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

D. C. Hartshorn
S. P. Reidel
A. C. Rohay

June 1998

for MASTER

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Prepared for the U.S. Department of Energy
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**Hanford Annual Second Quarter Seismic
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and Near the Hanford Site, Pasco Basin,
Washington**

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Pacific Northwest National Laboratory
Richland, Washington 99352

Summary

Hanford Seismic Monitoring provides an uninterrupted collection of high-quality raw and processed seismic data from the Hanford Seismic Network (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 42 individual sensor sites and 15 radio relay sites maintained by the Hanford Seismic Monitoring staff. The operational rate for the second quarter of FY98 for stations in the HSN was 99.92%. The operational rate for the second quarter of FY98 for stations of the EWRN was 99.46%. For the second quarter of FY98, the acquisition computer triggered 159 times. Of these triggers 14 were local earthquakes: 7 (50%) in the Columbia River Basalt Group, 3 (21%) in the pre-basalt sediments, and 4 (29%) in the crystalline basement. The geologic and tectonic environments where these earthquakes occurred are discussed in this report.

The most significant seismic event for the second quarter was on March 23, 1998 when a 1.9 M_c occurred near Eltopia, WA and was felt by local residents. Although this was a small event, it was felt at the surface and is an indication of the potential impact on Hanford of seismic events that are common to the Site.

Terms

BWIP	Basalt Waste Isolation Project
CRBG	Columbia River Basalt Group
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
UTC	Universal Time, Coordinated
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 Seismic Monitoring workscope, personnel, and associated contracts were transferred to the Pacific Northwest National Laboratory (PNNL).

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 the 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, the Seismic Monitoring Project works with Hanford Site Emergency Services Organization to provide assistance in the event of an earthquake on the Hanford Site.

1.3 Documentation

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

2.0 Network Operations

2.1 Monitoring Stations

The HSN and the EWRN had 42 sensor sites until July 25, 1997. The three-component Royal City site was removed at the request of the land developer. The Royal City site will be reinstalled during the third quarter of fiscal year 1998 with the new site name and designator Frenchman Hills West (FHW). Most sites are in remote locations and require solar panels and batteries for power. Both networks share sixteen sites; the HSN uses 21 sites (Table 1 and Fig. 1) and the EWRN uses 36 sites (Table 2 and Fig. 2). The networks have 46 combined data channels because Gable Butte and the new Frenchman Hills sites 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. 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 in the 300 Area. 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	Ektopia Three
FHW				Frenchman Hills West
*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 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
WTW	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
FHW				Frenchman Hills West
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	January	February	March	Second Quarter	FY98 ^(a)
Hanford	99.97%	100.00%	99.80%	99.92%	99.18%
Regional	99.63%	99.96%	99.74%	99.46%	99.87%
(a) Total for FY to date. Notes: The Hanford Seismic Network's goal is 98%. The Eastern Washington Regional Network's goal is 97%. The quarter period is January 1, 1998 through March 31, 1998.					

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 allow 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	Second Quarter	FY98	Event Type Definitions
Locals	23	14	37	Earthquakes within the 46-47 degrees north latitude and 119-120 degrees west longitude
Regionals	25	32	57	Earthquakes surrounding Hanford within the range of 80 to 500 kilometers
Teleseisms	86	59	145	Earthquakes from around the world greater than 500 km in distance.
Acoustical	39	49	88	Acoustical shock waves from artillery, thunder, and high-performance aircraft sonic booms.
Explosions	7	0	7	Confirmed blast, usually in borrow pits.
Probable Explosions	3	2	5	Believed to be a blast because of wave characteristics but cannot be confirmed.
Noise	1	6	7	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	162	346	

3.0 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, 1998 to March 31, 1998 (2 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		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		11 km east of 300 Area
97101323143W	97/10/13	23:14:30.95	46N10.04	119W25.66	6.48		310	14	3/6	0.01	AD	X	Webber Canyon
97101421242W	97/10/14	21:24:29.80	46N58.58	119W58.66	20.81		329	39	8/11	0.03	AD	P	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		11 km SW of 200 West Area
97102901520W	97/10/29	01:52:07.13	46N09.94	119W24.26	2.35		266	14	8/9	0.03	AD	X	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		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		4.7 km SE of Kennewick, WA
97110100153W	97/11/10	00:15:34.39	46N11.17	119W22.61	2.91		262	13	10/16	0.01	AD	X	Webber Canyon
97110523091W	97/11/05	23:09:15.01	46N09.32	119W21.09	5.01		293	17	10/16	0.04	AD	X	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		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		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		4 km SW of 200 West Area
97110919203W	97/11/09	19:20:42.16	46N32.18	119W42.39	20.14	2.95	78	2	18/24	0.07	AA		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		4 km SW of 200 West Area
97111007071W	97/11/10	07:07:25.00	46N32.05	119W42.12	18.38	1.2	76	2	12/20	0.04	AA		4 km SW of 200 West Area
97111123274W	97/11/15	23:27:47.41	46N08.64	119W25.37	1.18		290	17	8/8	0.06	AD	X	Webber Canyon
97111511233W	97/11/15	11:23:32.19	46N42.82	119W52.90	5.22	1.5	209	10	9/15	0.06	AD		18 km WNW of 100-K Area
97112423483W	97/11/24	23:48:34.44	46N10.98	119W27.07	0.03		238	12	11/15	0.05	AD	X	Webber Canyon
97120400322W	97/12/04	00:32:24.52	46N10.98	119W27.07	0.46		327	12	8/8	0.08	AD	X	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		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		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		24 km east of 200 East Area
97121419392W	97/12/14	19:39:32.00	46N28.01	119W43.86	15.72	1.2	102	5	14/18	0.03	AB		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		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		34 km NE of 100-N Area
97122622502W	97/12/26	22:50:16.12	46N38.82	119W46.00	0.4	-0.3	298	3	4/6	0.03	AD		11 km west of 100-K Area
9712262502W	97/12/26	22:50:26.37	46N38.53	119W46.03	0.91	0.5	239	3	8/10	0.02	AD		11 km west of 100-K Area

Table 6. (contd)

Event ID	Date	Time	Latitude	Longitude	Depth (km)	Mag	GAP	DMIN	NS/NP	RMS	Q	Type	Location
97122818345W	97/12/28	18:35:01.82	46N38.35	119W45.69	0.43	0.4	230	2	7/8	0.06	AD		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		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		1 km east of 200 East Area
98010809253W	98/01/08	09:25:43.52	46N32.42	119W43.93	10.78	-0.4	191	2	4/7	0.02	AD		7 km west of 200 West Area
98010809423W	98/01/08	09:42:56.58	46N32.27	119W42.67	8.65	0.3	143	2	4/7	0.01	AD		6 km west of 200 West Area
98010312021W	98/01/31	20:21:39.34	46N43.74	119W31.58	3.13	0.7	90	4	13/19	0.06	AA		7 km NE of 100 N Area
98020408144W	98/02/04	08:14:46.00	46N32.00	119W42.52	18.54	0.5	80	1	10/13	0.02	AA		6 km West of 200 West Area
98020520421W	98/02/05	20:42:17.35	46N36.88	119W46.00	15.33	0.0	177	0	7/12	0.05	AC		13 km WSW of 100 K Area
98020919355W	98/02/09	19:35:49.76	46N35.85	119W00.20	36.02		249	19	9/14	0.10	AD	P	Cornell Quarry
98020923302W	98/02/09	23:30:29.19	46N28.79	119W42.63	1.09	1.1	135	4	11/13	0.05	AB		10 km SW of 200 West Area
98021023062W	98/02/10	23:06:33.65	46N22.09	119W15.34	0.04	0.2	230	7	10/16	0.08	AD		South end of Johnson Island
98021317052W	98/02/13	17:05:24.43	46N40.41	119W28.41	11.99	-0.4	111	5	6/10	0.01	AC		5 km SE of 100 N Area
98021608064W	98/02/16	08:06:45.21	46N44.65	119W40.84	4.31	0.7	146	8	12/17	0.05	AC		12 km NNW of 100 K Area
98022518520W	98/02/22	18:52:12.54	46N44.92	119W41.57	5.07	0.1	150	9	7/8	0.02	AC		13 km NNW of 100 K Area
98022520190W	98/02/22	20:19:06.86	46N07.57	119W24.43	0.03		278	19	9/11	0.07	AD	P	Webber Canyon
98030122010W	98/03/12	22:01:05.14	46N19.13	119W43.04	2.12		208	19	15/21	0.07	AD	P	25 km S of 200 West Area, Sagebrush Ridge
98030515591W	98/03/05	15:59:15.54	46N23.27	119W15.45	0.02	0.7	222	5	10/16	0.08	AD		North end of Johnson Island
98030638063W	98/03/06	08:06:54.41	46N30.84	119W17.67	3.71	0.3	149	7	6/10	0.07	AC		28 km NE of 100 N Area
98032323323W	98/03/23	23:32:36.57	46N23.54	119W02.53	2.24	1.9	138	19	18/25	0.09	AC	F	25 km ESE of FFTF, Eltopia, WA
98032613383W	98/03/26	13:38:37.90	46N46.10	119W43.27	7.15	0.8	266	11	8/13	0.08	AD		16 km NW of 100 K Area

Explanation of Table 6

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). If Magnitude is blank no determination could be made.
GAP:	Azimuthal gap. The largest angle (relative to the epicenter) containing no stations.
DMIN	The distance from the earthquake epicenter to the closest station
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.
TYPE:	P is Probable Blast; X is Confirmed Blast; F is Felt Earthquake; H is hand picked from helicorder; S is surficial event (rock slide, avalanche) and not a explosion or tectonic earthquake; blank is local earthquake.

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

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Figure 3. Geologic Cross Sections Through the Columbia Basin

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 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 occur throughout much of the western North America. The stratigraphy west of the craton consists of 4 to 5 km of CRBG overlying greater than 6 km of pre-basalt sediments. This in turn overlies accreted terranes of Mesozoic age. The area west of the craton was subsiding during the Eocene and Oligocene, accumulating great thicknesses of pre-CRBG sediments. Continued subsidence in this area during the Miocene resulted in thicker CRBG compared to that on the craton. Subsidence continues today but at a greatly reduced rate (Reidel et al. 1994).

4.1.2 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 second quarter of FY98, 14 events were located (Table 6); 7 events (50%) in the basalt, 3 events (21%) in the pre-basalt sediments, and 4 events (29%) 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 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 January 1, 1998 and March 31, 1998 are shown on Figure 4. The locations of all seismic events from October 1, 1997 to March 31, 1998 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 1 event (7%) appears to have occurred on a thrust fault along a major anticlinal ridge. This was a small ($1.1 M_c$) event that occurred on 2/09/98 at a shallow depth (<2 km). It appears to have occurred on the Rattlesnake Mountain fault in the Snively basin area adjacent to Rattlesnake Creek.

4.3.2 Secondary Structures on Main Anticlinal

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

Figure 4. All Located Earthquakes Between January 1, 1998 and March 31, 1998 (Coda Length Magnitude (M_c) scale is shown at the side of the map.)

Figure 5. Locations of All Events Between October 1, 1997 and March 31, 1998 (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

4.3.3 Swarm Area Activity

During the reporting period, 4 events (28%) were located in earthquake swarm areas.

4.3.3.1 Saddle Mountains Swarm Area

There was 1 event (7%) in the Saddle Mountains swarm area on 3/06/98. It was a small event (0.3 M_c) that occurred in the CRBG about 1.5 km north of the Saddle Mountains thrust fault on the Royal Slope.

4.3.3.2 Wooded Island Swarm Area

There were 2 events (14%) in the Wooded Island swarm area, one on 2/10/98 and one on 3/05/98. Both were small ($<1 M_c$), shallow (<1 km) events located near Johnson Island and the 300 Area.

4.3.3.3 Coyote Rapids Swarm Area

There was 1 event (7%) on 1/31/98 at the north end of the Coyote Rapids earthquake swarm. The event was small ($<1 M_c$) and occurred at a shallow depth (<4 km).

4.3.3.4 Other Swarm Areas

Snively Basin. The event of 2/09/98 that is catalogued as occurring on the Rattlesnake Mountain fault was in the Snively basin swarm area. Its proximity to the Rattlesnake Mountain fault is the reason for classifying it as associated with the structure. However, it can not be ruled out as a seismic event associated with the Snively Basin swarm area.

4.3.4 Random or Floating Events

There were 8 events (57%) that are classified as random events this quarter because they did not occur in a known swarm or on a known geologic structure.

Three small ($<1 M_c$) events occurred about 7 km west of the 200 West Area. Two of the events occurred on 1/08/98 and one on 2/04/98. The events were centered under the Yakima Ridge anticline but because they were below the basalt and can not be fixed to a specific structure, they are classified as random events.

Another small (0 M_c) event occurred on 2/05/98 under Umtanum Ridge and 13 k west of 100 K Area. This event was in the crystalline basement and because previous studies suggest the Umtanum fault does not penetrate deeper than the CRBG, this event is classified as a random event.

On 2/13/98 a small event occurred in the crystalline basement under the Wahluke syncline southeast of 100 N Area. Because of its great depth and there are no known geologic structures near this location, it is classified as a random earthquake.

Three small ($<1 M_c$) events occurred on 2/16/98, 2/25/98 and 3/26/98 between 12 and 16 km northwest of 100 K Area. The events occurred in the Wahluke syncline and were either at the base of the CRBG or in the pre-basalt sediments. None of the events occurred near a known geologic structure and are therefore, classified as random events.

An earthquake that was **felt** occurred 25 km east of FFTF near Eltopia, Washington. The earthquake was small ($1.9 M_c$) and shallow (2.2 km). This earthquake does not occur on any known geologic structure so it is classified as a random event.

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