INL/EXT-06-11851

Seismic Reflection Project Near the Southern Terminations of the Lost River and Lemhi Faults, Eastern Snake River Plain, Idaho

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The INL is a U.S. Department of Energy National Laboratory
operated by Battelle Energy Alliance

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Prepared for the
U.S. Department of Energy
Office of Nuclear Energy
Under DOE Idaho Operations Office
Contract DE-AC07-05ID14517

SUMMARY

Thirteen seismic reflection lines were processed and interpreted to determine the southern terminations of the Lost River and Lemhi faults along the northwest boundary of the eastern Snake River Plain (ESRP). The southernmost terminations of the Arco and Howe segments were determined to support characterization of the Lost River and Lemhi fault sources, respectively, for the INL probabilistic seismic hazard analysis.

Four commercial seismic reflection lines (Arco lines 81-1 and 81-2; Howe lines 81-3 and 82-2) were obtained from the Montana Power Company. The seismic data were collected in the early 1980's using a Vibroseis source with station and shot point locations that resulted in 12-fold data. Arco lines 81-1 and 81-2 and Howe lines 81-3 and 82-2 are located within the basins adjacent to the Arco and Howe segments, respectively.

Seven seismic lines (Arco lines A1, A2, A3, and A4 and Howe lines H1, H2, and H3) were acquired by EG&G Idaho, Inc. Geosciences for this study using multiple impacts with an accelerated weight drop source. Station and shot point locations yielded 12-fold data. The seismic reflection lines are oriented perpendicular to and at locations along the projected extensions of the Arco and Howe fault segments within the ESRP.

Two seismic lines (Arco line S2 and Howe line S4) were obtained from Sierra Geophysics. In 1984, they acquired seismic reflection data using an accelerated weight drop source with station and shot point locations that yielded 6-fold data. The two seismic reflection lines are oriented perpendicular to and at locations along the projected extensions of the Arco and Howe fault segments within the ESRP. In 1992 for this study, Geotrace Technologies Inc. processed all of the seismic reflection data using industry standard processing techniques.

Based on interpretations of all seismic reflection lines, the southern termination of the Howe segment of the Lemhi fault was placed between Howe lines H1 and H2, 2.2 km south of the fault's southernmost surface expression. In the adjacent basin, south-dipping normal faults at the northern end of Howe line 81-3 and two southwest-dipping normal faults at the northeastern end of Howe line 82-2 that can be correlated with Howe segment. South of the surface

expression, two southwest-dipping normal faults on Howe line H1 can be correlated with the Howe segment. Further into the ESRP, Howe lines H2, H3, and S4 show continuous flat lying reflectors and indicate no fault offset.

The southern termination of the Arco segment of the Lost River fault was placed between Arco lines S2 and A3, a distance of 4.6 km south of the fault's southernmost surface expression. Within the basin, west-dipping normal faults interpreted on Arco lines 81-1 and 81-2 can be correlated with the Arco segment. Further south within the Arco volcanic rift zone (VRZ), three seismic lines (Arco lines A2, S2, and A3) permit two interpretations. The west- and south-dipping normal faults on Arco lines A2 and S2 could be associated with slip along the Arco segment. These normal faults have an opposite dip to an east-dipping fault on Arco line A3. The observed small-offsets (< 85 m) along the oppositely dipping normal faults could be a graben structure associated with dike intrusion within the Arco VRZ. Arco line A4 further south within the Arco VRZ shows flat lying reflectors with no fault offsets.

FOREWORD

This report was first compiled in 1995 in support of geophysical investigations for the New Production Reactor program. The report was not issued under INEL-95/0489 because the program was discontinued. The report is now being issued as INL/EXT-06-11851 since contents of the "INEL-95/0489" report have been referenced in several INL documents. The information and interpretations support the scenarios for fault terminations in the "Site-specific Probabilistic Seismic Hazard Analyses for the Idaho National Laboratory" report INEL-95/0536. The information and interpretations are also discussed in various site selection documents, environmental impact statements, and safety analysis reports at INL. Additionally, the text of the original report was revised to include current names for the Idaho National Laboratory.

ACKNOWLEDGMENTS

The U. S. Department of Energy (DOE), Office of Nuclear Energy, Science, and Technology funded this work under DOE Idaho Field Office Contract DE-AC07-05ID14517.

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TABLES

Seismic Reflection Project Near the Southern Terminations of the Lost River and Lemhi Faults, Eastern Snake River Plain, Idaho

1. Introduction

Seismic reflection data were obtained and evaluated in an effort to determine the termination positions of the Lost River and Lemhi faults near the northwestern boundary of the eastern Snake River Plain (ESRP). Since 1981 several seismic reflection surveys have been conducted near the southern ends of the Lemhi and Lost River faults near the Idaho National Laboratory (INL). Four commercially available lines were obtained from the Montana Power Company. Two seismic lines were obtained from the 1984 "Sierra Geophysics" INL geophysical investigations (Hadley and Cavit 1984). In 1991, seven seismic reflection lines were collected by EG&G Idaho, Inc., Geosciences under the New Production Reactor (NPR) program (this report). In 1992, Geotrace Technologies Inc. processed all of the seismic reflection data using the same sequential processing steps. This report discusses the acquisition, processing, and interpretation of the reflection seismic lines that were used to determine the locations of the fault terminations. The fault terminations were determined to support characterization of the Lost River and Lemhi faults for the INL probabilistic seismic hazard analysis.

2. Geologic Setting

The study area is located along the northwest boundary of ESRP near the southernmost terminations of the Lemhi and Lost River ranges (Figure 1). This region is a transitional zone between the seismically active Basin and Range Province and the aseismic ESRP (Jackson et al. 1993). Extension in the Basin and Range province is accommodated by repeated surface faulting earthquakes associated with predominantly normal faulting. The ESRP is a major volcanic province that is interpreted to be the track of the Yellowstone hotspot, which now rests under Yellowstone National Park in Wyoming (Pierce and Morgan, 1992). In contrast to the Basin and Range, the ESRP is aseismic, topographically subdued, and contains no major normal faults, suggesting dike intrusion may accommodate extension within the ESRP.

The ESRP has three northwest-trending volcanic rift zones (VRZ), which extend across regions of the INL (Figure 1). The VRZs are recognized by concentrated zones of aligned volcanic vents and ground deformational features. The ground deformational features include parallel sets of fissures, ground cracks, and small normal faults that in some cases form graben. These surface volcanic features result from basalt dike intrusion (Mastin and Pollard 1988; Rubin 1992). The northern end Arco VRZ overlaps with the southern end of the Arco segment of the Lost River Fault. Fissures and small normal faults in the Arco VRZ are thought to result from intrusion of dikes in the subsurface of the Arco VRZ (Smith et al.1989; Hackett and Smith, 1992). The features are also thought to represent the possible continuation of Basin and Range faulting into the ESRP (Kuntz et al. 1992). The southern termination of the Lemhi fault is located north of the Howe-East Butte VRZ and south of the Lava Ridge-Hell's Half Acre VRZ.

The Lemhi and Lost River faults are northwest-striking major range-bounding normal faults. The faults are 140 to 150 km long and bound eastward tilted crustal blocks with half-graben basin structures (Ruppel 1978). Faulting is predominately dip-slip with localized amounts of strike-slip (e.g., 1983 Borah Peak earthquake; Richins et al. 1987). The Lemhi and Lost River faults generally show less frequent earthquakes, longer recurrence intervals, and older "most recent earthquakes" on their southernmost segments (Hemphill-Haley et al. 1992). For this report the fault segments are referred to as the "Howe Segment" for the Lemhi fault and the "Arco Segment" for the Lost River fault (after Crone and Haller 1991).

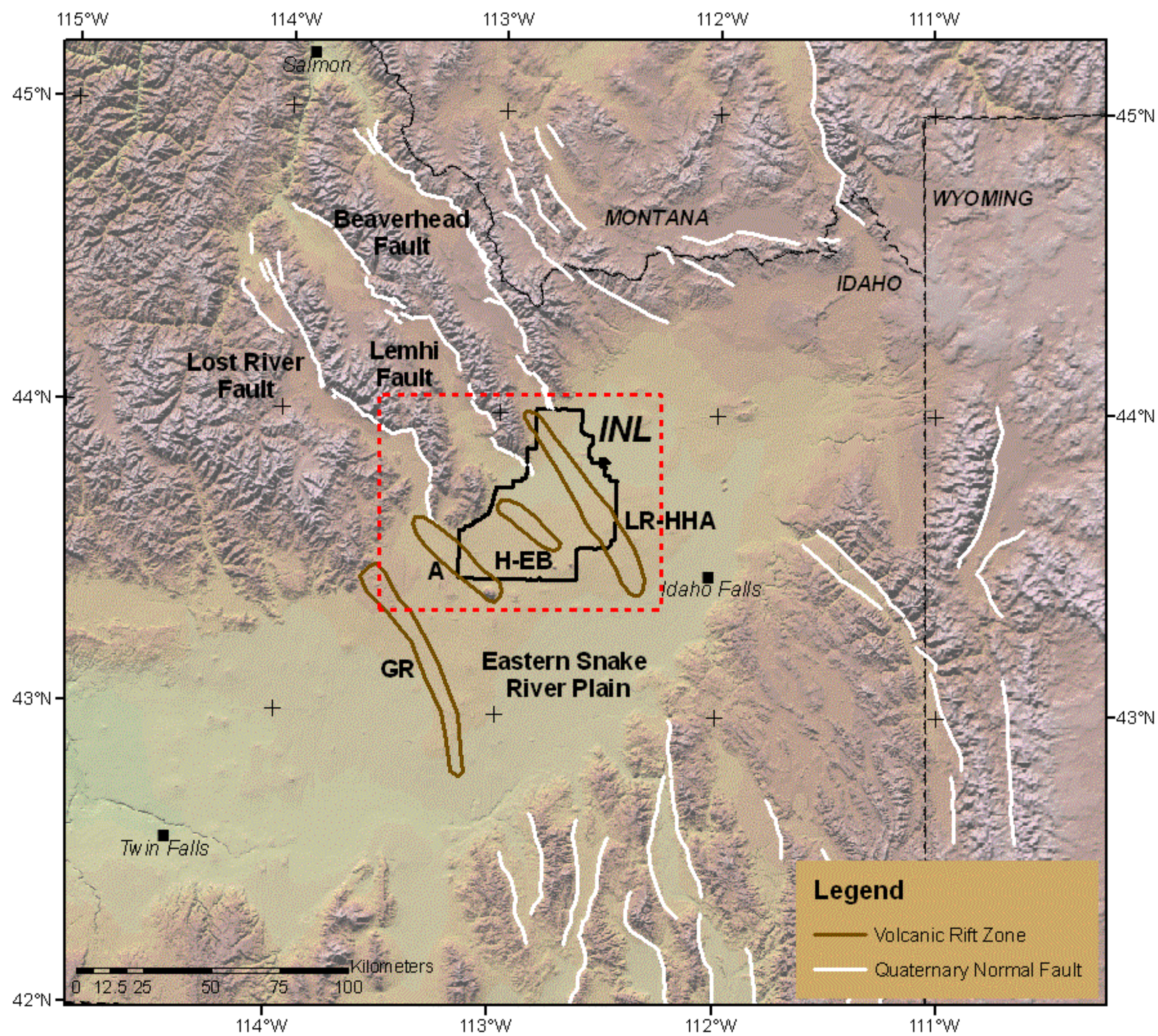

Figure 1. Map shows the location of the Idaho National Laboratory (INL), three Basin and Range normal faults located northwest of INL, and volcanic rift zones within the eastern Snake River Plain. Volcanic rift zones names are abbreviated as: Great Rift (GR); Arco (A); Howe-East Butte (H-EB); and Lava Ridge-Hell's Half Acre (LR-HHA). Red dashed box indicates the location of the map shown in Figure 2.

3. Data Acquisition and Processing

All seismic reflection data were collected and processed using standard petroleum industry practices. Four commercial seismic reflection lines were shot in the early 1980's for the Montana Power Company. Arco lines 81-1 and 81-2 and Howe lines 81-3 and 82-2 are located within the basins adjacent to the Arco segment of the Lost River fault and Howe segment of the Lemhi fault, respectively (Figure 2). The seismic data were collected with a 48-channel PELCO recording system. Stations were spaced at 33.5 m (110 ft) and the source spacing was 67 m (220 ft), which resulted in 12-fold data (Table 1). The energy source was a Vibroseis (mechanical wave generator mounted on a truck).

Seven seismic reflection lines (Arco lines A1, A2, A3, and A4, and Howe lines H1, H2, and H3) were shot by EG&G Idaho, Inc. Geosciences. The seismic reflection lines were located near the projected extensions of the Arco and Howe fault segments within the ESRP (Figure 2). The seismic data were acquired using a Bison 24-channel recorder. Stations were spaced at 16.8 m (55 ft) and the sources at 33.5 m (110 ft), which resulted in 12-fold data (Table 1). The energy source was the EG&G DYNA-source (an accelerated weight drop system) that produced vibrations from multiple impacts.

In 1984, Sierra Geophysics collected seismic reflection data as part of gravity, magnetic, and seismic investigations at the INL. Two seismic reflection lines, Arco line S2 and Howe line S4, were reprocessed and interpreted for this study. Arco line S2 is located within the Arco VRZ and Howe line S4 is located near the southern end of the Lemhi range (Figure 2). The 1984 seismic data were collected using the EG&G ES-2415F recorder and EG&G DYNA-source. The stations were spaced at 15.2 m (50 ft) and energy sources spaced at 30.5 m (100 ft), which resulted in 6-fold data (Table 1).

In 1992, Geotrace Technologies, Inc. processed all seismic reflection data. The seismic reflection data were reduced using refracted arrivals to resolve near surface velocity conditions and static corrections. The general sequence of processing included standard industry practices: 1) two passes of surface consistent static correction; 2) two passes of velocity analysis; 3) one pass of common depth point consistent static correction; 4) final stack; and 5) filter. The specific processing sequence that is identified on the seismic lines included:

1. Demultiplex
2. Geometry definition
3. Trace edit
4. Geotrace refraction statics (VCR = 9000 ft/sec; datum = 5300 ft; two-layer case)
5. Shot equalization
6. Wavelet deconvolution (Shots – zero phase output 20-44 Hz; 180 msec operator)
7. 500 msec Automatic Gain Control (AGC)
8. Common Depth Point (CDP) sort
9. Velocity analysis
10. Surface consistent statics

11. Velocity analysis
12. Normal Move Out (NMO)
13. NMO mute
14. Stack 12 fold
15. Two-dimensional noise reduction
16. Band pass filter (0.0 – 1.0 sec; 6/10 40/50 Hz)

Table 1. Instrumentation and recording parameter for the seismic reflection lines.

Line Names	Abbreviation	Instrumentation	Recording Parameters	Source
Arco Line 1 Arco Line 2 Arco Line 3 Arco Line 4 Howe Line 1 Howe Line 2 Howe Line 3	A1 A2 A3 A4 H1 H2 H3	Recorder: Bison 9024 Energy Source: EG&G DYNA-source	Record Length: 1 sec Sample Rate: 1 msec Group Interval: 55 ft Shot Point Interval: 110 ft Traces per Shot: 24 Fold: 12	EG&G Idaho, Inc. (this report)
Arco South Line 2 Howe Line 4	S2 S4	Recorder: EG&G ES-2415F Energy Source: EG&G DYNA-source	Record Length: 1 sec Sample Rate: 1 msec Group Interval: 50 ft Shot Point Interval: 100 ft Traces per Shot: 24 Fold: 6	Sierra Geophysics (Hadley and Cavit 1984)
Arco 81 Line 1 Arco 81 Line 2 Howe 82 Line 2 Howe 81 Line 3	81-1 81-2 82-2 81-3	Recorder: PELCO Energy Source: Vibroseis (Inline pattern; Sweeps/Vib = 16/4; Sweep Frequency 20-62 Hz; Sweep Length 14 sec)	Record Length: 4 sec Sample Rate: 2 msec Group Interval: 110 ft Shot Point Interval: 110 ft Traces per Shot: 48 Fold: 12	Industry reflection seismic lines shot for Montana Power Company

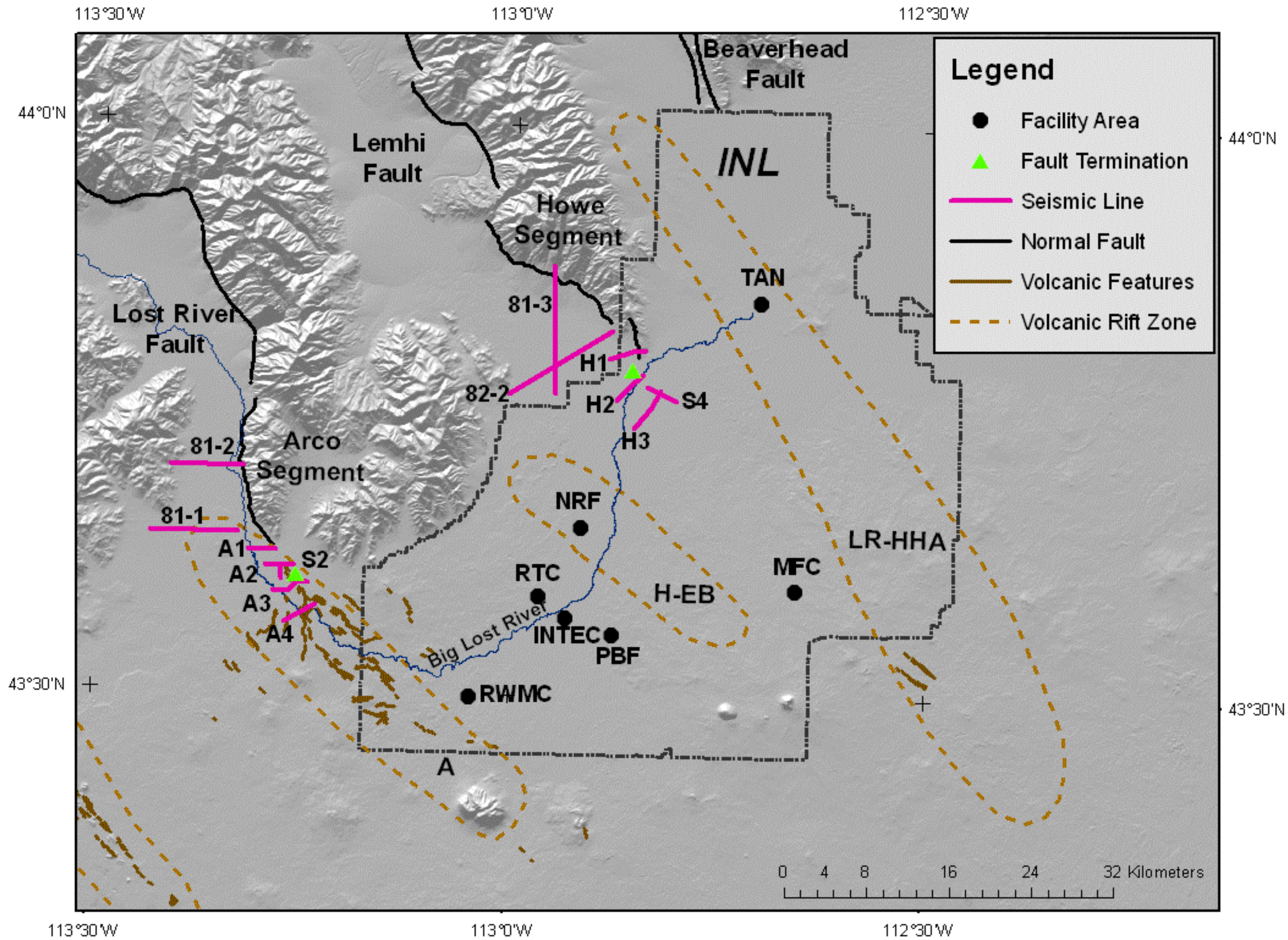

Figure 2. Map shows the locations of the seismic reflection lines (see Table 1 for abbreviations) relative to the normal faults and volcanic rift zones (see Figure 1 for names). The facility areas at the Idaho National Laboratory (INL) include: Materials and Fuels Complex (MFC), Power Burst Facility (PBF), Reactor Technology Complex (RTC), Idaho Nuclear Technology and Engineering Center (INTEC), Radioactive Waster Management Complex (RWMC), Naval Reactor Facility (NRF), and Test Area North (TAN).

4. Interpretation of Seismic Reflection Profiles

4.1 Howe Segment

Six seismic reflection lines are located in the area of the Howe segment of the Lemhi fault (Figure 2). Howe lines 81-3 and 82-2 cross the surface expression of the Howe segment within the basin; one is oriented north-south and the other northeast-southwest. Howe lines H1, H2, H3, and S4 are located within the ESRP southeast of the projected surface trace of the Howe segment. They are oriented approximately in a northeast-southwest direction perpendicular to the projected extension of the Howe segment. These seismic lines are also oriented in a manner to cross the steepest part of a local gravity anomaly, which may indicate extension of the Howe segment into the ESRP (Hadley and Cavit 1984).

Adjacent to the Howe fault segment, Howe line 82-2 shows a series of generally flat lying reflectors on the southwest end that dip down into a large depression that has been filled with a thick wedge of flat lying sediments (Figure 3). The northeast end of this line shows two normal faults that can be correlated with the Howe segment. Howe line 81-3 obliquely crosses the large depression seen in Howe line 82-2 (Figure 4). The seismic reflection data suggest the basin has been subsiding and tilting northeast toward the Lemhi Fault as indicated by the substantial dips of the deep reflectors toward the subsurface faults in Howe line 82-2, and flat lying reflectors that pinch out to the southwest in Howe line 81-3. These reflectors may represent basalt and sediment layers deposited in the early history of the basin (local water well logs indicate basalt and sediments but no wells extend to depths of the seismic data). Reflectors near the surface in Howe Line 82-2 are generally horizontal, dipping much less steeply toward the Lemhi fault. At the northern end of Howe line 81-3, displacements along the two northernmost normal faults can be correlated to the Howe segment.

Seismic reflection data for Howe lines H2, H3, and S4 show flat lying reflectors without any offsets whereas Howe line H1 shows offsets along two normal faults (Figure 5). The flat lying reflectors are inferred to represent basalt and sediments, but no direct well correlations could be made. Howe line H1 extends northeast-southwest across the southernmost topographic expression of the Howe segment. The seismic reflection data indicate offsets along possibly two southwest-dipping normal faults, which are consistent with the dip direction of the Howe segment along Howe line 82-2. The minimum offset of the normal fault in Howe line H1 is interpreted to be 30 m (98.2 ft). Further south, Howe lines H2 and H3 show generally flat lying reflectors without any offsets. Although Figure 5 shows discontinuous and inferred reflectors for Howe lines H2, H3, and S4, there is no clear offset along the reflectors that is indicative of normal faulting. The flat lying reflectors of Howe lines H1, H2, H3, and S2 suggests that little or no fault related tilting has occurred in these layers.

Based on the interpretations of the seismic reflection data, the termination for the Howe segment was placed between Howe lines H1 and H2, 2.2 km from the southernmost surface expression of the Howe segment (Figure 2). The flat lying reflectors without fault offset observed in Howe lines H2, H3, and S4 support this position for the termination of the Howe segment (Figure 5). Additionally, the flat lying reflectors of Howe lines H1, H2, H3, and S4 indicate no significant eastward tilting of the subsurface layers as observed adjacent to the Howe segment in Howe lines 82-2 and 81-3. The lack of such tilting suggests that significant offset along the Howe segment dies out a short distance within the ESRP.

4.2 Arco Segment

Seven reflection seismic lines are located near the Arco segment of the Lost River fault. Arco lines 81-1 and 81-2 extend in an east-west direction across the basin adjacent to the surface expression of the Arco segment. Arco lines A1, A2, A3, A4, and S2 are located south of the surface expression of the Arco segment within the Arco VRZ (Figure 2). These seismic reflection lines cross surface expressions of small-offset normal faults interpreted by Smith et al. (1989) to result from basalt dike injection within the Arco VRZ. An attempt was made to determine if significant offset is evident at depth to infer a volcanic or tectonic origin of the small-offset normal faults.

Arco lines 81-1 and 81-2 show flat-lying reflectors that gently dip to the east toward the Arco segment (Figures 6 and 7, respectively). The reflectors are offset by west-dipping normal faults at the eastern ends of the seismic lines. The west-dipping normal fault in Arco line 81-2 can be correlated with the Arco segment. The two west-dipping normal faults in Arco 81-1 suggest the Arco segment may have fault strands that step out into the basin adjacent to the Arco segment (Figure 2).

South of the surface expression of the Arco segment, Arco line A1 shows few reflectors that can be confidently traced across the seismic section. The eastern half of the east-west oriented Arco line A2 shows 85 m (279 ft) of offset associated with a west-dipping normal fault. Arco line A2 was taken along the same profile as the east-west section of Arco line S2 then extended further west. Arco line S2 shows similar offset along a south-dipping normal fault, which is most likely associated with the west-dipping fault in Arco line A2 (Figure 8). Less than 2 km (1.2 miles) south of Arco line S2, Arco line A3 shows a series of generally flat lying reflectors across most of the seismic line and a possible east-dipping normal fault with a minimum detectable displacement of 30 m (98.2 ft). An east-dipping normal fault is opposite to the Arco segment, which is a west-dipping normal fault. Further south, Arco line A4 shows a series of generally flat lying discontinuous seismic reflectors that have no significant fault offset (Figure 8).

Two interpretations are possible for the normal fault orientations on Arco lines A2, S2, and A3. The west- and south-dipping faults could be associated with slip along the Arco segment at this location or they could be associated with dike intrusion within the VRZ. The locations and orientations of Arco lines A2 and S2 (east-west and north-south, respectively) and A3 (east-west) permit an interpretation of a possible graben structure bounded by oppositely dipping normal faults shown in Figure 8. Such a graben structure bounded by small-offset (< 85 m) normal faults could result from slip along the Arco segment or dike intrusion within the Arco VRZ.

The termination of the Arco segment is interpreted to be south of Arco line S2, 4.6 km south of its southernmost surface expression (Figure 2). Within the basin, Arco lines 81-1 and 81-2 show west-dipping normal faults that can be correlated with the surface expression of the Arco segment (Figures 6 and 7). Further south, Arco lines A2 and S2 have west- and south-dipping normal faults that could be have resulted from slip along the Arco segment. However, the east-dipping fault on Arco line A3 permits an interpretation of small-offset normal faults that bound a graben structure. A graben structure at this location could result from dike-intrusion within the Arco VRZ. Additional investigations are needed to confirm the best interpretation, thus the southern termination of the Arco segment was placed south of Arco line S2.

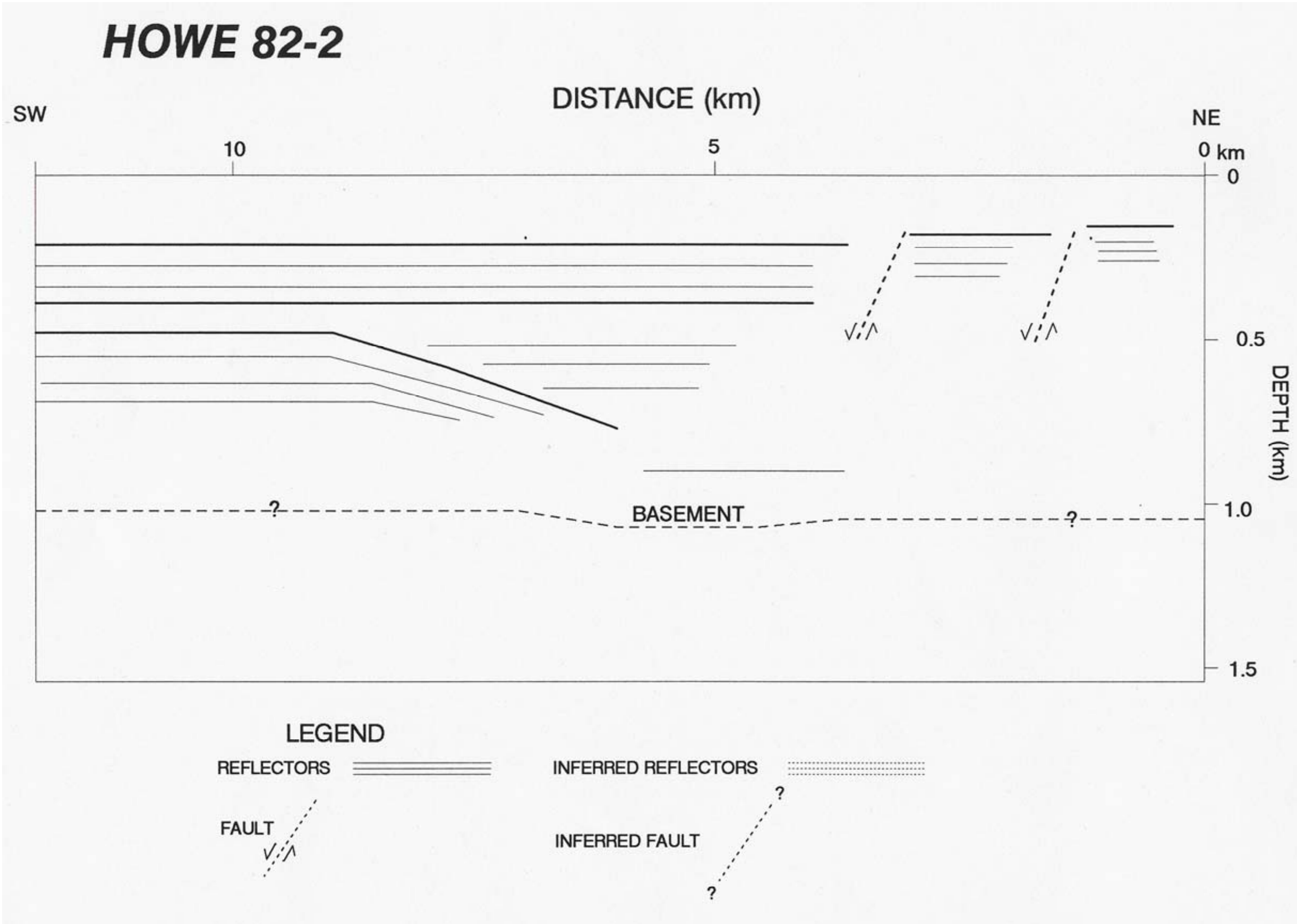

Figure 3. Schematic cross section shows the structural interpretation of the seismic reflection data for Howe Line 82-2.

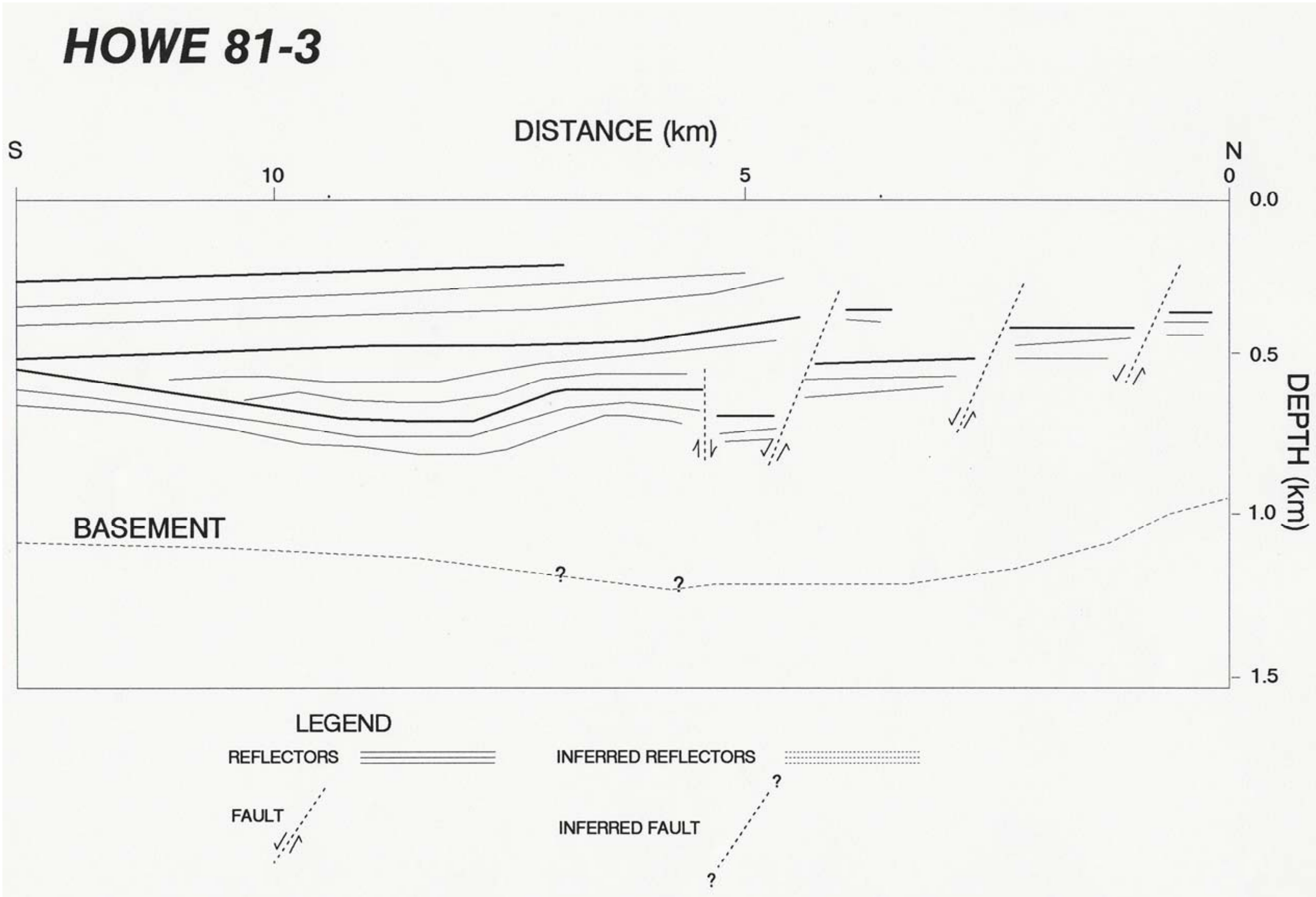

Figure 4. Schematic cross section shows the structural interpretation of the seismic reflection data for Howe Line 81-3.

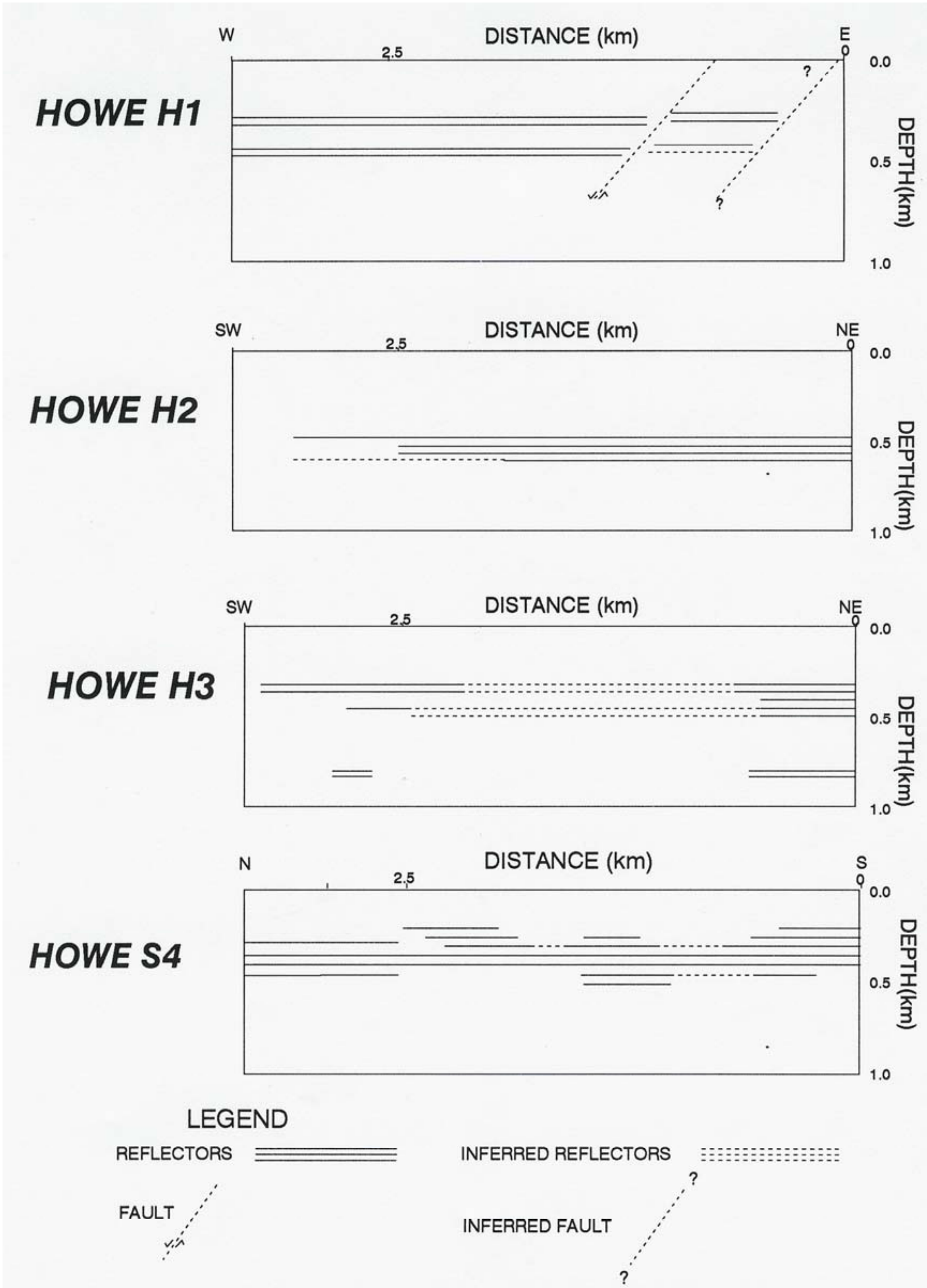

Figure 5. Schematic cross section shows the structural interpretation of the seismic reflection data for Howe Lines H1, H2, H3, and S4.

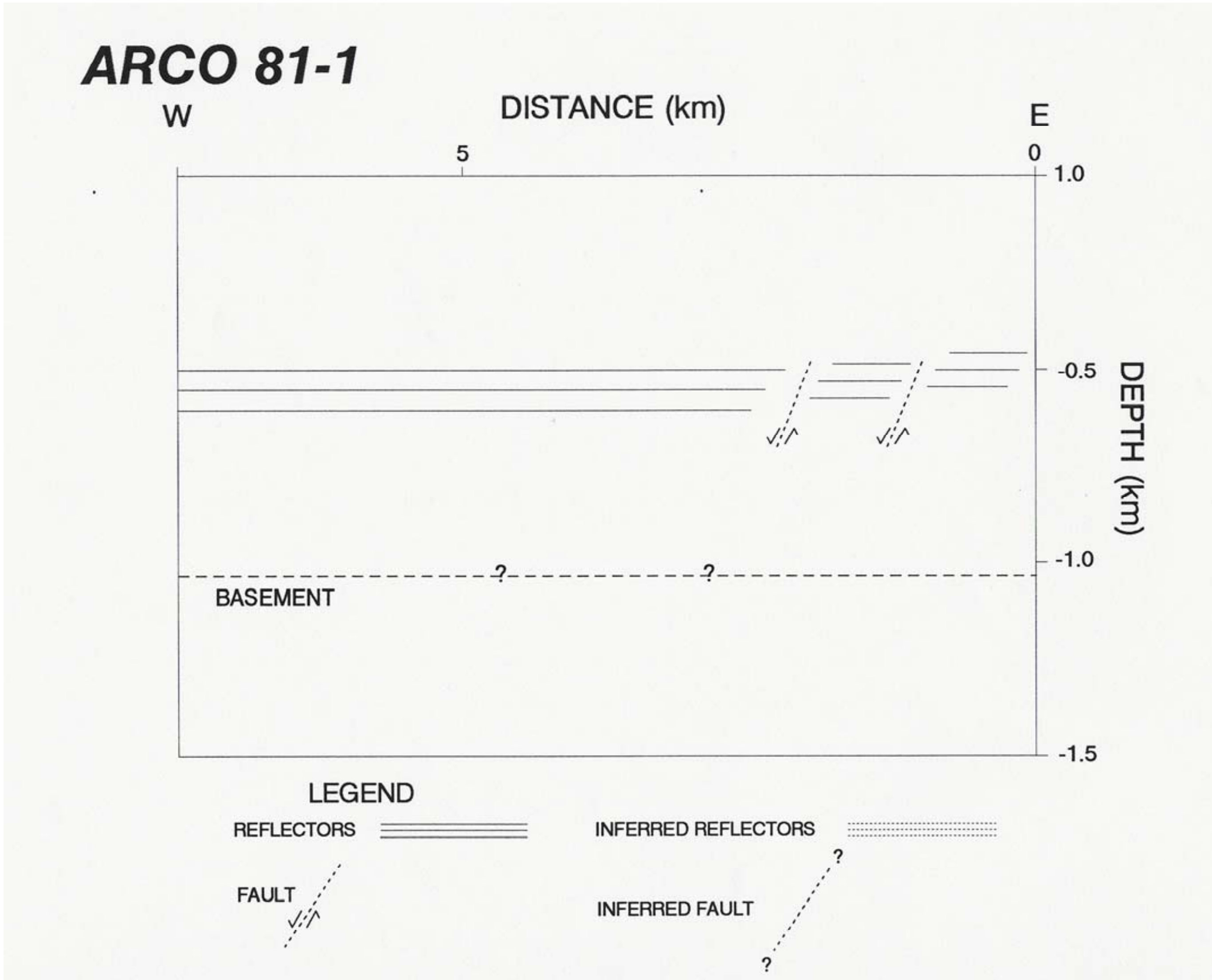

Figure 6. Schematic cross section shows the structural interpretation of the seismic reflection data for Arco Line 81-1.

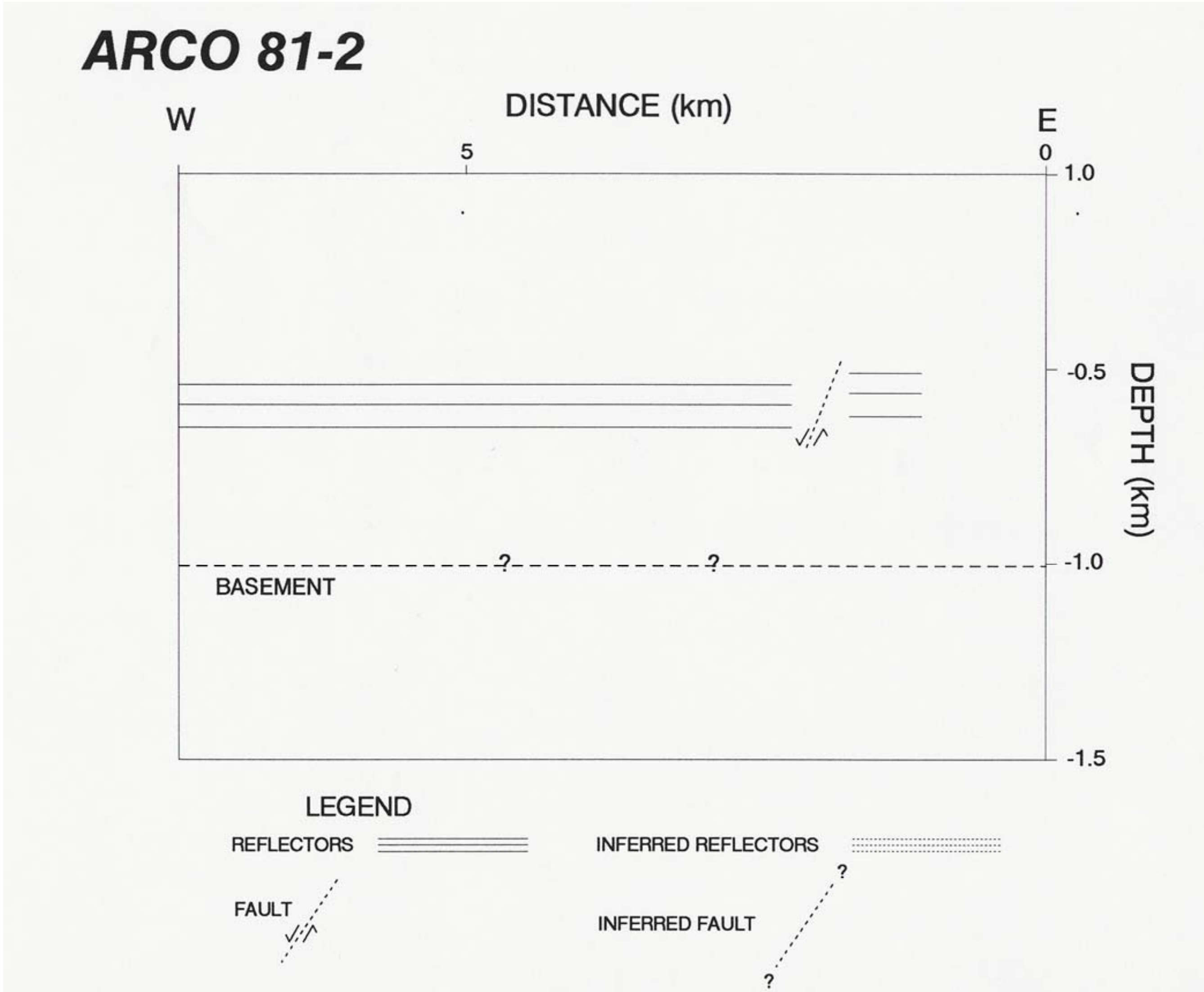

Figure 7. Schematic cross section shows the structural interpretation of the seismic reflection data for Arco Line 81-2.

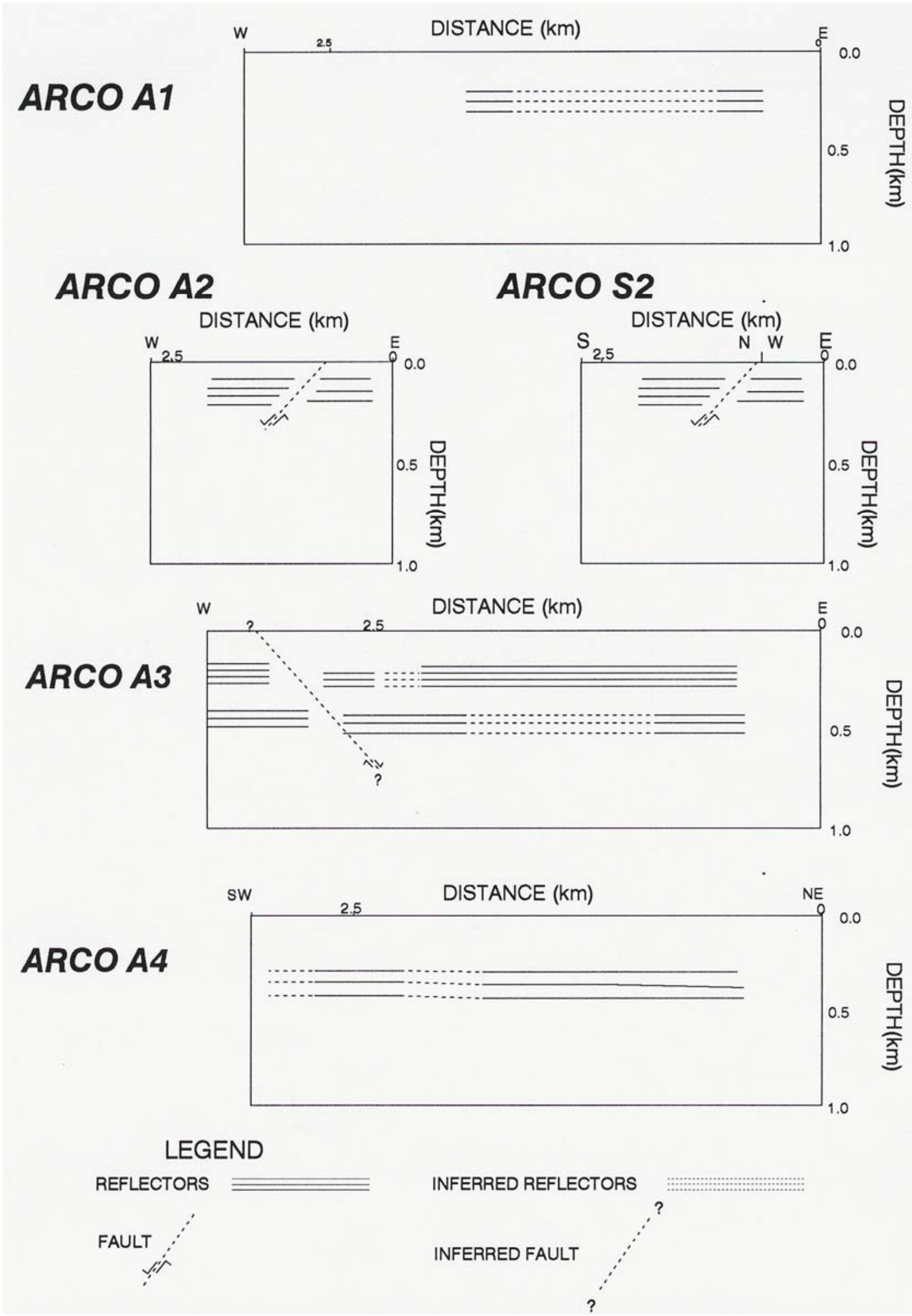

Figure 8. Schematic cross section shows the structural interpretation of the seismic reflection data for Arco Lines A1, A2, A3, A4 and S2.

5. Conclusions

Thirteen seismic reflection lines were processed and interpreted to determine the possible locations of the Lost River and Lemhi fault terminations within the ESRP. Four commercial seismic reflection lines shot for the Montana Power Company (Arco lines 81-1 and 81-2; Howe lines 81-3 and 82-2) were acquired using a Vibroseis source with station and shot point locations that resulted in 12-fold data. These seismic lines are located in the basins adjacent to the Arco segment of the Lost River fault and the Howe segment of Lemhi fault. Seven seismic lines (Arco lines A1, A2, A3, and A4 and Howe lines H1, H2, and H3) were acquired by EG&G Idaho, Inc. Geosciences for this study using multiple impacts with an accelerated weight drop source. Station and shot point locations yielded 12-fold data. These seismic lines are located near the projected southern extensions of the Arco and Howe segments into the ESRP. Two seismic lines (Arco line S2 and Howe line S4) shot by Sierra Geophysics in 1984 also used an accelerated weight drop source. Station and shot point locations yielded 6-fold data. These seismic lines are also located near the projected southern extensions of the Arco and Howe segments into the ESRP (Figure 2). For this study, Geotrace Technologies Inc. processed all of the seismic reflection data using an industry standard processing sequence.

The southern termination of the Howe segment was determined to be 2.2 km south of the fault's southernmost surface expression (Figure 2). Within the basin, south-dipping normal faults at the northern end of Howe line 81-3 and two southwest-dipping normal faults at the northeastern end of Howe line 82-2 can be correlated with Howe segment (Figures 3 and 4). South of the surface expression, the southwest-dipping normal faults on Howe line H1 can be correlated with the Howe segment. Further south, Howe lines H2, H3, and S4 show continuous flat lying reflectors and indicate no fault offset (Figure 5). The southern termination for the Howe segment was placed between Howe lines H1 and H2.

The southern termination of the Arco segment was determined to be 4.6 km south of the fault's southernmost surface expression (Figure 2). Within the basin, west-dipping normal faults interpreted on Arco lines 81-1 and 81-2 can be correlated with the Arco segment (Figures 6 and 7). Further south, two seismic lines (Arco lines A2 and S2) have west- and south-dipping normal faults that could be associated with slip along the Arco segment (Figure 8). However, an alternative interpretation is permitted with consideration of an east-dipping fault on Arco line A3. The observed small-offsets (< 85 m) along the oppositely dipping normal faults can be interpreted as a graben structure that resulted from dike intrusion within the Arco VRZ. Since additional investigations are needed to assess the origin of the normal faults, the southern termination of the Arco segment was placed between Arco lines S2 and A3.

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