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DECEMBER 1982

EARTHQUAKE CATALOG FOR THE EASTERN SNAKE RIVER PLAIN
REGION, IDAHO (43.0° - 44.5° N, 111.5° - 114.0° W)
OCTOBER 1972-JUNE 1982

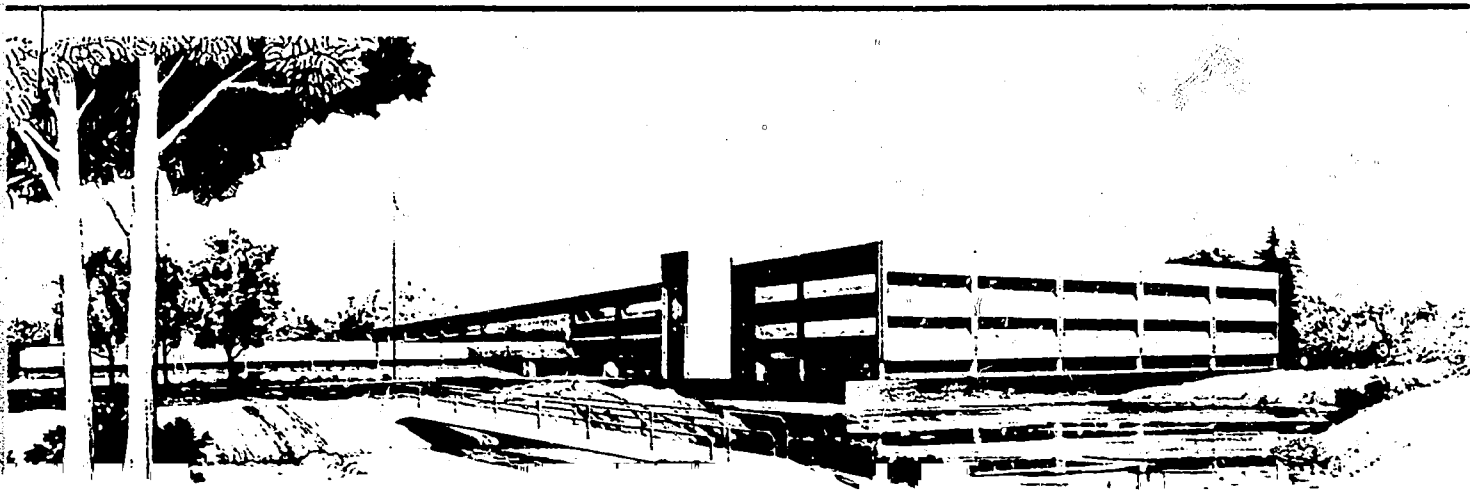
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ABSTRACT

The Idaho National Engineering Laboratory (INEL) has deployed a network of short-period high-gain vertical seismographs since December 1971 to monitor earthquake activity on and about the eastern Snake River Plain (ESRP), Idaho. This report summarizes the earthquakes located within a designated Special Study Area (43.0° - 44.5° N, 111.5° - 114.0° W) from October 1972 to June 1982. Seventy-eight events were located within the Special Study Area, with a Richter Local Magnitude (M_L) range of $0.8 \leq M_L \leq 2.7$. The mean M_L for these microearthquakes was 1.4. Only three small microearthquakes ($M_L \sim 1.0$) were detected on the ESRP. Fifty-nine microearthquakes were located northwest of the ESRP, primarily in the Birch Creek Valley - Beaverhead Range region. Sixteen microearthquakes were located southeast of the ESRP within the Special Study Area. The aseismicity within the ESRP can possibly be attributed to high crustal heat flow which allows aseismic creep to occur in response to regional tectonic forces, rather than earthquakes. The aseismic behavior of the Lost River, Lemhi, and Beaverhead Ranges northwest of the ESRP may also be associated with aseismic creep or possibly small strain accumulation rates. The very low seismic activity reported in this study is in agreement with the historical record of seismicity compiled for the ESRP region.

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I. INTRODUCTION

The Idaho National Engineering Laboratory (INEL) has maintained a seismic network for monitoring earthquake activity on and about the eastern Snake River Plain (ESRP) since December 1971. Initially, a single short-period vertical high-gain seismograph was installed by the U. S. Geological Survey to assess the frequency of earthquake occurrence within a 200-km radius about the INEL. This single station soon evolved into a tripartite network of high-gain seismographs during October 1972. In January 1977, the INEL began monitoring a station associated with the Teton Dam network and operated by Ricks College at Rexburg, Idaho. In November 1979, two additional stations were added to the INEL seismic network to bring the present day total of stations monitored to six.

Approximately 10 years of earthquake data have been acquired by the INEL seismic network. These data have been analyzed by different individuals and by various methods over this time interval. The purpose of this report is to summarize the seismicity of a major portion of the ESRP and its adjoining margins. A Special Study Area (SSA) has been chosen following incorporation of HYPO-71¹ in 1981 for locating earthquake epicenters. The SSA extends from 43.0° - 44.5°N and from 111.5° - 114.0°W. Seismograms from October 1972 to June 1982 were reanalyzed and earthquakes were relocated by using HYPO-71. The results of this analysis have produced a final earthquake epicenter map for which seismic data have been processed in a uniform manner.

In this report, a discussion is presented which briefly highlights geological structures within the ESRP and its adjoining margins. Previous microearthquake studies which have occurred within the SSA are noted in this report. The seismic instrumentation and methods of data reduction are discussed prior to presenting an earthquake map for the SSA. Possible mechanisms for interpreting the seismic behavior (or lack of) on the ESRP are explained and limited conclusions concerning future earthquake and volcanic activity within the SSA are noted in this study. This report also includes individual earthquake listings in the Appendix.

II. GEOLOGIC SETTING WITHIN THE SPECIAL STUDY AREA

Portions of three regional tectonic provinces are included within the Special Study Area (SSA) and are shown in Figure 1. The three tectonic provinces which fall within the SSA are the Snake River Plain, the Basin and Range structure northwest of the Snake River Plain, and portions of the Basin and Range Province southeast of the Snake River Plain.

The eastern Snake River Plain (ESRP) dominates the areal surface within the SSA. The ESRP is a Cenozoic volcanic feature which extends from Twin Falls to the Island Park Caldera, Idaho. The ESRP evolved during a 15 m.y. evolutionary sequence which initiated with silicic volcanism west of Twin Falls. This silicic volcanism has been characterized by 3 to 4 km of surface uplift and eruptions of rhyolytic lava, followed by caldera collapse after major pyroclastic eruptions.² The silicic volcanism has proceeded along the axis of the ESRP at an approximate rate of 3.5 cm per year to Yellowstone National Park--the present active center of silicic volcanism.³

After a period of two to five million years of silicic volcanism, surface volcanic eruptions are predominated by eruptions of basaltic magma. During the basaltic volcanic phase, the topography on the ESRP is subsiding due to thermal contraction and cooling of the upper crust.⁴ At the present, the ESRP is in the phase associated with basaltic volcanism.

Within the SSA, various rift zones have been identified on the ESRP which display repetitious basaltic eruptions. Quaternary rift zones have been identified which are perpendicular to the axis of the ESRP and appear to be extensions of Basin and Range faults northwest of the ESRP.^{5,6} Figure 2 displays three of these rift zones. The Arco volcanic rift zone, shown in Figure 2, also includes several eruptions which have been dated in Holocene time (see Reference 5). Also shown in Figure 2 is an outline of an inferred ring fracture zone associated with a caldera buried by basaltic lava. Lithologic log examination of drill cuttings and core samples of the 3,159m deep INEL-1 well are very supportive for such a caldera. They have shown 700m of basalt overlaying 1700m of welded tuff,

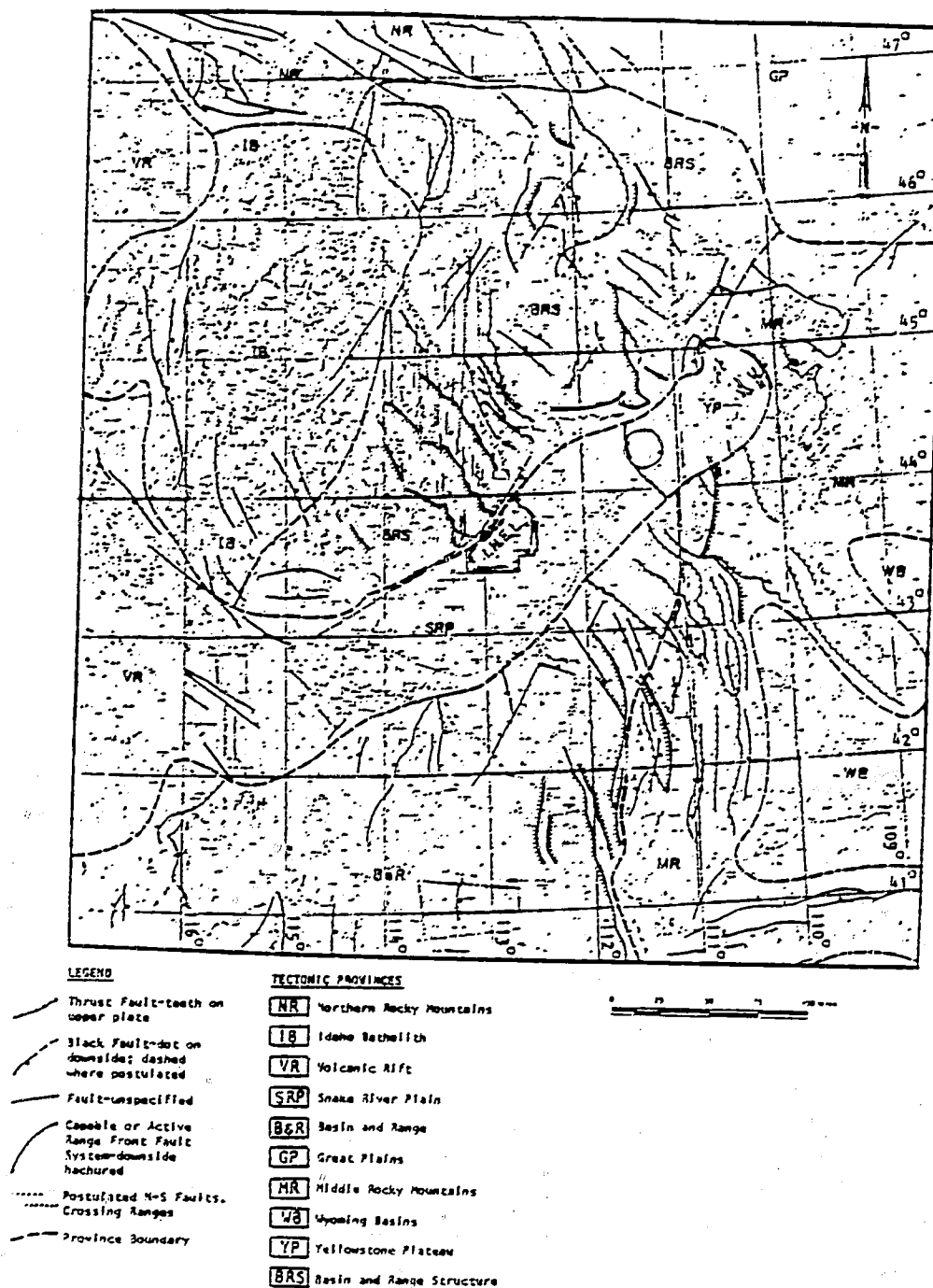


Figure 1. Map Showing Tectonic Provinces and Fault Locations (From Reference 14).

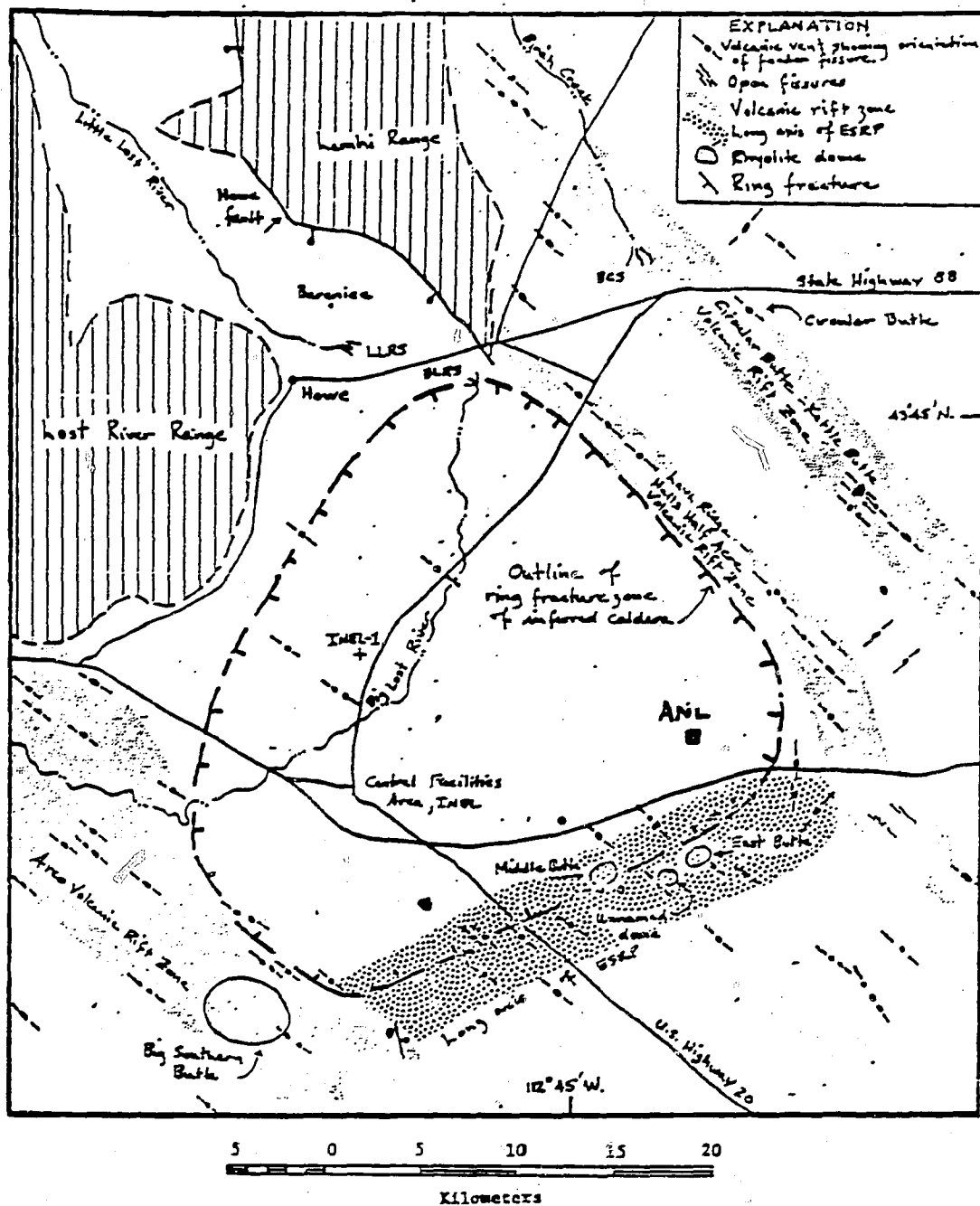


Figure 2. Map Displaying Volcanic Vents, Open Fissures, Volcanic Rift Zones, Ring Fracture of an Inferred Caldera, and Rhyolite Domes (From Reference 6).

which in turn overlies approximately 800m of hydrothermally altered rhyodacite.⁷ Silicic pyroclastic materials have been located on the northwest margin of the ESRP which may be associated with the inferred caldera in Figure 2.⁸

Figure 3 displays other volcanic features which are located within the SSA. The Craters of the Moon lava field was formed between 15,000 and 2,000 years ago during at least seven periods of volcanic activity. Some of these volcanic episodes have lasted as long as 1,000 years.⁹ The Hell's Half Acre lava field is approximately 4,100 years old and represents the youngest low shield volcano within the SSA (see Reference 6). On the basis of geochronological work to date, the Craters of the Moon lava field and the Arco volcanic rift zone appear to be areas that are most probable for future eruptions on the ESRP.

The Basin and Range structures northwest of the ESRP include the Lost River, Lemhi, and Beaverhead Ranges. These ranges are tilted fault blocks with late Quaternary normal faulting occurring on the west side of each range. Some of these faults have had movement as young as the Holocene age, but such age assignments are difficult to determine for individual fault segments. Detailed analysis of scarps by Malde¹⁰ at the south end of the Lost River and Lemhi Ranges has shown possible fault movement 4,000 to 30,000 years ago. Greensfelder¹¹ has identified approximately 142 linear km of probable Wisconsin-age faulting and 29 km of Holocene-age faulting for the Lost River, Lemhi, and Beaverhead Ranges. He has estimated for the three range fronts a recurrence interval of 1,000 to 2,000 years for earthquakes having a Richter Magnitude 6.5. Other fault studies, which have been done in these ranges and which have mapped various fault segments in more detail, are Woodward-Lundgren and Associates,¹² Agabian Associates,¹³ and Woodward-Clyde Consultants.^{14,15,16}

The southeast corner of the SSA includes Basin and Range terrain which terminates at the edge of the ESRP. The valleys marginal to the ESRP contain basalts which appear to be extensions of the ESRP but have probably been extruded from local vents or fissures.¹⁷ Within the SSA

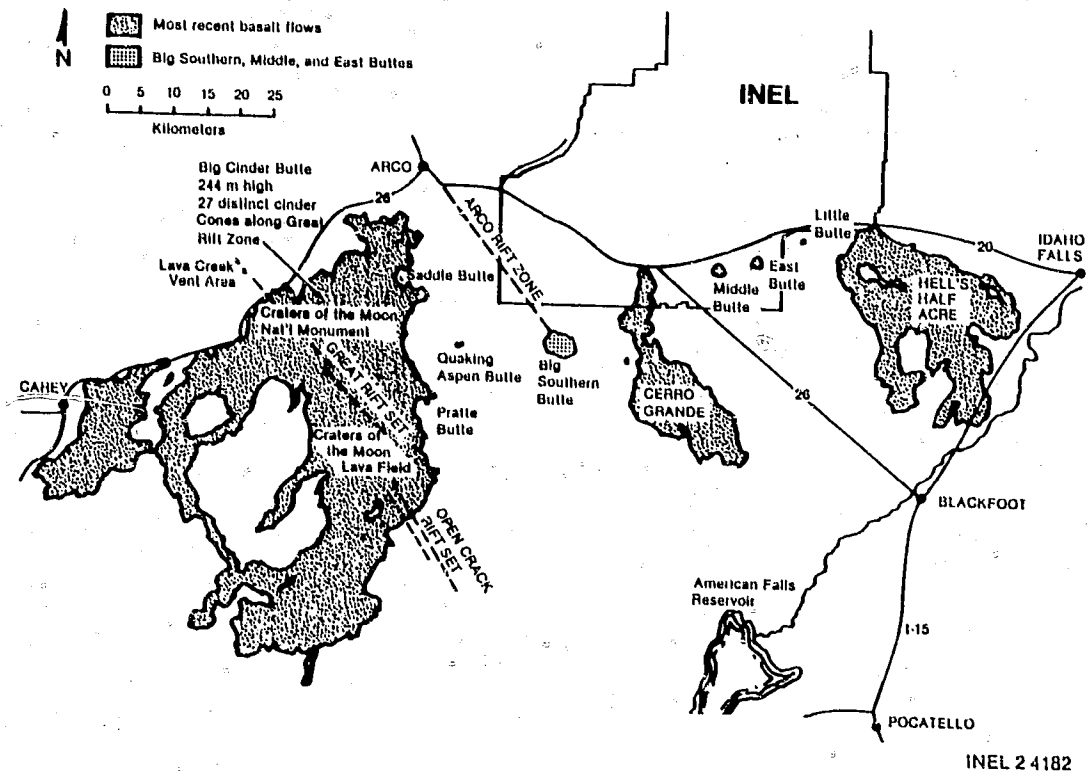


Figure 3. Map Showing Various Volcanic Features on the Eastern Snake River Plain.

in this region are the Blackfoot and Willow Creek lava fields. Rhyolite cones within the Blackfoot lava field have been dated to be approximately 50,000 years old, and are surrounded by younger basalts. The majority of normal faults within the SSA and southeast of the ESRP have been classified as Pleistocene or older.¹⁸ An exception to this statement involves an extension of the Grand Valley fault zone onto the ESRP, which has been mapped by Witkind (see Reference 18) to be of Wisconsin age.

III. EARTHQUAKE RECONNAISSANCE STUDIES WITHIN THE SPECIAL STUDY AREA PRIOR TO OCTOBER 1972

Several microearthquake reconnaissance investigations have occurred within the SSA prior to the establishment of a tripartite network at the INEL in October 1972.

Pitt and Ea' (see Reference 10) reported 52 earthquake locations for a six-station network operated in the vicinity of the INEL. The data were collected for nine months (December 1968 - September 1969), but were limited to telephone line transmission for an average of 12 to 15 hours per day. No events were located on the ESRP. Only one microearthquake was reported in the Lost River, Lemhi, and Beaverhead Ranges south of 44.5°N, the northern boundary of the SSA. This microearthquake was located in the Beaverhead Range east of Nicholia.

During the summer of 1972, Pennington, et al.,¹⁹ conducted a micro-earthquake survey by employing high-gain, high-frequency, portable seismographs in various regions of the Snake River Plain and Central Idaho. The Craters of the Moon National Monument was monitored for six days (June 14 - June 19) by four portable seismographs. No earthquakes were located in this area or in any of the three other regions studied on the Snake River Plain.

IV. SEISMIC STATION INSTRUMENTATION, EARTHQUAKE LOCATING PROCEDURES, AND METHOD OF LOCAL MAGNITUDE DETERMINATION

Figure 4 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 nominal ground displacement magnification for 10 Hz seismic waves at each active station.

Figure 5 is a schematic block diagram for components of a typical INEL seismic station. All INEL stations use FM radio to telemeter data to the seismic base station located on the INEL site at the Test Reactor Area. Figure 6 illustrates an approximate response curve for a typical station with an electronic gain of 78dB. This response curve is representative of the system shown in Figure 5, starting with the L-4c 1.0 Hz vertical seismometer which creates an electronic signal directly related to ground motion, and ending with the Helicorder which generates the actual seismogram.

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 Jeffreys-Bullen Tables²⁰ and locating the event by a graphical arc method on a large regional map. Those events which appear to be inside the SSA (43.0° - 44.5° N, 111.5° - 114.0° W) are then further analyzed.

Since January 1981, the INEL network has used HYPO-71 for final locations of earthquakes that have been graphically located within the SSA. The incorporation of HYPO-71 for locating earthquakes on a routine basis provides a method by which seismic data acquired prior to 1981 may be processed in a uniform manner. The purpose of this report is to present the final results of a retrostudy on seismic data acquired by the INEL after October 1972.

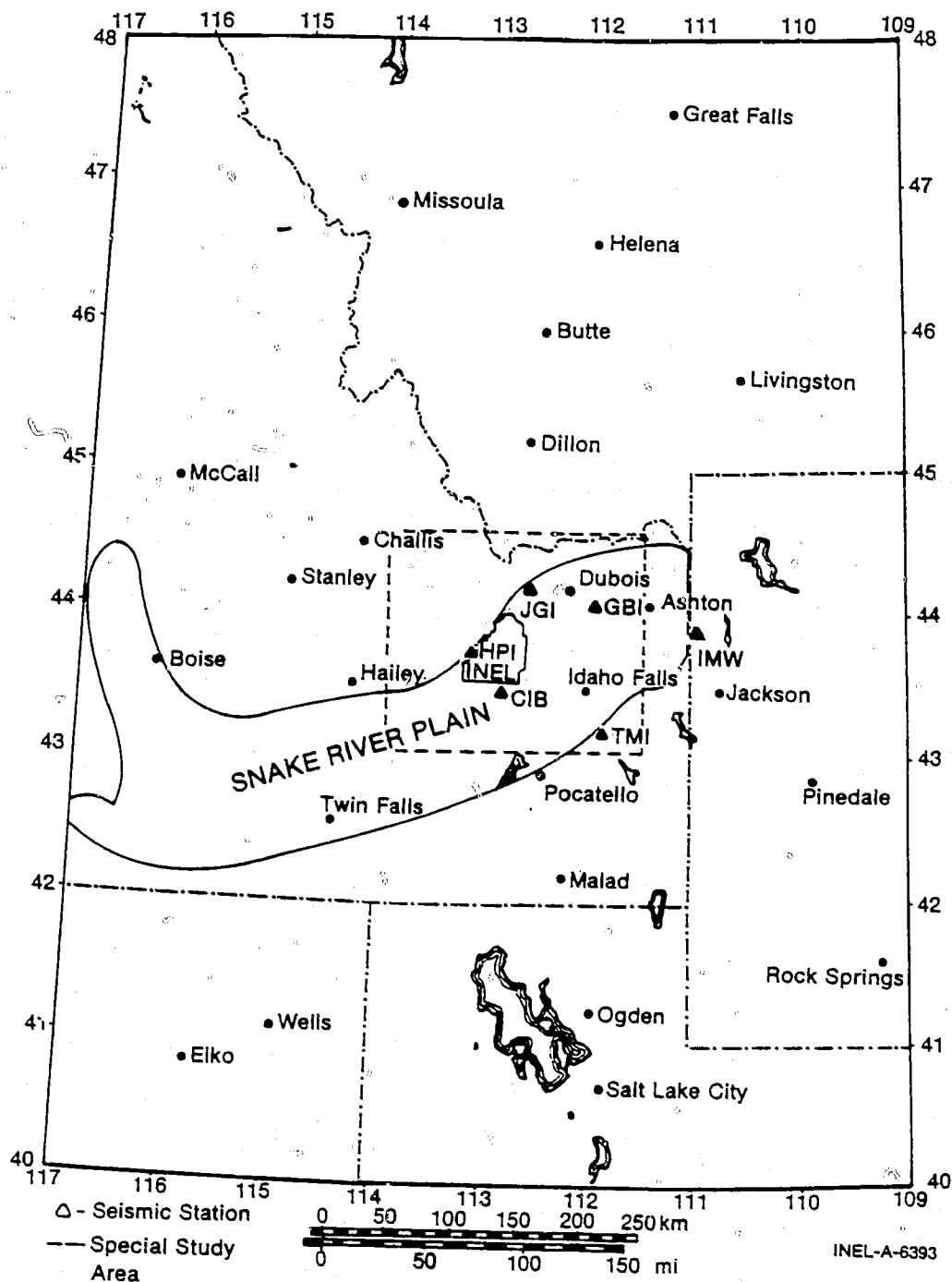
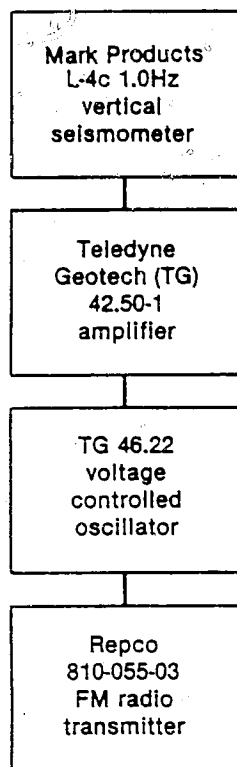
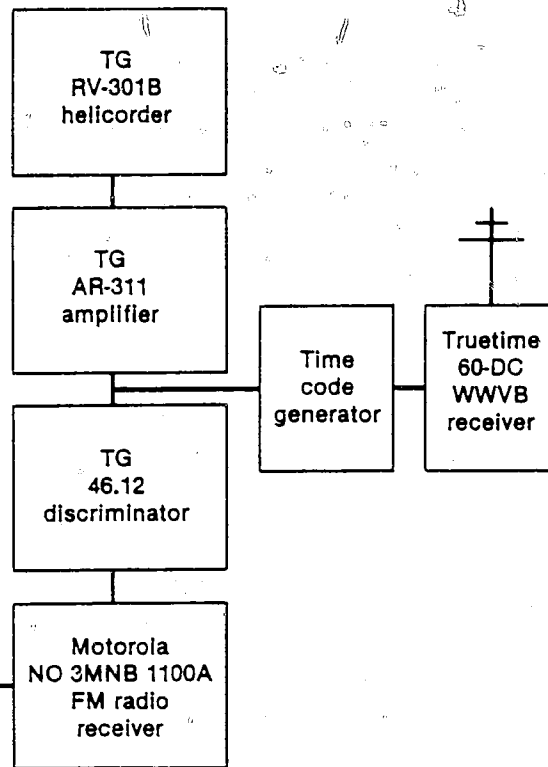


Figure 4. Regional Map Displaying INEL Seismic Station Locations.

Remote seismic station



Seismic base station



INEL 2 3115

Figure 5. Schematic Block Diagram of Components for a Typical INEL Seismic Station.

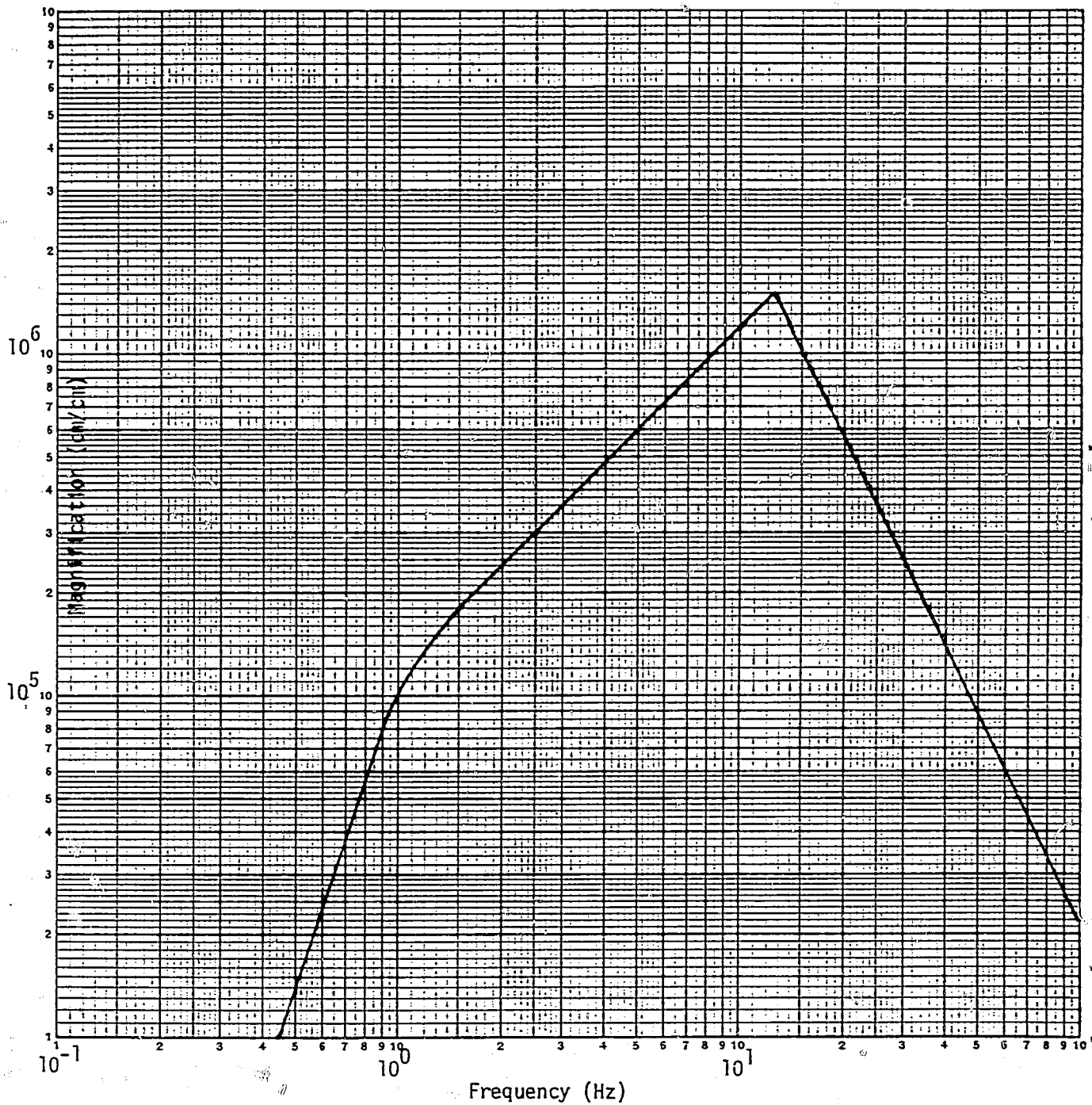


Figure 6. Approximate INEL Magnification Response Curve for 78 dB System Gain

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	-----	6/74	7/80
GBI ^b	Big Grassy Butte	43.9874	112.0633	1561	1180K	10/81	Open
HID ^b	Hammer Butte	43.9630	112.1638	1527	-----	8/73	10/81
HPI	Howe Peak	43.7113	113.0983	2597	2370K	10/72	Open
IMW ^a	Indian Meadow	43.8970	110.9392	2646	1520K	7/80	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	6/78
MBI ^d	Menan Buttes	43.7864	111.9706	1707	-----	9/73	7/74
TMI	Taylor Mountain	43.3056	111.9181	2179	2370K	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 79%. IMW has 63% critical damping. All active stations use FM telemetry for data transmission to the seismic base station, located at the Test Reactor Area (TRA).

The retrostudy on INEL seismic data was initiated by reviewing monthly seismic logs for any events located within 42.9° - 44.6°N, 111.4° - 114.1°W. This expanded region allowed a 0.1 degree margin of error beyond the SSA boundaries on initial earthquake locations. From October 1972 to June 1982, over 600 events were under preliminary consideration as potential HYP0-71 candidates. Seismograms for each of these events were individually reanalyzed. Table 2 shows the P-wave velocity model used to locate events analyzed by HYP0-71.^{21,22,23,24} A P-wave velocity to S-wave velocity ratio of 1.72 was assumed for the velocity layers shown in Table 2 (see Reference 17). This ratio compares favorably with recent findings of Greensfelder and Kovach²⁵ for the upper 20 km of the ESRP crust. (Using their Rayleigh wave phase velocity interpretation, a weighted mean velocity ratio of 1.72 is computed for the upper 20 km of the ESRP crust when ratios of individual layers are weighted by the layer thickness.)

Three P-wave arrival times and two S-wave arrival times were required for locating earthquakes with HYP0-71, since nearly all of the events were outside the INEL network. This criterion immediately eliminated the majority of the 600 preliminary events, as generally only two stations observed most of these earthquakes. Thorough efforts were undertaken to eliminate mine and construction blasts on the basis of recurrence, and P-wave first motions and amplitudes; also, S-wave frequencies, amplitudes, and signal structure relative to P-wave phase structure were used to identify blasts. Any events analyzed by HYP0-71 which were located within 42.95° - 44.55°N and 111.45° - 114.05°W were considered to be within the SSA as a result of absolute location uncertainties at the SSA boundaries.

Richter Local Magnitudes (M_L) were calculated by HYP0-71, using the following expression:

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

where

τ = Total signal duration in seconds

Δ = Epicentral distance from each station in km.

TABLE 2. VELOCITY MODEL FOR THE INEL SEISMIC NET

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

The duration 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.²⁶ 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 1.²⁷ Equation 1 is considered applicable when $1.0 \leq M_L \leq 3.5$ (see Reference 26).

V. RESULTS OF THE RETROSTUDY: EARTHQUAKE CATALOG FOR THE SPECIAL STUDY AREA FROM OCTOBER 1972 TO JUNE 1982

Figure 7 displays the location and size of 78 earthquakes which were analyzed by HYPO-71 and found to be within the SSA. All other events in the original preliminary data set were deleted for the following three reasons: observation on only two stations, location outside the SSA, or association with periodic mine blasts or construction blasts. A few of the events in Figure 7 have been included in previous reports concerning INEL seismic data by Dahl, et al.²⁸ and Navarro, et al.²⁹ However, the method of analysis and the study areas involved for those studies are different than this study. Also, the number of seismic wave phases required by HYPO-71 has eliminated a number of events previously reported in those studies.

The faults displayed in Figure 7 are known and suspected active faults compiled by Witkind (see Reference 18). These faults serve the purpose of portraying areas which have had earthquakes in the geologic past and may display movement in the future. They are not illustrated to provide the direct association of earthquake epicenters with the nearest shown fault segment.

It can immediately be seen that the SSA as a whole displays very low seismic activity. Fifty-nine microearthquakes have occurred northwest of the ESRP, primarily in the Birch Creek Valley - Beaverhead Range area. (Note the fault aligned with Nicholia which separates the Birch Creek Valley from the Beaverhead Range.) Sixteen microearthquakes were located southeast of the ESRP, with the majority occurring in the Grays Lake area. Only three microearthquakes can be considered to be located within the boundaries of the ESRP.

Epicentral location uncertainties vary with the distance from the center of the INEL seismic network. Those events on the ESRP are thought to have location uncertainties of 5 km or less. The majority of events

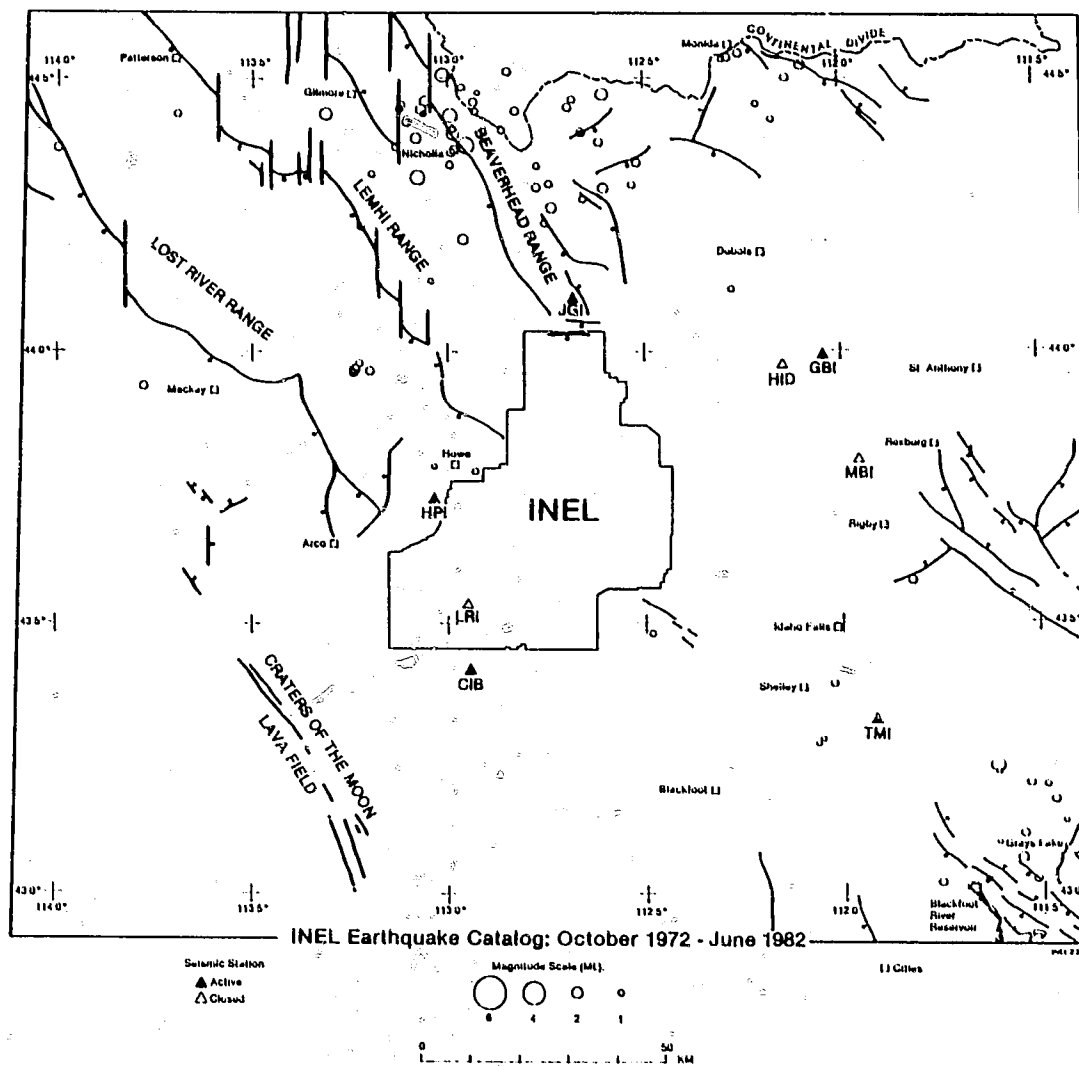


Figure 7.

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. A partial contributor to the location uncertainty is the error associated with P-wave and S-wave arrival times. P-wave arrival-time reading errors are thought to average 0.15 second. S-wave arrival-time reading errors are estimated to be 0.2 second or larger. Information concerning HYPO-71 analysis for each earthquake is given in the Appendix. 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. No evidence to date would indicate that focal depths should significantly differ with a value of 7 km, an average depth associated with the Intermountain Seismic Belt (see Reference 17).

The local magnitude range for the 78 events is $0.8 \leq M_L \leq 2.7$. The mean M_L of the 78 events is 1.4. Table 3 lists the number of earthquakes within specified magnitude increments, by year, for the 9.75-year study period. It should be noted that only three months are included during 1972 and only six months are included during 1982 in Table 3. The purpose of this table is to display the effect of station additions and increased station sensitivities upon yearly earthquake totals. In November 1979, two stations (CIB and JGI) were added to the INEL network which provided additional phase data to allow earthquakes to be located by HYPO-71. Modifications at existing stations have also increased station sensitivities by nearly a factor two. The combination of the above changes is demonstrated in Table 3 by the sharp increase in yearly totals after 1979, as well as the lowering of the M_L detection threshold outside the network. The yearly totals are also biased by station down time. Prior to November 1979, any station outages of the tripartite net eliminated the possibility of analyzing earthquake data with HYPO-71. With extra stations, the loss of a single station may imply a decreased detection sensitivity in a given zone within the SSA, but it does not eliminate the possibility that sufficient phase data will be acquired for HYPO-71 analysis.

TABLE 3. NUMBER OF EARTHQUAKES WITHIN SELECTED MAGNITUDE (M_L) RANGES BY YEAR FOR THE SPECIAL STUDY AREA (43.0°-44.5°N, 111.5°-114.0°W)

M_L Range	1972 ^a	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982 ^b	Total
≤ 0.9	0	0	0	0	0	0	0	0	0	3	6	9
1.0-1.4	0	1	2	3	3	2	1	3	6	14	12	47
1.5-1.9	0	0	0	0	1	1	0	1	3	6	2	14
2.0-2.4	0	0	0	1	0	0	0	0	3	1	0	5
2.4-2.9	0	0	0	0	0	0	0	1	0	2	0	3
TOTALS	0	1	2	4	4	3	1	5	12	26	20	78

a. Includes October-December 1972

b. Includes January-June 1982

The biases of data acquisition from October 1972 to June 1982 are quite significant when attempting to draw quantitative conclusions describing seismicity trends. These data acquisition biases, as well as the limited statistics available (i.e., aseismic behavior), do not allow for generating any recurrence relationships for estimating larger earthquakes within the SSA.

In the next section, a discussion is offered which may provide some insight as to the lack of seismic activity within the SSA.

VI. POSSIBLE MECHANISMS INDUCING ASEISMIC BEHAVIOR WITHIN THE SPECIAL STUDY AREA

The aseismic behavior of the SSA is in agreement with the historical seismicity of the ESRP and its margins. Figure 8 is an earthquake epicenter map based upon the recorded seismicity from 1872 to 1977. The data were compiled by the National Ocean Survey (see Reference 16). It can be seen that very few epicenters have been located within the SSA (43.0° - 44.5° N, 111.5° - 114.0° W). The seismicity in the southeastern corner of the SSA, as displayed in Figure 8, appears to parallel the axis of the ESRP. This trend was noted by Bones (see Reference 17) when evaluating earthquake activity in southeast Idaho from January 1976 to June 1977. Except for a few earthquakes at the northeastern end (Island Park area), the ESRP has been historically aseismic, as indicated in Figure 8. Several events are indicated north of Arco. Other than these few earthquakes, the Lost River, Lemhi, and Beaverhead Ranges also historically demonstrate aseismic behavior. Such aseismic consistency mandates some form of an explanation.

Various models have been proposed for the origin and evolution of the ESRP and surrounding provinces within the framework of extensional tectonic forces in western North America. A common aspect of some of these models dictates the origin of the Snake River Plain as being associated with a boundary at the northern end of the tectonically extending Great Basin (Basin and Range Province). Smith³⁰ has suggested that the Snake River Plain was formed by means of a propagating lithospheric fracture that is now located at the Yellowstone Plateau. The Snake River Plain, together with the High Lava Plains of eastern Oregon and the Columbia Plateau represent a diffuse subplate boundary at the northern edge of the Basin and Range Province. The lack of earthquakes on the Snake River Plain may be related to high crustal temperatures that restrict brittle fracture but allow aseismic creep. Another possibility for the aseismic behavior of the Snake River Plain may be related to a lack of stored elastic strain energy sufficiently large to generate earthquakes.

Christiansen and McKee³¹ support the concept of the Snake River Plain being associated with a transitional transform boundary zone of the Great Basin. The ESRP could be considered as a segment of a "soft" edge to the zone of oblique extension that occurs to the south. This boundary is a source of Quaternary volcanism, which should be indicative of high heat flow. Continued tectonic extension to the south and transform displacement along the boundary (Snake River Plain) result in continued basaltic magmatism, heating of the crust, and an aseismic shadow along this border zone.

Recent work by Brott, et al. (see Reference 4) has shown that the ESRP possesses heat flow values (190 m W/m^2 or 4.5 heat flow units) well above regional values. This result could only be determined when heat flow contributions absorbed within the Snake River Plain aquifer were added to surface heat flow measurements. On the basis of heat flow measurements, and their incorporation into a finite-width moving source model, Brott, et al. are able to predict the general consistency of elevation-distance-volcanic age relationship along the ESRP. Their findings suggest greater subsidence at the margins of the Snake River Plain than at the center, sufficiently high crustal temperatures to allow decoupling of the Snake River Plain margins, and only aseismic creep occurring in the Snake River Plain in response to regional tectonic stresses. They suggest that the primary cause of subsidence on the Snake River Plain is thermal contraction of the lithosphere, and they imply that longitudinal contraction along the axis of the Snake River Plain may be a mechanism for the opening of identified rift zones (see References 5 and 6).

Smith and Christiansen³² have noted that the Snake River Plain is subsiding at a rate of two to six millimeters per year relative to surrounding areas. This subsidence may be a potential source of small earthquakes. If sufficiently high crustal temperatures do exist within the ESRP, elastic strain accumulation from regional tectonic forces may not be occurring to generate earthquakes or even microearthquakes ($M_L < 3.0$). However, the greater subsidence at margins of the ESRP than at the center, as suggested by Brott, et al. (see Reference 4) would imply differential strain accumulation across the axis of the ESRP. This could possibly be a mechanism for shallow microearthquakes ($< 5 \text{ km?}$) within the ESRP, as well as the subsidence

itself, and may be a plausible explanation for the three small microearthquakes ($M_L \sim 1.0$) located within the ESRP, as shown in Figure 7.

The direction of the stress field within the ESRP has not been directly measured due to the lack of earthquakes (and thus earthquake focal mechanisms). Weaver, et al.³³ have concluded that the present dominant stress field direction in the ESRP is extension along the axis. This conclusion is supported by the northwest strike of six Quaternary volcanic rift zones mapped across the ESRP and the northwest trend of the major thermal zones, a line of rhyolitic vents, and mapped normal faults and earthquake focal mechanisms in the Yellowstone Caldera which display northwest-trending faulting. Weaver, et al. also point out the crustal stress field in the eastern Basin and Range Province, the ESRP, and the Yellowstone region are essentially the same. Zoback and Zoback³⁴ categorize the Snake River Plain as a separate stress province with extensions along the axis of the Snake River Plain, which appears to be oblique to the west northwest-east southeast extension that occurs in the Basin and Range Province directly to the south. Zoback and Zoback note that the extension along the axis of the Snake River Plain requires transform-like faulting along its margins, particularly on the north margin.

Zoback and Zoback have labeled the area north of Yellowstone and the Snake River Plain as the Hebgen Lake - Centennial Valley stress province. They consider it to be characterized by north-south extensions and tentatively extend this region westward to the Idaho batholith. This general classification would imply north-south extension in the Basin and Range structures (i.e., Lost River, Lemhi, and Beaverhead Ranges) which strike in a northwest direction. While Witkind (see Reference 18) has identified north-south trending strike-slip faults cutting across the Lost River, Lemhi, and Beaverhead Ranges, these faults have not shown the most recent movement within these ranges. Woodward-Clyde Consultants (see Reference 14) and Greensfelder (see Reference 11) show more recent movement on the high-angle normal faults associated with the western side of the Lost River, Lemhi and Beaverhead ranges. Movement associated with these faults implies northeast-southwest extension, in disagreement with north-south extension implied by Zoback and Zoback (see Reference 34).

The purpose of the previous paragraphs is to develop a background for possibly interpreting the pattern of seismicity seen for the Basin and Range structure in Figure 7. The seismic activity within the SSA in Figure 7 is primarily confined to the Birch Creek Valley - Beaverhead Range region. Seismic activity further to the west in the Lemhi - Lost River Range areas is practically nonexistent. It can be seen that the located microearthquakes in the Birch Creek Valley - Beaverhead Range are spread out in a diffuse manner, as are the faults mapped by Witkind (see Reference 18) near the Beaverhead Range. The precision for locating most of the events in the Beaverhead Range region is thought to be less than 5 km. This estimate is considered excessive when the variation in the spread for P-wave arrival times at stations CIB, HPI, and JGI (see Figure 7) is examined, with the assumption of a constant earthquake focal depth. When one incorporates crustal isotherms predicted by Brott, et al. (see Reference 4) for the ESRP and its margins and a 300°C limiting temperature for elastic brittle behavior relative to geologic time scales, as noted in Eaton, et al.³⁵, a maximum focal depth of 10 km can be hypothesized. This depth limit is seen to have only a slight variation in epicenters determined by HYPO-71, especially when the initial focal depth is assumed to be 5 km for HYPO-71 calculations.

The high heat flow calculated at the margins of the ESRP might imply that the microearthquakes observed in the Birch Creek Valley - Beaverhead Range area are associated with geothermal phenomena. Microearthquakes occurring in geothermal areas often exhibit swarm-like activity. Swarm-like activity has not dominated the trend of microearthquakes observed in the Birch Creek Valley - Beaverhead Range area. Only two thermal springs³⁶ (surface temperature < 50°C) have been mapped for the Birch Creek Valley - Beaverhead Range region within the pattern of seismicity shown in Figure 7. For purposes of a continuing discussion, it will be assumed that micro-earthquake activity in the Birch Creek Valley - Beaverhead Range area is not directly associated with geothermal phenomena.

Having accepted that the diffuse nature of epicentral locations in the Birch Creek Valley - Beaverhead Range area is representative of reality, a closer inspection of the mapped faults in this area is justified. The majority of the faults in the Birch Creek Valley - Beaverhead Range area are Quaternary age or younger. Some of the faults at the southeastern border of the Beaverhead Range are downthrown parallel to the axis of the ESRP or have components obliquely downdropping towards the ESRP. Beyond this zone and to the southwest, the faults are aligned parallel to the Beaverhead range-front fault and are perpendicular to the axis of the ESRP. It is possible that the change in orientation of the faults at the edge of the ESRP outlines a zone where the directions and magnitudes of local stress undergo a substantial shift. West of this area, the Lost River and Lemhi Ranges have normal faults that strike perpendicular to the axis of the ESRP. East-northeast of this area, the Centennial Valley has normal faults, exhibiting Holocene-age movement, that are parallel to the ESRP (see Reference 11). The morphology of the Beaverhead Range is highlighted by the Continental Divide paralleling the axis of the ESRP, and then suddenly turning northwest in alignment with the Beaverhead range-front fault. The change in direction of the Continental Divide can be correlated with the suggested alignment of the changing stress fields. The seismicity pattern in Figure 7 vaguely outlines the right-hand turn in the Continental Divide.

Hence, the seismic activity associated with the southwestern to northwestern turn of the Beaverhead Range may indicate a rotation of a local contemporary stress field beyond the northern margin of the ESRP. The correlation of this very low seismic activity with the strike of a number of Quaternary faults has been assumed to be valid; such assumptions may be substantiated by determining earthquake focal mechanisms within the Beaverhead Range region. Focal mechanisms for chosen segments of the Beaverhead Range region may be the only way to delineate the local stress field. Even then, the present seismicity may make such a study impractical.

The overall aseismic behavior of the Basin and Range structures northwest of the ESRP may represent a quiescent stage of a repetitive seismic cycle. The recurrence of moderate-to-large earthquakes along high-angle faults has been demonstrated by Malde (see Reference 10) for fault segments at the southern end of the Lost River and Lemhi Ranges. Seismic cycles

have been identified by Ryall³⁷ for Basin and Range earthquakes in Nevada. The lengths of the cycles are the order of thousands of years. Prior to major earthquakes, the seismicity of an area increases for at least several decades. Following the major earthquake, aftershock activity decays exponentially and reaches a minimum level after 1 century. Even such cycles may have irregular time periods. Cluff, et al.³⁸ note the importance of documenting prior earthquake frequency and size at the same location for assessing a future earthquake. The size of an earthquake that may occur in a region depends upon such factors as the relative dimensions of the rupture surface, total available fault surface, slip rate, stress conditions, and shearing resistance of the materials at the fault. The probability of a large earthquake occurring in the future will depend upon the rate of strain accumulation and the rate of strain release, the holding time between large events, and the elapsed time between the last large earthquake. Determination of such variables for a given fault can possibly be achieved by using data acquired from paleoseismological studies. However, no complete paleoseismological studies have been performed in the Basin and Range structures north of the ESRP.

The low level of seismicity in the Lost River, Lemhi, and Beaverhead Ranges probably represents a minimum level of seismic activity associated with a seismic cycle. The rate of strain accumulation in these ranges is unknown. If strain accumulation rates are significant, strain release may be occurring by means of aseismic creep. The historical seismicity in Figure 8 does indicate that strain release has not occurred for some time by means of moderate or larger earthquakes.

The ESRP has been entitled an asymmetric graben following the recent work of Sparlin and Braile.³⁹ Ray trace modeling of seismic refraction profiles across the ESRP has indicated a 4 km down-dropped fault along the northwest margin of the ESRP. Such a structure was not resolved along the southeastern margin of the ESRP; if it does exist, the magnitude of its displacement is much less than along the northwest margin. Kuntz (see Reference 5) has noted the existence of faults throughout the northern end of the

Arco volcanic rift zone. These faults appear to be extensions of the Lost River range-front fault. They are extensional faults with as much as 10 m of vertical displacement and surface lengths as long as 4 km. Kuntz points out that these faults have decreasing vertical displacement as one proceeds southeast along the Arco rift zone. Approximately 15 km southeast of Arco, the faults are transformed into open fissures that have purely horizontal displacement. Kuntz concluded that the ESRP must be a downwarp, since at that time no geological or geophysical evidence existed to the contrary. The continuation of the basin-range faults across the northwest margin of the ESRP strongly supported his viewpoint.

Zoback and Zoback (see Reference 34) have implied that transform faults should exist at the boundaries of the Snake River Plain to allow extension of this stress province. The discovery of a downdropped fault along the northwest margin of the ESRP by Sparlin and Braile (see Reference 39) might also include a strike-slip component for transform movement. Brott, et al. (see Reference 4) have suggested that the Snake River Plain should be decoupled along the edges and only aseismic creep should occur in response to regional tectonic stresses. It would appear that these viewpoints have a large degree of harmony. However, the work of Kuntz (see Reference 5) implies a lack of surface evidence for active faulting along the northwest margin of the ESRP, and demonstrates that active faulting and fissuring are mechanisms for tectonic extension within the Arco rift zone. This impulsive extension occurs within the ESRP rather than exclusively at the edges. The role of causative forces that produce fissuring and faulting becomes increasingly blurred when one attempts to examine possible correlations of range-front faulting north of the ESRP, faulting within the ESRP, and surface volcanic eruptions on the ESRP. At the present, insufficient data exist to resolve these issues.

The previous paragraph displays the complexity of understanding and relating assorted geological and geophysical concepts to the ESRP for estimating geological hazards. This is especially true when the historical record represents the ESRP as a dormant body. Approximately ten years of data have been gathered by the INEL seismic network which show the

ESRP, in particular, to be aseismic, and which document the surrounding region within the SSA as displaying aseismic behavior. These data provide a baseline which describes steady-state or quiescent behavior for the SSA.

Kuntz (see Reference 5) has estimated that the recurrence interval for shield volcanoes on the ESRP is about 1,500 years, and that the mean occurrence rate for all types of volcanism within the Arco-Big Southern Butte area is one eruption every 3,000 years. Kuntz, et al. (see Reference 9) have shown an approximate 2,000 year interval for return of volcanism at the Craters of the Moon lava field. Greensfelder (see Reference 11) has estimated a 1,000 to 2,000 year return period for Richter Magnitude 6.5 earthquakes within the Lost River, Lemhi, and Beaverhead Ranges. These recurrence interval estimates provide approximate time periods between significant geological events for different regions within the SSA. The coupling between these localized recurrence intervals and the day-to-day probability of occurrence for each is unknown.

A discussion concerning the potential for magma bodies under the ESRP is warranted. Brott, et al. (see Reference 4) have hinted at the possibility of magma pockets beneath the axis of the Snake River Plain, which may be a corollary of their predicted crustal isotherms under the ESRP. Using Rayleigh wave dispersion data and teleseismic shear-wave delays, Greensfelder and Kovach (see Reference 25) discerned a layer with a reduced shear-wave velocity. A shear-wave velocity of 3.61 km/s was found for the 20-41 km lower crustal layer under the ESRP. This was 0.24 km/s lower than what might be considered a normal value. A reduced shear-wave velocity can often be correlated with regions of partial melt within the crust. However, after extensive modeling, Greensfelder and Kovach concluded that the reduced shear-wave velocity was not caused by significant amounts of partial melt in the lower crust. Instead, such velocity anomalies could be explained by lower crust granulites nearly depleted of quartz as a result of their partial fusion to form rhyolytic magmas during the first phase of ESRP volcanism.

Their study, which was based upon seismograms recorded by intermediate-period portable seismographs at sites near Rexburg, Pocatello and Blizzard

Mountain (north of the Craters of the Moon National Monument), suggests that recent basaltic volcanism on the ESRP did not originate from magma bodies within the crust. Depths within the mantle are probably the source of recent basaltic magma. A similar conclusion was inferred by Leeman and Vitaliano, and Stout and Nicholls, as noted in Kuntz, et al. (see Reference 9). They felt that lava, which was transported to the surface in the Craters of the Moon lava field, may have originated in the mantle at depths of 60 km. This magma is thought to have moved to the surface rapidly without long residence times in upper crustal magma reservoirs.

Fifty to sixty km depths are the initial source of magma for extrusions of lava at the Kilauea Volcano in Hawaii. As noted in Decker and Decker,⁴⁰ the Hawaiian Volcano Observatory seismic network has been able to track movement of magma from the depths of 55 km to a shallow magma chamber 3 to 6 km beneath the Kilauea summit. Movement laterally of magma 40 km from this shallow magma chamber along a rift zone has also been observed. In both cases, microearthquakes are associated with the cracking and slipping of brittle rocks that suddenly fail by magma pressures and temperatures. Prior to volcanic eruptions on the ESRP, fracturing of rock by ascending magma should also produce observable earthquakes.

The change in the seismicity of the SSA is quite likely the most direct method for detecting precursory activity in advance of hazardous earthquakes or active volcanism. These precursors will reflect thermal or mechanical perturbations in the earth's crust that may signal an end to the present aseismic state that exists within the SSA. Such perturbations and their effects will not be accurately predicted but may only be recognized as they are detected in progress.

VII. CONCLUSIONS

The Idaho National Engineering Laboratory (INEL) has operated at least a tripartite seismic network since October 1972. These stations have used short-period high-gain vertical seismographs for monitoring earthquake activity on and about the eastern Snake River Plain (ESRP). Various methods have been used by several individuals to evaluate seismic data acquired by the INEL seismic net. This report has attempted to uniformly evaluate INEL seismic data from October 1972 to June 1982 by incorporating HYP0-71 for locating earthquake epicenters. A Special Study Area (SSA) was defined to include the region from 43.0° - 44.5° N, 111.5° - 114.0° W.

Initially, over 600 earthquakes were candidates for inclusion within the SSA and were individually reanalyzed. The majority of these events were seen on only two stations, and were immediately discarded from further consideration. Following removal of mine blasts and events computed by HYP0-71 to be outside the SSA ($> 0.05^{\circ}$ beyond the boundary), only 78 events were found to be inside the SSA.

Richter Local Magnitudes (M_L) were estimated by using a signal duration magnitude developed by the University of Utah Seismograph Stations. The M_L range for the 78 earthquakes was $0.8 \leq M_L \leq 2.7$. The mean M_L of the 78 events was 1.4. Sixty of the 78 events were located after November 1979, when two additional seismic stations were added to the INEL seismic net to bring the total to five. These additional stations, along with modifications to increase the sensitivities of the older stations, have resulted in the increased number of earthquakes located. The increased number of earthquakes after November 1979 should be interpreted to represent an expanded capability to resolve smaller microearthquakes ($M_L < 1.5$) outside the INEL seismic network rather than implying a trend of increased seismic activity within the SSA.

Fifty-nine microearthquakes were located northwest of the ESRP, primarily in the Birch Creek Valley - Beaverhead Range area. Sixteen microearthquakes were located southeast of the ESRP in the vicinity of Grays Lake. Only three microearthquakes can possibly be considered to be located within

the ESRP. They occurred near Dubois, Hell's Half Acre lava field, and east of Howe on December 3, 1975; January 22, 1981; and October 13, 1981, respectively. These three events were small microearthquakes ($M_L \sim 1.0$).

Approximately 10 years of seismic data have been acquired by the INEL seismic net. These data show the ESRP to be aseismic, and verify that the areas surrounding the ESRP within the SSA exhibit aseismic behavior. This trend has been supported by historical earthquake records which show the SSA to have very few earthquakes, based upon both felt reports and instrumentally located epicenters.

The reduced seismic activity within the SSA can be interpreted by a number of hypotheses. The ESRP appears to have high crustal heat flow values well above those of the surrounding area. The elevated crustal temperature associated with this high heat flow may allow aseismic creep to occur within the ESRP in response to regional tectonic forces, as compared to the brittle fracture associated with earthquakes. Possibly, the ESRP is unable to store elastic strain energy sufficiently large to generate earthquakes. The source of the three small microearthquakes observed on the ESRP may be associated with subsidence of the crust created by thermal contraction of the lithosphere. This mechanism could produce small shallow earthquakes that release strain accumulation generated by the subsidence of the ESRP.

The Lost River and Lemhi Ranges have produced very few microearthquakes even though they are bounded by high-angle normal faults which are considered active. Diffuse seismic activity is observed in the Birch Creek Valley - Beaverhead Range area. This activity can not be associated with any single mapped fault, but may represent a zone in which the rotation of the strike of mapped faults is correlated with a rotation of the local contemporary stress field. This hypothesis has yet to be proven, since no focal mechanisms have been determined within the SSA.

The low frequency of occurrence of earthquakes in the Basin and Range structures (Lost River, Lemhi, and Beaverhead Ranges) northwest of the ESRP indicates that accumulated elastic strain energy is presently not being

released through earthquake activity. If strain accumulation in these ranges is occurring at significant rates, then strain release may be resulting in the form of aseismic creep somewhat analogous to that which is hypothesized for the ESRP. At the present, the Lost River, Lemhi, and Beaverhead Ranges appear to be in a minimum-earthquake-activity stage of a seismic cycle. Such cycles may have intervals of thousands of years between large earthquakes. Without additional information, the present level of seismic activity in these ranges provides limited insight for understanding the active tectonic processes that are in progress.

Recent geologic evaluations have estimated recurrence intervals for large earthquakes and surface volcanic eruptions to be of the order of 1,000 to 3,000 years within the SSA. These events, when they occur, will represent impulsive, dynamic processes that may involve surface faulting and/or fissuring. The occurrence of such events must contradict the presently hypothesized view that allows for stored elastic strain energy to be released in the form of aseismic creep. If the SSA as a whole is categorized to be in a "quiescent state" at this time, then deviations from the present status should be expected in the form of mechanical or thermal perturbations within the earth's crust prior to large earthquakes or volcanic eruptions. These perturbations should induce precursory phenomena that can be detected. The change in the baseline seismicity within the SSA may be the best indicator of such precursory phenomena.

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APPENDIX

EARTHQUAKES LOCATED BY HYPO-71 WITHIN THE SPECIAL STUDY AREA (43.0°-44.5°N, 111.5°-114.0°)

Explanation of Earthquake List Headings^a

<u>Heading</u>	<u>Example</u>	<u>Explanation</u>
DATE	730516	Date of earthquake: year, month, and day. For this example, it is May 16, 1973.
ORIGIN	1414 52.4	Origin time: hour, minute, and second (Greenwich Meridian Time). For this example, it is 14 hr, 14 min, and 52.4 sec.
LAT N	44-27.30	Latitude of epicenter in degrees and minutes: 44° 27.30' North.
LONG W	112-55.85	Longitude of epicenter in degrees and minutes: 112° 55.85' West.
SOURCE AREA	N.E. of Nicholia	Location of epicenter relative to cities, landmarks, or bodies of water shown in Figure 7 of the text.
MAG	1.3	Local magnitude of the earthquake.
NO	5	Number of station readings used in locating the earthquake. P-wave and S-wave arrivals for the same station are regarded as two readings.
GAP	318	Largest azimuthal separation in degrees between stations.
DMIN	83.7	Distance in km from the epicenter to the nearest station.
RMS	.13	Root mean square error of time residuals in sec. $RMS = \sqrt{\sum R_i^2 / NO}$, where R_i is the time residual for the i th station.

- 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.

<u>Heading</u>	<u>Example</u>	<u>Explanation</u>
ERH	15.0	Standard error of the epicenter in km. The values are computed by HYP0-71 based upon assumptions which may not be met by certain earthquakes. Therefore, the standard errors may not represent actual error limits.
Q	D	Solution quality of the hypocenter. This measure is intended to indicate the general reliability of the solution:

<u>Q</u>	<u>Epicenter</u>	<u>Focal Depth</u>
A	excellent	good
B	good	fair
C	fair	poor
D	poor	poor

<u>DATE</u>	<u>ORIGIN</u>	<u>LAT N</u>	<u>LONG W</u>	<u>SOURCE AREA</u>	<u>MAG</u>	<u>NO</u>	<u>GAP</u>	<u>DMIN</u>	<u>RMS</u>	<u>ERH</u>	<u>Q</u>
730516	1414 52.4	44-27.30	112-55.85	N.E. of Nicholia	1.3	5	318	83.7	.13	15.0	D
740215	0447 50.6	44-26.68	112-41.41	E. of Nicholia	1.4	5	312	87.8	.08	7.6	D
740828	1107 28.7	44-22.89	112-36.59	E. of Nicholia	1.4	6	307	84.2	.14	4.9	D
750126	1421 00.3	43-34.54	111-49.15	E. of Idaho Falls	1.4	5	228	31.1	.05	1.7	D
750505	0312 31.4	44-27.58	112-40.69	E. of Nicholia	1.2	6	301	68.8	.16	7.1	D
750820	0224 37.4	44-28.20	112-36.04	E. of Nicholia	2.0	5	303	66.3	.08	2.6	D
751203	0258 15.9	44-06.83	112-16.36	Dubois	1.0	6	276	18.9	.20	3.4	D
760127	0455 23.9	44-26.25	112-55.64	N.E. of Nicholia	1.1	5	301	80.7	.25	26.4	D
760226	0413 38.1	43-03.66	111-33.06	Blackfoot River Reservoir	1.6	5	326	40.4	.08	2.9	D
761008	0350 15.2	44-24.23	112-51.41	N.E. of Nicholia	1.1	6	297	74.0	.37	5.6	D
761222	0800 47.6	43-13.40	111-36.48	N. of Blackfoot River Reservoir	1.1	5	319	26.8	.56	2.2	D
770320	0013 44.4	43-01.38	111-38.17	Blackfoot River Reservoir	1.0	6	280	38.9	.11	1.2	C
770322	1130 23.7	44-16.77	112-39.00	S.E. of Nicholia	1.3	5	282	52.5	.00	.1	C
770804	0726 55.8	43-01.32	111-30.87	Blackfoot River Reservoir	1.5	7	283	45.5	.19	2.8	D
781119	0221 05.7	43-06.41	111-32.65	N. of Blackfoot River Reservoir	1.4	6	326	37.6	.10	1.8	C
790607	1228 41.4	44-22.43	113-07.72	W. of Nicholia	1.3	6	303	73.7	.33	4.3	D

<u>DATE</u>	<u>ORIGIN</u>	<u>LAT N</u>	<u>LONG W</u>	<u>SOURCE AREA</u>	<u>MAG</u>	<u>NO</u>	<u>GAP</u>	<u>DMIN</u>	<u>RMS</u>	<u>ERH</u>	<u>Q</u>
791005	0021 42.9	44-15.86	112-43.91	S.E. of Nicholia	1.7	6	259	56.5	.15	3.5	D
791005	0022 48.8	44-14.24	112-44.95	S.E. of Nicholia	1.1	6	277	55.9	.24	3.9	D
791230	1730 14.5	43-14.06	111-36.61	N. of Blackfoot River Reservoir	2.6	9	252	26.2	.10	1.0	C
791230	2153 00.5	44-22.44	113-59.79	S.W. of Patterson	1.4	5	325	103.0	.06	2.4	C
800122	1246 14.6	44-23.97	112-58.92	Nicholia	2.0	7	317	41.9	.16	2.8	D
800129	1646 34.1	44-26.06	113-18.52	Gilmore	2.2	6	319	63.1	.15	3.7	D
800215	2145 24.6	43-57.92	113-11.82	N.W. of Howe	1.4	5	267	29.3	.18	.4	C
A-4 800220	2321 01.9	43-57.71	113-14.32	N.W. of Howe	1.4	5	273	30.0	.19	4.3	D
800221	0639 39.9	44-25.82	112-59.31	Nicholia	2.3	7	302	80.4	.13	2.2	C
800222	2023 30.9	43-58.25	113-13.91	N.W. of Howe	1.2	6	273	30.8	.26	221.8	D
800228	1713 33.3	43-58.82	113-13.37	N.W. of Howe	1.3	6	273	31.5	.22	3.8	D
800306	1607 42.7	43-58.15	113-14.12	N.W. of Howe	1.8	5	274	30.7	.32	10.9	D
800428	1620 58.5	44-18.14	112-46.20	E. of Nicholia	1.4	5	320	24.5	.03	2.2	C
800514	1720 38.7	44-18.47	112-44.31	E. of Nicholia	1.3	5	325	24.4	.05	1.8	C
800929	0913 36.0	44-27.44	113-03.33	N. of Nicholia	1.9	7	305	50.5	.07	5.9	D
801031	0440 28.2	44-31.36	112-05.43	E. of Monida	1.9	6	263	66.9	.17	3.7	D
810122	1455 22.0	43-28.89	112-28.85	Hells Half Acre Lava Field	1.0	7	143	38.4	.19	1.4	C
810204	1934 06.8	44-20.70	112-30.71	E. of Nicholia	1.4	5	293	31.0	.05	1.5	C

<u>DATE</u>	<u>ORIGIN</u>	<u>LAT N</u>	<u>LONG W</u>	<u>SOURCE AREA</u>	<u>MAG</u>	<u>NO</u>	<u>GAP</u>	<u>DMIN</u>	<u>RMS</u>	<u>ERI</u>	<u>Q</u>
810216	0848 44.1	44-18.31	112-31.49	E. of Nicholia	1.2	5	288	26.6	.17	5.6	D
810306	1534 45.0	43-56.21	113-46.50	W. of Mackay	1.5	6	307	59.9	.27	4.6	D
810417	1948 48.9	44-26.48	113-03.93	N. of Nicholia	1.8	5	319	49.6	.07	2.5	D
810420	1747 45.0	44-23.45	113-04.65	Nicholia	1.7	6	315	46.1	.06	.9	C
810519	0757 31.8	44-30.45	113-00.55	N. of Nicholia	2.7	5	325	53.2	.09	3.3	D
810524	0341 17.1	44-32.70	112-15.03	S.E. of Monida	1.4	6	268	60.7	.16	2.8	D
810615	2310 12.9	44-12.47	112-57.35	S. of Nicholia	1.6	7	282	25.7	.11	1.5	D
810628	0655 21.1	44-32.22	112-16.84	Monida	1.4	5	319	58.6	.03	.6	C
810628	0710 25.8	44-32.09	112-17.51	Monida	1.2	5	319	57.9	.02	.4	C
810902	1359 59.4	44-21.86	112-59.30	Nicholia	1.4	5	314	39.1	.05	1.4	C
810915	0737 32.5	43-29.86	113-59.82	W. of Arco	1.6	5	321	76.3	.12	24.2	D
810918	2104 18.7	44-13.85	113-13.16	S.W. of Nicholia	1.1	5	299	46.0	.27	3.1	D
810924	1850 18.8	44-22.60	112-57.00	Nicholia	2.6	8	297	38.4	.18	2.9	D
811002	2110 30.1	44-19.20	113-04.34	Nicholia	2.3	5	319	67.7	.05	4.7	D
811013	0832 29.5	43-46.67	112-55.68	E. of Howe	1.1	5	152	15.6	.02	.4	C
811013	0940 44.2	44-20.51	112-59.44	Nicholia	1.1	5	311	37.4	.06	2.0	C
811015	0133 08.6	44-25.11	113-06.12	N.W. of Nicholia	1.4	5	317	49.6	.05	1.7	D
811017	2254 04.2	43-47.24	113-01.93	Howe	0.9	6	188	10.0	.10	1.8	C
811022	2222 27.4	44-29.03	112-57.70	N. of Nicholia	1.1	5	325	49.0	.14	5.0	D

DATE	ORIGIN	LAT N	LONG W	SOURCE AREA	MAG	NO	GAP	DMIN	RMS	ERII	Q
811024	1215 57.2	44-28.35	112-55.19	N.E. of Nicholia	1.0	5	326	46.4	.15	5.3	D
811030	2048 47.3	44-29.96	112-07.81	S.E. of Monida	1.4	6	261	62.8	.03	.6	C
811031	1304 55.0	44-24.37	112-58.93	Nicholia	1.1	5	318	42.5	.01	.9	C
811109	2227 17.9	44-23.97	112-39.34	E. of Nicholia	1.6	5	338	34.1	.11	5.2	D
811123	0107 53.3	44-19.55	113-11.48	W. of Nicholia	1.0	5	308	48.6	.15	6.0	D
820102	1019 00.1	44-07.83	113-02.39	S. of Nicholia	0.9	5	272	29.4	.03	.8	C
820105	1513 55.0	43-16.62	112-03.74	E. of Blackfoot	0.8	6	206	12.1	.17	6.0	D
820107	0104 22.4	43-17.12	112-03.10	E. of Blackfoot	0.8	6	202	11.1	.05	1.2	C
820108	0036 41.4	43-23.35	112-01.20	E. of Shelley	1.2	6	206	12.4	.06	1.2	C
820124	0946 57.6	44-26.35	112-49.48	N.E. of Nicholia	1.4	5	328	40.3	.08	3.1	D
820211	1011 11.5	43-10.20	111-27.99	N. of Grays Lake	1.5	5	264	39.7	.26	2.2	C
820211	1049 48.9	43-07.82	111-26.45	N. of Grays Lake	0.8	5	270	43.4	.25	3.2	D
820211	1122 20.2	43-11.88	111-29.11	N. of Grays Lake	1.0	5	259	37.1	.54	3.7	D
820305	0059 47.4	44-26.04	113-03.50	N.W. of Nicholia	1.0	6	319	48.6	.05	.9	C
820307	0638 39.4	44-30.78	112-50.72	N.E. of Nicholia	1.3	6	310	48.6	.11	2.7	D
820316	1333 06.6	43-05.48	111-36.46	Blackfoot River Reservoir	0.8	5	282	34.7	.33	10.5	D
820320	1249 46.0	43-01.00	111-45.21	Blackfoot River Reservoir	1.3	6	260	34.8	.14	3.4	D
820408	0045 00.1	44-25.29	112-09.89	S.E. of Monida	0.9	6	257	108.7	.54	1.5	D

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820423	2127 15.9	43-12.11	111-31.61	N. of Blackfoot River Reservoir	1.4	5	249	33.8	.05	1.9	C
820429	1538 57.9	44-27.00	112-12.24	S.E. of Monida	1.0	7	258	54.8	.06	.9	C
820505	0015 59.1	44-26.06	113-41.31	W. of Gilmore	1.2	6	323	89.2	.15	2.4	D
820510	0217 15.8	44-20.42	112-46.19	E. of Nicholia	1.0	5	324	28.5	.10	3.1	D
820521	0038 33.8	44-17.97	112-35.96	E. of Nicholia	1.8	8	257	23.8	.14	2.8	D
820525	1224 25.7	44-26.63	113-07.22	N.W. of Nicholia	1.4	6	319	52.7	.22	6.6	D
820527	1355 03.9	44-27.03	113-06.89	N.W. of Nicholia	1.2	6	320	52.9	.15	2.4	C

END

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