Pacific Northwest National Laboratory

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U.S. Department of Energy

Hanford Annual First Quarter Seismic Report, Fiscal Year 1998: Seismicity on and Near the Hanford Site, Pasco Basin, Washington

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under Contract DE-AC06-76RLO 1830

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**Hanford Annual First Quarter Seismic Report,
Fiscal Year 1998: Seismicity On and Near the
Hanford Site, Pasco Basin, Washington**

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MASTER

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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 (HSN) for the U.S. Department of Energy and its contractors. The staff 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 an earthquake on the Hanford Site.

The HSN and the Eastern Washington Regional Network (EWRN) consist of 41 individual sensor sites and 15 radio relay sites maintained by the Hanford Seismic Monitoring staff. The operational rate for the first quarter of FY98 for stations in the HSN was 98.5%. The operational rate for the first quarter of FY98 for stations of the EWRN was 99.1%. For the first quarter of FY98, the acquisition computer triggered 184 times. Of these triggers 23 were local earthquakes: 7 in the Columbia River Basalt Group, and 16 in the crystalline basement. The geologic and tectonic environments where these earthquakes occurred are discussed in this report.

The most significant earthquakes this quarter were a series of six events which occurred in the Cold Creek Depression (approximately 4 km SW of the 200 West Area), between November 6 and November 11, 1997. All events were deep (> 15 km) and were located in the crystalline basement. The first event was the largest, having a magnitude of $3.49 M_c$. Two events on November 9, 1997 had magnitudes of 2.81 and $2.95 M_c$, respectively. The other events had magnitudes between 0.7 and $1.2 M_c$.

During this quarter, the largest earthquake to occur near the 200 Areas was recorded. The $3.49 M_c$ earthquake near 200 West Area is the largest event ever located on the Hanford Site south of the Columbia River. Although this event was not felt at 200 West Area, a slightly smaller event ($3.3 M_c$) at a depth of 1 km was felt in the 300 Area and surrounding area in 1995. Prior to the 1995 the last significant earthquake near the Hanford Site occurred in 1971 in the Coyote Rapids swarm area. It had a $3.8 M_c$ and was located near the 100-N Area.

TERMS

BWIP	Basalt Waste Isolation Project
CRBG	Columbia River Basalt Group
UTC	Universal Time, Coordinated
DOE	U.S. Department of Energy
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
PNNL	Pacific Northwest National Laboratory
RAW	Rattlesnake Mountain-Wallula Alignment
USGS	United States Geological Survey
UW	University of Washington

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1.0 INTRODUCTION

1.1 Background

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 and expanded the network. In 1979 the Basalt Waste Isolation Program (BWIP) became responsible for collecting seismic data for the Site as part of site characterization. Rockwell Hanford Operations followed by Westinghouse Hanford Company (WHC), Geosciences Group, operated the local network and were the contract technical advisors for the Eastern Washington Regional Network (EWRN) operated and maintained by the UW. Funding ended for BWIP in December 1988. Seismic Monitoring and responsibility for the University of Washington contract were then transferred to WHC's Environmental Division. Maintenance responsibilities for the EWRN were also assigned to WHC. Major upgrades were made to the sites for the next two years. Effective October 1, 1996, all of the Hanford Seismic Monitoring workscope, personnel, and associated contracts were transferred to the Pacific Northwest National Laboratory (PNNL¹).

Hanford Seismic Monitoring is part of PNNL's Applied Geology and Geochemistry Group, Energy Technology Division. The Seismic Monitoring Project operates, maintains, and analyzes data from the Hanford Seismic Network (HSN), and maintains the Site's historical seismic database. These activities fulfill U.S. Department of Energy, Richland Operations Office requirements and orders. Hanford Seismic Monitoring also maintains the EWRN. The UW uses the data from the EWRN and other seismic networks in the Northwest to provide the Seismic Monitoring team with necessary regional input for the seismic hazards analysis at the Hanford Site.

1.2 Purpose

Hanford Seismic Monitoring is tasked to provide an uninterrupted collection of high-quality raw seismic data from the HSN located on and around the Hanford Site. These unprocessed data are permanently archived. Hanford Seismic Monitoring also 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. Local earthquakes are defined as earthquakes that occur between 46 degrees and 47 degrees north latitude and between 119 degrees and 120 degrees west longitude. The data are used by the Hanford Site contractors for waste management activities, Natural Phenomena Hazards assessments, and engineering design and construction. In addition, Hanford Seismic Monitoring works with Hanford Site Emergency Services Organization to provide assistance in the event of an earthquake on the Hanford Site.

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

1.3 Documentation

Hanford Seismic Monitoring 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.

2.0 NETWORK OPERATIONS

2.1 Monitoring Stations

The HSN and the EWRN consists of 41 sensor sites. Most sites are in remote locations and require solar panels and batteries for power. Sixteen sites are shared by both networks; the HSN uses 20 sites (Table 1 and Fig. 1) and the EWRN uses 35 sites (Table 2 and Fig. 2). The networks have 42 combined data channels because Gable Butte is a three-component sites, consisting of one vertical, one north-south horizontal, and one east-west horizontal data channel. Both networks use 15 additional telemetry relay sites. All station data links pass through at least one of these relay sites. Some data links transit as many as three relay sites. The last section of the data link for all channels is commercial telephone lines. Three to eight channels are multiplexed per telephone line going to the Seismic Monitoring office in the 337 building. A major outage is considered to be a failure of the HSN data recording computer or three or more data channels.

Table 1. Seismic Stations in the Hanford Seismic Network

The first column is the three-letter seismic station designator. This is followed by the latitude and longitude, elevation above sea level in meters; and the full station name. An asterisk before the three-letter designator means it is a three-component station. The locations of the stations are all in Washington unless otherwise indicated; locations were derived from a Global Positioning Satellite 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
*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
MI2	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 Mt.
SNI	46N27.85	119W39.60	312	Snively Ranch
WA2	46N45.32	119W33.94	244	Wahluke Slope
WG4	46N01.85	118W51.34	511	Wallula Gap Four
WIW	46N25.76	119W17.26	128	Wooded Island
WRD	46N58.20	119W08.69	375	Warden

Figure 1. Locations of Seismograph Stations in the Hanford Seismic Network.
(See Table 1 for description of locations.)

Table 2. Seismic Stations in the Eastern Washington Regional Network.

The first column is the three-letter seismic station designator. This is followed by the latitude and longitude, elevation above sea level in meters; and the full station name. An asterisk before the three-letter designator means it is a three-component station. The locations of the stations are all in Washington unless otherwise indicated; locations were determined from a Global Positioning Satellite 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 Washington
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
GBL	46N35.92	119W27.58	330	Gable Mountain
LNO	45N52.31	118W17.11	771	Linton Mt., 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 Mt.
SAW	47N42.10	119W24.03	701	St. Andrews
SNI	46N27.85	119W39.60	312	Snively Ranch
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
WG4	46N01.85	118W51.34	511	Wallula Gap Four
WIW	46N25.76	119W17.26	128	Wooded Island
WRD	46N58.20	119W08.69	375	Warden
YA2	46N31.60	120W31.80	652	Yakima Two

Figure 2. Locations of Seismograph Stations in the Eastern Washington Regional Network.
(See Table 2 for location descriptions.)

2.2 Station Maintenance

The HSN's maintenance records for the seismic sensor and relay sites are filed in the Hanford Seismic Monitoring office. Periods of major outage are addressed in this report. Table 3 shows the operational percentage time for each network. Periods of major outages are addressed in this report. Table 3 shows the operational percentage time for each network. Winter conditions cause malfunctions due to icing of antennas, snow on solar panels, or long periods of overcast skies. Access to some sites within the EWRN may be impossible during winter months because of travel restrictions or severe damage to access roads.

Table 3. Seismic Channel Operational Time (%).

Network	October	November	December	First Quarter	FY98(1)
Hanford	95.68%	100%	99.73%	98.46%	98.46%
Regional	97.37%	100%	99.83%	99.06%	99.06%

Notes: The Hanford Seismic Network's goal is 98%.

The Eastern Washington Regional Network's goal is 97%.

The quarter period is October 1, 1997 through December 31, 1997.

The cause of the relatively low percentages during October is due to the shutdown of the Black Rock Valley (BRV) site during the move at Sunnyside BPA requested by BPA and the conversion of BRV to a solar powered/radio telemetry site. Battery failure accounted for all the outage during December.

2.3 Data Acquisition

Seismic data are recorded at the 337 building. The Hanford Seismic Network is divided into subnetworks using weighted factors to minimize false triggers but still allows very small seismic events to be recorded. All events that trigger the acquisition computer are analyzed for complex events. Complex events are more than one earthquake or an earthquake contained within a record triggered by another source. Table 4 shows the number of each event type recorded during the fourth quarter.

Table 4. Acquisition System Recorded Triggers.

Event Type	First Quarter	FY98	Remarks
Locals	23	23	Earthquakes within the 46-47 degrees north latitude and 119-120 degrees west longitude
Regionals	25	25	Earthquakes surrounding Hanford within the range of 80 to 500 kilometers
Teleseisms	86	86	Earthquakes from around the world greater than 500 km in distance.
Acoustical	39	39	Acoustical shock waves from artillery, thunder, and high-performance aircraft sonic booms.
Explosions	7	7	Confirmed blast, usually in borrow pits.
Probable Explosions	3	3	Believed to be a blast because of wave characteristics but cannot be confirmed.
Noise	1	1	Triggers caused by data line circuits, lightning, maintenance triggers during system testing, high winds, coincidental noise at multiple sites within a trigger subnet, etc.
Total Triggers	184	184	

3.0 EXPLANATION OF MAGNITUDE, VELOCITY MODELS, AND QUALITY FACTORS

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 by Crosson (1972).

3.2 Velocity Model

The velocities and layer depths given in Table 5 are used by the program XPED in the SUN operating system. XPED was developed at the UW and the velocity model used in XPED is based on Rohay et al. (1985). XPED is an interactive earthquake seismogram display program used to analyze seismic events.

3.3 Quality Factors (Q)

XPED assigns a two-letter **Quality factor** (Table 6) 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 $NP > 8$, $GAP < 90^\circ$, and $DMIN < 5$ km (or the hypocenter depth if it is greater than 5 km). If $NP \leq 5$, $GAP > 180^\circ$, or $DMIN > 50$ km, the solution is assigned Quality **D**.

Table 5. Seismic Velocities for Columbia Basin Stratigraphy.
(See 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 6. Local Earthquake Data, October 1, 1997 to December 31, 1997. (3 sheets)

EVENT ID	DATE	TIME	LATITUDE	LONGITUDE	DEPTH (KM)	MAG	GAP	DMIN	NS/NP	RMS	Q	TYPE	LOCATION
97100416574W	97/10/04	16:57:47.13	46N28.24	119W44.05	14.52	1.1	225	5	9/14	0.03	AD	L	10 km SW of 200 West Area
97100814594W	97/10/08	14:59:45.60	46N22.82	119W08.62	0.35	0.5	236	12	7/10	0.05	AD	L	11 km east of 300 Area
97101323143W	97/10/13	23:14:30.95	46N10.04	119W25.66								CB	16 km SW of Richland, WA
97101421242W	97/10/14	21:24:29.80	46N58.58	119W58.66								PB	2.1 km NNE of Vantage, WA
97102419004W	97/10/24	19:00:55.05	46N27.70	119W42.59	15.36	0.6	217	3	10/15	0.04	AD	L	11 km SW of 200 West Area
97102901520w	97/10/29	01:52:07.13	46N09.94	119W24.26								CB	Webber Canyon
97103104121W	97/10/31	04:12:12.42	46N28.80	119W20.36	16.69	0.0	222	8	4/5	0.03	AD	L	6 km NE of 400 Area
97110217332W	97/11/02	17:33:23.68	46N10.57	119W04.61	9.8	1.4	162	23	13/22	0.06	AC	L	4.7 km SE of Kennewick, WA
97110100153W	97/11/10	00:15:34.39	46N11.17	119W22.61								CB	Webber Canyon
97110523091W	97/11/05	23:09:15.01	46N09.32	119W21.09								CB	Webber Canyon
97110601241W	97/11/06	01:24:21.16	46N31.78	119W42.70	20.04	3.49	80	1	13/18	0.05	AA	L	6 km SW of 200 West Area
97110602145W	97/11/06	02:15:02.99	46N32.00	119W42.65	18.18	0.7	80	1	10/12	0.03	AA	L	4 km SW of 200 West Area
97110912494W	97/11/09	12:49:54.13	46N31.85	119W42.46	18.67	2.81	79	1	14/18	0.06	AA	L	4 km SW of 200 West Area

EVENT ID	DATE	TIME	LATITUDE	LONGITUDE	DEPTH (KM)	MAG	GAP	DMIN	NS/NP	RMS	Q	TYPE	LOCATION
97110919203W	97/11/09	19:20:42.16	46N32.18	119W42.39	20.14	2.95	78	2	18/24	0.07	AA	L	4 km SW of 200 West Area
97110919244W	97/11/09	19:34:55.20	46N31.87	119W42.31	18.64	1.0	170	1	11/13	0.02	AC	L	4 km SW of 200 West Area
9711100707W	97/11/10	07:07:25.00	46N32.05	119W42.12	18.38	1.2	76	2	12/20	0.04	AA	L	4 km SW of 200 West Area
97111123274W	97/11/11	23:27:47.41	46N08.64	119W25.37								CB	
97111511233W	97/11/15	11:23:32.19	46N42.82	119W52.90	5.22	1.5	209	10	9/15	0.06	AD	L	18 km WNW of 100-K Area
97112423483W	97/11/24	23:48:34.44	46N10.98	119W27.07								CB	Webber Canyon
97120400322W	97/12/04	00:32:24.52	46N11.16	119W25.88								CB	Webber Canyon
97121103091W	97/12/11	03:09:17.36	46N34.45	119W16.75	21.64	0.7	163	6	12/17	0.03	AC	L	23 km east of 200 East Area
97121119275W	97/12/11	19:28:00.17	46N34.81	119W15.36	24.93	1.1	97	8	16/26	0.05	AB	L	24 km East of 200 East Area
97121214441W	97/12/12	14:44:17.77	46N34.82	119W14.86	22.96	0.3	156	8	8/10	0.03	AC	L	24 km east of 200 East Area
97121219571W	97/12/12	19:57:10.68	46N53.96	119W21.24								PB	32.2 km SSW of Kennewick, WA
97121419392W	97/12/14	19:39:32.00	46N28.01	119W43.86	15.72	1.2	102	5	14/18	0.03	AB	L	10 km SW of 200 West Area
97121502145W	97/12/15	02:14:54.63	46N34.66	119W15.17	24.14	0.6	99	16	11/13	0.03	AB	L	14 km east of 200 East Area
97122308493W	97/12/23	08:49:31.49	46N57.82	119W22.20	21.68	1.5	300	27	8/11	0.05	AD	L	34 km NE of 100-N Area
97122622500W	97/12/26	22:50:16.12	46N38.82	119W46.00	0.4	-0.3	298	3	4/6	0.03	AD	L	11 km west of 100-K Area

EVENT ID	DATE	TIME	LATITUDE	LONGITUDE	DEPTH (KM)	MAG	GAP	DMIN	NS/NP	RMS	Q	TYPE	LOCATION
97122625020W	97/12/26	22:50:26.37	46N38.53	119W46.03	0.91	0.5	239	3	8/10	0.02	AD	L	11 km west of 100-K Area
97122818345W	97/12/28	18:35:01.82	46N38.35	119W45.69	0.43	0.4	230	2	7/8	0.06	AD	L	11 km west of 100-K Area
97122914180W	97/12/29	14:18:12.72	46N38.48	119W46.27	0.45	1.2	169	3	11/15	0.03	AC	L	11 km west of 100-K Area
97123000173W	97/12/30	00:17:35.76	46N33.88	119W30.10	2.98	0.2	105	4	7/10	0.03	AB	L	1 km east of 200 East Area

- EVENT ID:** The identification number is created by the analysis program, XPED. XPED uses the year, month, day and time to create a unique number for each event.
- 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).
- GAP:** Azimuthal gap. The largest angle (relative to the epicenter) containing no stations.
- NS/NP:** Number of stations/number of phases used in the solutions.
- 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.
- DMIN** The distance from the earthquake epicenter to the closest station.
- B** Blast; P is probable; C is confirmed.

4.0 GEOLOGY AND TECTONIC ANALYSIS

4.1 Earthquake Stratigraphy

Studies of seismicity at the Hanford Site have shown that the seismicity is related to crustal stratigraphy (layers of rock types) (Rohay et al., 1985; DOE 1988). The main geologic units at Hanford and the surrounding area are:

- The Miocene Columbia River Basalt Group (CRBG)
- The Paleocene, Eocene, and Oligocene sediments
- The crystalline basement (Precambrian and Paleozoic craton; accreted terranes).

4.1.1 Geologic structure beneath the monitored area. Between the late 1950s and the early 1980s, deep boreholes were drilled for hydrocarbon exploration. 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 7 and the thicknesses of the crustal layers in the velocity model in Table 5 reflect data specific to the University of Washington's crustal velocity model for eastern Washington. Table 7 is derived from Figure 3 and was developed for the geologic interpretation in Section 4.0. Figure 3 shows north-south and east-west cross sections through the Columbia Basin based on the surface mapping, deep boreholes, geophysical data (including the work of Rohay et al. [1985]), and magnetotelluric data obtained as part of BWIP (DOE 1988). The thicknesses of these units are highly variable across the monitored area. Table 7 summarizes the approximate thicknesses at the borders of the monitored area.

Table 7. Thickness of Stratigraphic Units across 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 North America (late Precambrian/Paleozoic continental margin and craton) is located in the eastern portion of the monitored area. The stratigraphy on the craton consists of CRBG overlying crystalline basement; the crystalline basement is continental crustal rocks that underlie much of the western North America. The stratigraphy west of the craton consists of 4-5 km of CRBG overlying greater than 6 km of pre-basalt sediments. This in turn overlies accreted terranes of Mesozoic age. The area west of the craton was subsiding during the Eocene and Oligocene, accumulating great thicknesses of pre-basalt sediments. Continued subsidence in this area

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Figure 3. Geologic Cross Sections through the Columbia Basin.

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).

4.1.2 Depth of Earthquakes. Since records have been kept, about 75 percent of the earthquakes at the Hanford Site have originated in the CRBG layer. The pre-basalt sediments have had about 7 percent of the events and the crystalline basement has had 18 percent.

For the first quarter of FY98, twenty three events were located (Table 6); six events (26 percent) in the basalt, one event (4 percent) in the pre-basalt sediments, and 16 events (70 percent) in the crystalline basement.

4.2 Tectonic Pattern

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

- **Reverse/thrust faults.** 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 are associated with the major anticlinal ridges.
- **Swarm areas.** Small geographic areas of unknown geologic structure produce clusters of events (swarms), usually in the CRBG in synclinal valleys. These clusters consist of a series of small shocks with no one 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. Three principal swarm areas are known at the Hanford Site. One is the Wooded Island Swarm Area along the Columbia River near the 300 Area. The second area, the Coyote Rapids Swarm Area, extends from the vicinity of the 100 K Area north-northeast along the Columbia River Horn to the vicinity of the 100 N Area. The third major swarm area is along the Saddle Mountains on the northern boundary of the Hanford Site. Other earthquake swarm areas are present, but activity is less frequent.
- **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. It is classified as a random event by Seismic Monitoring 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 for seismic hazards analysis and seismic design.

- **The Cascadia Subduction Zone.** This source recently 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 (Geomatrix 1996), the University of Washington monitors and reports on this earthquake source for the U.S. Department of Energy (DOE). Ground motion from any moderate or larger Cascadia Subduction Zone earthquake is detected by seismometers in the HSN.

4.3 Current Tectonic Activity

The locations of all events with M_c greater than 0.5 that occurred between October 1, 1997 and December 31, 1997 are shown on Figure 4. The locations of all seismic events for Fiscal Year 1997 (October 1, 1996 to September 30, 1997) are shown in Figure 5. Figure 6 is a tectonic map of the Yakima Fold Belt and Hanford Site. The Yakima Fold Belt is the main tectonic province of concern for the Hanford Site. The figure shows all the major mapped ridges and faults that are potential seismic sources. These figures should be referred to for the following discussions.

4.3.1 Reverse/Thrust Faults on Major Anticlinal Ridges

During the reporting period no events were associated with major anticlinal ridges.

4.3.2 Secondary Structures on Main Anticlinal Ridges

During the reporting period, no events occurred on any secondary structures that are part of major anticlinal folds in the area.

4.3.3 Swarm Area Activity

During the reporting period, 18 events (78 percent) were located in earthquake swarm areas.

4.3.3.1 Saddle Mountains Swarm Area. There were no events in the Saddle Mountains swarm area.

4.3.3.2 Wooded Island Swarm Area. There were no events in the Wooded Island swarm area.

4.3.3.3 Coyote Rapids Swarm Area. Four shallow events in the Columbia River Basalt Group occurred on the west side of the Coyote Rapids earthquake swarm between December 26 and December 29, 1997. All four were located approximately 11 km west of 100-K Area. The largest event was 1.2 M_c .

4.3.3.4 Other Swarm Areas.

Cold Creek Depression. Six events occurred in the Cold Creek Depression which is located approximately 4 km SW of the 200 West Area, between November 6 and November 11, 1997. All events were deep (> 15 km) and were located in the crystalline basement. The first event was the largest event having a magnitude of $3.49 M_c$. Its depth of 20 km was too deep for it to be felt at the surface. Two events on November 9, 1997 had magnitudes of 2.81 and 2.95 M_c , respectively but were also too deep to be felt. The other events had magnitudes between 0.7 and 1.2 M_c .

Snively Basin. Three events occurred in the Snively Basin 10 km south of the 200 West Area and 6 km from the Cold Creek Depression swarm. The events occurred on October 4 and 24, and on December 14, 1997 and were located in the crystalline basement at depths greater than 14 km. The largest event of this group was 1.2 M_c .

Savage Island. Five events occurred northeast of Savage Island swarm area. All events were less than 1.1 M_c . Four events occurred between December 11 and December 15, 1997, and one event occurred on October 31, 1997; all were deep in the crystalline basement.

4.3.4 Random or Floating Events

Five events occurred during the first quarter of FY98 that are classified as random events because they did not occur near a known swarm or a geologic structure.

On October 8, 1997 a small event ($0.5 M_c$) occurred 11 km east of the 300 Area in Franklin County. This was a shallow event (approximately 0.35 km) in the Columbia River Basalt Group and was not near any known geologic structure.

On November 2, 1997 a small earthquake ($1.4 M_c$) occurred approximately 5 km SE of Kennewick, Washington. The earthquake was deep (9.8 km) probably either at the base of the Columbia River Basalt Group or in the pre-basalt sedimentary rocks. This is near the trend of the Olympic-Wallowa lineament.

On November 15, 1997 a small ($1.5 M_c$) event occurred 18 km NW of 100-K Area near the town of Desert Aire, Washington. The earthquake was shallow (5.2 km) and near the base of the basalt or in the pre-basalt sediments. This event occurred along the axis of the Wahluke syncline.

On December 23, 1997 a small ($1.5 M_c$) event occurred along the Frenchman Hills anticline. The event was deep (> 21 km) in the crystalline basement and is not thought to be related to the Frenchman Hills anticline or any other known geologic structure.

On December 30, 1997 a small ($0.2 M_c$) event occurred 1 km east of the 200 East Area. This event was in the Columbia River Basalt Group but is not along any known geologic structure.

Figure 4. All Located Earthquakes: October 1, 1997 to December 31, 1997. (Coda Length Magnitude (M_c) scale is shown at the side of the map.)

Figure 5. Locations of All Events between October 1, 1996 and September 30, 1997.
(Coda Length Magnitude (M_c) scale is shown at the side of the map.)

Figure 6. Structural and Tectonic Map of Columbia Basin Showing Major Seismic Source Structures.

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