion Accelerometer Sites in the Hanford Seismic Network (see Table 2.1 for description of locations)

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.

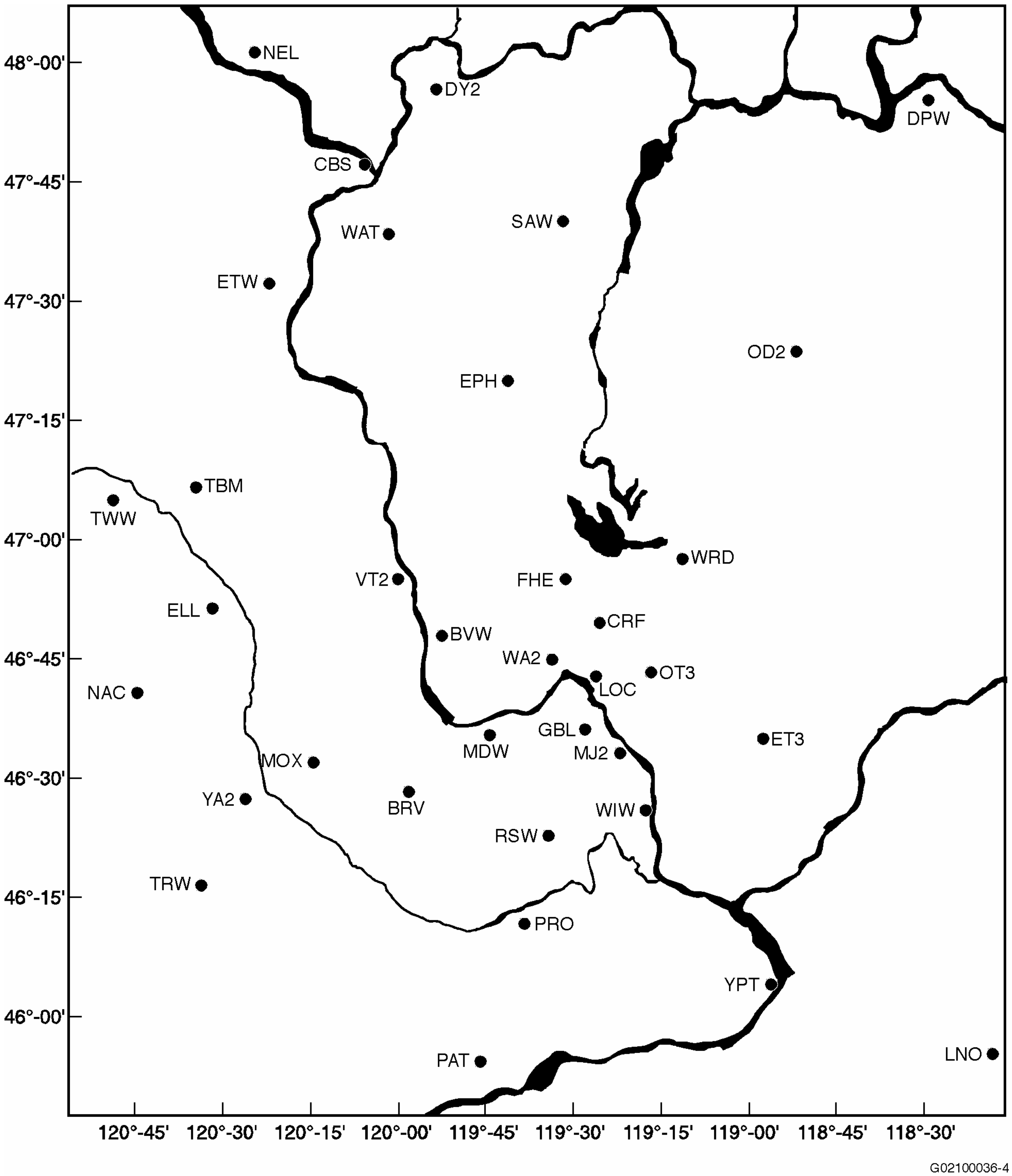

Figure 2.2. Locations of Seismograph Stations in the Eastern Washington Regional Network (see Table 2.2 for location descriptions)

2.1.1 Station Maintenance

The HSN's maintenance records for the seismic sensor and relay sites are on file in the HSAP 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 United States 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 the Hanford Site 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 3.0). Although the two systems are practically identical, there is enough granularity (signal-to-noise) in the trigger timing that they sometimes record exclusive events. In nearly all cases, these exclusive triggers are "false" triggers, not earthquakes or quarry blasts (i.e., from acoustic sources). The remainders are from barely detectable, small signals from regional and teleseismic earthquakes.

The types and numbers of triggers recorded during FY 2004 by the seismic acquisition system are summarized in Table 2.3.

2.2 Strong Motion Accelerometer Sites

2.2.1 Location

The Hanford Site 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 200-West Area SMA was moved to a new location during the fourth quarter because an equipment parking area was constructed around the site, which was causing contin-uous triggers rendering the SMA useless. The new site is about 1 km west of the old site and came on-line during October 2004. With the termination of the Fast Flux Test Reactor, plans are being made to terminate the 400 Area site and move the instrument to a new location.

Table 2.3. Acquisition System Recorded Triggers

Event Type	First Quarter	Second Quarter	Third Quarter	Fourth Quarter	Total	Description
South-Central Washington	12	23	35	52	122	Seismic events in south-central Washington and north-central Oregon that triggered the HSN.
Regional	31	23	27	60	141	Seismic events in the Western United States and Canada.
Teleseism	51	55	57	59	222	Seismic events at farther distances from around the world.
Total Earthquake Events	94	101	119	171	485	Total number of earthquake triggers.
Local Explosions	2	6	6	6	20	Quarry blasts, typically, within the 46-47 degrees north latitude and 119-120 degrees west longitude.
Local Earthquakes	3	13	16	31	63	Seismic events within the 46-47 degrees north latitude and 119-120 degrees west longitude.
Total Triggers	283	319	473	554	1,629	

Table 2.4. Free-Field Strong Motion Accelerometer Sites

Site	Site ID	Location	Latitude Longitude Elevation
100-K Area	H1K	South of K Basins outside 100 Area fence lines.	46° 38.51’ 119° 35.53’ 152 m
200 East Area	H2E	East of B Plant; north of 7th Street and east of Baltimore Avenue.	46° 33.58’ 119° 32.00’ 210 m
200 West Area	H2W	West of Plutonium Finishing Plant (PFP) and 200-West Area tree barrier.	46° 33.11’ 119° 38.64’ 201 m
300 Area	H3A	South end of 300 Area inside fence lines (NE 1/4, SW 1/4, Sec. 11, T10N, R28E).	46° 21.83’ 119° 16.55’ 119 m
400 Area	H4A	500 ft from fence line on east side of facility and north of parking area).	46° 26.13’ 119° 21.30’ 171 m

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 the Hanford Site are 200-East and West Areas, 100-K Area, the Fast Flux Test Facility (400 Area), and the 300 Area. 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 waste treatment plant is being constructed in 200-East Area. The 100-K Area contains the K Basins where spent fuel rods from the N Reactor were stored prior to encapsulation, but sludge from eroded fuel rods still remains. 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-gal galvanized drums. Each solar panel has a maximum 42-watt output. The two 30-gal 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 internet service provider. This CDPD system, along with the solar regulator, is housed in a small enclosure mounted at the rear of the solar array. The enclosure also serves as a junction box for all cabling used in the system. 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 FY 2005. The new system is currently being installed and debugged. Once the new system has been shown to be fully functional, the CDPD system will be terminated.

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 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 HSAP's 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.[1] 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

[1] The GPS antenna is mounted on the enclosure at the rear of the solar array.

Table 2.5. Instrument Parameters for the Kinematrics 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	24-bit resolution @ 200 samples/second
Digital Output	Real-time, RS-232 Output Stream
Seismic Trigger	
Filter	0.1 - 12.5 Hz
Trigger level	0.10% - 0.20% g [b]
Alarm (call-out) Threshold	Not activated
Pre-Event Memory	10 sec
Post-Event Time	40 sec

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

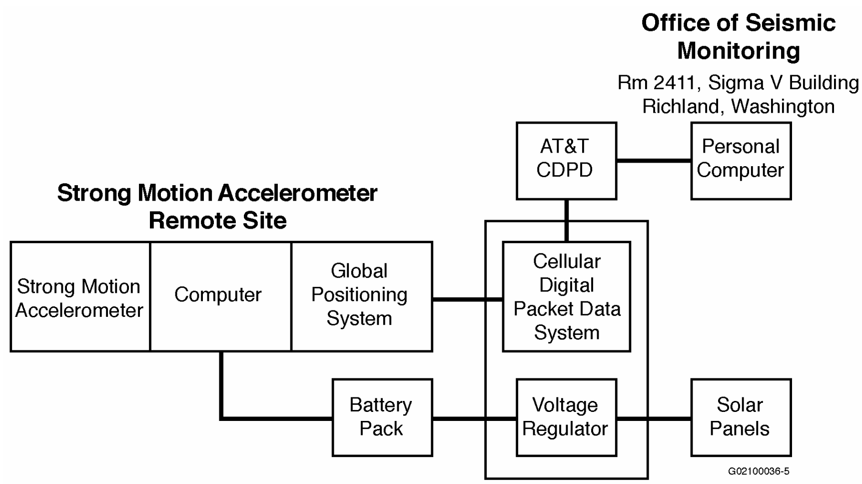

Figure 2.3. Schematic Diagram of a Strong Motion Accelerometer Installation

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 HSAT.

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 0.10% of the full-scale range of 2.0 g (g is the acceleration of gravity, 9.8 m/s^2 or 32 ft/s^2) or 0.001 g. Threshold trigger levels are adjusted to trigger infrequently on the noise sources (e.g., vehicles, sonic booms) near each site. This provides 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

The HSAT uses an interactive program, XPED, developed at UW 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^o - 47^o N, 119^o - 120^o W) are reported in this report (Table 3.1). 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 3.2. This model does not include a surficial layer for the Hanford or Ringold Formation 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.

3.3 Quality Factors (Q)

XPED assigns a two-letter **Quality factor** (Table 3.1) that indicates the general reliability of the solution (**A** is best quality, **D** is worst). Similar quality factors are used by the USGS for events located with the computer program HYPO71. The first letter of the quality code is a measure of the hypocenter quality based primarily on 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**.

Table 3.1. Local Seismic Data, October 1, 2003 to September 30, 2004

Event ID	Type	Date	Time	Latitude	Longitude	Depth	Mag	NS/NP	Gap	Dmin	RMS	Q	Location
03102019535	P	03/10/20	19:54:21.27	46N16.26	119W23.58	2.89		12/12	127	4	0.06	AB	7.9 km W of Richland
03102417325	P	03/10/24	17:32:20.31	46N16.81	119W23.33	2.19		8/08	123	4	0.09	AB	7.5 km W of Richland
03110605544		03/11/06	05:55:09.61	46N47.16	119W41.67	0.75	1.7	19/19	86	10	0.10	AC	17.7 km NNW of 100-K Area
03111512093		03/11/15	12:10:04.22	46N40.03	119W26.79	15.49	0.6	21/23	61	5	0.14	AA	11.9 km ENE of 100-K Area
03123108183		03/12/31	08:18:58.64	46N24.86	119W15.48	0.02	0.8	10/12	173	2	0.07	AC	6.5 km NNE of 300 Area
04010315183		04/01/03	15:18:56.73	46N27.23	119W35.22	14.50	-0.3	9/14	98	5	0.04	AB	12.2 km SSE of 200 West
04010800280		04/01/08	00:28:29.91	46N29.25	119W37.45	21.14	0.1	9/11	69	3	0.13	AA	7.9 km S of 200 West
04011204331		04/01/12	04:33:37.57	46N12.92	119W34.73	8.48	-0.2	5/08	217	8	0.03	AD	14.6 km E of Prosser
04011204332		04/01/12	04:33:51.59	46N12.99	119W35.31	9.43	-0.3	5/08	214	7	0.06	AD	13.9 km E of Prosser
04011205014		04/01/12	05:02:07.60	46N12.63	119W34.75	10.42	0.7	9/12	223	8	0.07	AD	14.6 km E of Prosser
04011213592		04/01/12	13:59:45.44	46N41.02	119W44.21	21.87	0.2	6/09	225	8	0.07	AD	11.7 km WNW of 100-K Area
04020620295	P	04/02/06	20:30:09.91	46N54.19	119W05.15	0.04		8/09	194	8	0.19	BD	10.5 km NE of Othello
04021223124		04/02/12	23:12:56.14	46N42.12	119W57.05	6.53	0.1	5/06	195	13	0.13	AD	27.9 km WNW of 100-K Area
04022019504	P	04/02/20	19:51:07.06	46N15.75	119W23.25	3.25		4/04	266	5	0.00	AD	7.7 km WSW of Richland
04022216545		04/02/22	16:55:16.39	46N27.37	119W37.51	16.71	0.0	12/14	128	2	0.05	AB	11.4 km S of 200 West
04022418195	P	04/02/24	18:20:03.20	46N55.12	119W06.89	0.46		4/04	219	6	0.19	CD	11.0 km NNE of Othello
04022801241		04/02/28	01:24:21.79	46N01.00	119W06.39	8.45	1.2	10/11	163	11	0.16	BC	20.8 km S of Kennewick
04022802012		04/02/28	02:01:47.74	46N01.79	119W01.86	0.03	2.8	28/32	156	5	0.70	DC	20.6 km SSE of Kennewick
04031718214	P	04/03/17	18:22:05.81	46N19.77	119W40.82	0.40		10/10	167	9	0.15	AC	15.2 km NNE of Prosser
04031722134	X	04/03/17	22:14:07.89	46N14.33	119W43.07	0.40		7/07	216	3	0.15	BD	5.2 km NE of Prosser
04032204062		04/03/22	04:06:40.37	46N41.96	119W51.05	0.47	0.8	7/07	198	11	0.08	AD	20.5 km WNW of 100-K Area
04032603000		04/03/26	03:00:25.44	46N49.81	119W28.67	14.16	0.0	11/11	117	6	0.11	AB	22.8 km NNE of 100-K Area
04032719073		04/03/27	19:07:56.50	46N37.52	119W57.66	5.57	0.4	12/14	126	15	0.28	BC	25.9 km WNW of 200 West
04032919330	P	04/03/29	19:33:26.94	46N13.71	119W45.62	0.46		5/05	258	6	0.12	BD	2.5 km NNE of Prosser
04040219003	P	04/04/02	19:00:55.96	46N13.71	119W43.64	1.75		11/11	173	3	0.09	AC	3.9 km NE of Prosser
04040520411		04/04/05	20:41:40.39	46N29.46	119W20.87	0.49	0.2	6/06	152	7	0.10	AC	N of 400 Area

Table 3.1. (contd)

Event ID	Type	Date	Time	Latitude	Longitude	Depth	Mag	NS/NP	Gap	Dmin	RMS	Q	Location
04041421212	P	04/04/14	21:21:48.32	46N56.11	119W31.67	0.05		7/07	205	3	0.14	AD	28.3 km SW of Moses Lake
04042111191		04/04/21	11:19:37.04	46N23.86	119W27.46	10.73	-0.1	9/14	91	2	0.08	AB	8.7 km WSW of 400 Area
04042302191		04/04/23	02:19:40.89	46N17.82	119W38.82	0.05	1.1	9/11	148	9	0.14	AC	13.7 km NE of Prosser
04042617382		04/04/26	17:38:48.08	46N18.72	119W32.08	7.55	0.2	11/11	226	7	0.07	AD	19.0 km W of Richland
04043016134		04/04/30	16:14:13.86	46N29.32	119W21.02	0.48	0.9	9/09	119	7	0.07	AB	6.0 km N of 400 Area
04043016594		04/04/30	17:00:07.39	46N29.17	119W20.87	0.23	0.8	10/10	120	7	0.10	AB	5.7 km N of 400 Area
04050605480		04/05/06	05:48:21.47	46N19.63	119W41.38	0.05	0.3	11/15	250	10	0.12	AD	14.7 km NNE of Prosser
04050808261		04/05/08	08:26:34.09	46N34.11	119W31.73	21.65	-0.5	7/08	125	6	0.04	AB	1.1 km NNE of 200 East
04050918435		04/05/09	18:44:21.52	46N29.27	119W20.29	0.04	-0.1	6/08	160	7	0.15	AC	6.1 km NNE of 400 Area
04050918451		04/05/09	18:45:41.52	46N29.37	119W20.46	3.11	-0.4	4/05	158	7	0.13	CD	6.2 km NNE of 400 Area
04051701132		04/05/17	01:13:47.16	46N32.11	119W43.42	18.03	0.5	12/16	108	1	0.15	AB	7.0 km WSW of 200 West
04052022500	X	04/05/20	22:50:33.55	46N16.29	119W23.62	3.60		9/09	127	4	0.07	AB	8.0 km W of Richland
04052423224	P	04/05/24	23:23:03.91	46N46.44	119W45.72	4.78		11/11	144	10	0.04	AC	19 km NW of 100-K Area
04052615035		04/05/26	15:04:15.60	46N51.83	119W34.14	13.41	-0.2	11/11	133	11	0.10	AB	24.8 km N of 100-K Area
04052615051		04/05/26	15:05:33.18	46N51.74	119W34.30	12.61	-0.3	7/08	133	11	0.06	AB	24.6 km N of 100-K Area
04052615055		04/05/26	15:06:05.05	46N51.86	119W34.71	13.17	-0.1	10/12	136	11	0.4	AC	24.8 km N of 100-K Area
04052615083		04/05/26	15:08:49.26	46N51.87	119W35.42	11.25	-0.2	7/08	141	12	0.6	AC	24.8 km N of 100-K Area
04052615121		04/05/26	15:12:25.55	46N51.51	119W31.90	14.82	-0.5	7/07	161	10	0.04	AC	24.6 km NNE of 100-K Area
04060118550	P	04/06/01	18:55:32.42	46N15.98	119W23.24	3.61		10/10	232	5	0.05	AD	7.6 km WSW of Richland
04062001523	P	04/06/20	01:52:55.16	46N45.84	119W20.66	16.31		4/05	298	8	0.02	AD	15.3 km WSW of Othello
04071106402		04/07/11	06:40:45.55	46N00.57	119W06.14	10.00	1.3	17/18	119	11	0.25	BB	21.6 km S of Kennewick
04072510103		04/07/25	10:10:55.62	46N44.00	119W36.08	15.33	-0.5	14/20	78	3	0.11	AA	10.2 km N of 100-K Area
04072819081	P	04/07/28	19:08:28.19	46N01.10	119W12.51	20.23		6/06	147	19	0.54	DC	21.6 km SSW of Kennewick
04072821280		04/07/28	21:28:26.76	46N10.26	119W08.58	0.02	1.1	11/11	155	19	0.22	BC	3.9 km SSW of Kennewick
04080119071		04/08/01	19:07:40.28	46N26.73	119W37.79	17.05	-0.1	10/14	159	3	0.06	AC	12.5 km S of 200 West
04080703222		04/08/07	03:23:23.09	46N53.96	119W56.75	0.32	0.8	7/07	147	8	0.28	BC	7.2 km SSE of Vantage

Table 3.1. (contd)

Event ID	Type	Date	Time	Latitude	Longitude	Depth	Mag	NS/NP	Gap	Dmin	RMS	Q	Location
04080806332		04/08/08	06:33:48.33	46N43.83	119W31.37	2.32	-0.1	8/10	102	4	0.09	AB	11.4 km NNE of 100-K Area
04080812492		04/08/08	12:49:45.74	46N43.90	119W31.82	3.51	0.2	15/20	81	3	0.15	BA	11.2 km NNE of 100-K Area
04080813320		04/08/08	13:32:31.36	46N43.66	119W31.72	0.03	0.3	14/16	100	4	0.11	AB	10.9 km NNE of 100-K Area
04080822293		04/08/08	22:30:02.44	46N29.37	119W19.90	5.59	-0.4	5/08	168	7	0.11	AD	6.4 km NNE of 400 Area
04081201502		04/08/12	01:50:48.37	46N29.13	119W20.75	7.75	-0.1	7/09	151	7	0.12	AC	5.7 km N of 400 Area
04081215283	P	04/08/12	15:28:56.15	46N08.96	119W10.87	0.54		9/09	186	20	0.08	AD	7.5 km SW of Kennewick
04081222191		04/08/12	22:19:34.70	46N10.43	119W31.85	5.14	0.9	14/16	256	12	0.12	AD	18.7 km ESE of Prosser
04081719121		04/08/17	19:12:37.37	46N04.88	119W37.55	7.83	0.7	10/11	169	15	0.08	AC	17.8 km SE of Prosser
04081719253		04/087/17	19:25:57.06	46N04.16	119W38.31	8.53	0.5	7/08	315	16	0.10	BD	18.3 km SSE of Prosser
04081719442		04/08/17	19:44:51.33	46N05.12	119W37.77	9.26	1.4	16/20	140	14	0.13	BC	17.3 km SE of Prosser
04081720151		04/08/17	20:15:36.76	46N04.87	119W36.97	7.47	0.6	10/12	172	15	0.10	BC	18.3 km SE of Prosser
04081720155		04/08/17	20:15:03.70	46N04.15	119W37.60	7.64	0.5	5/07	314	16	0.04	AD	18.8 km SE of Prosser
04081720435		04/08/17	20:44:14.78	46N05.21	119W37.54	7.98	0.9	10/11	171	14	0.07	AC	17.3 km SE of Prosser
04081721244		04/08/17	21:25:05.41	46N05.20	119W37.68	8.09	1.0	12/14	168	14	0.06	AC	17.2 km SE of Prosser
04081810593		04/09/18	10:59:56.73	46N03.59	119W37.46	6.67	0.2	4/07	315	17	0.05	AD	19.8 km SE of Prosser
04081905103		04/08/19	05:11:01.05	46N03.57	119W37.32	6.90	0.4	5/07	315	17	0.07	BD	19.9 km SE of Prosser
04082321405	P	04/08/23	21:41:07.68	46N12.64	119W14.40	0.43		8/08	140	18	0.34	CC	9.0 km SSE of Richland
04082622153	P	04/08/26	22:15:46.27	46N20.02	119W25.71	0.43		4/04	177	4	0.18	BD	11.9 km WSW of 300 Area
04090118210		04/09/01	18:21:26.73	46N38.10	119W50.19	0.02	-0.2	5/06	315	6	0.07	AD	17.5 km WNW of 200 West
04090121270		04/09/01	21:27:27.93	46N39.21	119W51.60	0.41	-0.4	6/06	321	8	0.15	CD	20.1 km WNW of 200 West
04090216380		04/09/02	16:38:26.52	46N40.97	119W53.68	2.83	0.1	5/06	343	12	0.17	CD	23.2 km WNW of 100-K Area
04090217554	P	04/09/02	17:56:07.02	46N09.06	119W10.79	0.02		12/12	185	20	0.13	AD	7.3 km SW of Kennewick
04090219360		04/09/02	19:36:26.11	46N40.00	119W54.13	0.49	0.5	5/06	337	12	0.16	BD	23.5 km W of 100-K Area
04090723433		04/09/07	23:43:54.77	46N40.10	119W52.33	0.52	0.3	6/06	324	10	0.07	BD	21.3 km W of 100-K Area
04090919155		04/09/09	19:16:18.64	46N37.65	119W51.37	8.35	-0.3	4/05	314	7	0.13	CD	18.4 km WNW of 200 West
04091819523		04/09/18	19:53:01.46	46N10.09	119W34.06	20.14	1.1	19/25	148	10	0.10	AC	16.1 km ESE of Prosser

Table 3.1. (contd)

Event ID	Type	Date	Time	Latitude	Longitude	Depth	Mag	NS/NP	Gap	Dmin	RMS	Q	Location
04092018190		04/09/20	18:19:25.57	46N33.38	119W51.64	0.98	-0.1	5/05	279	9	0.03	AD	17.1 km W of 200 West
04092118262	P	04/09/21	18:26:46.59	46N08.24	119W10.40	8.55		7/07	160	19	0.25	BC	8.3 km SSW of Kennewick
04092717493		04/09/27	17:49:57.21	46N33.91	119W51.86	4.83	0.2	4/05	290	9	0.07	BD	17.4 km W of 200 West
04092719180		04/09/27	19:18:30.76	46N32.30	119W54.25	0.41	0.5	4/05	299	13	0.14	BD	20.5 km W of 200 West
04092720522		04/09/27	20:52:44.05	46N33.44	119W56.41	0.03	0.1	4/04	309	15	0.12	BD	23.2 km W of 200 West

Explanation of Table 3.1

Event ID:	The Earthworm Recording System creates the identification number. XPED uses the year, month, day, and time to create a unique number for each event.
Type:	P is Probable Blast; X is Confirmed Blast; F is Felt Earthquake; S is surficial event (rockslide, avalanche) and not an explosion or tectonic earthquake; blank is local earthquake.
Date:	The year and day of the year in Universal Time Coordinated (UTC). UTC is used throughout this report unless otherwise indicated.
Time:	The origin time of the earthquake given in UTC. To covert UTC to Pacific Standard Time, subtract eight hours; to Pacific Daylight Time, subtract seven hours.
Latitude:	North latitude, in degrees and minutes, of the earthquake epicenter.
Longitude:	West longitude, in degrees and minutes, of the earthquake epicenter.
Depth:	The depth of the earthquake in kilometers (km).
Mag:	The magnitude is expressed as Coda-Length magnitude M_c, an estimate of local magnitude M_L (Richter 1958). If magnitude is blank, a determination was not made.
NS/NP:	Number of stations/number of phases used in the solutions.
Gap:	Azimuthal gap. The largest angle (relative to the epicenter) containing no stations.
DMIN:	The distance from the earthquake epicenter to the closest station
RMS:	The root-mean-square residual (observed arrival times minus the predicted arrival times) at all stations used to locate the earthquake. It is only useful as a measure of quality of the solution when five or more well-distributed stations are used in the solution. Good solutions are normally characterized by RMS values of less than about 0.3 seconds.
Q:	The Quality Factors indicate the general reliability of the solution/location (A is best quality, D is worst). See Section 3.3 of this report, "Quality Factors."

Table 3.2. 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

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 the Hanford Site and the surrounding area are:

- The Miocene Columbia River Basalt Group (CRBG)
- Pre-basalt sediments of Paleocene, Eocene, Oligocene, and Miocene age
- The crystalline basement consisting of two layers composed of Precambrian and Paleozoic craton
- Mesozoic accreted terranes.

4.2 Geologic Structure Beneath the Monitored Area

Between the late 1950s and the early 1980s, deep boreholes were drilled for hydrocarbon exploration in the Columbia Basin. These boreholes provided accurate measurements of the physical properties of the CRBG and the pre-basalt sediments (Reidel et al. 1989, 1994), but the thickness of the pre-basalt sediments and nature of the crystalline basement are still poorly understood. The difference between the thicknesses listed in Table 4.1 and the thicknesses of the crustal layers in the velocity model in Table 3.2 reflect data specific to UW's crustal velocity model for eastern Washington. Table 4.1 is derived from Reidel et al. (1994) and was developed for the geologic interpretation in this report. The thicknesses of these units are variable across the monitored area. Table 4.1 summarizes the approximate thickness at the borders of the monitored area.

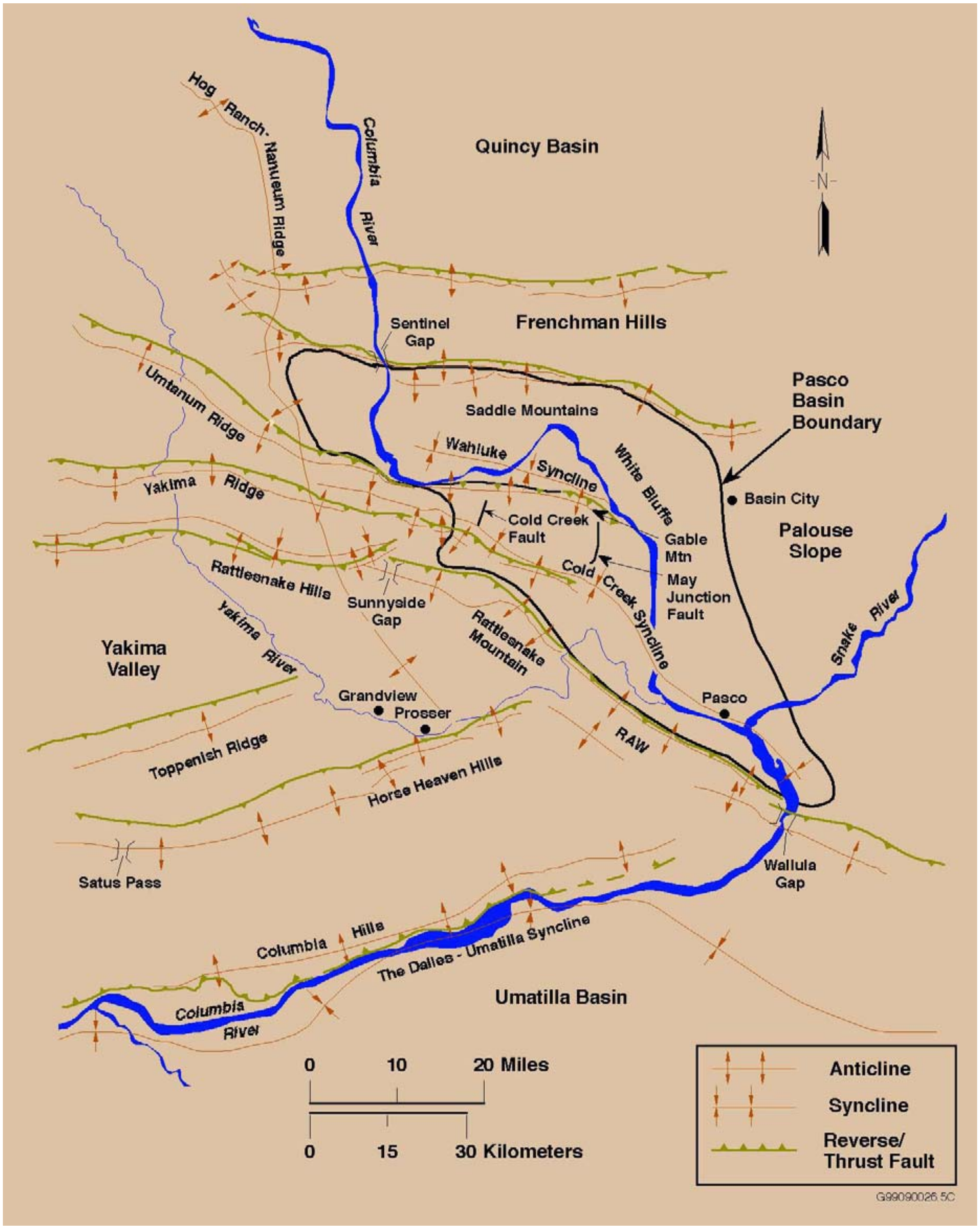

Figure 4.1. Tectonic Map of Columbia Basin Showing Major Seismic Source Structures

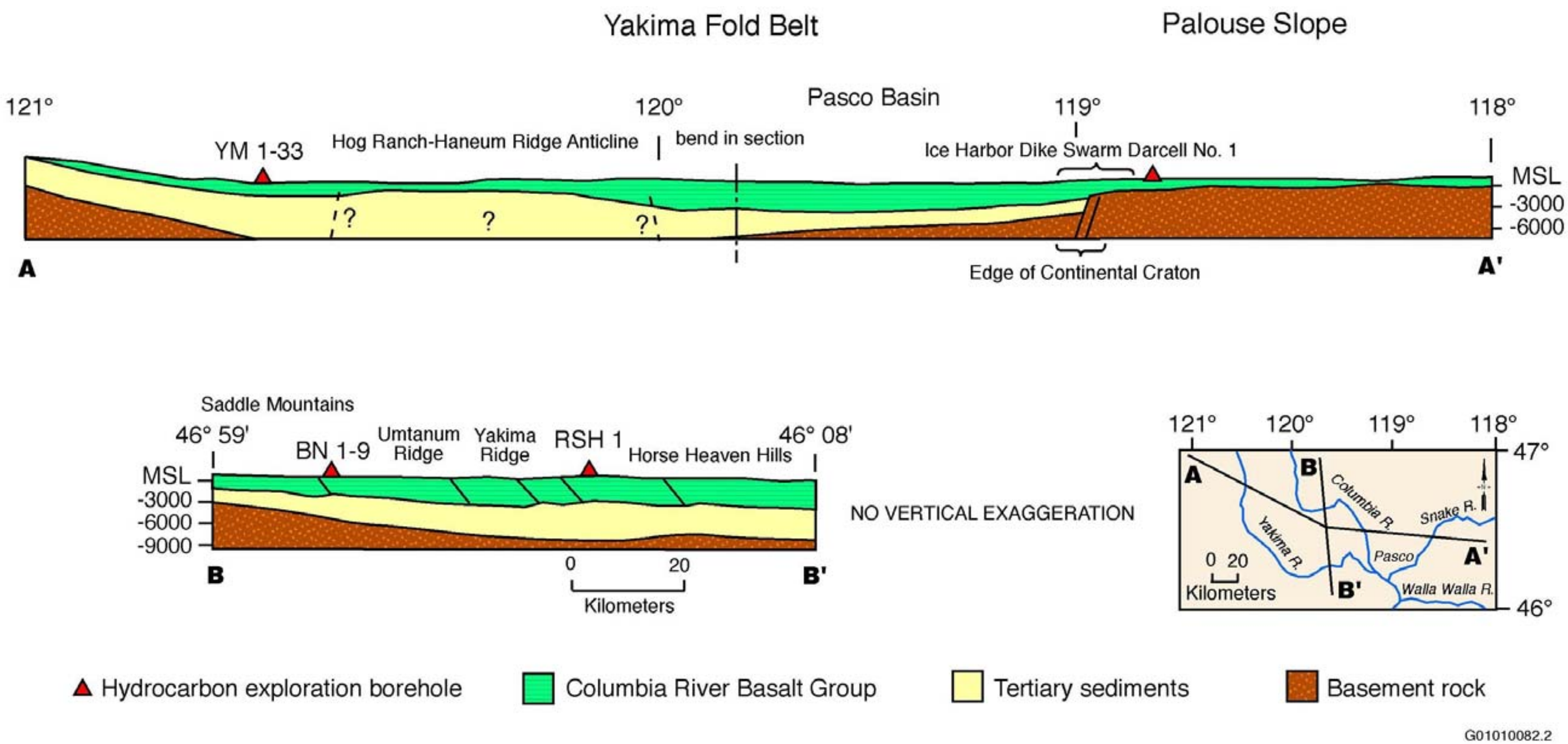

Figure 4.2. Geologic Cross Sections Through the Columbia Basin (Reidel et al. 1994)

Table 4.1. Thicknesses of Stratigraphic Units in the Monitoring Area

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

The thickness of the basalt and the pre-basalt sediments varies as a result of different tectonic environments. The western edge of the North American craton (late Precambrian/Paleozoic continental margin and Precambrian craton) is located in the eastern portion of the monitored area (Reidel et al. 1994). The stratigraphy on the craton consists of CRBG overlying crystalline basement; the crystalline basement is continental crustal rock that underlies much of the western North America. The stratigraphy west of the craton consists of 4 to 5 km of CRBG overlying at least 6 km of pre-basalt sediments. This, in turn, overlies accreted terranes of Mesozoic age. The area west of the craton was subsiding during the Eocene, Oligocene, and Miocene while accumulating great thickness of pre-CRBG sediments. Continued subsidence in this area during the eruption of the flood basalts resulted in thicker CRBG west of the craton 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 to 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 (Figure 4.3). These clusters consist of a series of small shocks with no outstanding principal event. Swarms occur over a period of days or months and the events may number into the hundreds and then quit, only to start again at a later date. This differs from the sequence of foreshocks, mainshock, and trailing-off aftershocks that have the same epicenter or are associated with the same fault system. In the past, swarms were thought to occur only in the CRBG. Most swarm areas are in the basalt but swarm events also appear to occur in all geologic layers. However, typically a swarm event at a specific time is usually restricted to one layer. There are at least nine earthquake swarm areas that we recognize in the monitoring area but this list will be updated as new swarm areas develop. The Saddle Mountains, Wooded Island, Wahluke, Coyote Rapids, Rattlesnake Mountain, and Horse Heaven Hills swarm areas are typically active at one time or another during the year. The other earthquake swarm areas are active less frequently.

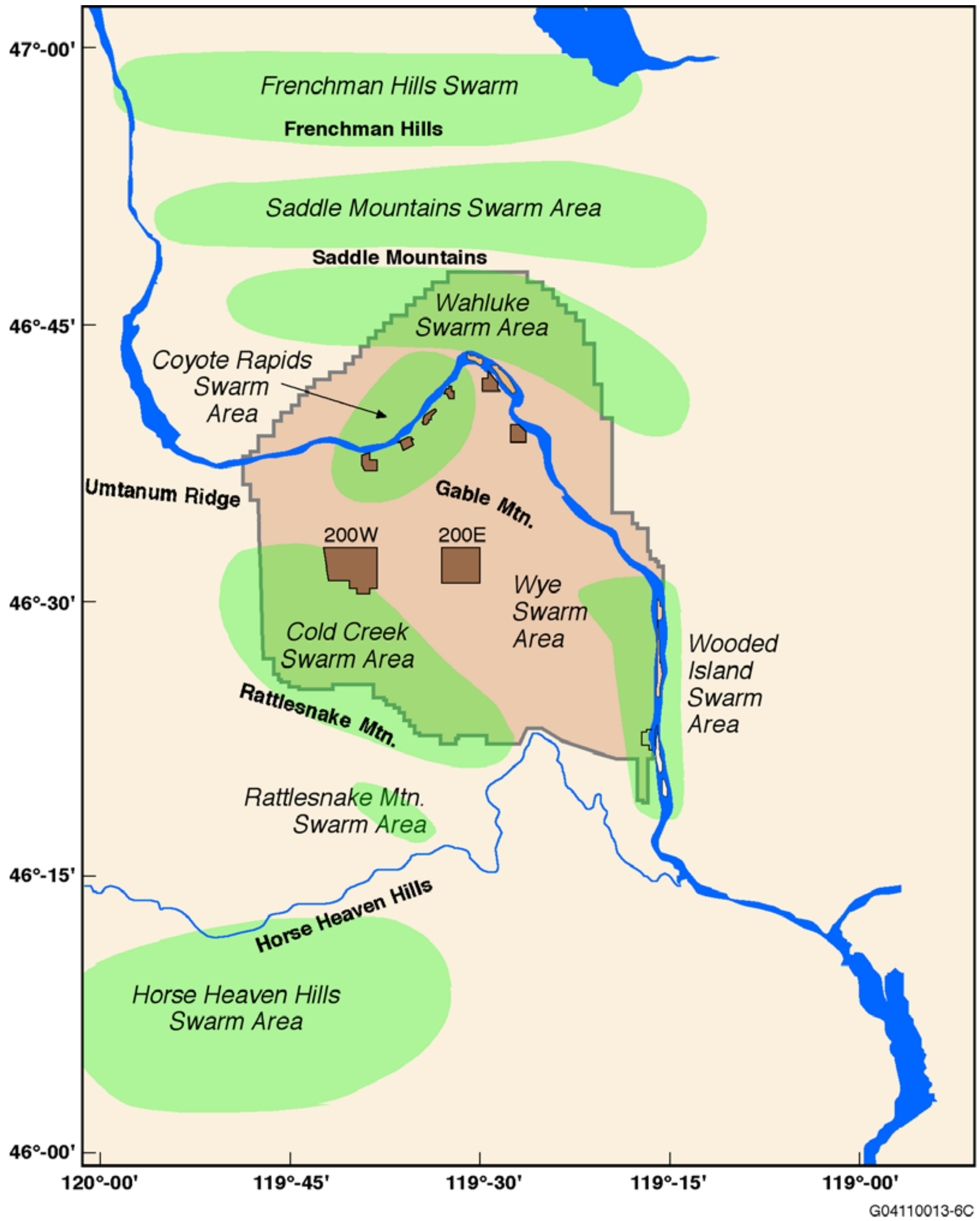

Figure 4.3. Locations of Known Earthquake Swarm Areas in the Hanford Monitoring Network Area

- **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 interpretation classifies it as a random event for purposes of seismic design and vibratory ground motion studies.

- **Basement source structures**. Studies (Geomatrix 1996) suggest that major earthquakes can originate in tectonic structures in the crystalline basement. Because little is known about geologic structures in the crystalline basement beneath the Hanford Site, earthquakes cannot be directly tied to a mapped fault. Earthquakes occurring in the crystalline basement without known sources are treated as random events.

- **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 FY 2004 are listed in Table 4.2.

Table 4.2. Number of Local Earthquakes Occurring in Stratigraphic Units

Unit	First Quarter	Second Quarter	Third Quarter	Fourth Quarter	FY 2004
Basalt	2	2	7	14	25 (40%)
Pre-Basalt Sediments	-	6	1	13	20 (32%)
Crystalline Basement	1	5	8	4	18 (28%)
Total	3	13	16	31	63

4.5 Tectonic Activity

4.5.1 Annual Summary

During FY 2004, there were 63 earthquakes that occurred within the Hanford Seismic Monitoring Network (Table 4.3; Figure 4.4). Twenty-five (40%) events occurred in the CRBG; 20 (32%) occurred in the pre-basalt sediments; and 18 (28%) events occurred in the crystalline basement. Eight (13%) events are interpreted as occurring along major geologic structures; 34 events are interpreted as occurring in earthquake swarms (54%); and 21 (33%) events are interpreted as random events.

Table 4.3. Summary of Earthquake Locations for FY 2004

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 2004
Geologic Structure		1	-	-	7	8 (13 %)
Swarm Areas	Frenchman Hills	-		-	-	-
	Saddle Mountains/ Royal Slope	1	1	5	-	7 (11%)
	Coyote Rapids	-	-	-	4	4 (6%)
	Wahluke Slope	-	-	-	-	-
	Wooded Island	-	-	-	-	-
	Cold Creek	-	-	-	-	-
	Wye	-	-	5	2	7 (11%)
	Rattlesnake Mt.	-	-	2		2 (3%)
	Horse Heaven Hills	-	3	-	11	14 (22%)
	Total for swarms	1	4	12	17	34 (54%)
Random Events		1	9	4	7	21 (33%)
Total for all earthquakes		3	13	16	31	63

4.5.2 First Quarter

4.5.2.1 Depth of Earthquakes

During the first quarter of FY 2004, there were only three earthquakes in the monitoring area. Two of the earthquakes occurred in the CRBG, no earthquakes occurred in the underlying pre-basalt sediments, and one earthquake occurred in the crystalline basement.

4.5.2.2 Location of Earthquakes

During the first quarter of FY 2004, one event occurred in the Saddle Mountains swarm area; one event was classified as having some association with major geologic structures and one event was classified as a random event. Earthquakes typically are classified as random if they occur below the CRBG. 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.

4.5.2.2.1 Major Anticlinal Ridges

During the first quarter of FY 2004, we interpret one seismic event to have occurred on a major geologic structure. On November 11, a 1.7 M_c event occurred in the basalt on the south flank of the Saddle Mountains (Figure 4.5).

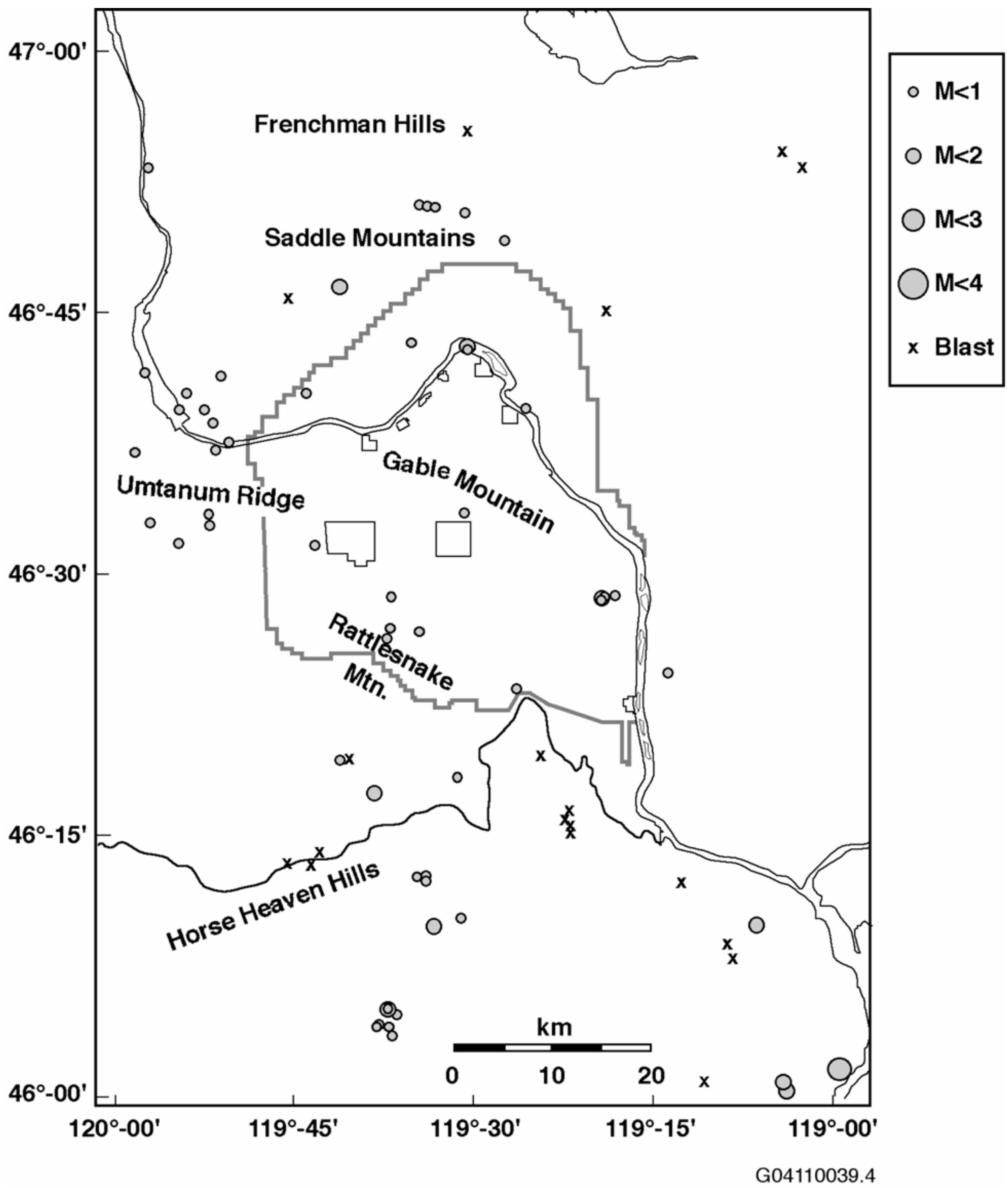

Figure 4.4. Location of all Earthquakes that Occurred in the Monitoring Area Between October 1, 2003 and September 30, 2004

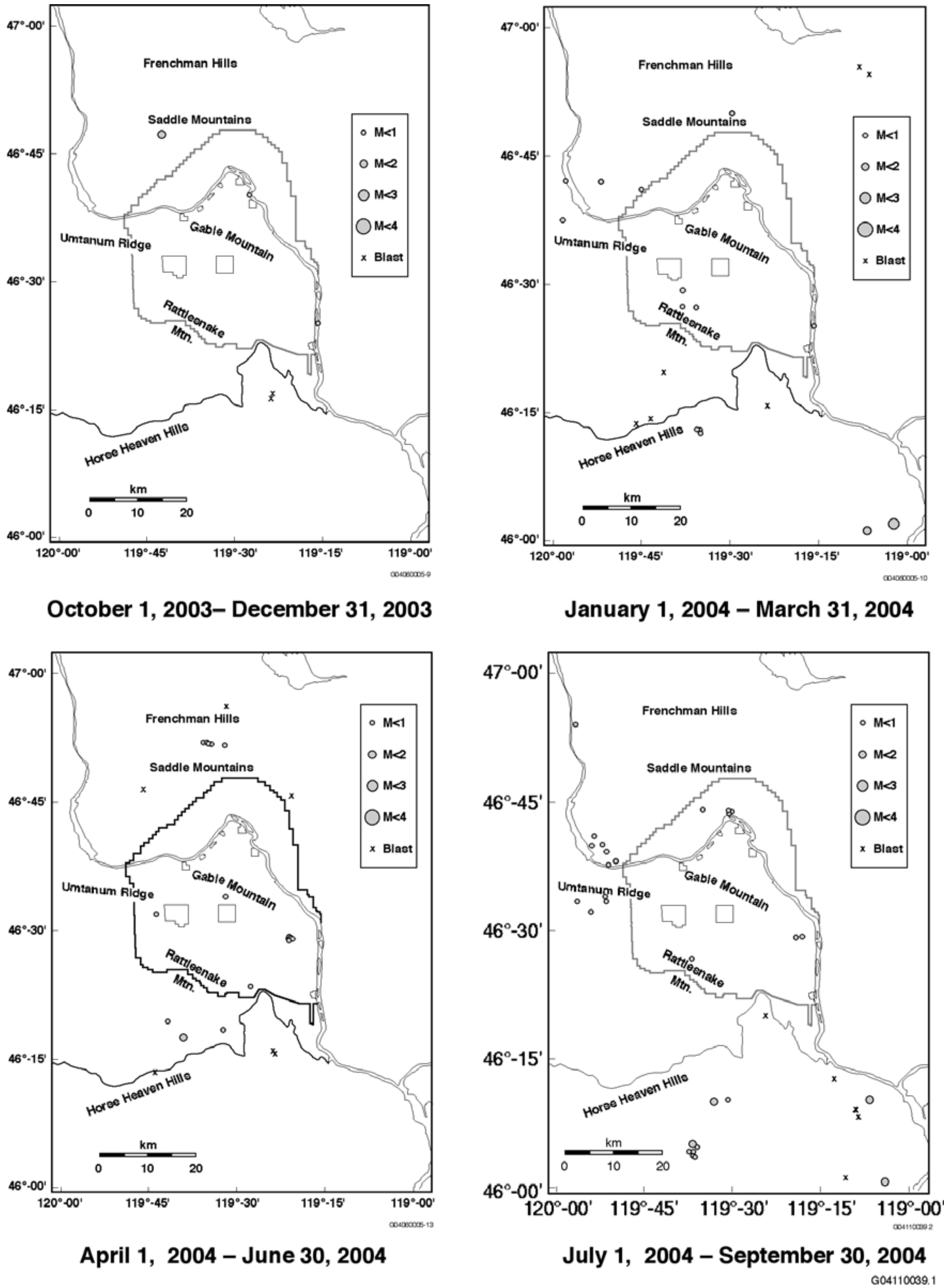

Figure 4.5. Distribution of all Earthquakes in the Monitoring Area Between October 1, 2003 and September 30, 2004 by Fiscal Year Quarter

4.5.2.2.2 Earthquake Swarm Areas

During the first quarter of FY 2004, we interpret one seismic event to have occurred in the Wooded Island swarm area (Figure 4.5). This was a small event (0.8 M_c) that occurred on December 31 in the basalt below the White Bluffs.

4.5.2.2.3 Random or Floating Events

During the first quarter of FY 2004, we interpret one random event to have occurred in the monitoring area. It occurred in the crystalline basement. On November 15, 2003, a small (M_c<1) earthquake occurred along the Columbia River east of the 100-D Area and under Locke Island.

4.5.3 Second Quarter

4.5.3.1 Depth of Earthquakes

During the second quarter, there were 13 earthquakes in the monitoring area. Two (15.4%) events occurred in the basalt, six (46.1%) occurred in the pre-basalt sediment, and five (38.5%) occurred in the crystalline basement.

4.5.3.2 Location of Earthquakes

During the second quarter, there were four (31%) earthquakes in swarm areas; no event was classified as being associated with a major geologic structure; and nine (69%) events were classified as random events.

4.5.3.2.1 Major Anticlinal Ridges

We interpret no second quarter seismic events to have occurred on a major geologic structure in the monitoring area.

4.5.3.2.2 Earthquake Swarm Areas

We interpret four seismic events to have occurred in swarm areas (Figure 4.5).

Saddle Mountains Swarm Area. An earthquake occurred in the Saddle Mountains swarm area (Figure 4.5) on March 26, 2004. It was a very small earthquake (approximately 0 M_c) that occurred in the crystalline basement near the intersection of the Smyrna Bench and Saddle Gap segments. Although most of the events in the Saddle Mountains earthquake swarm area have been in the basalt, we now recognize that swarms may also occur in deeper layers.

Horse Heaven Hills Swarm Area. On January 12, 2004, three small events (<1 M_c) occurred in the upper part of the crystalline basement on the south flank of the Horse Heaven Hills. These events occurred where three events had occurred in FY 2003 (October 6, 2002 and August 7, 2003).

4.5.3.2.3 Random or Floating Events

We interpret nine random events to have occurred during the second quarter. Two were in basalt, three in pre-basalt sediment, and four were in the crystalline basement.

The first random event occurred on January 3 in the Benson Ranch syncline. Two other events occurred there in the second quarter; the next was January 8 and the last was February 22. This is in the Cold Creek swarm area and another event in the crystalline basement occurred there in FY 2003 (February 18, 2003). Because it appears that this area is experiencing repeated events in the crystalline basement, these may be reclassified as swarm events in the future.

During the second quarter, three small events occurred in the Wahluke syncline northwest of Hanford. On January 12, a small (0.2 M_c) event occurred in the crystalline basement in the Wahluke syncline area north of Umtanum Ridge. Another small event (0.1 M_c) occurred on February 12 in the pre-basalt sediment just west of there. The third event occurred on March 22, just to the east of the January 12 event. This event was also small (0.8 M_c) but occurred in the basalt.

On February 28, two events occurred about 20 km south of Kennewick on the south slope of the Horse Heaven Hills. The two events were separated by about 4 km. The first event (1.2 M_c) was the westernmost one and occurred in the pre-basalt sediment. The second event was larger (2.8 M_c) and occurred in the basalt. No known geologic structure is near either event.

The last random event for the quarter occurred on March 27 beneath Umtanum Ridge in the upper portion of the pre-basalt sediment. This was a small event (0.4 M_c) and occurred where an event had occurred on February 12, 2002, February 14, 2002, and February 12, 2003.

4.5.4 Third Quarter Summary

4.5.4.1 Depth of Earthquakes

During the third quarter of FY 2004, there were 16 earthquakes. Seven (44%) earthquakes occurred in the CRBG; one (6%) earthquake occurred in the underlying pre-basalt sediments; and eight (50%) earthquakes occurred in the crystalline basement.

4.5.4.2 Location of Earthquakes

During the third quarter of FY 2004, 12 (75%) events occurred in swarm areas; 4 events (25%) were classified as random events and no earthquake is interpreted to have occurred along a major geologic structure.

4.5.4.2.1 Earthquake Swarm Areas

Saddle Mountains Swarm Area. During the third quarter of FY 2004, we interpret five seismic events to have occurred in the Saddle Mountains swarm area (Figure 4.5). All events occurred in the Smyrna Bench area and were on the same day, May 26. These earthquakes, however, were deep (>11 km) and occurred in the crystalline basement.

Rattlesnake Mountain Swarm Area. Two earthquakes occurred in the Rattlesnake Mountain swarm area (Figure 4.5). The first one occurred on April 23 and the second occurred on May 6. Both were small, (1.1 M_c and 0.3 M_c, respectively) and occurred in the basalt.

Wye Swarm Area. Five earthquakes occurred in the Wye Barricade depression along the Cold Creek syncline. We call this area the Wye swarm area (Figure 4.3) because it fits the typical pattern of an earthquake swarm in the Columbia Basin. All five earthquakes were small (<1 M_c) and occurred in the basalt. The first event occurred on April 5; this was followed by two events on April 30 with the last two events occurring on May 9.

4.5.4.2.2 Random or Floating Events

During the third quarter of FY 2004, we interpret four random events to have occurred in the Hanford monitoring area (Figure 4.5).

The first random event occurred on April 21 and was in the crystalline basement. That event was small (approximately 0 M_c) and occurred on the north of Rattlesnake Mountain.

On April 26, a small (<1 M_c) earthquake occurred under the south limb of Rattlesnake Mountain in the pre-basalt sediments. This occurred 10 km east of the Rattlesnake Mountain earthquake swarm which has had some past events in the pre-basalt sediment.

On May 8, a small (approximately 0 M_c) event occurred in the crystalline basement several kilometers north of the 200-East Area and south of Gable Mountain.

The last random event for the quarter occurred on May 17. The earthquake occurred in the crystalline basement under Yakima Ridge, about 16 km west of 200-West Area. This event was less than 1 M_c.

4.5.5 Fourth Quarter Summary

4.5.5.1 Depth of Earthquakes

During the fourth quarter of FY 2004, 31 earthquakes occurred in the monitoring area. Fourteen (45%) earthquakes occurred in the CRBG, 13 (42%) earthquakes occurred in the underlying pre-basalt sediments, and 4 (13%) earthquakes occurred in the crystalline basement.

4.5.5.2 Location of Earthquakes

Seventeen (54%) earthquakes occurred in swam areas; seven earthquakes (23%) are interpreted to have occurred along major geologic structures; and seven events (23%) were classified as random events.

4.5.5.2.1 Major Anticlinal Ridges

During the third quarter of FY 2004, we interpret seven seismic events to have occurred on a major geologic structure.

On July 28, a small (1.1 M_c) earthquake occurred in the basalt at one of the doubly plunging anticlines along the Rattlesnake Mountain-Wallula Alignment (RAW; Figure 4.1). Because of its seismic pattern, location, and shallow depth, this earthquake is interpreted to be associated with this geologic structure. Three quarry blasts occurred there this year (August 12, September 2, and September 21) and were probably related to the Zintel Canyon flood control dam and adjacent quarry.

Between September 1 and September 9, six events occurred on or near Umtanum Ridge. All but one of the events were shallow (basalt) and all were less than 1 M_c. The last event occurred in the pre-basalt sediments. The first two events occurred on September 1 within 3 hours of each other. The first event was located on Umtanum Ridge and the second event was about 1 km to the northwest. Both are classified as occurring on Umtanum Ridge because of their shallow depth and proximity to the structure. On September 2, two more events occurred about 20 hours later but were farther to the northwest than the first two earthquakes. These two events are classified as random because they were not on Umtanum Ridge. The September 9 event was midway between the events of September 1 and September 2 and also classified as a random event. The last event was on September 9 and occurred along Umtanum Ridge but was deeper (8.4 km) and, thus, classified as a random event. Although these six earthquakes are classified differently, there appears to be some commonality between them as in an earthquake swarm. The location uncertainty, however, is poor for these events, and may be causing the differences in location. This area will be monitored in the future for continuation of this pattern or a change in the pattern.

On September 20, a small event (>1 M_c) occurred in the basalt along Yakima Ridge. Three more events occurred near there within 3 hours of each other on September 27. The three later events were also shallow (basalt) and had a magnitude less than 1 M_c. Because of their locations and shallow depths, these events are classified as having some association with Yakima Ridge. It is interesting to note that the Yakima Ridge events occurred directly south of the Umtanum Ridge events.

4.5.5.2.2 Earthquake Swarm Areas

Coyote Rapids Swarm Area. Four earthquakes are interpreted to have occurred in the Coyote Rapids earthquake swarm area. Three were in basalt and one was in the crystalline basement; all events were magnitude near magnitude 0. The first event occurred on July 25 and was in the crystalline basement. The three other events occurred on August 8 and were in the basalt. The first event that was in the crystalline basement was about 2 km west of the three events.

Wye Swarm Area. Two earthquakes occurred in the Wye Barricade swarm area. The first event was on August 8 and the second event was on August 12. Both events were approximately 0 M_c and occurred in the pre-basalt sediments. Five events occurred at this same location during the third quarter; the first event occurred on April 5; this was followed by two events on April 30 with the last two events occurring on May 9. All were in the pre-basalt sediments.

Horse Heaven Hills Swarm Area. Eleven earthquakes occurred in the Horse Heaven Hills swarm area. The first event occurred on August 12, followed by eight events on August 17, and one event on August 19. The last event occurred on September 18. The largest event was 1.4 M_c on August 18 with most events having a magnitude less than 1 M_c. All events except for the last event were in the pre-basalt sediment. The last event was in the crystalline basement. In addition, the first and the last events were clustered about 10 km north of the other events. Three second quarter (January 12) events also occurred at this northern location. They were in the crystalline basement. The main cluster of events farther south occurred where three events had occurred in FY 2003 (October 6, 2002 and August 7, 2003).

4.5.5.2.3 Random or Floating Events

The first earthquake that we classify as a random event occurred on July 11 on the south flank of the Horse Heaven Hills, south of Kennewick, Washington. This event was deep (10 km) and had a magnitude of 1.3. It occurred adjacent to an earthquake that occurred on near the same depth (9 km) that had a magnitude of 1.2 in the second quarter.

On August 1, a small (>1 Mc) earthquake occurred in the Snively Basin area along the northwestern extent of the RAW trend. This earthquake occurred in the crystalline basement and is classified as a random event.

The third random event of the quarter occurred on August 7. It was a small event (0.8 Mc) and occurred in the basalt between the Saddle Mountains and Frenchman Hills. There are no known geologic structures where that earthquake occurred.

On September 2, two small random (>1 M_c) earthquakes occurred in the basalt northwest of Umtanum Ridge. Then on September 9, another small (>1 M_c) earthquake occurred midway between the two events of September 1 that occurred on Umtanum Ridge (Section 4.5.5.2.1) and the September 2 earthquakes. On September 9, an earthquake occurred along Umtanum Ridge, which was deeper (8.4 km) and, thus, also classified as a random event. These six earthquakes are discussed together in Section 4.5.5.2.1 because there appears to be some weak temporal association (similar to an earthquake swarm). These earthquake locations are not well controlled by the available station distribution.

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 2004 Triggers of the Hanford SMA Network

The Hanford SMA network did not trigger from a seismic event during the FY 2004.

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 the HSAP to support Hanford Site emergency services organizations in complying with DOE Order G 420.1-1, Section 4.7, "Emergency Preparedness and Emergency Communications," by providing area ground motion data in the event of an earthquake on the Hanford Site. This section summarizes the capabilities of the HSAT 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, and the 300 and 400 Area facilities, which have the greatest concentration of people and also contain hazardous materials (Moore and Reidel 1996).

Many facilities at the Hanford Site have undergone various degrees of seismic analysis either during design or during 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 re-occupied 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 HSAT in the Sigma V Building. This is done through the Hanford Site Emergency Services Organization. Normal hours of operation for the HSAP are between 6 a.m. and 4:30 p.m., Monday through Friday. If a SMA is triggered, the HSAT 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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