SEISMIC CAT SCAN OF AN ANCIENT EARTHQUAKE ALONG THE OQUIRRH FAULT, UTAH

by

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A thesis submitted to the faculty of
The University of Utah
in partial fulfillment of the requirements for the degree of

Master of Science

in

Geophysics

Department of Geology and Geophysics

The University of Utah

March 1998

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ABSTRACT

Two-dimensional (2-D) and three-dimensional seismic (3-D) surveys were conducted across the Oquirrh fault, of Northern Utah with the purpose of imaging the fault related structure to a depth of 40-60 ft. The scientific objective was to use the resulting reflectivity and tomographic images to deduce the paleoseismic history of this fault zone. The tomographic images were generated by conducting a seismic CAT (computer axial tomography) scan of the fault zone by inverting first-arrival traveltimes of 3-D seismic data.

The 3-D seismic data (112,896 traces) were collected over a 145 ft x 30 ft patch of ground along the Oquirrh fault Their first arrival traveltimes were then picked and inverted by a 3-D tomographic technique. To complement the 3-D tomogram, a 2-D reflectivity image was obtained by a 570 ft long reflection survey that cut across the fault. Results show that the 3-D tomogram clearly delineates the fault and a colluvial wedge, both of which correlate well with the geologic cross-section taken from the adjacent trench. The thickness of the colluvial-wedge image provided an estimate of 22.8 ft for the surface displacement of the last surface-rupturing event on the Oquirrh fault. This thickness measurement was also used with the layer dip angles measured from the 2-D reflectivity section to give a moment magnitude estimate of 6.8 for the most recent earthquake. This is in very good agreement with the magnitude estimate of 7.0 based on a nearby trenching study.

This study demonstrates that seismic imaging methods can clearly delineate the shape and depth of a colluvial wedge associated with a normal fault earthquake. It also shows that information from reflectivity images and tomographic images can be combined to accurately estimate the size of prehistoric earthquakes. It is conjectured that a wider recording aperture could have enabled the imaging of multiple colluvial wedges at depth, and so provided the necessary information to estimate recurrence

intervals of large magnitude earthquakes. This assumes that the timing of the colluvial wedge formation can be obtained by dating of cores drilled through the wedges. Thus, a useful tool in paleoseismology is established where 3-D tomography combined with 2-D reflection imaging has the possibility of providing deeper and wider, but less resolved, images of fault systems than the excavation of trenches across faults. In some cases, this may provide a viable alternative to the intrusive task of fault trenching.

To my parents

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ACKNOWLEDGMENTS

I would like to thank my adviser Gerard Schuster for his knowledge and his patience to share it with me. I have learned many lessons from Dr. Schuster during my stay at the University of Utah, many in the classroom and many on the basketball court. Dr. Schuster is a dedicated and hard working geophysicist who has extensive knowledge on the subject and the creativity to always be a leader in the field. I am proud to have worked with Dr. Schuster. Thanks Jerry! Thanks are also offered to the members of my advisory commitee, Bob Smith and Marjorie Chan, for reviewing this manuscript. Bob Smith and Art Sylvester sparked my interest in geophysics. I will always remember working in the Tetons and Yellowstone. Special thanks go to Dr. Ron Bruhn for sharing his ideas on this project and his evaluation of the results.

I would like to thank my parents for the years of support along this journey. They have given me the solid foundation that has made it possible for me to come this far. My wife has been along my side for the duration of this project, she has provided the love and support that have made this possible. She has always been patient on those late nights necessary to complete this project.

Thank you to all those who helped in the collection of this data. Jing Chen, Zhaojun Liu, Fanlin Meng, Hougchuan Sun, Yue Wang, and Chengjun Wu worked many hard, long hours during this process. I benefited from financial support administered by the Department of Geology and Geophysics (Chevron Fellowship), the College of Mines (Dougan Fellowship), and the Society of Exploration Geophysicists. Finally I would like to thank the 1996 and 1997 members of the UTAM project for their financial support.

1. INTRODUCTION

1.1 Purpose and Scope

The purpose of this thesis research is to reconstruct the shallow structure ($0 < Z < 150$ ft) of the Oquirrh fault zone, Northern Utah, with two-dimensional (2-D) and three-dimensional (3-D) seismic imaging techniques and use these images to deduce the paleoseismic history of the fault. The 3-D survey is over a 145 ft x 30 ft patch of ground, whereas the 2-D seismic survey is a single line of length 570 ft. The imaging techniques are common midpoint (CMP) reflection stacking, poststack migration and traveltime tomography. The target body is a colluvial wedge system along the Oquirrh fault scarp. The colluvial wedge is the product of a large surface normal faulting event and can give information about the event that produced it. For example, the size of the colluvial wedge can give information on the magnitude of the event (Ostenaa, 1984); and the number of multiple wedges can provide information on the recurrence interval for surface rupturing events on the fault (Keaton, 1993). Trenching studies suggest that this normal fault erupts every 13,300 to 22,100 yrs with a magnitude 7.0 or larger earthquake (Olig et al., 1996). This study uses seismic imaging to probe deeper than the 10-ft deep trench and gain additional information on the size, geometry, and recurrence interval of earthquakes on the Oquirrh fault. The implication of this work suggest that seismic imaging methods can complement or even replace many trenching studies in paleoseismology.

1.2 Site Geology

The Oquirrh Fault zone lies at the western base of the Oquirrh Mountains, east Tooele County, Utah (Soloman, 1996). A west-dipping normal fault, the Oquirrh Fault is located at the eastern extent of the Basin and Range extensional province. The fault zone shown in Figure 1 extends for about 21 km from Lake Point to just

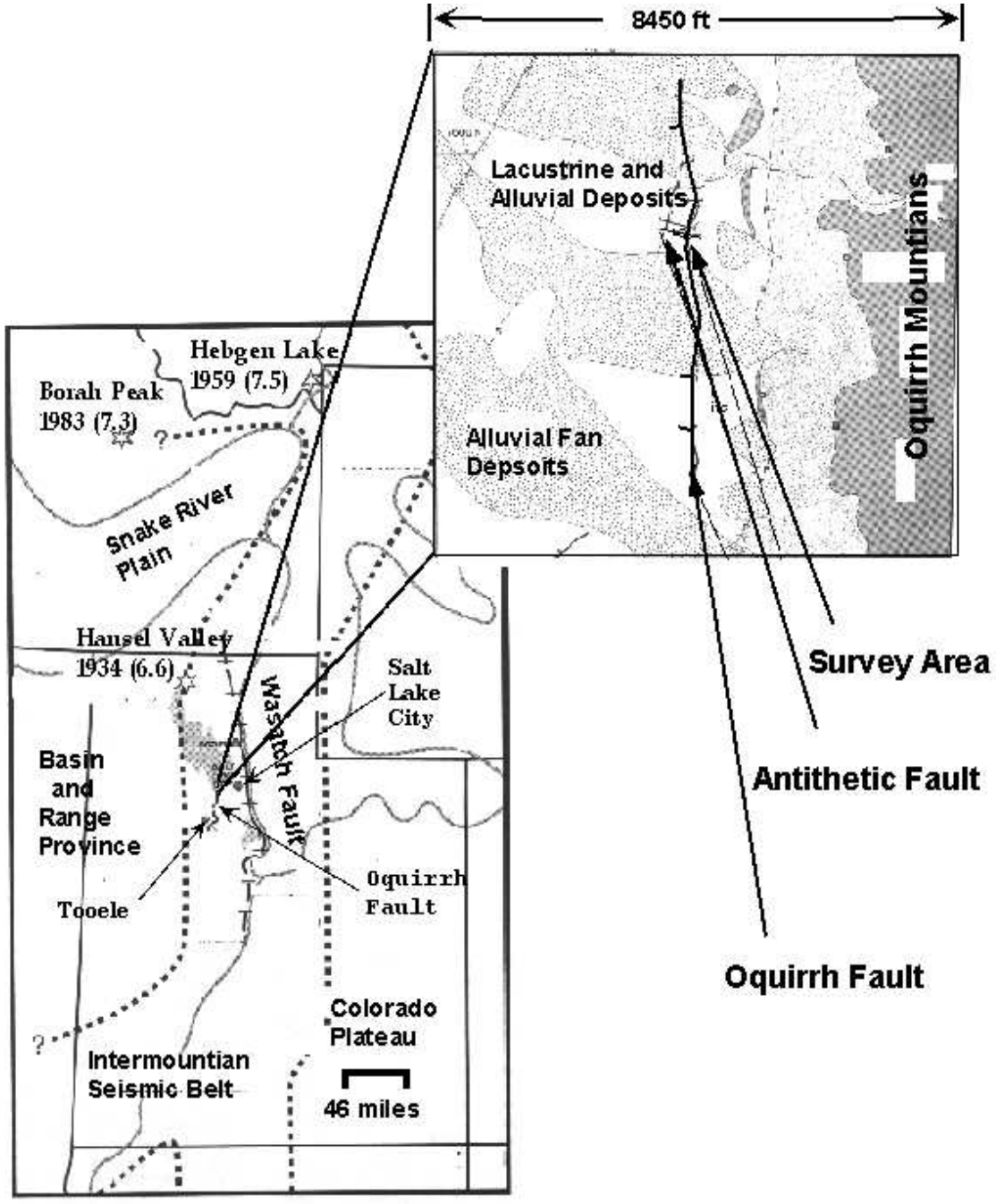

Figure 1: Map of Utah and the northern section of the Oquirrh fault. The dashed lines in the lower left figure define the boundaries of major geologic provinces and the stars indicate the location and magnitude of major earthquakes.

south of Tooele, Utah, and lies about 35 km west of the Wasatch Fault zone which is the most active Quaternary fault in Utah and marks the eastern boundary of the Basin and Range extensional province (Machette et al., 1991). The Oquirrh fault is also located within the Intermountain Seismic Belt (Smith and Sbar, 1974; Smith and Arabasz, 1991) and has not experienced a historic earthquake since 1847 (Olig et al., 1996). Seismicity in the Intermountain Seismic Belt and well-bore breakouts along the Wasatch front indicate that extension is still occurring in the west-northwest to west direction (Zoback, 1983, 1989; Eddington et al., 1987; Bjornadottir and Pechmann, 1989). This suggests that the area is subject to future large earthquakes threatening the communities of Tooele and Salt Lake City and the Tooele Army Depot.

Faulting along the Oquirrh fault was first recognized by geomorphologist G.K. Gilbert in July 1880: "Approaching Tooele there is a fine view of the fault scarp in the embayment of the mts (mountains)" (Hunt, 1982, p. 170). Deposition in the area of the Oquirrh fault has been dominated by alluvial-fan sediments shed from the Oquirrh Mountains to the east and paleolake deposited lacustrine sediments (Soloman et al., 1992). The Tooele Valley, bounded on the east by the Oquirrh fault, was repeatedly inundated by paleolakes in the late Quaternary (Olig et al., 1996). Lake Bonneville produced three distinct shorelines in the Tooele Valley: the Stansbury, Bonneville, and Provo in chronological order. These two depositional environments (alluvial and lacustrine) produce the surficial geology in the northern section of the Oquirrh fault zone. The lacustrine sediments form a thin mantle (3 ft) over older alluvium and are buried by the most recent alluvial-fan deposition (Olig et al., 1996). Bedrock outcrops in the Oquirrh Mountains to the east with the Rogers Canyon Nappe (Soloman, 1996).

A trenching study (Olig et al., 1996) on the Oquirrh fault penetrated to a depth of about 12 ft and revealed the shallow geology. The strata adjacent to the fault is shown in Figure 2 and is characterized by colluvium overlaying fault-scarp colluvium, debris-flow deposits, shallow- to deep-water lacustrine deposits, shallow-water lacustrine deposits, and transgressive beach deposits in order of increasing depth (Olig et al., 1996).

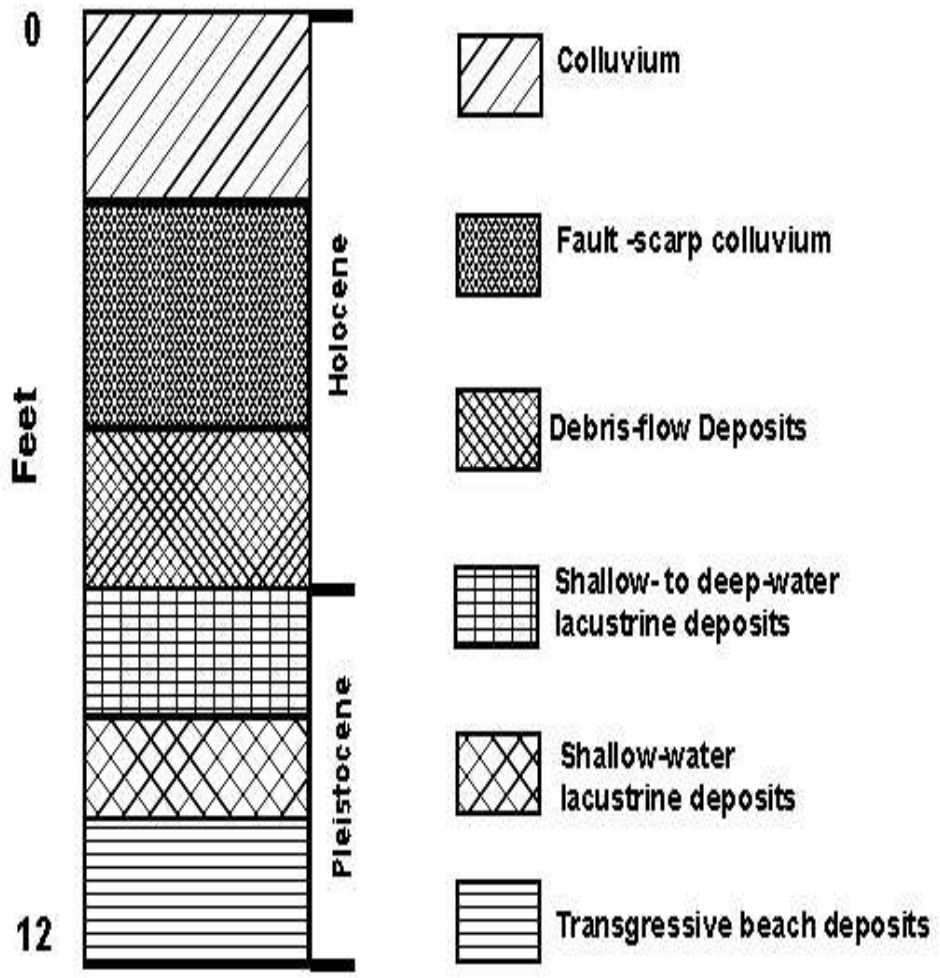

Figure 2: Log interpretation showing the shallow geology adjacent to the Oquirrh fault (Olig et al., 1996).

The trenching study exposed a 2.2 m thick colluvial wedge associated with the most recent surface rupturing event (Olig et al., 1996). A paleoseismic study on the fault yielded an age estimate for this event between 4340 ± 60 yrs. B.P. to 7650 ± 90 yrs. B.P. and gave a recurrence estimate of 13,300-22,100 yrs (Olig et al., 1996). These dates were obtained by radiocarbon dating of faulted and unfaulted horizons in the trench. However, there is some uncertainty in these dates due to the inability of the trenching study to reveal multiple colluvial wedges. This is attributed to the shallow penetration of the trenches.

1.3 Survey Location

University of Utah personnel conducted seismic surveys over the northern part of the Oquirrh Fault zone adjacent to a trench excavated across the fault by the Utah Geological Survey (UGS) near the mouth of Big Canyon (see Figures 3 and 4).

Figure 1 shows a map of the Northern Oquirrh fault and indicates the location of the trench and the 2-D and 3-D seismic surveys. The site was located approximately 2 km southeast of Lake Point, Utah, and 0.3 km west of Big Canyon (Figure 1). This location was selected for several reasons: first, the availability of detailed geologic information from the adjacent trench; second, the Quaternary geology of the area is reasonably well-known; third, the combination of alluvial and lacustrine deposits in the area should provide measurable seismic reflections. Finally, the Oquirrh fault has not received as much attention as the more famous faults in the Intermountain Region even though the fault is 30 km west of Salt Lake City and 7 km east of the Tooele Army Depot.

1.4 Previous Seismic Imaging of Shallow Fault Zones

Investigating shallow fault zones with seismic techniques has been used for several years (Treadway et al., 1988; Miller et al., 1986; Ali et al., 1991). The majority of these investigations have used reflection methods to image the fault zone reflectivity providing information on the location and offset of the fault being investigated (Pratt

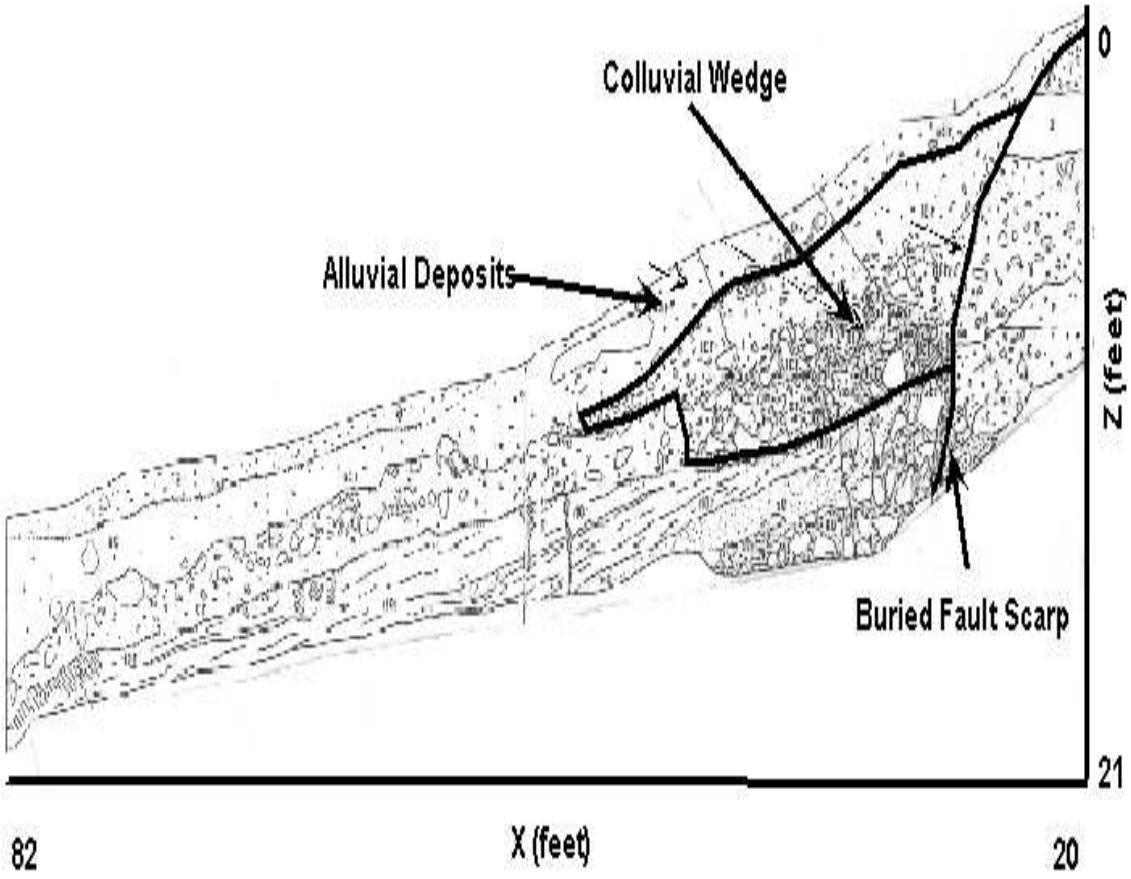

Figure 3: Cross-section of main fault zone in Trench BC-3 (Olig et al., 1996). The colluvial wedge is the result of rapid deposition following a surface rupturing earthquake and is a reliable indicator of a large magnitude event.

et al., 1997; Odem et al., 1997). Problems arise in this method because shallow reflections are difficult to collect due to a variety of problems including statics, strong surface waves, and poor signal-to-noise ratios (Louis and Karastathis, 1996). Thus, obtaining paleoseismic information on a shallow fault zone using seismic techniques can be a difficult task.

As an example, seismic investigations have been conducted on the Wasatch Fault (Stephenson, 1991) and the West Valley Fault (Keaton, 1993) which are in the Intermountain Seismic Belt and within 30 km of the Oquirrh fault. Both of these investigations were able to identify the location of the fault indicated by offsets in subsurface horizons, but the identification of colluvial wedges was ambiguous. Thus,

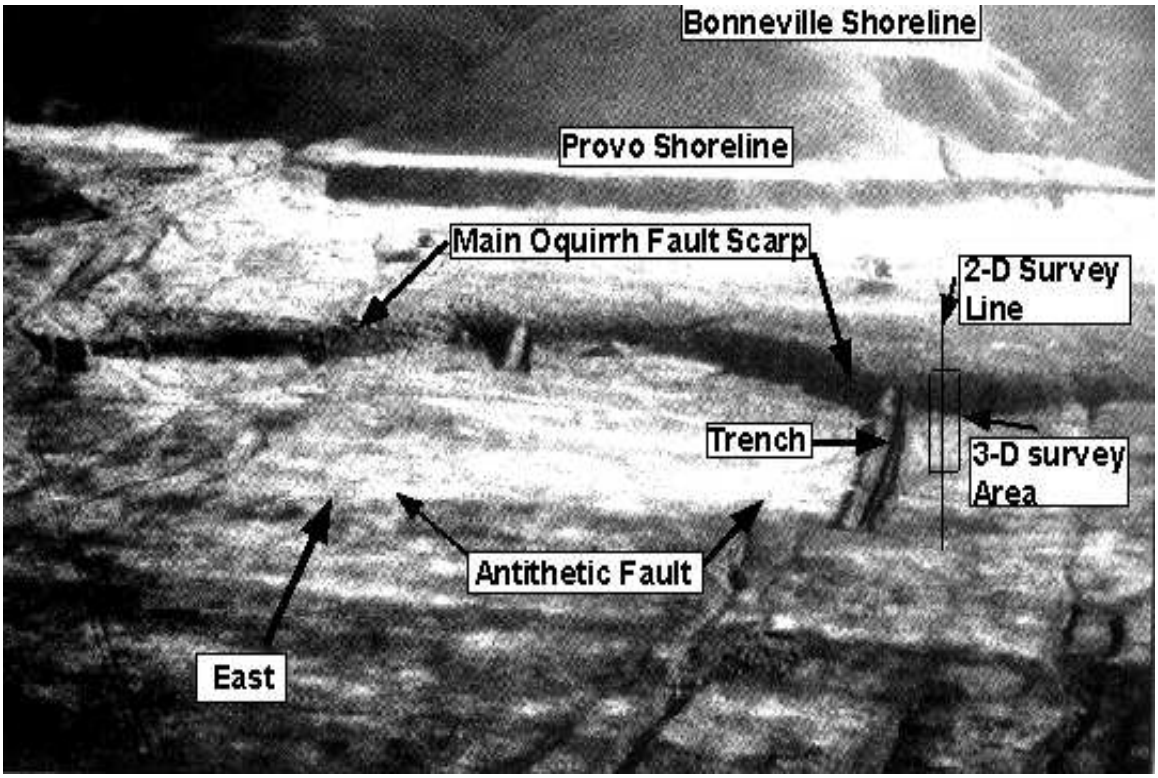

Figure 4: Eastward aerial view of survey location and trench excavated by the UGS. The approximate location of the 2-D and 3-D surveys are indicated, where the 3-D survey encompasses an area of 145 ft x 30 ft.

irrefutable paleoseismic information was not obtained. The shallow reflection events were polluted by near-surface scattering, surface-waves, and static shifts and so prevented the clear imaging of the colluvial wedge.

1.5 Oquirrh Fault Imaging

To overcome the problems with statics, near-surface scattering, and coherent noise, I use a refraction traveltime tomography method as well as common depth point (CDP) reflection methods to provide information about the fault zone. The refraction arrivals are almost never obscured by random or coherent noise, so the refraction traveltimes can be picked with little error. I also use 3-D tomographic imaging to provide a more complete image of the fault, including lateral velocity variations along the fault. This technique offers greater confidence in the interpretation because the horizons are laterally continuous in three dimensions.

To collect the data for tomography, University of Utah personnel conducted 2-D and 3-D seismic surveys over a portion of the Oquirrh fault in May 1996 and May 1997 (see Figure 4). The data were collected on a fine grid in order to image the shallow ($0 < z < 150$ ft) detailed features of this fault using 2-D reflection imaging and 3-D traveltime tomography. The 2-D data set consists of one seismic line that is 570 ft long and intersects the center of the 3-D survey grid. The 3-D survey covers a 145 ft x 30 ft patch of ground adjacent to a trench excavated by the UGS. This trench clearly reveals detailed geologic features of the Oquirrh fault over a vertical interval of 10 ft, and so it gives a calibration model for our reconstructed reflection and velocity images.

Processing of the seismic data includes 2-D reflection processing along with 2-D and 3-D tomography. The results are compared to the geologic cross-section (Figure 3) taken from the UGS trench.

1.6 Organization of the Thesis

This thesis, whose goal is to develop paleoseismic imaging methods, is organized into five sections. Section 1 is the introduction and Section 2 contains information on data acquisition. Section 3 describes the processing of the data, and the fourth section contains the seismic and velocity images along with their interpretation. The final section contains the conclusions.