**Pacific Northwest
National Laboratory**

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

**Hanford Quarter Seismic Report - 98C
Seismicity On and Near the Hanford
Site, Pasco Basin, Washington:
April 1, 1998 Through June 30, 1998**

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

RECEIVED
NOV 05 1998
OSTI

October 1998

Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or Battelle Memorial Institute.

PACIFIC NORTHWEST NATIONAL LABORATORY

operated by

BATTELLE

for the

UNITED STATES DEPARTMENT OF ENERGY

under Contract DE-AC06-76RLO 1830

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,
U.S. Department of Commerce, 5285 Port Royal Rd., Springfield, VA 22161**

This document was printed on recycled paper.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, make any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

**Hanford Quarter Seismic Report - 98C
Seismicity On and Near the Hanford Site,
Pasco Basin, Washington: April 1, 1998
Through June 30, 1998**

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

October 1998

Prepared for
the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

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 third quarter of FY 1998 for stations in the HSN was 99.99%. The operational rate for the third quarter of FY 1998 for stations of the EWRN was 99.95%. For the third quarter of FY 1998, the acquisition computer triggered 133 times. Of these triggers 11 were local earthquakes: 5 (45%) in the Columbia River Basalt Group, 2 (18%) in the pre-basalt sediments, and 4 (36%) in the crystalline basement. The geologic and tectonic environments where these earthquakes occurred are discussed in this report.

Acronyms

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

Contents

Summary	iii
Acronyms	v
1.0 Introduction.....	1.1
1.1 Background.....	1.1
1.2 Purpose	1.1
1.3 Documentation.....	1.2
2.0 Network Operations	2.1
2.1 Monitoring Stations	2.1
2.2 Station Maintenance	2.2
2.3 Data Acquisition	2.5
3.0 Magnitude, Velocity Models, and Quality Factors	3.1
3.1 Coda Length Magnitude	3.1
3.2 Velocity Model	3.1
3.3 Quality Factors.....	3.1
4.0 Geology and Tectonic Analysis	4.1
4.1 Earthquake Stratigraphy	4.1
4.1.1 Geologic Structure Beneath the Monitored Area.....	4.1
4.1.2 Depth of Earthquakes.....	4.3
4.2 Tectonic Pattern	4.3
4.3 Current Tectonic Activity	4.4
4.3.1 Reverse/Thrust Faults on Major Anticlinal Ridges	4.4
4.3.2 Secondary Structures on Main Anticlinal Ridges.....	4.4
4.3.3 Swarm Area Activity	4.4
4.3.4 Random or Floating Events	4.8
5.0 References.....	5.1

Figures

2.1	Locations of Seismograph Stations in the Hanford Seismic Network	2.2
2.2	Locations of Seismograph Stations in the Eastern Washington Regional Network	2.4
4.1	Geologic Cross Sections Through the Columbia Basin	4.2
4.2	All Located Earthquakes Between April 1, 1998 and June 30, 1998.....	4.5
4.3	Locations of All Events Between October 1, 1997 and June 30, 1998.....	4.6
4.4	Structural and Tectonic Map of Columbia Basin Showing Major Seismic Source Structures	4.7

Tables

2.1	Seismic Stations in the Hanford Seismic Network	2.1
2.2	Seismic Stations in the Eastern Washington Regional Network.....	2.3
2.3	Seismic Channel Operational Time	2.5
2.4	Acquisition System Recorded Triggers	2.5
3.1	Seismic Velocities for Columbia Basin Stratigraphy.....	3.1
3.2	Local Earthquake Data.....	3.2
4.1	Thickness of Stratigraphic Units Across the Monitoring Area.....	4.1

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 EWRN 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)¹.

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

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 first quarter of fiscal year (FY) 1999 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 2.1 and Figure 2.1) and the EWRN uses 36 sites (Table 2.2 and Figure 2.2). The networks have 46 combined data channels because Gable Butte and Royal City are three-component sites, each consisting of one vertical, one north-south horizontal, and one east-west horizontal

Table 2.1. Seismic Stations in the Hanford Seismic Network

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
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
WIW	46N25.76	119W17.26	128	Wooded Island
WRD	46N58.20	119W08.69	375	Warden
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. An asterisk before the three-letter designator indicates 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).

Figure 2.1. Locations of Seismograph Stations in the Hanford Seismic Network
(see Table 2.1 for description of locations)

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 at the Hanford Site. A major outage is considered to be a failure of the HSN data-recording computer or three or more data channels.

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 outages are addressed in this report. Table 2.3 shows the operational percentage time for each network.

Table 2.2. Seismic Stations in the Eastern Washington Regional Network

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
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. An asterisk before the three-letter designator indicates 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).

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

Table 2.3. Seismic Channel Operational Time (%)

Network	April	May	June	Third Quarter	FY 1998 ^(a)
Hanford	99.8%	100%	100%	99.99%	99.45%
Regional	99.85%	100%	100%	99.95%	99.62%
(a) Total for fiscal year to date. Notes: The Hanford Seismic Network's goal is 98%. The Eastern Washington Regional Network's goal is 97%. The quarter period is April 1, 1998 through June 31, 1998.					

2.3 Data Acquisition

Seismic data are recorded at the 337 building at the Hanford Site. 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 2.4 shows the number of each event type recorded during the fourth quarter.

Table 2.4. Acquisition System Recorded Triggers

Event Type	First Quarter	Second Quarter	Third Quarter	FY 1998	Remarks
Local	23	14	10	47	Earthquakes within the 46-47 degrees north latitude and 119-120 degrees west longitude
Regional	25	32	31	88	Earthquakes surrounding Hanford within the range of 80 to 500 km
Teleseism	86	59	60	205	Earthquakes from around the world greater than 500 km in distance.
Acoustical	39	49	9	97	Acoustical shock waves from artillery, thunder, and high-performance aircraft sonic booms.
Explosion	7	0	0	7	Confirmed blast, usually in borrow pits.
Probable Explosion	3	2	4	9	Believed to be a blast because of wave characteristics but cannot be confirmed.
Noise	1	6	19	26	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	133	479	

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 3.1 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 3.2) that indicates the general reliability of the solution (A is best quality, D is worst). Similar quality factors are used by the USGS for events located with the computer program HYPO71. The first letter of the quality code is a measure of the hypocenter quality based primarily on travel time residuals. For example: Quality A requires a root-mean-square residual (RMS) less than 0.15 seconds while a RMS of 0.5 seconds or more is D quality (other estimates of the location uncertainty also affect this quality parameter). The second letter of the quality code is related to the spatial distribution of stations that contribute to the event's location, including the number of stations (NS), the number of p-wave and s-wave phases (NP), the largest gap in event-station azimuth distribution (GAP), and the closest distance from the epicenter to a station (DMIN). Quality A requires a solution with NP > 8, GAP < 90°, and DMIN < 5 km (or the hypocenter depth if it is greater than 5 km). If NP ≤ 8, GAP > 180°, or DMIN > 50 km, the solution is assigned Quality D.

Table 3.1. Seismic Velocities for Columbia Basin Stratigraphy (see Rohay et al. 1985)

Depth to Top of Velocity Layer (km)	Stratigraphy	Velocity (km/s)
0.0	Saddle Mountains and Wanapum Basalts and intercalated Ellensburg Formation	3.7
0.4	Grande Ronde Basalt and pre-basalt sediments	5.2
8.5	Crystalline Basement, Layer 1	6.1
13.0	Crystalline Basement, Layer 2	6.4
23.0	Sub-basement	7.1
38.0	Mantle	7.9

Table 3.2. Local Earthquake Data (October 1, 1997 to June 30, 1998)

Event ID	Date	Time	Latitude	Longitude	Depth	MAG	NSNP	GAP	DMIN	RMS	Q	Type	Location
97100416574	97/10/04	16:57:47.13	46N28.24	119W44.05	14.52	1.1	9/14	225	5	0.03	AD		10 km SW of 200-West Area
97100814594	97/10/08	14:59:45.60	46N22.82	119W08.62	0.35	0.5	7/10	236	12	0.05	AD		11 km east of 300 Area
97101323143	97/10/13	23:14:32.73	46N10.04	119W25.66	6.48	0.0	3/06	310	14	0.01	AD	X	Webber Canyon
97101421242	97/10/14	21:24:22.29	46N58.58	119W38.66	20.81	0.0	8/11	329	39	0.03	AD	P	2.1 km NNE of Vantage, WA
97102419004	97/10/24	19:00:55.05	46N27.70	119W42.59	15.36	0.7	10/15	217	3	0.04	AD		11 km SW of 200-West Area
97102901520	97/10/29	01:52:05.14	46N09.94	119W24.26	2.33	1.6	8/09	266	14	0.03	AD	X	Webber Canyon
97103104121	97/10/31	04:12:12.42	46N28.80	119W20.36	16.69	0.0	4/05	222	8	0.03	AD		6 km NE of 400 Area
97110100153	97/11/01	00:15:34.54	46N11.17	119W22.61	2.91	0.0	10/16	262	13	0.01	AD	X	Webber Canyon
97110217332	97/11/02	17:33:23.68	46N10.57	119W04.61	9.80	1.4	13/22	162	23	0.06	AC		4.7 km SE of Kennewick, WA
97110523091	97/11/05	23:09:17.84	46N09.32	119W21.09	5.01	1.8	10/16	293	17	0.04	AD	X	Webber Canyon
97110601241	97/11/06	01:24:21.16	46N31.78	119W42.70	20.04	3.5	13/18	80	1	0.05	AA		6 km SW of 200-West Area
97110602145	97/11/06	02:15:02.99	46N32.00	119W42.65	18.18	0.7	10/12	80	1	0.03	AA		4 km SW of 200-West Area
97110912494	97/11/09	12:49:54.13	46N31.85	119W42.46	18.67	2.8	14/18	79	1	0.06	AA		4 km SW of 200-West Area
97110919203	97/11/09	19:20:42.16	46N32.18	119W42.39	20.14	2.9	18/24	78	2	0.07	AA		4 km SW of 200-West Area
97110919344	97/11/09	19:34:55.20	46N31.87	119W42.31	18.64	1.1	11/13	170	1	0.02	AC		4 km SW of 200-West Area
97111007071	97/11/10	07:07:25.00	46N32.05	119W42.12	18.38	1.1	12/20	76	2	0.04	AA		4 km SW of 200-West Area
97111123274	97/11/11	23:27:50.27	46N08.64	119W25.37	1.18	0.0	8/08	290	17	0.06	AD	X	Webber Canyon
97111511233	97/11/15	11:23:32.19	46N42.82	119W52.90	5.22	1.5	9/15	209	10	0.06	AD		18 km WNW of 100-K Area
97112423483	97/11/24	23:48:38.81	46N10.98	119W27.07	0.03	1.7	11/15	238	12	0.05	AD	X	Webber Canyon
97120400322	97/12/04	00:32:24.33	46N11.17	119W25.88	0.45	1.5	7/08	327	12	0.08	AD	X	Webber Canyon
971211103091	97/12/11	03:09:17.36	46N34.45	119W16.75	21.64	0.7	12/17	163	6	0.03	AC		23 km east of 200-East Area
97121119275	97/12/11	19:27:50.17	46N34.81	119W15.36	24.93	1.1	16/26	97	8	0.05	AB		24 km East of 200-East Area
97121214441	97/12/12	14:44:17.77	46N34.82	119W14.86	22.96	0.3	8/10	156	8	0.03	AC		24 km east of 200-East Area
97121419392	97/12/14	19:39:32.00	46N28.01	119W43.86	15.72	1.2	14/18	102	5	0.03	AB		10 km SW of 200-West Area
97121502145	97/12/15	02:14:54.63	46N34.66	119W15.17	24.14	0.6	11/13	99	16	0.03	AB		14 km east of 200-East Area

Table 3.2. (contd)

Event ID	Date	Time	Latitude	Longitude	Depth	MAG	NSNP	GAP	DMIN	RMS	Q	Type	Location
97122308493	97/12/23	08:49:31.49	46N57.82	119W22.20	21.68	1.5	8/11	300	27	0.05	AD		34 km NE of 100-N Area
97122622501	97/12/26	22:50:16.12	46N38.82	119W46.00	0.46	-0.3	4/06	298	3	0.03	AD		11 km west of 100-K Area
97122622502	97/12/26	22:50:26.37	46N38.53	119W46.03	0.91	0.5	8/10	239	3	0.01	AD		11 km west of 100-K Area
97122818345	97/12/28	18:35:01.82	46N38.35	119W45.69	0.43	0.4	7/08	230	2	0.06	AD		11 km west of 100-K Area
97122914180	97/12/29	14:18:12.72	46N38.48	119W46.27	0.45	1.2	11/15	169	3	0.03	AC		11 km west of 100-K Area
97123000173	97/12/30	00:17:35.76	46N33.88	119W30.10	2.98	0.2	7/10	105	4	0.03	AB		1 km east of 200-East Area
98010809253	98/01/08	09:25:43.52	46N32.42	119W43.93	10.78	-0.4	4/07	191	2	0.02	AD		7 km west of 200-West Area
98010809425	98/01/08	09:42:56.58	46N32.27	119W42.67	8.65	0.3	4/07	143	2	0.01	AD		6 km west of 200-West Area
98013120213	98/01/31	20:21:39.34	46N43.74	119W31.58	3.13	0.7	13/19	90	4	0.06	AA		7 km NE of 100-N Area
98020408144	98/02/04	08:14:46.00	46N32.00	119W42.52	18.54	0.5	10/13	80	1	0.02	AA		6 km West of 200-West Area
98020520421	98/02/05	20:42:17.35	46N36.88	119W46.00	15.33	0.0	7/12	177	0	0.05	AC		13 km WSW of 100-K Area
98020919355	98/02/09	19:35:49.78	46N35.95	119W00.54	36.25	1.6	8/13	248	18	0.10	BD	P	Connell Quarry
98020923302	98/02/09	23:30:29.09	46N28.59	119W43.23	1.30	1.1	11/15	140	4	0.04	AC		10 km SW of 200-West Area
98021023062	98/02/10	23:06:33.76	46N22.40	119W15.90	0.23	1.0	10/16	227	6	0.05	AD		South end of Johnson Island
98021317052	98/02/13	17:05:24.43	46N40.42	119W28.41	11.98	0.4	6/10	111	5	0.01	AC		5 km SE of 100-N Area
98021608064	98/02/16	08:06:45.21	46N44.65	119W40.84	4.31	1.5	13/17	146	8	0.05	AC		12 km NNW of 100-K Area
98022518520	98/02/25	18:52:12.54	46N44.92	119W41.57	5.07	0.6	7/08	150	9	0.02	AC		13 km NNW of 100-K Area
98022520190	98/02/25	20:19:06.86	46N07.57	119W24.43	0.03	2.0	9/11	278	19	0.07	AD	P	Webber Canyon
98030122010	98/03/01	22:01:05.14	46N19.13	119W53.04	2.12	1.8	15/21	208	19	0.07	AD	P	30 km SW of 200-West Area, Sagebrush Ridge
98030515591	98/03/05	15:59:15.54	46N23.27	119W15.45	0.02	0.7	10/16	222	5	0.08	AD		North end of Johnson Island
98030608065	98/03/06	08:06:54.41	46N50.84	119W17.67	3.71	0.3	6/10	149	7	0.07	AC		28 km NE of 100-N Area
98032323323	98/03/23	23:32:36.57	46N23.54	119W02.54	2.24	1.9	18/25	138	19	0.09	AC	F	25 km ESE of FFTF; Eltopia, WA
98032613383	98/03/26	13:38:37.90	46N46.10	119W43.27	7.15	0.8	8/13	266	11	0.08	AD		16 km NW of 100-K Area
98040108122	98/04/01	08:12:26.26	46N42.32	119W50.63	0.49	1.6	10/11	190	12	0.05	AD		20 km WNW of 100-K Area

Table 3.2. (contd)

Event ID	Date	Time	Latitude	Longitude	Depth	MAG	NS/NP	GAP	DMIN	RMS	Q	Type	Location
98040520113	98/04/05	20:11:33.92	46N20.34	119W01.42	6.18	0.5	5/08	282	22	0.04	AD		10 km E of 300 Area
98040606575	98/04/06	06:57:55.12	46N44.65	119W40.00	8.29	0.2	10/13	146	7	0.06	AC		11 km NW of 100-K Area
98040606584	98/04/06	06:58:46.18	46N44.25	119W40.06	3.23	0.4	10/10	139	8	0.07	AC		12 km NW of 100-K Area
98040706310	98/04/07	06:31:08.46	46N42.80	119W52.22	0.03	1.9	12/18	154	10	0.07	AC		20 km WNW of 100-K Area
98041904072	98/04/19	04:07:26.08	46N18.07	119W33.49	15.92	1.6	16/26	169	9	0.10	AC		20 km SW of FFTF
98042809033	98/04/28	09:03:40.85	46N44.59	119W40.45	4.94	1.0	11/13	145	8	0.09	AC		12 km NW of 100-K Area
98042903024	98/04/29	03:02:45.27	46N52.54	119W13.15	13.00	1.3	16/25	126	11	0.05	AB		42 km NE of 200-East Area
98051708480	98/05/17	08:48:03.22	46N49.97	119W31.90	22.32	1.1	7/13	272	15	0.10	AD		22 km NE of 100-K Area
98052912103	98/05/29	12:10:41.21	46N34.45	119W30.28	16.50	-0.3	6/07	124	4	0.02	AC		3 km ENE of 200-East Area
98060311523	98/06/03	11:52:35.80	46N44.58	119W39.43	2.78	1.4	14/16	123	7	0.08	AB		12 km NW of 100-K Area

Explanation of Table 3.2

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.
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."
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 in the Columbia Basin. These boreholes provided accurate measurements of the physical properties of the CRBG and the pre-basalt sediments (Reidel et al. 1989, 1994), but the thickness of the pre-basalt sediments and nature of the crystalline basement are still poorly understood. The difference between the thicknesses listed in Table 4.1 and the thicknesses of the crustal layers in the velocity model in Table 3.1 reflect data specific to the University of Washington's crustal velocity model for eastern Washington. Table 4.1 is derived from Figure 4.1 and was developed for the geologic interpretation in Section 4.0 of this report. Figure 4.1 shows north-south and east-west cross sections through the Columbia Basin based on 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 4.1 summarizes the approximate thicknesses at the borders of the monitored area.

The thickness of the basalt and the pre-basalt sediments varies as a result of different tectonic environments. The western edge of 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

Table 4.1. 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

SP98020037.3

Figure 4.1. Geologic Cross Sections Through the Columbia Basin

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 third quarter of FY 1998, 11 events were located (see Table 3.2); 5 events (45 %) in the basalt, 2 events (18 %) in the pre-basalt sediments, and 4 events (36 %) 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 that occurred between April 1, 1998 and June 30, 1998 are shown on Figure 4.2. The locations of all seismic events from October 1, 1997 to April 30, 1998 are shown in Figure 4.3. Figure 4.4 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. Figure 4.4 shows all the major mapped ridges and faults that are potential seismic sources. Table 3.1 and Figures 4.2, 4.3, and 4.4 should be referred to for the following discussions.

4.3.1 Reverse/Thrust Faults on Major Anticlinal Ridges

During the reporting period, no events occurred along any major anticlinal ridge.

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, 2 events (18 %) were located in earthquake swarm areas.

Figure 4.2. All Located Earthquakes Between April 1, 1998 and June 30, 1998 (Coda Length Magnitude (M_c) scale is shown at the side of the map)

Figure 4.3. Locations of All Events Between October 1, 1997 and June 30, 1998 (Coda Length Magnitude (M_c) scale is shown at the side of the map)

SP98020037.6

Figure 4.4. Structural and Tectonic Map of Columbia Basin Showing Major Seismic Source Structures

4.3.3.1 Saddle Mountains Swarm Area

There were 2 small events (1.3 and 1.1 M_c) in the Saddle Mountains swarm area on April, 29, 1998 and May 17, 1998, respectively. The first event occurred in the crystalline basement at a depth of about 13 km and was along the south flank of the Frenchman Hills.. The second event also occurred in the crystalline basement at a depth of nearly 22 km near Smyrna Bench on the north side of the Saddle Mountains.

4.3.4 Random or Floating Events

There were 9 events (82 %) (see Table 3.1) that are classified as random events this quarter because they did not occur in a known swarm or on a known geologic structure.

On April 1, 1998 and April 7, 1998, two small events (1.6 and 1.9 M_c) occurred in the basalt in the Wahluke syncline west of 100-K Area. Because there are no known geologic structures near this location, they are classified as random earthquakes.

On April 5, 1998, a small event ($<1 M_c$), occurred 10 km east of the 300 Area. Its depth was near the interface between the CRBG and pre-basalt sediments. Because there are no known geologic structures near this location, it is classified as a random earthquake.

A small event (1.6 M_c) occurred in the crystalline basement on the south flank of Rattlesnake Mountain on April 19, 1998. Because there are no known geologic structures near this location and because of the great depth of the earthquake, it is classified as a random earthquake.

A very small event (0.0 M_c) occurred on May 29, 1998 about 3 km north of the 200-East Area at 16.5 km depth. Because there are no known geologic structures at that depth near this location, it is classified as a random earthquake.

Four small ($\leq 1 M_c$) events occurred on April 6, 1998 (2 events), April 7, 1998, and June 3, 1998 between 10 and 12 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. Six events occurred here earlier this year. We investigated this area for the possibility of explosions but no evidence was found. There is no known geologic structure near this area and the earthquakes are therefore, classified as random events.

5.0 References

- Crosson, R. S. 1972. *Small Earthquakes, Structure and Tectonics of the Puget Sound Region*. Bulletin of the Seismological Society of America, v. 62, no. 5, pp. 1133-1171.
- DOE. 1988. *Site Characterization Plan for the Reference Location, Hanford, Washington-Consultation Draft*. Report DOE/RW-0164, Vol. 1, U.S. Department of Energy, Washington, D.C.
- Geomatrix. 1996. *Probabilistic Seismic Hazard Analysis, DOE Hanford Site, Washington*. WHC-SD-W236A-TI-002, Rev. 1, Westinghouse Hanford Company, Richland, Washington.
- Reidel, S. P., N. P. Campbell, K. R. Fecht, and K. A. Lindsey. 1994. "Late Cenozoic Structure and Stratigraphy of South-Central Washington." In E. Cheney and R. Lasmanis, (eds.), *Regional Geology of Washington State, Washington Division of Geology and Earth Resources Bulletin 80*, pp. 159-180, Olympia, Washington.
- Reidel, S. P., K. R. Fecht, M. C. Hagood, and T. L. Tolan. 1989. "Geologic Development of the Central Columbia Plateau." In S. P. Reidel and P. R. Hooper, (eds.), *Volcanism and Tectonism in the Columbia River Flood-Basalt Province Geological Society of America Special Paper 239*, pp. 247-264.
- Richter, C. F. 1958. *Elementary Seismology*. W. H. Freeman and Company, p. 768.
- Rohay, A. C., D. W. Glover, and S. D. Malone. 1985. *Time-term Analysis of Upper Crustal Structure in the Columbia Basin, Washington*. Report RHO-BW-SA-435 P, Rockwell Hanford Operations, Richland, Washington.

Distribution

<u>No. of</u> <u>Copies</u>		<u>No. of</u> <u>Copies</u>	
ONSITE		3	Fluor Daniel Hanford, Inc.
6 DOE Richland Operations Office		M. V. Berriochoa	B3-30
M. J. Furman	H0-12	J. T. Curtis	B3-15
R. D. Hildebrand	H0-12	Lockheed Martin Hanford Corporation	
J. E. Mecca	R3-79	R. R. Thompson	R2-12
M. R. Moreno	A5-55	Numatec Hanford Corporation	
K. M. Thompson	H0-12		
J. L. Tokarz-Hames	A5-55		
2 Bechtel Hanford, Inc.		T. J. Conrads	H5-25
K. R. Fecht	H0-02	2 Waste Management Federal Services, Inc.	
P. J. Mackey	B3-15	M. I. Wood	H6-06
B&W Hanford Company		M. T. York	T3-01
D. A. Conners	T5-11	25 Pacific Northwest National Laboratory	
DE&S Hanford, Inc.		D. C. Hartshorn (15)	K6-81
R. Whitehurst	R3-86	G. R. Holdren	K6-81
DynCorp Tri-Cities Services, Inc.		S. P. Reidel	K6-81
T. P. Morales	A3-05	R. M. Smith	K6-96
		Information Release Office (7)	K1-06