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January 1 - December 31, 1983

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Earth and Life Sciences Branch

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INEL ANNUAL SEISMIC REPORT

January 1 - December 31, 1983

J. J. King and D. M. Anderson

1.0 Introduction

During January, 1978, the first quarterly seismic report was issued by the Physics Division of EG&G Idaho, Inc. which covered the time period from September 1 - December 31, 1977. The last quarterly seismic report to be generated involved the time interval from October 1 - December 31, 1982. This report represents the first annual seismic report and covers the calendar year of 1983 (January 1 - December 31, 1983).

This report lists 19 earthquakes that were specifically located inside the Special Study Area (43.0°-44.5°N, 111.5°-114.0°W) by the Idaho National Engineering Laboratory (INEL) seismic net. One of these events was located on the INEL site and had an estimated Richter Local Magnitude (M_L) $\sim$ 0.7.

On October 28, 1983 at 8:06 a.m. Mountain Daylight Time (MDT), a major earthquake occurred within the Special Study Area and had a Richter Magnitude = 7.3. This document includes some preliminary findings on the Borah Peak earthquake and its aftershocks. A preliminary total of 376 earthquakes has occurred since the main shock from October 28 - December 31, 1983 that have $M_L \geq 2.5$.

Thirteen Strong Motion Accelerographs (SMA's) provided records on the INEL site from the Borah Peak earthquake. Four additional SMA records at the Loss-Of-Fluids Test (LOFT) facility were recorded from a large aftershock (M_L = 5.8) on October 29, 1983. A detailed listing of peak accelerations from these accelerograms is presented in this report.

2.0 Summary of Seismicity Within the Special Study Area During 1983

2.1 Results of Analysis for Specific Earthquakes Located Within the Special Study Area

Figure 1 is a regional map which displays INEL seismic stations which are presently active, and station Indian Meadow (IMW), which is operated by Ricks College at Rexburg, Idaho, and monitored by the INEL. Table 1 lists siting information for the INEL seismic stations (including closed stations) and station IMW. Also, listed in Table 1 is the estimated nominal ground displacement magnification for 10 Hz seismic waves at each active station.

Analysis of seismograms for the INEL net is accomplished by measuring P-wave arrival times and S-wave arrival times for stations observing a local earthquake. A preliminary epicenter is determined by using surface-focus near-earthquake-phase tablesfrom Jeffreys and Bullen[1] and locating the event by a graphical arc method on a large regional map. Those events which appear to be inside the Special Study Area (43.0° - 44.5°N, 111.5° - 114.0°W) are then further analyzed.

Since January 1981, the INEL network has used the computer program HYPO-71[2] for final locations of earthquakes that have been graphically located within the Special Study Area (SSA). Three P-wave arrival times and two S-wave arrival times were chosen as minimum phase requirements for locating earthquakes with HYPO-71, since nearly all of the located events were outside the INEL network. Table 2 shows the P-wave velocity model used to locate earthquakes analyzed by HYPO-71, (Olsen et al.,[3] Sparlin et al.,[4] Braile and Smith,[5] and Ackerman[6]). This model is primarily based upon seismic refraction profiles perpendicular to the axis of the Eastern Snake River Plain (ESRP) that partially incorporate the mountainous margins on both sides of the ESRP. A P-wave velocity to S-wave velocity

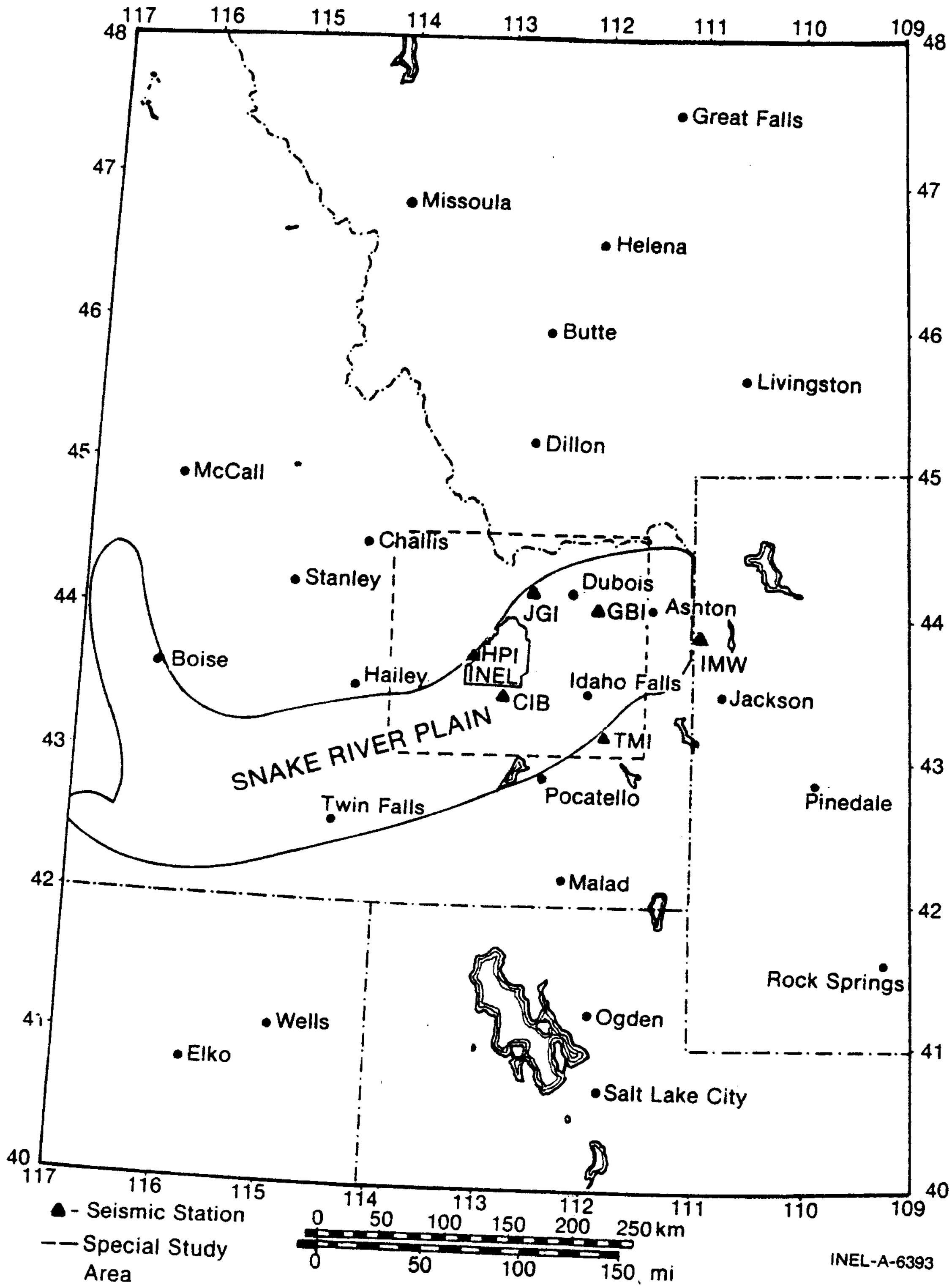


Figure 1. Regional Map Displaying INEL Seismic Station Locations.

TABLE 1. INEL Seismic Stations with Siting Information

Code	Station Name	Latitude (deg. N)	Longitude (deg. W)	Elev. (meters)	Magnification @ 10 Hz[e]	Date Opened	Date Closed
CIB	Cedar Butte	43.4012	112.9418	1611	1180K	11/79	Open
DCI[a]	Dry Creek	43.9548	111.0958	2020	-----	06/74	07/80
GBI[b]	Big Grassy Butte	43.9874	112.0633	1561	1180K	10/81	Open
HID[b]	Hamer Butte	43.9630	112.1638	1527	-----	08/73	10/81
HPI	Howe Peak	43.7113	113.0983	2597	2370K	10/72	Open
IMW[a]	Indian Meadow	43.8970	110.9392	2646	Not Known	07/80	Open
JGI	Juniper Gulch	44.0926	112.6769	1657	590K	11/79	Open
LRI[c]	Big Lost River	43.5283	112.9483	1509	-----	12/71	06/78
MBI[d]	Menan Buttes	43.7864	111.9706	1707	-----	09/73	07/74
TMI	Taylor Mountain	43.3056	111.9181	2179	1180K	10/72	Open

a. DCI was operated by Ricks College for the Bureau of Reclamation. It has been monitored by the INEL since January 1977. In July 1980, IMW was opened. It is operated by Ricks College and monitored by the INEL.

b. HID was closed on 10/02/81 because of excessive cultural and electronic noise. GBI was opened on 10/08/81 as a replacement for HID. The HID facility is still used to retransmit data from GBI, IMW, and JGI to the seismic base station at the Test Reactor Area (TRA).

c. LRI was used sparingly during its existence due to cultural noise problems.

d. MBI existed for a brief period as an alternative to HID. It was closed and HID was reopened following its closure.

e. All INEL stations and station IMW use Mark Products L-4c 1.0 Hz vertical seismometers. The critical damping for all INEL seismometers is calculated to be 79%. All active stations use FM telemetry for data transmission to the seismic base station, located at the Test Reactor Area (TRA).

ratio of 1.72 was selected, and was based upon studies done by Bones[7] and Greensfelder and Kovach[8]. This value was assumed for the velocity layers shown in Table 2.

TABLE 2. Velocity Model for the INEL Seismic Net

P-Wave Velocity (km/sec)	Depth to Top (km)	Thickness (km)
4.9	0.0	2.0
6.0	2.0	15.0
6.7	17.0	23.0
7.9	40.0	Semi-Infinite

Richter Local Magnitudes (M_L) were calculated by HYPO-71, using the following expression:

$$M_L = -3.13 + 2.74 \log\tau + 0.0012\Delta \qquad (1)$$

where

τ = Total signal duration in seconds

Δ = Epicentral distance from each station in km.

The duration (τ) is measured from the P-wave arrival to the time when the signal (coda) disappears into the background noise. This expression has been used by the University of Utah Seismograph Stations when determining local magnitude for INEL stations monitored by the University of Utah.[9]

An earthquake is assigned a local magnitude by averaging computed magnitudes for individual stations. The standard error of estimation is 0.27 when using Equation 1[10]. Equation 1 is considered applicable when $1.0 \leq M_L \leq 3.5$ (See Reference 9).

Nineteen specific earthquakes with a local magnitude range of $0.7 \leq M_L \leq 3.2$ were located by HYPO-71 within the SSA during 1983. (This list excludes the 1983 Magnitude 7.3 Borah Peak earthquake and associated aftershocks, which are discussed in the next section.) The results of the HYPO-71 analysis for these nineteen events are listed in the Appendix.

Two of these earthquakes are worthy of further comment. On February 25, 1983 an earthquake occurred near the Blackfoot River Reservoir with an $M_L = 3.2$. This is the first event located within the SSA by the INEL net since October, 1972 for which $M_L \geq 3.0$. Three other earthquakes having an $M_L = 1.8$, 2.0, and 2.2 accompanied this event. On November 27, the first earthquake occurred that was confirmed by HYPO-71 to be located on the INEL site. This event had an $M_L \sim 0.7$ and was about 6-8 km east of the Naval Reactors Facilities (NRF). The uncertainty on this location involves a circle with a radius of 5 km or less.

Figure 2 displays the cumulative number of earthquakes located by the INEL network with HYPO-71 within the SSA from October 1972 to December 1983. (As noted earlier, the 1983 Borah Peak earthquake sequence is discussed in the next section.) A total of 104 earthquakes are plotted outside the Borah Peak earthquake aftershock zone, and have a magnitude range of $0.7 \leq M_L \leq 3.2$. The reader should consult King and Doyle[11] for a discussion concerning this earthquake data base. The faults displayed in Figure 2 are known and suspected active faults compiled by Witkind[12].

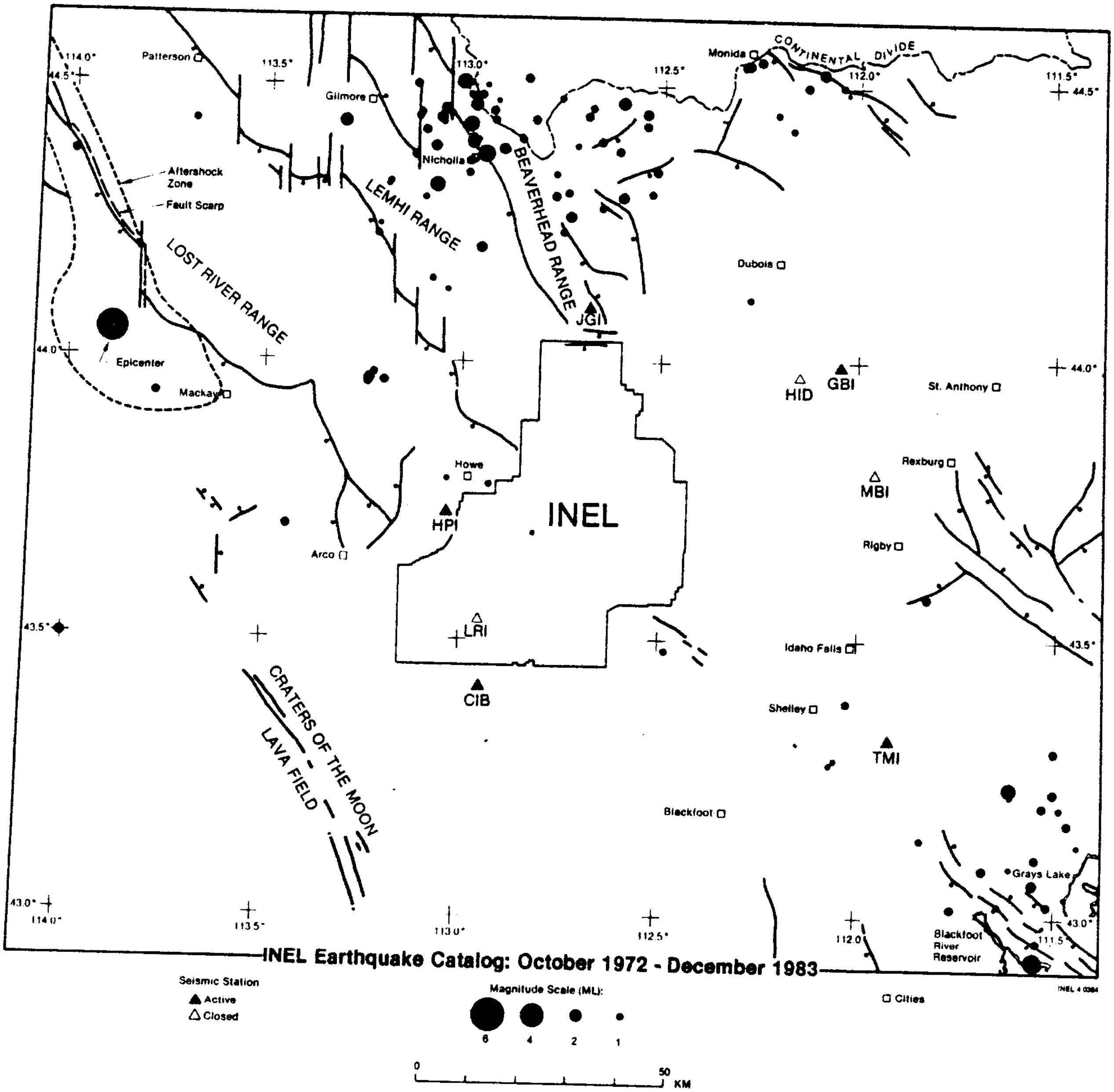


Figure 2. Map Displaying a Total of 104 Earthquakes Located Outside the Borah Peak Earthquake Aftershock Zone by the INEL Seismic Network from October, 1982 - December, 1983.

The few events shown on the ESRP in Figure 2 are thought to have location uncertainties of 5 km or less. The majority of earthquakes shown outside the ESRP have location uncertainties which can vary from 5 to 10 km. Some events located near the perimeter of the SSA may have location uncertainties exceeding 10 km due to poor station coverage at the boundaries. None of the earthquakes analyzed during this study have been located within a proper geometry with a sufficient number of stations to determine an accurate focal depth. The final focal depth obtained by HYPO-71 for a given earthquake may reflect depth uncertainties similar to the epicentral uncertainties noted above. No evidence to date would indicate that the actual focal depths should significantly differ with a value of 7 km, an average depth associated with the Intermountain Seismic Belt (See Reference 7).

2.2 Preliminary Analysis of the Aftershocks of the 1983 Borah Peak Earthquake

The aseismic behavior that has characterized the SSA ended abruptly at 8:06 a.m. Mountain Daylight Time on October 28, 1983, with the occurrence of the Richter Magnitude 7.3 Borah Peak earthquake. This earthquake surface-ruptured in a region that has been aseismic for the last century, and has produced only two microearthquakes (M_L = 1.4 and M_L = 1.5) that have been observed by the INEL seismic network within 30 km of the epicenter since October, 1972 (See Reference 11).

Many large earthquakes (M>7) are often preceded by a series of foreshocks. This was not the case for the Borah Peak earthquake. The only possible foreshock observed prior to the main shock was a small microearthquake ($M_L \sim$ 0.7) that occurred 2 minutes and 3 seconds in advance of the main shock. This event was observed on stations HPI and JGI, but could not be located by HYPO-71 due to insufficient seismic wave phase data.

Figure 3 displays the instrumentally located epicenter, for the Borah Peak earthquake, the approximate length of the surface fault rupture or scarp, and a zone that roughly identifies where aftershocks have occurred. This zone extends from Mackay northwest to the Challis area and beyond (not shown on Figure 3) for a total length of about 90 km. This estimate is based upon graphical locations using INEL seismic stations and should not be interpreted to be an accurately defined zone.

The epicenter was located by incorporating data from many regional seismic stations through the National Earthquake Information Service of the U.S. Geological Survey. The published location for the epicenter is 44.06^{o}N, 113.86^{o}W with the fault scarp extending for

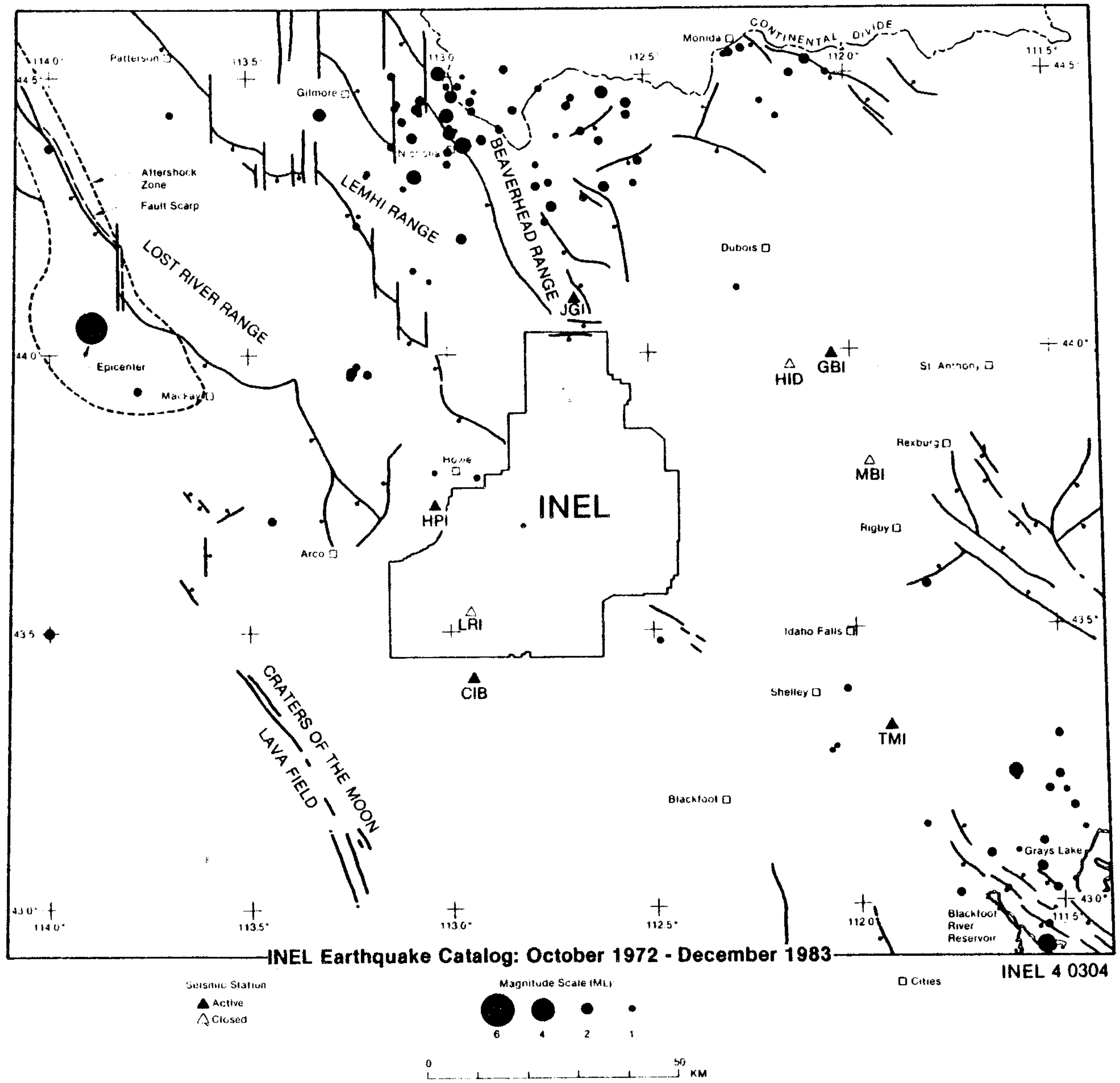


Figure 3. Approximate Location of Epicenter, Fault Scarp, and Aftershock Zone for the Borah Peak Earthquake.

more than 35 km with a maximum vertical displacement of 2.7 meters.[13] Preliminary evaluation of teleseismic waves indicates that the main shock focal mechanism was dip-slip (normal) faulting with a strong component of left-lateral strike-slip faulting.[14] Since the epicenter was located at the southwest edge of the surface rupture (about 30 km northwest of Mackay), it appears that the fault rupture proceeded in a northwest direction away from Mackay and toward Challis. However, such a simple observation may incorrectly overlook the complexities of the fault rupture physics.

Earlier it was noted that the region about the Borah Peak earthquake epicenter has historically displayed very low seismic activity. However, if one extends the time scale over the past 100,000 years, a different interpretation arises. Hait and Scott[15] have performed trenching studies across the Lost River range-front fault prior to the Borah Peak earthquake. One trench was located near Willow Creek about 35 km northwest of Mackay. Their work indicates that 1.5 - 2.0 meters of offset occurred within the past 500-10,000 years (Holocene age). They suggested that if the Holocene movement occurred in a single event, the resulting surface break of 35 km may have produced an earthquake of magnitude 6-7 with a maximum vertical displacement of 2-3 meters. In retrospect, their analysis 5 years in advance of the Borah Peak earthquake is phenomenal.

Two weeks prior to the Borah Peak earthquake, the voltage-controlled-oscillator frequency at station HPI was changed. This fortuitous modification enabled HPI to be added to the group of seismic data signals that are monitored by the University of Utah Seismograph Stations (UUSS). On the morning of the Borah Peak earthquake, HPI was patched onto the leased phone line to the UUSS, thus assuring a backup recording capability for the six seismic stations that are recorded at the INEL. This redundancy helped to fill data gaps which did occur due to incidents of broken pens on INEL Helicorders. It also has greatly aided the data reduction process.

Two portable seismographs (Teledyne-Geotech RV-320B) were emplaced on the aftershock zone between 11:00 p.m., October 28 and 1:00 a.m., October 29. These instruments recorded crucial aftershock data until their removal on November 22. The INEL portable seismographs performed flawlessly during this time interval and have produced high-quality data that have been incorporated with seismic data acquired by the University of Utah, the U.S. Geological Survey, the University of Washington, Boise State University, and others.

The enormity of the data acquisition and data evaluation overload can be partially conveyed by viewing the earthquake totals presented in Table 3. Table 3 displays aftershock totals from $2.5 \leq M_L \leq 5.9$ in 0.5 M_L increments for three different time intervals from October 28 - December 31, 1983. The first interval consists of the initial 3.4 days following the main shock at 14:06 Greenwich Mean Time (GMT) on October 28, 1983. The other two intervals are the months of November and December, respectively. The three largest aftershocks (M_L = 5.8, 5.8, and 5.4) occurred on October 28 and October 29. Thereafter, no aftershocks exceeded the M_L =

TABLE 3. Preliminary Earthquake Totals With Indicated Time Intervals Covering Specified M_L Ranges for Borah Peak Aftershocks Having $M_L \geq 2.5$

Aftershock M_L Range	Aftershocks From October 28 - October 31, 1983	Aftershocks From November 1 - 30, 1983	Aftershocks From December 1-31, 1983	Total Aftershocks From October 28 - December 31, 1983
5.5 - 5.9	2	0	0	2
5.0 - 5.4	1	0	0	1
4.5 - 4.9	2	1	2	5
4.0 - 4.4	5	1	1	7
3.5 - 3.9	8	11	10	29
3.0 - 3.4	25	38	33	96
2.5 - 2.9	67	109	60	236
TOTAL	110	160	106	376

5.0 threshold. A cutoff magnitude of $M_L = 2.5$ was selected due to the copious quantities of microearthquakes that resulted. The earthquake magnitudes were assigned on the basis of Wood-Anderson seismograph records at the UUSS,[16] published magnitudes by the NEIS,[17] and assignments made by INEL stations using Equation 1 in Section 2.1 of this report. Magnitudes exceeding $M_L =$ 3.5 were generally assigned by the first two sources, with INEL stations being the nearest permanent stations for identifying magnitudes below this level. Efforts were undertaken to account for reduced magnifications on INEL stations by choosing stations that were operating at nominal or near-nominal gains, and by picking subsets of stations which represented mean M_L's for the whole INEL net.

A total of 376 earthquakes having $M_L \geq 2.5$ are listed in Table 3 for the time period from October 28 - December 31, 1983. The largest aftershocks occurred within the first 3.4 days following the main shock. Ten events having $M_L \geq 4.0$ were produced during this first time period, with only 2 events having $M_L \geq 4.0$ from November 1-30, and only 3 events having $M_L \geq 4.0$ from December 1-31, 1983. The incidence of earthquakes in which $M_L \geq 2.5$ appears to fall off with time as 1983 progressed. In fact the total number of earthquakes with $M_L \geq 2.5$ in the first 3.4 days is about equal to the total number from December 1-31, 1983.

Approximately 300 earthquakes are under investigation for detailed seismological analysis that will involve an integration of measurements from about 40 portable seismographs. Data acquired by INEL stations and portable seismographs are an important contribution to this effort. The results of preliminary analyses of Borah Peak aftershocks are to be given by Richins, et al.[18] at the May 30 - June 1, 1984, meeting of the Seismological Society of America at Anchorage, Alaska.

3.0 Strong-Ground-Motion Measurements at the INEL from the Borah Peak Earthquake and a Large Aftershock

Since 1973, at least thirteen strong motion accelerographs (SMA's) have been installed at various INEL facilities. These instruments serve the purpose of recording ground acceleration time histories that are produced by nearby moderate or larger earthquakes. Three orthogonal components of ground acceleration can be recorded on 70mm-wide film, which can then be developed to unveil a linear analog history of ground acceleration.

The Magnitude 7.3 Borah Peak earthquake produced the first accelerograph records (accelerograms) ever recorded at the INEL. Ground motion from the main shock at 8:06 a.m. local time (MDT) was recorded on thirteen accelerographs located at the INEL site. Two other accelerographs at the INEL failed to operate properly. A recently installed instrument at the Idaho Laboratory Facility (ILF) in Idaho Falls did not receive sufficient vertical ground acceleration to turn on and record ground motion.

Within two hours following the earthquake, the process of gathering film records was initiated by D. M. Anderson and T. E. Doyle. It was decided that the two facilities at the INEL which should be visited first were the Advanced Test Reactor (ATR) and Experimental Breeder Reactor (EBR) No. II. These facilities were in operation at the time of the earthquake and were automatically scrammed by acceleration-sensitive earthquake detectors.

The scram threshold is 0.01g at ATR while the threshold at EBR-II is 0.005g.

Film records at ATR and the Engineering Test Reactor (ETR) were retrieved by noon on October 28, 1983. By mid-afternoon, the two records at EBR-II had been gathered. Preliminary peak accelerations were scaled for the four accelerograms by late afternoon of that same day.

On Saturday, October 29, the four SMA's at the Loss-Of-Fluids Test (LOFT) facility and the "remote" SMA at Old Fire Station No. 2 were visited. The three SMA's at the Chemical Processing Plant (CPP) and the three instruments at the Power Burst Facility (PBF) were visited on Monday, October 31.

Table 4 displays locations and orientations for sixteen SMA's installed for operation prior to the Borah Peak Earthquake. Figure 4 presents SMA locations on a map of the INEL. Table 5 lists peak accelerations scaled from the thirteen accelerograms associated with the main shock. Peak accelerations and their uncertainties are given for the longitudinal (L), vertical (V), and transverse (T) components of ground motion based upon tilt-test calibrations performed on individual instruments prior to October 28, 1983. The uncertainties ΔL, ΔV, ΔT were determined by incorporating the error associated with the smallest unit capable of being determined on each record (0.1mm) along with the cross-axis sensitivity (non-orthogonality) that exists for each individual accelerometer. These errors were considered independent and were combined in quadrature. The cross-axis sensitivity error is generally less than 4% of the scaled value. Any nonlinear response for small angles of accelerometer rotation, which is pertinent to deflections that occurred during the Borah Peak earthquake, has not been measured and has been assumed to be negligible. The peak accelerations for each component were determined by measuring the largest peak-to-peak deflection for each record and then dividing by two. If this peak-to-peak deflection is asymmetric about the "zero acceleration" baseline, then this method underestimates the

TABLE 4. INEL Strong Motion Accelerograph Locations and Orientations

Location	Coordinates	Model Number	Instrument Serial Number	Accelerometer[a] Serial Number	Component[b] Orientation For Upward Trace Deflection	Date Installed
ANL-767 Reactor Plant (Basement)	43.595 N 112.656 W	RFT-250	322	L 4850 V 4800 T 4750	196° Up 106°	1973
ANL-768 Power Plant (Basement)	43.595 N 112.656 W	RFT-250	321	L 4700 V 4800 T 4850	180° Up 90°	1973
CPP-601 Process Building (2nd Basement)	43.573 N 112.934 W	RFT-250	323	L 4650 V 4800 T 4700	179° Up 89°	1973
CPP-601 Process Building (1st Floor)	43.573 N 112.934 W	RFT-250	328	L 4800 V 4900 T 4800	181° Up 91°	1973
CPP-610 Old Guard House (Free Field)	43.567 N 112.934 W	RFT-250	336	L 4700 V 4700 T 5000	180° Up 90°	1973
Old Fire Station No. 2 (Free Field)	43.597 N 112.939 W	RFT-250	319	L 4750 V 4700 T 4750	150° Up 60°	1973
PBF-620 Reactor Building (1st Basement)	43.554 N 112.875 W	RFT-250	324	L 4700 V 4800 T 4800	179° Up 89°	1973
PBF-620 Reactor Building (Crane Beam)	43.554 N 112.875 W	RFT-250	325	L 4700 V 4650 T 4700	179° Up 89°	1973
PBF-620 Reactor Building (2nd Basement)	43.554 N 112.875 W	RFT-250	331	L 4750 V 4700 T 4850	180° Up 90°	1973

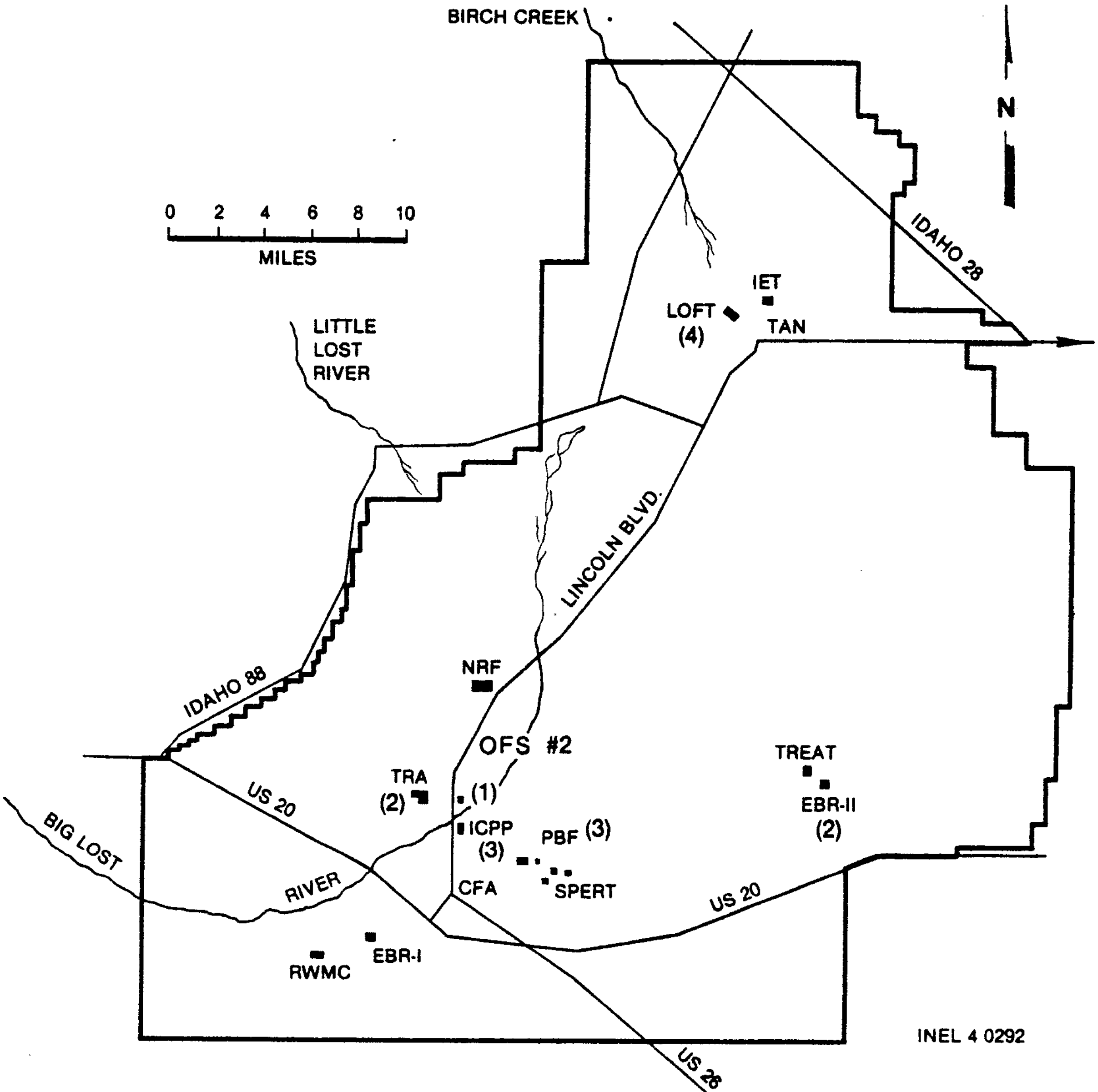
TABLE 4. Continued

Location	Coordinates	Model Number	Instrument Serial Number	Accelerometer[a] Serial Number	Component[b] Orientation For Upward Trace Deflection	Date Installed
TAN-650 Containment and Service Building Tower (4th Floor)	43.857 N 112.728 W	RFT-350	1052	L 2064 V 2069 T 2021	153° Up 63°	11/78
TAN-650 Containment and Service Building Vessel (Basement)	43.857 N 112.728 W	RFT-350	1053	L 2076 V 2083 T 2086	169° Up 79°	11/78
TAN-650 Containment and Service Building Vessel (Top of Dome)	43.857 N 112.728 W	RFT-250	326	L 4700 V 4900 T 4800	330° Up 240°	9/79
E. of Shielded Roadway - TAN-719 (Free Field)	43.857 N 112.725 W	RFT-350	1051	L 2095 V 2022 T 2037	350° Up 260°	8/79[c]
TRA-642 ETR Reactor Bldg. (Basement)	43.585 N 112.962 W	RFT-250	327	L 4800 V 4700 T 4850	179° Up 89°	1973
TRA-670 ATR Reactor Bldg. (Basement)	43.588 N 112.965 W	RFT-250	329	L 4700 T 4750 T 4800	269° Up 179°	1973
Idaho Laboratory Facility (1st Floor)	(not yet determined)	RFT-250	333	L 4800 V 4750 T 4900	90° Up 0°	8/30/83

a. L, V, T refer to longitudinal, vertical, and transverse accelerometers.

b. Azimuthal direction relative to geographical north (0° = North) for accelerograph case acceleration which produces upward accelerometer trace deflection.

c. A Teledyne Geotech RFT-250 was installed at this location in 1973, and was later replaced by a Terra Technology RFT-350 during August, 1979.



Number of Accelerographs at Each Location

ICPP	(3)	Old Fire Station No. 2	(1)
EBR-II	(2)	PBF	(3)
LOFT	(4)	TRA	(2)

Figure 4. INEL Strong Motion Accelerograph Locations.

TABLE 5. Peak Acceleration in Terms of "g" for Accelerograms Recorded at the INEL During the Magnitude 7.3 Borah Peak Earthquake

Instrument Serial Number	Facility[a]	Longitudinal	Vertical	Transverse	$\pm \Delta L$[b]	$\pm \Delta V$	$\pm \Delta T$	Distance From[c] Epicenter (km)
321	ANL-768 (Basement)	0.040	0.029	0.040	0.002	0.001	0.002	110
322	ANL-767 (Basement)	0.031	0.030	0.028	0.002	0.002	0.002	110
323	CPP-601 (2nd Basement)	0.030	0.037	0.042	0.002	0.001	0.001	92
324	PBF-620 (1st Basement)	0.055	0.035	0.050	0.003	0.001	0.002	97
325	PBF-620 (1st Floor High-Bay Bridge-Crane Beam)	0.156	0.068	0.210	0.006	0.001	0.003	97
326	TAN-650 (Top of Dome)	0.111	0.055	0.151	0.004	0.002	0.008	94
327	TRA-642 (ETR) (Basement)	0.026	0.021	0.025	0.002	0.001	0.002	90
328	CPP-601 (1st Floor)	0.034	0.038	0.067	0.003	0.001	0.003	92
329	TRA-670 (ATR) (Basement)	0.023	0.023	0.022	0.001	0.002	0.001	89
331	PBF-620 (2nd Basement)	0.049	0.034	0.051	0.002	0.001	0.006	97
336	CPP-610 (Free Field)	0.072	0.044	0.069	0.003	0.001	0.004	93

TABLE 5. Continued

Instrument Serial Number	Facility[a]	Longitudinal	Vertical	Transverse	$\pm \Delta L$[b]	$\pm \Delta V$	$\pm \Delta T$	Distance From[c] Epicenter (km)
1051	TAN-719 Area (Free Field)	0.032	0.018	0.040	0.003	0.003	0.003	94
1052	TAN-650 (4th Floor)	0.037	0.025	0.081	0.003	0.003	0.003	94

a. 1st basement implies the basement nearest to the ground level.

b. $\pm \Delta L$, $\pm \Delta V$, $\pm \Delta T$ represent uncertainties in Longitudinal, Vertical, and Transverse components respectively, for peak accelerations in terms of "g".

c. These distances assume an epicenter at 44.06°N, 113.86°W, as reported by the National Earthquake Information Service.

true maximum peak acceleration associated with impulsive "up" or "down" motion. However, it does represent an average peak acceleration for the largest sinusoidial cycle associated with individual accelerometers.

The peak acceleration for the ground level and the basement records varied from a low value of 0.022g for the basement transverse component at ATR (TRA-670) to a high value of 0.072g for the longitudinal component at the old guard house (CPP-610), which was recorded at ground level. Instruments placed above ground level (TAN-650, 4th floor and dome top, and the crane beam, PBF-620) enjoyed both amplification and some high-frequency excitations which resulted in much larger levels of acceleration. As an example, No. 326 recorded a peak acceleration of 0.15 g for the transverse component at the top of the LOFT dome (10 story height) and had frequency components as high as 20 Hz. The largest peak acceleration (0.040 g) recorded at the LOFT "free field" ground location (No. 1051) was on the transverse component and was associated with a 5 Hz frequency. (A partial explanation for the high frequencies seen on the LOFT dome can also arise from resonance effects derived from the metal frame on top of the LOFT dome to which No. 326 is attached.) The largest level of peak acceleration occurred on the first floor high-bay bridge crane beam at PBF-620. A momentary peak acceleration of 0.21g was recorded at this instrument.

Table 5 reveals that the SMA's at the INEL site had a distance variation of 89-110 km from the epicenter. These distances were calculated by assigning the Borah Peak earthquake epicenter at 44.06°N, 113.86°W, and using the short distance calculation method of Richter[19] to determine the separation between the epicenter and the individual accelerographs. It should be noted that over the 89-110 km distance range peak acceleration did not fall off uniformly with distance from the epicenter. In fact, the lowest levels of peak acceleration at the INEL were recorded at stations nearest the epicenter (ATR and ETR).

The two instruments at the INEL which did not record ground acceleration failed for different reasons. No. 319 at Old Fire Station No. 2 probably did not turn on due to the cold air temperature the morning of October 28. Examination of this instrument on the afternoon of October 29 demonstrated that it functioned properly. The thermostat for the heater inside the metal shack which houses No. 319 was adjusted to ensure a warmer environment thereafter.

No. 1053 (TAN 650 basement) failed to operate properly on October 28 because the light bulb, which provides the light source for recording accelerometer deflection, failed to switch on. All four LOFT SMA's turned on but no light traces were recorded on the film of No. 1053. Earlier, on October 12, this instrument had functioned properly during a tilt-test calibration. A poor connection on this instrument was repaired October 29.

Following the main shock, the three largest aftershocks to date were of Richter Magnitude 5.8, 5.8, and 5.4. These events were reportedly felt by various reactor personnel at facilities across the INEL. However, no reactor scrams occurred at any INEL facilities. Since EBR-II did not scram (threshold $\geq$ 0.005 g), it was assumed that accelerographs with starters set at 0.007g (vertical acceleration) did not record additional events following the main shock.

Routine quarterly SMA maintenance during January 1984 produced an unexpected result. The processing of records retrieved at LOFT revealed that all four instruments had recorded ground acceleration from one of the aftershocks. Table 6 displays peak acceleration for the measurable components recorded at LOFT. The largest peak accelerations occurred for the longitudinal and transverse components for instruments located on the 4th floor at TAN-650 and on the top of the dome. The uncertainties are large fractions of the peak values because the smallest measureable unit (0.1mm) represents a significant portion of the accelerometer trace displacement. In other words, these measurements just exceed the minimum threshold of strong ground acceleration that conventional analog SMA's are capable of recording.

The RFT-350 SMA's sited at LOFT (Serial Numbers 1051-1053) have starters which are set at 0.01 g vertical acceleration. No. 326 on the dome has no starter since it is susceptible to false triggering from wind noise. However, all four units are interconnected so that any of the RFT-350 instruments can turn on all four. No. 1052 represents the only self-starting SMA sited at the INEL above ground level. Since it is situated on the fourth floor of TAN-650, it is subject to amplified ground motion. It would seem logical that No. 1052 briefly experienced a vertical component of ground acceleration exceeding 0.01 g, and started itself and the other three instruments at LOFT. The duration of the records for the four instruments was only 8-9 seconds before shutting off.

The question concerning which aftershock caused the recordings at LOFT must be answered. The SMA's at the INEL

TABLE 6. Peak Acceleration in Terms of "g" for Accelerograms at LOFT for the Magnitude 5.8 Aftershock on October 29, 1983.

Instrument Serial Number	Location	Longitudinal	Vertical	Transverse	$\pm \Delta L$[a]	$\pm \Delta V$	$\pm \Delta T$	Distance[b] To Epicenter (km)
1051	TAN-719 Area (Free Field)	0.005	Not Measurable	0.006	0.003	-----	0.003	116
1052	TAN-650 (Fourth Floor)	0.011	0.005	0.014	0.003	0.003	0.003	
1053	TAN-650 (Reactor Basement)	0.003	Not Measurable	0.005	0.003	-----	0.003	
326	TAN-650 (Top of Dome -10th Floor)	0.011	0.004	0.014	0.002	0.001	0.001	

a. $\pm \Delta L$, $\pm \Delta V$, $\pm \Delta T$ represent uncertainties in Longitudinal, Vertical, and Transverse components, respectively, for peak accelerations in terms of "g".

b. This distance assumes an epicenter at 44.23°N, 114.10°W, as reported by the National Earthquake Information Service.

produce internal timing marks on the recording film, but they are not associated with accurate time-of-day information sources such as National Bureau of Standards radio station WWVB. Thus, the records themselves do not identify the earthquake source. However, as described below, the unique turn of events on October 29 allows for identification of the earthquake source.

The SMA's at LOFT were visited and the film records for the main shock were retrieved on the morning of October 29. Later that day, two of the largest aftershocks occurred at 5:29 p.m. (M_L = 5.8) and 5:39 p.m. (M_L = 5.4) local time.

The indicated Richter Magnitudes represent average values measured by Wood-Anderson seismographs operated by the University of Utah Seismograph Stations (See Reference 16). Since October 29, 1983 to present (March 31, 1984), no aftershocks exceeding Richter Magnitude 5.0 have occurred. The M_L = 5.8 earthquake occurred slightly southeast of the M_L = 5.4 earthquake, according to preliminary locations given by the National Earthquake Information Service (See Reference 13). Thus, its larger size and closer location to LOFT make it the prime candidate for triggering the SMA's at LOFT.

The scaling of the accelerograms from the main shock represents only preliminary information that can be extracted from each record. Further data analysis is to be performed by the Structural and Earthquake Engineering Consultants (SEEC) Inc. in Arcadia, California. The components of each accelerogram will be digitized and corrected to eventually produce time histories of corrected acceleration, velocity, and displacement. In addition, each component will have plots displaying pseudo relative displacement, and a Fourier spectrum. It is hoped that this processing will be completed in the next few months.

Following the Borah Peak earthquake, two strong motion accelerographs were installed in buildings at the Naval Reactors Facilities. In November of 1983, a Kinemetrics SMA-1 (No. 4773) was sited in the A1W building on the ground floor and a Teledyne-Geotech RFT-250 (No. 334) was installed on the ground floor of the S1W building. These spare instruments were located at the Naval Reactors Facilities at the request of NRF (L. W. Rossiter) to replace instruments previously removed.

4.0 References

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Appendix

Earthquakes for 1983 Located by HYPO-71 Within the Special Study Area

(43.0° - 44.5°N, 111.5° - 114.0°W)

Explanation Of Earthquake List Headings[a]

Heading	Example	Explanation
DATE	830127	Date of earthquake: year, month, and day. For this example, it is January 27, 1983.
ORIGIN	2345 21.6	Origin time: hour, minute, and second (Greenwich Mean Time). For this example, it is 23 hr, 45 min. and 21.6 sec.
LAT N	44-24.82	Latitude of epicenter in degrees and minutes: 44° 24.82′ North.
LONG W	112-54.33	Longitude of epicenter in degrees and minutes: 112° 54.33′ West.
SOURCE AREA	E. of Nicholia	Location of epicenter relative to cities, landmarks, or bodies of water shown in Figure 2 of this document.
MAG	1.9	Local magnitude of the earthquake.
NO	8	Number of station readings used in locating the earthquake. P-wave and S-wave arrivals for the same station are regarded as two readings.

Heading	Example	Explanation
GAP	294	Largest azimuthal separation in degrees between stations.
DMIN	40.1	Distance in km from the epicenter to the nearest station.
RMS	.09	Root mean square error of time residuals in seconds. $RMS = \sqrt{\Sigma R_i^2/NO}$, where R_i is the time residual for the ith station.
ERH	1.1	Standard error of the epicenter in km. The values are computed by HYPO-71 based upon assumptions which may not be met by certain earthquakes. Therefore, the standard errors may not represent actual error limits.
Q	C	Solution quality of the hypocenter. This measure is intended to indicate the general reliability of the solution:

Q	Epicenter	Focal Depth
A	Excellent	Good
B	Good	Fair
C	Fair	Poor
D	Poor	Poor

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a. HYPO-71 calculates a focal depth and standard error of focal depth for each of the earthquakes shown in this Appendix. These calculated values have been eliminated from the earthquake listings since no earthquakes have occurred within the Special Study Area for which a proper seismic station geometry has existed for supporting a calculated focal depth. A discussion on focal depths is given in Section 2.1 of this report.

DATE	ORIGIN	LAT N	LONG W	SOURCE AREA	MAG	NO	GAP	DMIN	RMS	ERH	Q
830127	2345 21.6	44-24.82	112-54.33	E. of Nicholia	1.9	8	294	40.1	.09	1.1	C
830225	0026 23.3	42-56.0	111-31.10	Blackfoot River Reservoir	2.0	8	271	52.7	.38	5.8	D
830225	0137 29.0	42-56.31	111-31.55	Blackfoot River Reservoir	2.2	10	270	51.8	.38	3.4	D
830225	0528 05.1	42-56.36	111-31.98	Blackfoot River Reservoir	3.2	9	270	51.4	.40	5.1	D
830301	1828 09.4	42-57.82	111-31.63	Blackfoot River Reservoir	1.8	8	268	49.6	.37	4.3	D
830329	1235 14.0	44-26.65	112-31.73	S.W. of Monida	1.8	8	294	40.8	.27	3.1	D
830330	0511 19.3	44-27.46	112-31.54	S.W. of Monida	2.0	7	296	64.0	.39	4.9	D
830410	0901 58.6	44-30.50	113-07.66	E. of Gilmore	1.4	6	324	58.5	.11	1.9	C
830703	2357 23.5	43-13.62	111-28.80	N. of Grays Lake	1.6	7	249	36.6	.24	3.2	D
830802	1323 16.5	44-08.82	113-05.04	S.W. of Nicholia	1.0	6	279	33.2	.12	2.6	D
830806	0311 52.7	44-28.20	112-45.36	W. of Humphrey	1.0	6	333	42.4	.18	3.8	D
830921	2258 32.3	44-30.30	112-57.18	N. of Nicholia	0.9	8	285	19.7	.23	2.6	D
830922	1957 51.0	44-15.12	113-13.20	S.W. of Nicholia	0.7	8	255	22.7	.35	2.7	D
831002	0935 28.5	44-27.36	112-58.56	N. of Nicholia	2.2	8	284	14.3	.12	2.3	C
831003	0014 57.6	44-28.74	112-59.58	N. of Nicholia	1.2	7	324	17.0	.31	29.9	D
831017	0201 20.8	44-23.76	112-58.98	W. of Nicholia	0.9	6	317	41.7	.39	11.6	D
831026	1758 43.7	44-23.28	112-43.26	N.W. of Nicholia	0.9	6	332	33.1	.24	53.5	D
831127	1700 14.1	43-41.28	112-49.74	INEL Site	0.7	6	203	21.9	.09	1.0	D
831128	0423 27.5	43-05.28	111-40.50	Blackfoot River Reservoir	1.6	8	255	31.3	.18	1.9	C