The Surficial Geology and Neotectonics of Hansel Valley, Box Elder County, Utah

Robert M. Robison
Utah State University

Follow this and additional works at: https://digitalcommons.usu.edu/etd

Recommended Citation
Robison, Robert M., "The Surficial Geology and Neotectonics of Hansel Valley, Box Elder County, Utah" (1986). All Graduate Theses and Dissertations. 4865.
https://digitalcommons.usu.edu/etd/4865

This Thesis is brought to you for free and open access by the Graduate Studies at DigitalCommons@USU. It has been accepted for inclusion in All Graduate Theses and Dissertations by an authorized administrator of DigitalCommons@USU. For more information, please contact dylan.burns@usu.edu.
1986

The Surficial Geology and Neotectonics of Hansel Valley, Box Elder County, Utah

Robert M. Robison
Utah State University

Follow this and additional works at: http://digitalcommons.usu.edu/etd

Recommended Citation
Robison, Robert M., "The Surficial Geology and Neotectonics of Hansel Valley, Box Elder County, Utah" (1986). All Graduate Theses and Dissertations. Paper 4865.
THE SURFICIAL GEOLOGY AND NEOTECTONICS OF HANSEL VALLEY, 
BOX ELDER COUNTY, UTAH

by

Robert M. Robison

A thesis submitted in partial fulfillment 
of the requirements for the degree 
of 
MASTER OF SCIENCE 
in 
Geology

Approved:

UTAH STATE UNIVERSITY
Logan, Utah
1986
I would like to express my thanks to Dr. James P. McCalpin for suggesting this thesis, arranging funding, and having the expertise and patience to guide the investigation to completion. I would also like to thank Dr. Peter T. Kolesar, and Dr. Donald W. Fiesinger for their careful review and pertinent comments. Funding for this project was provided by the United States Geological Survey, contract no. 14-08-001-21899, as part of the Earthquake Hazards Reduction Program.

The person most responsible for this thesis is my wife Ruth, who has spent the last two years almost singlehandedly raising the four children (and keeping them from disturbing my desk). My mother also deserves credit and acknowledgement for encouraging me to continue my education.

I dedicate this thesis to my father, H. P. Robison, who has devoted his life to geology, but who never had the opportunity to attend graduate school. He studied geology at Utah State University, and was in Dr. J. Stewart Williams first class.

A special thanks is extended to Craig V. Nelson (1986) for help on the sieve data and tolerating my computer ignorance. Finally, I would like to thank the faculty and students at the Geology department for expanding my geological horizons.

Robert M. Robison
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACKNOWLEDGEMENTS</td>
<td>ii</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>vi</td>
</tr>
<tr>
<td>LIST OF PLATES</td>
<td>viii</td>
</tr>
<tr>
<td>ABSTRACT</td>
<td>ix</td>
</tr>
<tr>
<td>INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>PURPOSE</td>
<td>1</td>
</tr>
<tr>
<td>LOCATION</td>
<td>3</td>
</tr>
<tr>
<td>GEOLOGIC SETTING</td>
<td>3</td>
</tr>
<tr>
<td>PREVIOUS WORK</td>
<td>5</td>
</tr>
<tr>
<td>METHODS OF INVESTIGATION</td>
<td>8</td>
</tr>
<tr>
<td>GEOLOGIC UNITS</td>
<td>10</td>
</tr>
<tr>
<td>PRE-QUATERNARY UNITS</td>
<td>10</td>
</tr>
<tr>
<td>Paleozoic Deposits</td>
<td>10</td>
</tr>
<tr>
<td>Paleozoic Rock, Undifferentiated - Pu</td>
<td>10</td>
</tr>
<tr>
<td>Tertiary Deposits</td>
<td>12</td>
</tr>
<tr>
<td>Tertiary Basalts - Tb</td>
<td>12</td>
</tr>
<tr>
<td>Tertiary Tuffaceous Conglomerate - Ttc</td>
<td>13</td>
</tr>
<tr>
<td>Tertiary Salt Lake Formation - Tsl</td>
<td>14</td>
</tr>
<tr>
<td>QUATERNARY DEPOSITS</td>
<td>14</td>
</tr>
<tr>
<td>Pre-Bonneville Lacustral Cycle</td>
<td>15</td>
</tr>
<tr>
<td>Alluvial Fan - Qaf</td>
<td>15</td>
</tr>
<tr>
<td>Landslide - Qml</td>
<td>18</td>
</tr>
<tr>
<td>Lake Deposits</td>
<td>19</td>
</tr>
<tr>
<td>Little Valley cycle deposits</td>
<td>20</td>
</tr>
<tr>
<td>Hansel Valley cycle deposits</td>
<td>21</td>
</tr>
</tbody>
</table>
Bonneville Lacustral Cycle Deposits

Bonneville Deposits

- Lake gravel deposits - Qlg
- Lake shore deposits - Qls
- Lake delta deposits - Qld
- Lake lagoon deposits - Qll
- Lake bottom deposits - Qlb
- Lake shore deposits, overlying
  - Paleozoic bedrock, undifferentiated - Qls/Pu
- Lake shore deposits, overlying
  - Tertiary tuffaceous conglomerate - Qls/Ttc
- Lake shore deposits, overlying
  - Tertiary basalts - Qls/Tb

Provo Deposits

- Lake gravel deposits - Qlg
- Lake shore deposits - Qls
- Lake lagoon deposits - Qll
- Lake bottom deposits - Qlb
- Lake shore deposits, overlying lake bottom deposits - Qls/Qlb
- Lakeshore deposits, overlying
  - Paleozoic bedrock, undifferentiated - Qls/Pu

Post-Bonneville Lacustral Cycle Deposits

- Lake Gravels - Qlg
- Lake Lagoon Deposits - Qll
- Lake Bottom Deposits - Qlb
- Mud Flat - Qmf
- Lake Shore Deposits, Overlying Lake Bottom Deposits - Qls/Qlb
- Alluvial Sediments - Qas
- Alluvial Fan - Qaf
- Talus - Qmt
- Slope Wash - Qms
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Location map showing Hansel Valley study area</td>
<td>2</td>
</tr>
<tr>
<td>2. Map showing the generalized geology and fault locations in Hansel Valley, Utah</td>
<td>4</td>
</tr>
<tr>
<td>3. Photograph of the fault scarp formed during the 1934 M 6.6 event</td>
<td>6</td>
</tr>
<tr>
<td>4. Photograph of 1934 fault scarp, 50 years after the event, taken in the same area as the photograph in Figure 3</td>
<td>7</td>
</tr>
<tr>
<td>5. Stratigraphic column of sediments logged in the West Gully</td>
<td>11</td>
</tr>
<tr>
<td>6. Graph showing fluctuations of Lake Bonneville</td>
<td>16</td>
</tr>
<tr>
<td>7. Fault scarp profiles taken along the east margin fault</td>
<td>52</td>
</tr>
<tr>
<td>8. Scarp height versus maximum slope angle for fault scarps</td>
<td>53</td>
</tr>
<tr>
<td>9. Sketch showing faults in Rattlesnake Pass roadcut</td>
<td>55</td>
</tr>
<tr>
<td>10. Map showing profile location and scarp height (in meters) of the southwest margin fault</td>
<td>60</td>
</tr>
<tr>
<td>11. Fault scarp profiles taken along the southwest margin fault</td>
<td>61</td>
</tr>
<tr>
<td>12. Cross sectional diagram of a rotational slump forming simultaneously with or over a fault scarp</td>
<td>62</td>
</tr>
</tbody>
</table>
13. Schematic map of shorelines in relation to a fault scarp formed during a lacustrine transgression, i.e., Lake Bonneville.


15. Schematic cross section of the West Gully, showing the relationship of lacustrine units to later Holocene channel fill.

16. Fault in arroyo by Rattlesnake Pass roadcut (Fig. 2, d).

17. Sketch of fault at the Hansel Valley Exit roadcut.
LIST OF PLATES

PLATE 1: SURFICIAL GEOLOGIC MAP OF HANSEL VALLEY, BOX ELDER COUNTY, UTAH ....... Back Pocket

PLATE 2: LOG OF NORTH WALL, WEST GULLY ..... Back Pocket
ABSTRACT

The Surficial Geology and Neotectonics of
Hansel Valley, Box Elder County, Utah

by

Robert M. Robison, Master of Science
Utah State University, 1986

Major Professor: Dr. James P. McCalpin
Department: Geology

Hansel Valley, located at the north end of the Great Salt Lake in Box Elder County, Utah, has exposures of the lacustrine sediments of the Little Valley, Bonneville, and Gilbert lake cycles. A 1:50,000 scale map was constructed of the surface geology. Although no trenches were dug for this study, about 240 m of logs were compiled in an arroyo in lake bottom sediments. Sediments from at least three lake cycles were found in this gully: 1) compact bottom deposits from the Little Valley cycle; 2) bottom sediments from an intermediate cycle (the Hansel Valley cycle); and 3) beach gravel and bottom sediments from the Bonneville cycle. Evidence gathered indicates that a previously undescribed lake, the Hansel Valley cycle, which reached a maximum elevation of about 1342 m (4400 feet). Thermoluminescence (TL) dating, supplemented by ostracode identification and stratigraphic position, dates the Hansel Valley cycle at about 80 ka (late Oxygen Isotope Stage 5).
Hansel Valley is seismically very active and the site of the largest and only historic earthquake to rupture the ground surface in Utah. Scarp heights up to 50 cm were measured from the 1934 M6.6 event, which was contiguous with an older 6 km long scarp that crosses Lake Bonneville recessional shorelines. Scarp heights range from 1.6 m to 9.0 m and control recessional shorelines (instead of simply displacing them). This morphologic evidence suggests that a portion of the scarp was formed underwater, and that slumping occurred along the trace of the fault. The fault scarp intersects the gully mentioned above and reveals highly fractured sediments with 11 main faults within a 240 m zone. Movement on individual faults ranges from 0.1 to 2.5 m, with a net displacement of 1.3 m down to the east, which agrees with the offset measured on the scarp on both sides of the gully. Most faults offset Little Valley, and transgressive Bonneville shoreline sediments, but are not continuous through intensely convoluted Bonneville lake bottom sand, silt and clay. Two units of Bonneville bottom sediments show convolutions, roll structures, liquefaction features and slump blocks. Fault scarps, liquefaction features, and subsurface faults indicate one pre-Bonneville, possibly two Bonneville, and one post-Bonneville-age large earthquakes.
INTRODUCTION

PURPOSE

The purpose of this investigation is 4-fold: 1) to map the surficial deposits; 2) to develop a stratigraphic sequence; 3) to identify and map tectonic features; and 4) to reconstruct the Quaternary geologic history.

Hansel Valley is the site of the largest historic earthquake in Utah, an M_L 6.6 event which shook the area in March 1934 (Walter, 1934). Scarpes up to 50 cm high were formed in addition to ground cracking, liquefaction features, springs, and a general subsidence of the area.

This area contains one of only three scarps produced by historic faulting in the intermountain seismic belt. The other two events are the 1959 Hebgen Lake earthquake (Witkind, 1959), and the Borah Peak event of 1983 (Crone and Machette, 1984). Thousands of earthquakes have occurred in Hansel Valley since the 1934 event (Richins, 1979). It is possible that this area presents a significant risk to the populated northern Wasatch Front, only about 50 km east (Fig. 1). Damage on the Wasatch Front from a seismic event in Hansel Valley could result from shaking, liquefaction, mudslides triggered by the event, and possibly sieche flooding. This study should be useful in determining earthquake potential in the Wasatch Front area.
Figure 1. Location map showing Hansel Valley study area.
LOCATION

Hansel Valley is located in Box Elder county, north central Utah. This remote valley is bounded on the west by the Hansel (or Summer Ranch) Mountains, and on the east by the North Promontory Mountains. The Great Salt Lake bounds the southern end, and the northern end is bordered by Interstate Highway 84 (previously 80) and a set of low hills southwest of Pocatello Valley (Fig. 2). A few ranchers are the only permanent residents. Access to the southern end of Hansel Valley may be accomplished by gravel roads maintained for the local ranchers, and the northern end is easily accessed by Interstate Highway 84. The mapped area corresponds to the physiographic boundaries of Hansel Valley, and includes parts of the the Bulls Pass, Lake Ridge, Monument Peak, Monument Point, Rattlesnake Pass, Salt Wells, Snowville, and Sunset Pass 7 1/2 minute quadrangles.

GEOLOGIC SETTING

Hansel Valley is a 30 km long by 10 km wide northeast-trending graben, similar to other valleys of the eastern Basin and Range province (Adams, 1962). The overall structure of the Basin and Range province may be more complex than simple horsts-and-grabens. The mountain ranges which flank Hansel Valley may be tilted blocks and may possibly be riding on a listric fault at depth (Stewart,
**Figure 2.** Map showing the generalized geology and fault locations in Hansel Valley, Utah. Small letters refer to sections of the respective faults: a) east margin fault; b) northwest margin fault; c) southwest margin fault; d) valley floor faults. Bar and ball are on the downthrown block, faults are dashed where inferred. See the neotectonics section for further discussion.
1980). The North Promontory mountains and the Hansel Mountains, which are predominantly composed of Pennsylvanian-Permian age Oquirrh formation (Doelling, 1980), flank the east and west margins, respectively. The most prominent features in the valley are the Lake Bonneville deposits. These pluvial lake materials cover a large portion of the valley floor and are exhibited on the edges of the valley as well-formed shorelines, spits, and deltas.

PREVIOUS WORK

Gilbert (1890) was probably the first geologist to examine Hansel Valley. He noted faults as well as Lake Bonneville deposits. In 1934, an $M_L$ 6.6 earthquake that shook Utah drew some geologists to this area (Shenon, 1934; Walter, 1934; Neuman, 1936; Adamson, 1938). Although several descriptions were made of the faulting phenomenon, the only map constructed was a Brunton-and-pace map, which was subsequently lost (Walter, 1984, personal communication). Several photographs taken by Wilber Smith in 1934 (located in a collection at the University of Utah) are probably the best evidence which has survived, and serve as a valuable tool when used to compare features with modern photographs (Fig. 3, 4).

Adams (1962) mapped the bedrock geology of the Summer Ranch and North Promontory Mountains, but he did not
Figure 3. Photograph of a fault scarp formed during the 1934 M 6.6 event. A 50 cm offset was measured in this area.
Figure 4. Photograph of the 1934 fault scarp, 50 years after the event, taken in the same area as the photograph in figure 3. A profile taken across the scarp revealed 50 cm offset.
describe the surficial geology. Doelling (1980) compiled a map with surficial deposits delineated, but the scale, 1:125,000, is too small to be used in differentiating the geomorphic features and surficial deposits in any detail.

A map of Lake Bonneville was produced by Currey and others, (1984). The scale of this map is also very small, but the delineation of prehistoric lake elevations is helpful. Many studies have been done on Lake Bonneville (Gilbert, 1890; Eardley, and others, 1957; Morrison, 1965; Currey, 1980; Currey and others, 1983; Scott, 1983; Currey and Oviatt, 1985), and of these studies, the Currey and Oviatt (1985) interpretation is presently accepted as the most accurate by the author.

METHODS OF INVESTIGATION

A base map, scale 1:50,000, was made by combining eight 7 1/2 minute quadrangles which were then photo-reduced. Vertical aerial photographs, 1:40,000 scale, flown in 1974, were used to map the surficial deposits. Mylar was used over the air photos for the initial mapping. The sketch was then compiled visually on the 1:50,000 scale base map. On site reconnaissance was performed to verify base map.

A 4 1/2 meter extendable fiberglass leveling rod was used in conjunction with an Abney level placed on the rod
to make the scarp profiles. Abney measurements on the slopes were taken to the nearest 1/2 degree of slope. A more detailed description of this method of scarp-slope profiling is defined in Bucknam and Anderson (1979, p. 12).

A 4 1/2 meter rod and a Brunton compass were used to measure the walls of the West Gully for logging, sketching, and to extract strike and dip data (see Plate 2). A 6 meter steel tape was used to measure stratigraphic sections.

Samples were collected and sieved by standard methods (Folk, 1974). Color comparisons taken for unit descriptions were made with a Munsell color chart. Samples taken for thermoluminescence dating were carefully protected from light contamination. Samples were collected in tin cans, approximately 10 oz., which were cut completely out on one end and serrated with aviation snips. The cans were then pushed while rotating by hand into a freshly exposed surface of the desired material. When the cans were full, the sediments surrounding the can were removed and a blade was used across the end of the can to smoothly separate the sample in the can from the deposit. Aluminum foil was then placed over the exposed end of the can, and opaque duct tape wrapped around the container to prevent material or moisture leakage or light contamination. For a detailed description of thermoluminescence dating, see Wintle and Huntley (1982).
GEOLOGIC UNITS

Geologic units which crop out at the surface are either pre-Quaternary (Paleozoic and Tertiary) bedrock formations, or Quaternary unconsolidated deposits (alloformations). The names and symbols of the unconsolidated units and bedrock formations used in this investigation are a compilation of previously used, common terminology from other authors studying in the Bonneville Basin, and some previously unpublished map unit designators (Fig. 5, and Plate 1).

PRE-QUATERNARY DEPOSITS

Paleozoic Deposits

Paleozoic Rock,
Undifferentiated - Pu

The exposed Paleozoic bedrock in the Hansel Valley area is predominantly the grey limestone of the Pennsylvanian-Permian Oquirrh Formation. There is a relatively small outcrop of Mississippian-Pennsylvanian Manning Canyon shale present in the northern end of this study area in T. 13 N., R. 7 W. (Doelling, 1980, Adams, 1962), but it is not differentiated on the map which
<table>
<thead>
<tr>
<th>STRATIGRAPHIC UNITS</th>
<th>SEDIMENTOLOGY and DEFORMATION</th>
<th>OSTRACOODES (See Appendix B)</th>
<th>LAKE BONNEVILLE CHRONOLOGY</th>
<th>OXYGEN ISOTOPE STAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Qlb3</td>
<td>well laminated silt and clay</td>
<td>mixture of species</td>
<td>Bonneville cycle</td>
<td></td>
</tr>
<tr>
<td>upper</td>
<td></td>
<td>mixed alkaline species</td>
<td>Bonneville cycle</td>
<td></td>
</tr>
<tr>
<td>9 laminated silt</td>
<td></td>
<td>poor and alkaline rich waters; lake regressing</td>
<td>Bonneville cycle regression from Provo shoreline</td>
<td>1</td>
</tr>
<tr>
<td>Qlb2</td>
<td>intact, rotated blocks of well laminated silt and clay, similar to Unit 9</td>
<td>drop to Provo shoreline?</td>
<td>Bonneville flood?</td>
<td>2</td>
</tr>
<tr>
<td>lower</td>
<td>alternating silt and clay, laminated with 5 cm thick clay, silt, and sand; floating pebbles; roll structures common</td>
<td>&quot;profundal assemblage&quot;</td>
<td>Bonneville cycle highstand</td>
<td>2</td>
</tr>
<tr>
<td>7 laminated silt</td>
<td></td>
<td>alkaline rich water; deep lake</td>
<td></td>
<td></td>
</tr>
<tr>
<td>lower</td>
<td>internally convoluted mixture of clay, silt, and sand; floating pebbles; roll structures common</td>
<td>deepening water</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 convoluted silt</td>
<td></td>
<td>Bonneville cycle transgression</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Qls2</td>
<td>well laminated silt</td>
<td>alkaline poor water; lake level rising</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Major Unconformity</td>
<td></td>
<td>Bonneville cycle transgression</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 brown laminated silt</td>
<td>cross-bedded, well sorted medium pebble gravel</td>
<td>beach</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 gravel</td>
<td>green silt with some clay, poorly laminated</td>
<td>lake level rising</td>
<td>Hanseal Valley</td>
<td>cycle</td>
</tr>
<tr>
<td>Qlb1</td>
<td>brown massive silt, gyspum at top, may overlie lacustrine bar gravel</td>
<td>Heterocyclops n.sp.</td>
<td>alkaline poor water;</td>
<td>5</td>
</tr>
<tr>
<td>Major Unconformity</td>
<td>compact well laminated silt and clay very compact; intensely fractured with steeply dipping, small faults</td>
<td>L. staplini</td>
<td>groundwater present</td>
<td>5</td>
</tr>
<tr>
<td>2 silt</td>
<td>compact well laminated silt and clay very compact; intensely fractured with steeply dipping, small faults</td>
<td>L. caudata type</td>
<td>alkaline rich</td>
<td>Little Valley</td>
</tr>
<tr>
<td>1 silt</td>
<td>compact well laminated silt and clay very compact; intensely fractured with steeply dipping, small faults</td>
<td>L. staplini</td>
<td>alkaline rich</td>
<td>Little Valley</td>
</tr>
</tbody>
</table>

Figure 5. Stratigraphic column of sediments logged in the West Gully. Absolute age data is contained in Appendix C.
accompanies this report. The Oquirrh formation in the Hansel and North Promontory Mountain ranges is estimated to be about 8500 feet thick (Adams, 1962, p. 26).

The limestone of the Oquirrh Formation is probably the source of the majority of the Lake Bonneville deposits in this area. The vast majority of the clasts of the cobble-through-pebble size in the shoreline deposits are limestone, and although no diagnostic tests were performed to establish whether these clasts are definitely Oquirrh, there is no other limestone source readily available. Few exposures of bedrock exist below the Bonneville Lake shoreline except near the Monument point area (T. 11 N., R. 9 W.).

Tertiary Deposits

Tertiary basalts - Tb

Basalt crops out primarily in the northern end of Hansel Valley. Basalt flows cap the southern hills in the north end of Hansel Valley (Plate 1). Adams (1962) identified these rocks as "vesicular olivine-basalt, aphanitic dark colored", and measured sections with a maximum thickness of 40 to 50 feet.

The exact correlation of the basalt flows with other Tertiary-age units in the area is uncertain, although the basalt is probably younger than the Salt Lake formation (Adams, 1962). One exposure was noted by Wang (1985) of
basalt overlying Salt Lake Formation. A 405-foot-deep water well was drilled in the valley sediments in the Salt Wells Flat area (Plate 1). Although the entire log of the well was not definitive as to sediment type, the log noted that a "material resembling brecciated lava" was encountered at the bottom (Carpenter, 1913). The volcanic material in the well bottom may suggest a different age of volcanic activity from the basalt outcrops to the north, or it may be the result of down-faulting of the same volcanic material found at the northern end of the valley.

**Tertiary Tuffaceous Conglomerate - Ttc**

Outcrops of Tertiary tuffaceous conglomerate were encountered in several road-cuts in the northern part of the valley in Section 6, T. 13 N., R. 6 W. The conglomerate has a brown-to-pink color and consists of poorly sorted, angular welded tuff, sandstone, and limestone clasts which have been fractured and indurated by caliche. Bedding in the exposures is nearly horizontal. Clasts range in size from about 15 cm to >50 cm, with a matrix of silt and clay. Adams (1962) recognized this material as different from the Salt Lake Formation because of the more poorly sorted and lighter-colored tuffaceous sandstone clasts in the conglomerate. The presence of welded tuff clasts in the conglomerate indicates that the conglomerate is younger than the welded tuffs.
**Tertiary Salt Lake Formation - Tsl**

The Salt Lake Formation crops out on the eastern and northern margin of this study area, and is composed of such diverse lithologies as light-colored fanglomerate, conglomerate, and tuffaceous sandstone and limestone (Doelling, 1980).

The Salt Lake Formation encountered in southern Hansel Valley is a highly fractured fanglomerate(?). In the North Promontory Mountains, the Salt Lake Formation deposits consist of white tuffaceous material, which is more typical of this formation as seen in valleys to the east. Adams (1962) estimated a thickness of 400 to 500 feet for the Salt Lake Formation in this area and stated the age of the formation as probably Miocene-Pliocene.

**QUATERNARY DEPOSITS**

The Quaternary deposits discussed in this report were divided according to age, geomorphology, and where applicable, material or composition. The deposits were broken into four categories: (1) Pre-Bonneville Lacustral cycle, before about 32 ka; (2) Lake Bonneville deposits, about 32 ka to 15 ka; (3) Provo Lake deposits, about 15 ka to 11 ka; and (4) the Post-Provo Lake deposits. The shorelines of the major lake cycles and their respective
lake deposits are reasonably well dated and provide a basis of relative dating of other deposits and geomorphic features (Fig. 6). For a more complete explanation of age parameters, see the Quaternary History section.

Pre-Bonneville Lacustral Cycle

Alluvial Fan - Qaf 1

Pre-Bonneville cycle fans occur along the east margin of the valley. Intermittent streams have cut gullies in the surface, and in places, a younger fan will have been deposited on the surface of the older pre-Bonneville fans.

The fans consist of poorly sorted sediments with angular to subangular clasts that may exceed 20 cm in long dimension. The matrix ranges in size from pebbles to clay. Caliche has generally indurated the subsurface below the present soil. Total deposit thickness could not be measured, although a road cut into the fans on the east central side of the valley exposes a thickness in excess of 5 m. The environment of deposition was probably similar to the environment today, as modern alluvial fans (Qaf 4) have a similar construction and form.

The absolute age of the sediments could not be determined because no organic material was found, and grain size was too coarse for thermoluminescence dating. The Bonneville shoreline is cut into or deposited on the fan, indicating that the fans are older than the Bonneville
Figure 6. Graph showing fluctuations of Lake Bonneville. Line A on graph represents unrebounded shoreline elevations and line B represents rebounded elevations in the central portion of Hansel Valley, Utah. Adapted from Currey and Oviatt (1985).
transgression at the elevation of the lowest $Q_{lg_2}$ bar atop $Q_{af_1}$ (about 18 ka?). The average elevation of the Bonneville shoreline in Hansel Valley is about 1586 m (5200 feet), which rebounded from an original elevation of 1552 m (5092 feet), and the Provo shoreline, average elevation about 1464 m (4800 feet) in Hansel Valley, has rebounded from an original elevation of 1444 m (4737 feet). Original or pre-rebound elevation data is from Currey and Oviatt (1985). Gilbert shorelines have rebounded less than about 7 m (20 feet) in Hansel Valley, which suggests that the majority of the rebound occurred in the very short time between the desertion of the Bonneville shoreline and the stabilization at the Provo shoreline, and was nearly complete by the time the Gilbert shoreline was established. Shorelines of Bonneville Lake age and older have a maximum rebound in Hansel Valley of 34 m (108 feet) (Fig. 6), which is less than half of the maximum rebound for the Bonneville Basin of 74 m (243 feet) (Currey and Oviatt, 1985).

The rate of downward deflection of the Bonneville Basin is uncertain. If the unloading of the lake caused rebound, then it is probable that the filling of the lake caused the depression. Figure 6 suggests that the downward deflection of the lake basin was somewhat linear, i.e. the basin subsided as the lake filled. The stillstand at the Stansbury shoreline should give evidence as to the elevation of the shorelines shortly after the start of the
transgression of Lake Bonneville. The Stansbury shoreline would be expected to be at about 1368 m (4485 feet) if it were not rebounded. Although not delineated on Plate 1, the Stansbury shoreline was located at Lake Ridge in section 7, T. 11 N., R. 7 W., at slightly over 1373 m (4500 feet), which would be expected if the basin were subsiding as the basin filled, and then rebounded. Also, further north and west, in Curlew Valley (not in this study area), in sections 34 and 35, T. 13 N., R. 9 W., a large bay-mouth bar with an elevation at or slightly below 1373 m (4500) was found which suggests that rebound on the Stansbury shoreline decreases toward the north.

The fans are inferred to be locally deposited on various Tertiary formations, and are apparently younger. These fans are probably early to middle Pleistocene in age (Christenson and Purcell, 1985).

Landslide - Qml

The landslides in Hansel Valley occur in the northwest corner, in the Manning Canyon shale. These slides have a rotational morphology, although some of the original details have been eroded. Evidence of differing ages in sliding is evident in aerial photos, as some of the slides appear more eroded than others. The slides appear to be a poorly sorted mix of shale fragments, although some larger
rocks are visible in the slides. The slides vary in area and volume, but most are probably several meters deep.

The Bonneville shoreline is cut into the slides, therefore dating them as about pre-18 ka (Fig. 6). None of the slides were found to involve Bonneville age sediments. The slides may have formed during wetter climatic conditions from today, although the possibility still exists for landslide activity in this area.

**Lake Deposits**

Several deposits were found in a gully in Section 10 and 11, T. 12 N., R. 8 W., that were not exposed areally (Fig. 5). This arroyo was tentatively named West Gully to prevent confusion with Hansel Valley Wash located about 4 miles to the east. Map units found at the surface and mapped on Plate 1 and also found in the West Gully (Fig. 5) are the Qls_2, Bonneville Lake gravel, and Qlb_3, Provo Lake bottom deposits. Plate 2, the wall log of the West Gully has another deposit, unit 11, which is mapped as Qas_4, alluvial sediment, on Plate 1. Some of the upper units (units 7, 8, and 9) described from Figure 5 are not found on Plate 2 because the deposits are located higher in the section and were not visible in the logged section of the gully, but were located in an intersecting gully.

The lake deposits of the Little Valley cycle (Scott and others, 1983) (Fig. 5, unit 1), and the newly proposed
Hansel Valley cycle (Fig. 5, units 2 and 3) are not found in surface exposures large enough to be located on the accompanying map. These sediments have a maximum exposed thickness for the units (combined) of about 6 meters. These units were found in both the West Gully (Fig. 5, unit 1) and in Hansel Valley Wash (Section 34, T. 13 N., R. 7 W., and undoubtedly extend under Bonneville age transgressive sediments throughout the Bonneville Basin.

**Little Valley cycle deposits.** The Little Valley deposits described in this report were found in the West Gully (Fig. 5, unit 1). These sediments are composed of well laminated, light brown (Munsell color is 5Y 7/2) silt and clay of the Little Valley Cycle (Appendix A). This material is poorly sorted, and is generally more dense than the overlying sediments. Small fractures with little or no displacement are noticeable in certain areas, and are clustered around larger fault planes (unit 1, Plate 2), and cut cleanly through the sediments. The total thickness of this deposit is unknown because the bottom of the sediments was not encountered, but the deposit must exceed 3 m. A major unconformity overlies this deposit.

Several species of ostracodes were found in these sediments (Fig. 5). The inferred depositional environment is a deep, alkaline rich, lake (Appendix B). The absolute
age of these sediments, as determined by thermoluminescence (TL) dating, is 138 ka, and is equivalent to Oxygen Isotope Stage 6 (Appendix C) (Bowen, 1978).

**Hansel Valley cycle deposits.** The two units overlying unit 1 represent a newly named lake cycle, the Hansel Valley cycle. Units 2 and 3 may be one of only a few exposures of lacustrine deposits of the newly proposed "Hansel Valley" cycle. Evidence for the existence of this previously undefined lake cycle is not unequivocal, but is very suggestive. This cycle is stratigraphically between the Little Valley and Bonneville cycles. A more complete discussion of the depositional interaction of this lake cycle with other lake cycles is presented in the Quaternary History section.

The sediments of unit 2 are predominantly poorly sorted silts and clays (Appendix A). Laminations are present at the bottom of the deposit, but become increasingly difficult to decipher toward the top. Gypsum crystals are present at the top of the deposit. Munsell color is 5Y 6/2. A lacustrine gravel bar is present locally (between 65 and 85 meters in Plate 2), and is overlain by unit 3 deposits.

The total thickness of unit 2 is roughly 1.2 meters where exposed in the West Gully. These deposits were not recognized outside of the area logged in the West Gully.
The deposit is separated from underlying sediments by a distinct unconformity, and is separated from unit 3 by a smaller, less prominent unconformity. Lateral contacts are either faults (Plate 2, 40 m east) or gradational with unit 3 (Plate 2, 80-90 m east).

Several species of ostracodes were found in these sediments (Fig. 5). The inferred depositional environment is a shallow, alkaline poor lake, with groundwater influences dominant (Appendix B). The ostracode sample was taken in sediments that were apparently near the shore of the lake. The marginal lacustrine type ostracodes, and the lack of unit 2 sediments above this elevation suggest that this lake cycle did not exceed about 1,342 m (4400 feet) elevation. A TL sample yielded a date of 76 ka, which is equivalent to late Oxygen Isotope Stage 5 (Appendix C).

Unit 3 consists primarily of silt and clay, with some sand present (Appendix A). These sediments are poorly-to-very poorly sorted. Some weak laminations are present, which have been either bioturbated or disturbed by crystal growth. Gypsum crystals are present in the lower 2/3 of the deposit. Munsell color is 5Y 8/2 to 6/2.

A prominent unconformity overlies the unit (the Bonneville transgression), and the previously mentioned smaller unconformity separates this unit from unit 2. The lateral boundaries of this unit are difficult to determine.
from other units because contacts are gradational and/or are separated by less conspicuous unconformities.

The inferred environment of deposition was a low-stand lake, but sediments were probably exposed as a mudflat after the regression of the water. As was the case for unit 2, this lake probably never exceeded 1342 m (4,400 feet) elevation. TL dates suggest deposition at about 82 ka, which equates to late Oxygen Isotope Stage 5 (Appendix C).

Bonneville Lacustral Cycle Deposits

Bonneville Deposits

The deposits herein assigned to the Bonneville lacustral cycle were deposited during the transgression, highstand at the Bonneville shoreline, drop to and stillstand at the Provo shoreline, and the rapid regression to below the present level of the Great Salt Lake (Fig. 6). Following previous workers, sediments deposited during the transgression and at the Bonneville highstand will be discussed under the heading Bonneville Deposits, whereas sediments of the Provo stillstand and subsequent regression will be termed Provo deposits. Sediments deposited during the rise to the Gilbert shoreline (about 10 ka; Currey and Oviatt, 1985) will be discussed under the section Post-Bonneville Deposits, as will all remaining Holocene units.
Sediments deposited before and at the time of the Bonneville shoreline are covered by younger lake-bottom or shoreline material (Provo, Post-Bonneville), and are exposed only in gullies. Because of this, no exposures of Bonneville bottom deposits large enough to merit delineation on the accompanying map were found. In the West Gully, a conformable stratigraphic section of transgressive gravels (unit 4, Fig. 5) and lake bottom sediments (units 5 through 8, Fig. 5) occurs.

**Lake gravel deposits - Qlg₂.** Bonneville gravels, as defined in this classification, are distinct from the Bonneville shore deposits because of the abundance of cobbles, pebbles, and sand, and a lack of fine grained sediments. The Qlg₂ deposits predominantly constitute spits and bars, and would be the best locations for gravel pits in the area. The Qlg₂ deposits are usually in contact with shore facies (Qls₂). The two map units intertongue, and have the same limits on elevation. Although the gravel deposits are technically shore deposits, their increased thickness and coarseness allows separate delineation.

Rounded clasts average 8 cm to 10 cm in diameter, and maximum dimensions of >30 cm were found. The thickness of these deposits may be over 10 m, but most average about 5 m. The west side of the valley, below Monument Peak in Section 8, T. 12 N., R. 8 W., contains numerous Qlg₂ deposits. A stack of beach gravels, over 15 m deep, is
exposed in a gully east of and below Monument Peak, elevation about 1555 m (5100 feet). On the east side of the valley, a breached bay mouth bar north of Sunset Pass in Section 31, T. 12 N, R. 6 W., is over 20 m thick.

The environment of deposition was a very high-energy beach, usually in an inferred setting of strong lake currents. No fossils were found in the gravel deposits; the grinding action by these sediments would preclude the preservation of fragile shells.

Not all of the Qlg2 deposits are at the highest lake level of the Bonneville Lake. The sediments below 1586 m (5200 feet) elevation are inferred to have been deposited while the lake was filling. The rapid drop of the lake from the Bonneville shoreline to the Provo shoreline would not allow the development of well defined shorelines. In some areas the fine grained sediments, deposited between the Bonneville and Provo levels while the lake was at the Bonneville level, were not redistributed by longshore currents over transgressive gravel deposits during the 105 m decline of the lake during the Bonneville flood. Also, it is possible that the fine grained sediments were eroded after the decline of the lake or were never deposited on top of the transgressive gravel deposits.

The Qlg2 deposits between the Bonneville and Provo shorelines are transgressive, and are between 20 ka and 15
ka (Currey and Oviatt, 1985). These dates are corrected for rebound in (central) Hansel Valley. The $Q_l g_2$ deposits at the Bonneville shoreline, approximately 1586 m (5200 feet), are dated at about 15 ka (Currey and Oviatt, 1985).

Lake shore deposits - $Q_l s_2$. The Bonneville shore deposits constitute a band of sediments present in most areas at the surface in Hansel Valley from about 1464 m (4800 feet) elevation to about 1586 m (5200 feet) elevation. The lake shore deposits represent gradual facies changes and consist of deposits ranging in size from beach gravel through sand and silt. The thickness of this deposit is variable, from less than a meter to several meters. Several sections were measured over 3 meters thick. A thin veneer of gravel, deposited during the rapid regression of Lake Bonneville from the Bonneville shoreline to the Provo shoreline, overlays practically the entire deposit. This gravel averages 6 to 8 cm in length, with a maximum long dimension of about 20 cm. Some 'floating' pebbles were noted in the sediments below the gravel veneer. These floating pebbles average 1 to 2 cm, and no larger clasts were found in the lower sediments. These pebbles were probably dropped into the finer-grained sediments from rafting ice. No fossils were found in these sediments.

Unit 4 is found in the West Gully (Fig. 5) and is equivalent to $Q_l s_2$ mapped on Plate 1. The cobbles in this
unit average 8-10 cm, with a maximum of 15 to 20 cm. Although this unit consists predominantly of gravels, sieve analysis following Folk (1974), classifies this unit as poorly sorted (Appendix A). The clasts show moderate rounding. The gravel clasts are imbricated in places, and may dip east or west, depending on relative position in transgressive bars. Unit 4 is usually about 1 meter thick.

The base of unit 4 is a distinct erosional unconformity cut into either unit 1 or unit 3 (Plate 2). The top of the unit may be either an erosional unconformity with much younger sediments, or a gradational contact with finer-grained sediments of later (and deeper) lake deposits. No fossils were found in this unit.

These gravels represent the transgression of the Bonneville cycle of the lake. The imbrication indicates bar formation, although no completely dissected bars were logged in the West Gully (Plate 2). The transgression of the Bonneville lake cycle has been dated at about 32 ka (Currey and Oviatt, 1985). The age of the Bonneville shoreline may be as late as 15 ka (Currey and Oviatt, 1985), which allows an inferred age of 19 ka to 15 ka for these deposits mapped on Plate 1. However, unit 4 in the West Gully (elevation about 1342 m, 4400 feet) was deposited about 26 ka (from interpolation of Fig. 6).
Lake delta deposits - Qld$_2$. The only Bonneville delta in Hansel Valley is located in the north-east corner about 1.6 km south of Rattlesnake Pass, at the intersection of Sections 4, 5, 8, and 9, T.13 N., R. 6 W. This deposit has the characteristic deltaic shape, and is visible from Interstate Highway 84. A small stream cuts the delta, and makes a small 1.5 m to 2 m wide terrace. The deposit is poorly sorted with the average size for cobbles 8 cm to 15 cm surrounded by a finer grained matrix. Some caliche coatings are present on the surface clasts.

The edges of the deposit interfinger with shoreline deposits of the same age (Qls$_2$). The delta was formed during the highest sustained level of the Bonneville Lake, at about 1586 m (5200 feet) elevation.

Lake lagoon deposits - Qll$_2$. The lagoon deposits are found behind well defined bay-mouth bars (Qlg$_2$). The lagoon deposits are typically lens shaped in cross section, with the land-side of the deposit lapped onto older deposits with a poorly defined beach present at the contact of the lagoon deposits and the older land-side material.

The deposits consist of silts and clays, buried beneath a few centimeters of loess and alluvium. Scattered layers of gravel were encountered in the lagoon deposits, having an average clast size of 8 cm. Several small test
pits were dug by hand, and none reached the bottom of the deposits. The total thickness is estimated to be 3 to 10 meters. No fossils were found in the pits.

The lagoon deposits represent still-water sediments located behind bars. The landward shores of the lagoons were of lower energy than open-water shores, and did not develop the definition of the unprotected shorelines. Hence, the landward boundaries of the lagoon deposits are harder to locate and define. The age of the lagoons correlates with the transgressive bars that protected them.

Lake bottom deposits - Qlb\(_2\). Lake bottom deposits of Bonneville age are well exposed in the West Gully (Fig. 5, Units 5, 6, and 7), where these units have been differentiated. Relative ages of the deposits are 5 (oldest) through 7 (youngest). These three units are about 3.8 m thick combined. These units were not found at the surface and hence do not have a designator relative to Plate 1.

Unit 5 consists of silt and clay. These sediments are poorly sorted (Appendix A). Laminations are present, and Munsell color is 5Y 8/2 with streaks colored 10YR 7/8. This unit is approximately 50 cm thick. Unit 5 is not present everywhere in the West Gully, and the best exposure was at approximately 90 meters east of the section line (Plate 2).
The bottom of the unit rests on the transgressive gravels of unit 4 in most areas, but may overlie an unconformity on older units. The top of unit 5 is generally a conformable contact with unit 6.

Ostracodes indicate that this unit was deposited in alkaline-poor water at the edge of a rising lake (Appendix B). The age of this deposit is inferred to be about 26 ka, because of its stratigraphic position immediately above the transgressive gravels of the Bonneville lake cycle.

Unit 6, found in West Gully, consists of Bonneville lake bottom fine sand, silt and clay, with scattered lenses of gravel. A layer of cobbles was found at the bottom of this deposit in some places. The sediments are poorly-to-very poorly sorted (Appendix A), and were originally laminated, but now exhibit intense convolutions (Plate 2). These roll structures are probably the result of seismically induced liquefaction. For a more complete discussion on the convolutions (roll structures) see the Neotectonics section. The thickness of this unit may exceed 3 1/2 meters, but it is generally about 2 meters thick.

The bottom of this unit is usually on top of unit 5, but due to the inconsistent presence of unit 5, unit 6 may rest on unit 4. The top of the unit is marked by the undisturbed beds of unit 7. Some gastropod fossils were recovered from this unit and dated by $^{14}$C and amino acid racemization (Appendix C). This unit was deposited in a
deep water lake, probably about 22 ka to about 20 ka, inferred from dates obtained on the gastropods, and from the stratigraphic position of the unit.

Unit 7, which consists of layered Bonneville age bottom sediments exposed in West Gully, has fine grained layers (Appendix A, 7a) and layers containing a coarser sand (Appendix A, 7b). Both samples are poorly sorted. This unit attains a maximum thickness of about 2 meters, but most exposures showed only about 1.5 meters thick due to slope wash and erosion.

The beds overlying the top of this unit are not present in the logged section of West Gully, but the unit was traced northward in a gully that intersected West Gully (at 133 m east, Plate 2). The top of unit 7 is conformably overlain by unit 8. The bottom of unit 7 rests conformably on unit 6.

Ostracodes were found in this unit, and identified by Forester (Appendix B). These fossils indicate a profundal environment of deposition, and support the conclusion that a deep lake occupied this area at that time. An absolute date was not available for this unit, but stratigraphic correlation to the dated Bonneville chronology of Currey and Oviatt (1985) suggests that these sediments were deposited before the lake reached the highest level of the Bonneville shoreline.
Unit 8 is listed on the stratigraphic column (Fig. 5), but was not encountered on the logged section of the wall of the West Gully (Plate 2). These sediments are predominantly silt and clay. The material is apparently very similar to unit 9 (appendix A), which is poorly sorted. Unit 8 is uniformly about 1.5 m thick. Discrete blocks of silt have been rotated about 40°, with the bottom of the blocks merging into a discrete horizon. Small undulations in the bedding are noticeable in the bottom layers of the overlying units, but no rotated blocks were noted. This depositional contact indicates continued deposition after rotation of the blocks. No fossils were found in this unit.

The environment of deposition for this unit was a deep lake. The rotated blocks may be attributed to seismic shaking. This unit has been dated by thermoluminescence at 13 ka (Appendix C).

Lake shore deposits, overlying Paleozoic bedrock, undifferentiated - Qls₂/Pu. This map unit, Qls₂/Pu, denotes areas where the lake shore sediments are inferred to be less than 3 m thick overlying Paleozoic bedrock. Outcrops of Paleozoic bedrock are common in this deposit. The lake sediments were deposited on an irregular surface of bedrock, and currents or later erosion exposed the Paleozoic rock. This unit occurs where longshore currents
intercepted bedrock and dragged material off of the resistant surface.

Lake shore deposits, overlying Tertiary tuffaceous conglomerate - Qls₂/Ttc. This map unit, Qls₂/Ttc, was delineated to separate lake shore sediments which are underlain by tuffaceous conglomerate from areas of thicker shore sediments and/or lake shore sediments underlain by other material (Plate 1). The shore sediments are estimated to be less than 1 m thick in this unit. The lateral extent of this map unit is not well defined. The lake shore deposits are relatively easy to delineate, but the boundaries of the tuffaceous conglomerate are uncertain due to the limited number of exposures. Tuffaceous conglomerate was found only in the northwest corner of the study area.

Lake shore deposits, overlying Tertiary basalts - Qls₂/Tb. The areal extent of the subsurface basalts is uncertain. In some areas, a slight break in slope may be the delineating feature, but most areas are too irregular to depend on such a marker. Exposures are limited, but the extent of basalt in the subsurface in the north end of the valley probably doesn't exceed the surface exposures by much, unless the basalt encountered by Carpenter (1913) can be correlated to these deposits.

The lake shore sediments vary in thickness over the basalts. The sediments have been stripped away by erosion
in some areas, but the average thickness of the lacustrine deposits is 1 to 2 meters.

**Provo Deposits**

*Lake gravel deposits - Qlg₃.* The Provo gravels are not as prominent as the Bonneville gravels in Hansel Valley. These deposits generally constitute spits and bars. The most obvious deposits are located on the northwest corner of the hills west of Bulls Pass in Sections 23 and 26, T. 13 N., R. 7 W. (Plate 1).

Clasts in the Qlg₃ deposits range in size from pebbles to cobbles over 20 cm maximum long dimension. Average clasts are 6 cm to 8 cm in diameter. Deposits vary in thickness, but the average is 3 m to 4 m. The top of the Provo gravels may locally be cemented by tufa. This phenomenon is not peculiar to Hansel Valley, as Currey (1980) noted tufa-cemented gravels elsewhere in the Bonneville Basin at the level of the Provo shoreline.

Provo gravel deposits are located from about 1433 to 1464 m (4700 to 4800 feet), with the most prominent deposits located on the Provo shoreline at approximately 1464 m (4800 feet). The edges of this unit are generally not abrupt, because of the tendency of the deposit to be spread-out from erosion, but a change in slope usually
accompanies the basal contact of these thicker gravels. No fossils were found in this deposit. If any were present at the time of deposition, they would probably have been demolished by wave action.

The environment of deposition was undoubtedly the high-energy shoreline at the still-stand of the lake at about the 1464 m (4800 feet) elevation. The presence of relatively well sorted gravels with few fines indicates the waves and/or longshore currents must have been quite strong. The Provo shoreline has been dated at about 15 ka to 14 ka by Currey and Oviatt (1985). No material was sampled for absolute dates in these deposits.

Lake shore deposits - Qls3. The Provo shoreline sediments are similar in texture to Bonneville shoreline sediments. The relative stratigraphic position of the deposits is usually the best method of differentiation, where datable material is not present. The Provo age shoreline deposits are located below the Bonneville shoreline deposits (elevation), but are above statigraphically (Plate 1). These deposits intertongue, except where older or younger shorelines are encountered. The Provo age shore deposits consist of cobbles, pebbles, sand, silt, and clay, arranged in a gradual facies change from the prominent Provo shoreline, about 1470 m (4820
feet), to the Gilbert shoreline at about 1296 m (4250 feet). The entire deposit is veneered by a sparsely distributed layer of moderately-to-well rounded gravel, with an average clast diameter of 7 cm to 8 cm, and a maximum length of 12 cm to 15 cm.

These shoreline facies are stratigraphically in the same position as the other Provo age deposits. The lack of abundant gravel may be used as a guide to separate this unit from Provo lake gravel deposits.

These deposits were formed during the Provo stillstand and as the lake receded from the Provo shoreline. These events have been dated at about 15 ka to about 11 ka (Currey and Oviatt, 1985). Many recessional shorelines were found in these deposits.

Lake lagoon deposits, - Q113. The largest deposit of Provo lagoon sediments occurs in the north-central part of Hansel Valley. The lagoon is butted against a discontinuous gravel bar, the crest elevation of which is 1464 m (4800 feet). The contact on the shore side of the deposit is poorly defined, and the sediments lap onto fine grained Bonneville age shore material.

These sediments are predominantly silt and clay, with few pebble size clasts. No complete section was observed, but the deposit probably does not exceed 2 m to 3 m in
thickness. The origin of the material was probably the (then) recently exposed Bonneville age sediments, which were washed or blown into the recently established lagoons.

**Lake bottom deposits - Qlb 3.** Lake bottom facies silts and clays which were deposited during or after the occupation of the Provo shoreline were exposed in the West Gully (Fig. 5, unit 9). Only limited exposures were found at the surface, and hence mapped on Plate 1. Unit 9 consists of poorly sorted silt and clay (Appendix A). Laminations are present, and show disturbance in layering only on the bottom of the unit, where it was deposited on unit 8. These undulations decrease toward the top of the bed. The unit was measured over 1.1 m thick north of the West Gully.

Ostracodes found in unit 9 were a mixture of alkaline poor water and alkaline rich water species (Forrester, Appendix B). This unit has an inferred age of 14 ka to 13 ka (interpreted from Currey and Oviatt, 1985), the period when the lake receded from the Provo shoreline to below 1310 m (4,300 feet), the elevation of the outcrop.
Lake shore deposits, overlying lake bottom deposits — $Q_{ls3}/Q_{lb3}$. This deposit covers the largest surface area of the pluvial sediments in Hansel Valley. It is typically shore facies materials (discussed above) deposited on bottom silts and clays. These deposits cover a significant portion of the southeastern corner of Hansel Valley. The elevation limits on this map unit are from 1464 m (4800 feet) down to 1296 m (4250 feet).

The shore facies is a relatively thin veneer approximately 1 m thick over the bottom sediments, and locally the bottom fines are exposed from erosion. These bottom sediments were measured over 2 m thick. A large number of regressive shorelines are noticeable in this unit. Forty-six shorelines were counted in the southwest portion of the valley, and fifty were noted in Curlew Valley to the west. These two counts include only one shoreline of Bonneville age. Occasional Holocene alluvial fans have been built onto this unit.

The bottom sediments were deposited when the lake was occupying the Provo shoreline, at about 1464 m (4800 feet) elevation. The lake then began to recede, at a much slower rate than when the Bonneville shoreline was abandoned. The slower decline allowed the lake to carve or deposit the previously mentioned shore features in/on the bottom sediments.
The age of the deposits is determined to be between 14 ka, when the Provo shoreline was abandoned, and 11 ka, when the lake returned to establish the Gilbert shoreline at 1296 m (4250 feet) (Currey and Oviatt, 1985).

Lake shore deposits, overlying Paleozoic bedrock, undifferentiated - Qls₃/Pu. The largest deposit of Provo sediments overlying Paleozoic bedrock is located in the east-central portion of Hansel Valley. These deposits range from about 1464 m to about 1312 m (4800 to about 4300 feet) elevation.

The lake shore facies sediments range in size from cobbles to fine silts. Thickness of the lakeshore deposits ranges from >2 meters to zero, where the bedrock is exposed at the surface. This map unit is very similar to the Qls₂/Pu both geomorphically and texturally. Some recessional shorelines are visible in this deposit.

These sediments were deposited somewhat continuously from the time that the Provo Lake shoreline was occupied through the gradual regression of the lake. No absolute dates were determined for this deposit, but the age of the deposit is from about 14 ka to about 11 ka by correlation (Currey and Oviatt, 1985).
Post - Bonneville Lacustral Cycle Deposits

Lake Gravel Deposits - Qlg₄

The post-Bonneville cycle gravels are not as abundant as the older Bonneville and Provo gravel deposits. The sediments most typical of this deposit are located at the south end of Monument Point. The lake that deposited these gravels was not as large as the lakes responsible for the enormous bars and spits of Provo and Bonneville ages. These sediments are characteristically found deposited as bars and spits. The deposit was estimated to range in thickness from 1 m to over 15 m, but may have been deposited on older gravels with similar features. The edges of the deposit are generally defined by a break in slope at the edge of the increased gravel thickness.

The gravels in this deposit are well sorted, and contain few fines. The gravel sampled at Monument Point averaged 6 cm to 8 cm in diameter and the maximum clast found was about 60 cm.

The environment of deposition was the shoreline of the Gilbert age lake at about 1296 m (4250 feet) elevation, about 10 ka (Currey and others, 1983). No absolute dates were determined for this deposit.
Lake Lagoon Deposits - Qll₄

Only two small lagoons of post-Bonneville cycle age occur, both in south-central Hansel Valley in Sections 6 and 7, T. 11 N., R. 7 W. The lagoons are somewhat poorly preserved due to erosion and recent sediments washing into the depressions. These lagoons are oblong in shape, and are somewhat poorly defined. Provo sediments underlie these deposits. Small bars are located on what would have been the deep-water side of the lagoons.

No test pits were dug into these lagoons, but surface materials are fine grained silts and clays. Some clasts from the contiguous gravel bars may have been transported into these depressions.

These lagoons were formed during the Gilbert Lake stand approximately 10,500 years ago (Currey and others, 1984). No datable material was gathered from these lagoons.

Lake Bottom Deposits - Qlb₄

The lake bottom sediments of post-Bonneville cycle age are exposed at the southern end of Hansel Valley. A thin cover of recessional shoreline sand and gravel remains on the top of a few of the outcrops, but most exposures reveal laminated silt and clay. The bottom contact is gradational, and is very difficult to determine, as carbon datable
material was not found. About 2 m of material was measured in outcrop, but this unit is possibly thicker, up to several meters.

The sediments are of various colors. The top approximately 50 cm is white weathering silt and clay and is locally topped by several centimeters of brown gravel, sand and silt. The next +/- 70 cm is brownish-red silt and clay. The bottom layer in the outcrop is +/- 60 cm of greenish silt and clay. The brown and green layers under the top (white) 50 cm may have been deposited by older lakes. These sediments are fairly uniform in their respective colors.

These sediments appear white when viewed in aerial photographs, and care should be taken not to confuse them with the Provo and Bonneville age shore and bottom sediments, which may also appear white. The relative elevation of the post-Bonneville age sediments is a clue to their age, as the Gilbert shoreline is the upper limit of these deposits, at about 1296 m (4250 feet) elevation, and the lower limit is where the modern mudflats cover the deposit. These lake bottom sediments were deposited during the approximately 1000 year duration of the lakestand at the Gilbert shoreline, about 10 ka. No material for absolute dates was collected in these deposits.
Mud Flat - Qmf₄

The mud flats exposed in Hansel Valley are on the margins of the Great Salt Lake. These brownish colored deposits will be the first to be inundated with water if the lake rises. At the time of this report, the level of the Great Salt Lake is 1285 m (4213 feet) above mean sea level. On May 12, 1986, the lake surface topped the previous historic high of 1873 (Currey and others, 1984). Thus, the lower mud flats on Plate 1 are presently under water. The streams that issue in the Salt Wells area drain into the mud flats forming meandering streams in small channels, and occasional marshes. In drier seasons crusts of salt form on the surface of the flats.

The exact thickness of this deposit is unknown, as no test holes were dug into this material. Estimations of thickness would range from several centimeters at the edges of the deposit, to several meters toward the middle of Salt Wells Flat. The water table is generally very close to the surface in this area.

These sediments are typically fine grained, with some coarser sediments being deposited by the intermittent streams that drain into this area. No large cobbles were found in these sediments. Sizes vary widely, but no clasts were found exceeding about 30 cm in diameter.
These mud flats were deposited by sediments carried onto the flat by small intermittent streams. Also, some wind blown material was probably deposited on these surfaces, but not in masses large enough to differentiate from other mudflat sediments. The processes of sedimentation that developed these deposits are probably still at work.

Lake Shore Deposits, Overlying Lake Bottom Sediments - Qls₄/Qlb₄

The post-Bonneville lake shore deposits that cap the post-Bonneville lake bottom sediments are generally thin, less than 0.5 m, but are usually found together. The largest deposit is located northeast of Monument Point. These shore deposits represent a gradual facies change from deeper-to-shallower water, and are typically composed of sparse gravel, sand, and silt. The size of the gravel is uniform, with clasts averaging 6 cm to 8 cm in long dimension, with a maximum length of 20 cm. The lake bottom sediments are equivalent to the Qlb₄ deposits described above.

The boundaries of this deposit are the Gilbert shoreline, at the higher contact at about 1296 m (4250 feet) elevation, and the mud flat deposits on the lower edge. A thin soil has developed on these sediments. Vegetation is sparse, partially from the lack of fresh water, and partially from the underdeveloped soil.
These sediments were deposited as the lake receded from about the 1296 m (4250 feet) elevation contour. The age of the deposit is equal to or less than that of the Gilbert shoreline, about 10.5 ka. No absolute dates were derived from this deposit.

Alluvial Sediments - Qas$_4$

Alluvial sediments are found in the bottom of stream channels primarily in the northeast area of Hansel Valley. These sediments are generally poorly sorted, with the exception of small lenses of sand or gravel. The majority of the clasts are moderately-to-well rounded. These alluvial deposits are mostly reworked from other lacustrine deposits.

The thickness of these deposits is highly variable, but probably does not exceed 3 m to 4 m in most deposits. The average thickness is usually >2 m. The thickest section of the deposit is inferred to be the center portion of the stream channel, thinning toward the edge.

Unit 11 was logged in the West Gully (Plate 2), and studied in more detail than other deposits of similar composition (Qas$_4$) which exist by other active drainages in the area (Plate 1). This unit is composed mostly of silt and clay (Appendix A). These sediments are poorly sorted, and lenses of gravel are common, as are "floating" pebbles.
This unit overlays all other deposits it contacts because the processes that formed this unit are still active. No fossils were found in this deposit.

**Alluvial Fan - Qaf**

Numerous post-Bonneville cycle fans occur in Hansel Valley, both above and below the Bonneville shoreline. Fans are present at the mouths of most intermittent streams that drain into the valley. Modern channels are cut into the surface of these deposits.

The material in the fans is poorly sorted, with size ranging from boulders to silt. The deposits may be many meters thick, but no complete section was observed in the field.

The fans generally have the characteristic 'cone' shape. The surface of these fans is rough and vegetation is sparse. Soil formation is minimal to absent. The depositional processes that built these fans include both stream deposition and debris flows and are still active.

**Talus - Qmt**

The talus deposits in Hansel Valley are located along the east and west margins in narrow exposures that parallel the mountains which generated them.

The source of the talus deposits is the Paleozoic bedrock exposed on the upthrown side of the major bounding
faults. The material in these deposits is predominantly angular limestone blocks. The cobbles and boulders are poorly sorted on a small scale, but each deposit as a unit is fairly homogeneous. These deposits lack fines and older exposures were probably a major source for the gravels deposited as beaches and bars in previous lake cycles. Large boulders may approach 1 meter in length. The thickest portion of the talus is inferred at the base of the slope, and appears to thin toward the top of the ridge and toward the valley.

The bottoms of the deposits interfinger with other units of various ages. The mechanism that produced these rock slopes was undoubtedly active during previous lake cycles, but the surface layers subject to mapping are recent.

Slope Wash - Qms₄

Slope wash deposits are located on the more gentle slopes overlying Paleozoic bedrock, primarily in the mountains. The material in these deposits is angular to subrounded and grain size ranges from cobbles through silt. They are generally fine grained with varying sized clasts, and have thin soils forming in some areas.
These sediments are thin, usually <2 m, and were deposited by gravity and surface water. Although the processes that compiled this unit were probably working during several lake cycles, the surface deposits are recent.
NEOTECTONIC FEATURES IN HANSEL VALLEY

The general structure of the valley is a northeast trending graben, flanked by mountain blocks on both sides. The neotectonic features in Hansel Valley will be analyzed in alphabetical order as the faults are listed in Figure 2: 

a) the east margin (North Promontory) fault, 
b) northwest margin fault, 
c) southwest margin fault, and 
d) valley floor faults. Fault scarps in recent sediments and the abundance of small earthquakes common to this area (Richins, 1979), indicate that faulting forces are still active here.

EAST MARGIN FAULT

The east margin fault is located on the eastern edge of Hansel Valley, along the boundary of the North Promontory Mountains (Fig. 2, a). The total length of the fault is over 25 km, with a general north-south trend. The northern end of the fault is mapped approximately at the point where Interstate Highway 84 enters Hansel Valley. The southern end of the fault is mapped about 3 km southwest of Sunset Pass (Doelling, 1980), south of the area covered by Plate 1. The difference in elevation between the peaks in the North Promontory Mountains and the down dropped valley floor to the west is over 610 m (2000 feet), and may be a minimum (total) offset of the fault.
The east margin fault exhibits features typical of many Basin and Range mountain flank faults. Faceted spurs are common and talus is present on most of them. Towers of carbonate-cemented breccia extend through the talus in some places, and indicate the general location of the fault (Adams, 1962). Slope wash, talus and colluvium, and Bonneville Lake sediments cover practically the entire length of the fault.

The North Promontory Mountains are predominantly Paleozoic limestone, but Tertiary basalt crops out on the northern end, and Tertiary Salt Lake Group is found on both the northern and southern ends of the range (Adams, 1962; Doelling, 1980). All of these units have been involved in faulting events, but not all contacts are faulted (i.e. both depositional contacts and fault contacts are found between units).

Smaller bedrock faults are present east of the main bounding fault. These small faults are arranged at various angles to the north-south trend of the mountains (Jordan, 1985). No age has been assigned to the bedrock faults, although some of them have moved since the deposition of the Tertiary units.

Two areas along the North Promontory fault exhibit evidence of movement in the late Quaternary. The northernmost of these faults (Fig. 2, a2) is located in a Bonneville delta, elevation approximately 1580 m (5180
feet). The delta is located where the corners of Sections 4, 5, 8, and 9 meet in T. 13 N., R. 6 W.

Two profiles were made of this scarp, and one of the profiles is represented on Figure 7. Scarp height and slope were plotted on a diagram from Bucknam and Anderson (1979) to determine an approximate age (Fig. 8). The maximum scarp height measured for this scarp is 10 m, with a steepest scarp angle of 25°. The data reveals an age based on the most recent event (steepest scarp angle) slightly older than the Bonneville shoreline, as plotted on the graph. This determination is consistent with the age of the material in which it was formed.

The southern scarp (Fig. 2, a_3) along the east margin fault, is located east of the Bulls Pass Hills. This west facing scarp offsets pre-Bonneville cycle alluvial fans. The fault strikes in a general southwest direction, bifurcating from the main east margin fault. Three profiles were made of this scarp (Fig. 7). Data were plotted on a scarp height-versus-slope angle diagram (Bucknam and Anderson, 1979) to determine the age of the scarp (Fig. 8). The profiles showed a maximum scarp height of 12.9 m, and a steepest slope of 25.5°. Data plots exceed the time of the Bonneville shoreline and an estimation of age for the scarp indicates that the scarp probably formed before the Bonneville shoreline.
Figure 7. Fault scarp profiles taken along the east margin fault. Top profile is on Bonneville age deltaic deposits (Fig. 2, a2). Bottom three profiles are on pre-Bonneville Lake cycle age alluvial fans (Fig. 2, a3). Adapted from McCalpin (1985).
Figure 8. Scarp height versus maximum slope angle for fault scarps. Numbered data points are from the southwest margin fault and indicate a scarp age between 3.6 - 5.7 ka and 15 ka. See Figure 10 for profile locations. Other data from Bucknam and Anderson (1979), and Hanks and others (1984).
A fault is visible on the south wall of the freeway road-cut immediately before entering Hansel Valley from the east (Fig. 2, a4). This fault is a probably an antithetic feature of the North Promontory fault, which is located several hundred meters to the west. Displacement in the lower portion of the fault is limited to one main fracture, but toward the ground surface bifurcations are prevalent (Fig. 9). This pattern of branching probably represents a small scale model of the phenomena seen on some larger fault zones such as the Wasatch Fault, where more than one fault scarp is seen in a relatively narrow zone of deformation.

A total of 2.6 m displacement was measured across the main fault, and about 0.3 m on the smaller fault to the east. The soils displaced by the fault exhibit varying degrees of carbonate development. All of the soil layers were faulted except for the surface Holocene colluvium. Because the displacement of the older deposits was equal to the displacements of the younger units, the fault probably represents only one movement. The age of this faulting event is uncertain, as no absolute dates were obtained in these sediments, but it is apparent that the event occurred before the deposition of the Holocene colluvium. The soil labeled \( k_1 \) in Figure 9 is probably penecontemporaneous with, or slightly younger, than the fault.
Figure 9. Sketch showing faults in Rattlesnake Pass roadcut. The main fault displaces all beds 2.6 m, except for the surface colluvium. Stratigraphic groups are labeled with Roman numerals. Pattern intensity indicates degree of soil B (⊥) and K (⊤) horizon development. Lower sketch is not to scale.
NORTHWEST MARGIN FAULT

The northwest margin fault flanks the eastern margin of the Hansel Mountains (Fig. 2, b). The fault extends from the northwest end of Hansel Valley, south-southwest approximately 15 km toward the Salt Wells Flat area. An elevation change of over 460 m (1500 feet) exists between the peaks in the Hansel Mountains and the down-faulted valley to the east, and may represent minimum total movement on this fault.

The Hansel Mountains consist primarily of Pennsylvanian-Permian Oquirrh limestone, with an outcrop of Mississippian-Pennsylvanian age Manning Canyon shale about 2 km south of the north end of the fault (Doelling, 1980). This outcrop of shale was the source of several landslides, some of which occur in the area of the fault. The headscarps of these mass-movements are arcuate, and do not resemble the tectonically-produced scarp found elsewhere in Hansel Valley.

The range front is linear, and faceted spurs are present, but pre-Bonneville alluvial fans are absent. These fans are common across the valley to the east, and contain Quaternary fault scarps. Bonneville Lake deposits cover the range front below about 1586 m (5200 feet), and no faults were found in these sediments. Any fault scarps that may have occurred prior to the transgression of Lake Bonneville are presumed obliterated.
A small scarp sub-parallel to the inferred southern end of the northwest margin fault was located by personnel from M.I.T. (Craig Jones, personal communication, 1986). The scarp is located in thin lake sediments overlaying bedrock on the hill south of the Hansel Mountains in section 6, T. 12 N., R. 7 W. This scarp indicates relative movement of about 4 m down-to-the-east, and appears to cut shorelines below about 1388 m (4550 feet). No profiles were measured on this scarp and no exposures were reported which revealed a fault plane. The age of this scarp is unknown, and it may not have been formed tectonically.

A shorter fault, about 4 km in length, is inferred to parallel the northwest margin fault along the east side of a small valley at the southern end of the Hansel Mountains (Fig. 2, b_2) (Adams, 1962; Doelling, 1980). This fault may be related to the northwest margin fault, creating a horst at the southern end of Hansel Mountain, and decreasing in displacement toward the north. This smaller fault is conspicuously aligned with the trace of the 1934 scarp, and may be a much older extension of that fault plane (Robison and McCalpin, 1985), only the sense of displacement is opposite. This fault is characterized by aligned faceted spurs, with spur height decreasing toward the north.

The presence of the faceted spurs and linear trend of the mountain front indicate that a fault is responsible for the Hansel Mountains. The lack of Holocene or late
Pleistocene fault scarps may be because no earthquakes of sufficient magnitude to induce surface rupture have occurred on the northern end of northwest margin fault. Deformation may be in the form of sediments tilted toward the valley. Late Quaternary earthquakes in the vicinity of the southern end of the northwest margin fault, possibly including the MIT fault, were definitely of sufficient magnitude to produce surface rupture (the magnitude 6.6 1934 event).

SOUTHWEST MARGIN FAULT

The margin fault in the southwestern portion of Hansel Valley is markedly different from the margin faults previously described. No mountains abut the east facing scarp (Fig. 2, c1), but Monument Peak is located 3 to 4 km to the west. This scarp is approximately 10 km long, and trends north-south.

At the surface, this scarp offsets only Bonneville lake sediments and recent mud flat deposits. The southern portion of the scarp, the 1934 rupture (discussed below), was limited to the silts and clays in the Salt Wells Flat area. The 1934 rupture was contiguous with an older prehistoric fault, mapped as the northern end of fault c1, and c2 in Figure 2. The total length of the combined scarps is about 10 km. The older portion of the scarp is preserved in generally more coarse sediments, compared to mud flat
deposits, which probably overlay bedrock at a fairly shallow depth.

Eleven profiles were made along the scarp (Fig. 10). The profiles reveal an increase in the height of the scarp, up to 9m, toward the center (Fig. 11). The scarp becomes arculate toward the segment of increased height. This increase is attributed to syntectonic landsliding, with the headscarp of the landslide coincident with the trace of the fault scarp. This phenomenon of increased scarp height is due to the addition of the slide scarp plus the fault scarp (Fig. 12). A trench across the scarp would be needed to determine the actual contribution of each offset, and the exact location of the fault plane.

The mechanism that triggered the slide is unknown, but one would surely suspect earthquake activity. The material involved in the sliding, beach gravel and sand, is not generally susceptible to this type of mass movement, although a lens of silt and/or clay may be present at the slide plane. It is probable that pore pressures were increased at the time the slide moved, either from ground water saturation or submersion under Lake Bonneville.

The geomorphic relationship of the shorelines (both transgressive and regressive) to the fault scarp indicates that the faulting must have occurred between the time when the Bonneville cycle transgression exceeded 1403 m (4600 feet) elevation, at about 26 ka (Scott and others, 1983),
Figure 10. Map showing profile location and scarp height (in meters) of the southwest margin fault. The 1934 event scarp is on the extreme southern end of the fault. Scarp heights increase in the central portion of the scarp due to syntectonic slumping (see Figure 12).
Figure 11. Fault scarp profiles taken along the southwest margin fault. Profile numbers correlate with Figure 10. Adapted from McCalpin (1985).
Figure 12. Cross sectional diagram of a rotational slump forming simultaneous with or over a fault scarp. Fault scarp height ($T_1$) would be increased by the addition of the slump head scarp ($T_2$). The exact location of the fault plane beneath the slump may be obscured. Theoretically, surface offset would not be affected if scarp profiles were extended beyond the toe of the slump.
and when the Provo Lake cycle regression fell below 1312 m (4300 feet) elevation, at about 12 ka (Currey and others, 1984). The relationship of the fault scarp to the shorelines could conceivably include the following cases: 1) the faulting occurred before the lake transgressed above the base of the scarp; 2) the faulting occurred during the transgression of the lake through the elevations crossed by the scarp; 3) the faulting occurred after the lake had transgressed above the top of the scarp; 4) the faulting occurred during a regression of the lake through the elevations crossed by the scarp; or 5) the faulting occurred after the regression passed below the base of the scarp. Any small scarps that would have formed before the lake rose past the base (case 1) would have been obliterated by wave action from the slowly rising water, as large gravel deposits at the base of the Bonneville Lake cycle transgression indicate high energy. Scarps which formed during the transgression of the lake (case 2) would have two geomorphic expressions: 1) scarps below wave base would be protected and preserved, and 2) scarps above the waterline would be destroyed (Fig. 13). Fault scarps that occurred during the highstand (case 3), below wave base, would be preserved, with only moderate degradation of the scarp from the receding water which was less intense than the transgressive lake.
Figure 13. Schematic map of shorelines in relation to a fault scarp formed during a lacustrine transgression, i.e. Lake Bonneville. Time of shoreline formation is indicated by t, with t = 1 the oldest, and t = 6 the youngest. Faulting occurred at t = 4.
If faulting occurred during a regression (case 4), there are two possibilities for the relationship between the fault and the shoreline: 1) regressive (and transgressive) shorelines above the waterline would be offset and preserved, and 2) at the waterline and below, regressive shorelines would be fault controlled and wrap around the scarp to maintain constant elevation across the scarp (Fig. 14). The uppermost shoreline which wraps around the scarp would indicate the level of the lake when the faulting occurred.

Faulting which occurs after the water has receded below the base of the scarp (case 5) would offset all shorelines. These offsets would be preserved in both the transgressive and regressive shorelines.

The southwestern margin scarp offsets shorelines up to approximately 1403 m (4600 feet) elevation, where it becomes parallel to the shorelines, and then descends northward into the West Gully. This fault shows a relationship like that suggested by scarp formation during the lake regression (case 4). Small regressive shorelines were noted to wrap around the scarp at about 1327 m (4350 feet) elevation, and older transgressive shorelines were clearly offset. Currey and Oviatt (1985) indicate that the lake was at this elevation a little over 12 ka. Profiles
TECTONIC GEOMORPHOLOGY OF A FAULT SCARP FORMED DURING A LAKE REGRESSION

EXISTING
REGRESSIVE
SHORELINES ARE FAULTED

FUTURE
REGRESSIVE
SHORELINES ARE CONTROlLED BY FAULT SCARP

Figure 14. Schematic map of shorelines in relation to a fault scarp formed during a lacustrine regression. Time is indicated by t, with t = 1 the oldest and t = 5 the youngest. Faulting occurred at t = 3.
made along the scarp were plotted on a scarp height-versus-slope diagram to determine an approximate age of the scarp (Fig. 8). The plot indicates that the event occurred between approximately 3.6-5.7 ka and 15 ka. However, scarps which occurred underwater may not be directly comparable to subaerial scarps. Two factors which differentiate subaqueous from subaerial scarps should counteract each other. First, subaerial scarps are subjected to erosion from the time of formation, whereas subaqueous scarps are protected below wave base. On the other hand, steeper initial slopes are possible for scarps formed subaerially, as compared to the subaqueous material.

The pre-historic fault scarp projects across the West Gully about 4 miles west of the Hansel Valley Wash, the main drainage from Hansel Valley (Plate 1, Fig. 10). The fault scarp decreases in surface offset immediately on both the north and south sides of the West Gully compared to the other sections of the scarp. This decrease in scarp height may be due to farming activity (?) or possibly to erosion and surface flooding in these finer grained sediments. The exposures in the gully offered exceptional exposures of Bonneville lake sediments. Approximately 240 m of the north wall of the West Gully was logged in the vicinity of its intersection of the fault scarp (Plate 2). The total combined thickness of exposed sediments is about 19 m vertically, but a complete section is not visible in any
one place, due to varying bed thicknesses, tectonic offset of the beds, and slope wash. Stratigraphic horizons were not traceable across the gully due to the relationship shown in Figure 15. Older channels have been filled, and a new gully incised into the channel fill sediments, unit 11.

Faulting events previous to the 1934 event have deformed, fractured, and faulted pre-Bonneville Lake cycle sediments in the area about 40 m west of the section line (Plate 2). Most of the small fractures show little or no vertical displacement. The abundance of the small faults increases toward the larger faults, which have several cm of offset. Many of the small fractures were not traceable into the overlying Bonneville transgressive gravels. The transgression of the Bonneville Lake cycle has eroded the top off of the small fault blocks. The attitudes of the smaller fractures were similar to the larger offsets. At the faulted area 35 m west of the section line (Plate 2), the fractures strike N 05° E, and dip 77° E. The total offset for this fault is 2.25 m, down to the east.

The bounding fault on the east side of the graben in the West Gully was the down to the west fault 40 m east of the section line. This fault has a total offset of 2.20 m, strike is N 40° E, and dip is 54° W. The presence of this west dipping fault was somewhat of a surprise because the scarp that was mapped on the north and south side of the gully was down-to-the-east. The displacement across the
Figure 15. Schematic cross section of the West Gully, showing the relationship of lacustrine units to later Holocene channel fill. The darkest lines represent the faulting relationship to bedding. Numbers refer to Figure 5, and Plate 2.
small graben indicates that unit 4 has practically no net offset, but when the faults of the rest of the log were considered, offset approached about 2 m, which is consistent with the offset measured on the scarp on the north and south side of the gully.

Small faults (displacement \( \leq 10 \) cm) which formed after the deposition of the Bonneville Lake cycle transgressive sediments (unit 4), but before the uppermost layers, (labeled 8-through-9 in Figure 5) are also visible. Faults in the Bonneville cycle sediments were traceable into the lower convoluted silt (Fig. 5, unit 6), but only one could be tracked into the upper layers (Plate 2, 175 m E). This phenomenon strongly suggests that the convolutions are the result of seismic shaking. The upper convoluted layer (Fig. 5, unit 8) is probably the result of an earthquake also. The type of deformation is dissimilar, with unit 8 exhibiting discrete blocks that have rotated on a single plane. The fault at 175 m East in Plate 2 may be related to unit 8. The possibility that the convolutions were caused by a subaqueous debris flow is very remote. The beds are dipping only slightly east, and no higher source areas are near that could have produced a slide of this magnitude. Also, the top of the convoluted layers has beds of similar composition and description deposited on them indicating that the disturbance occurred underwater during continuous sedimentation.
Several subsurface faults were found which showed no apparent surface expression. The northernmost of these (Fig. 2, d_1) is located in an arroyo which parallels Interstate Highway 84 in the northeast portion of the study area in Section 5, T. 13 N., R. 6 W. The faulted deposits are predominantly silt and clay, and are probably Little Valley Lake cycle deposits, although no absolute dates were obtained from these deposits (Fig. 16). The fault displaces a dark layer of basaltic sand, about 25 cm thick, with a total net offset of 340 cm, in two sub-parallel fractures (Fig. 16). The two fractures contribute 120 cm, and 220 cm of slip on the northeast and southwest respectively. The fault strikes N 60° E and dips 55° N. A 270 cm high waterfall has migrated about 8 m upstream (northeast) from the fault. The waterfall is not consistent with the direction of the displacement of the fault, and may have formed from the weakness formed by the disturbed area at the plane of the fault, or the juxtaposition of less resistant deposits. The area around the waterfall consists of beds that strike N 10° W, and dip 22° E. Downstream from the fault, the bedding strikes N 5° E, and dips 29° E. A zone of deformation, consisting primarily of down-warping immediately next to the fault, exists on the down-thrown side of the fault. The number of faulting events is
Figure 16. Fault in arroyo by Rattlesnake Pass roadcut (Fig. 2, d). Fault has a total offset of about 340 cm. No scarp was visible at the ground surface, which is several meters above the top of the sketch. Bottom of figure is the gully floor, which dips 1° to 2° to the southwest. Silt located at about 3 m above the gully floor on the northeast side of the sketch lenses-out at about the location of the fault.
uncertain, as the displacement may be the result of a single event, or possibly two smaller events. The magnitude of the earthquake(s) that formed this fault was undoubtedly greater than about Richter M6, the threshold for surface rupture, but due to the lack of a surface scarp, and the uncertainty of the number of events, a closer approximation to the actual magnitude is not possible. The age of the event(s) is also uncertain, but may be bracketed to before the regression from the Bonneville shoreline, about 15 ka, but after the Little Valley cycle, which is the probable age of the silts that compose the logged portion of the sediments.

The southernmost of the valley floor faults (Fig. 2, d2; Plate 1, Section. 23, T. 12 N., R. 7 W.) is inferred from the condition of the Paleozoic bedrock visible in the gully. As is the case for the northern valley floor fault, no surface expression is evident. There has been no apparent movement on this fault in Holocene time. Brecciated and fractured bedrock are butted against Lake Bonneville sediments. A waterfall about 5 m high is situated at the bedrock contact. A fracture is visible in the wall and represents the fault plane. Displacement could not be measured because no beds could be traced across the fault. The presence of bedrock this distance from the main
east bounding mountains may indicate that bedrock structure below the valley fill may be more complex than previously thought.

The north side of the road-cut at the main exit to Hansel Valley from Interstate Highway 84 exposes a west dipping fault (Fig. 2, e; Plate 1, above the northwestern corner of Section 5, T. 13 N., R. 6 W.). Paleozoic bedrock is in fault contact with Tertiary basalts and Quaternary alluvium/colluvium containing a white volcanic ash (Fig. 17). This ash was tentatively identified as the Bishop Ash (740 ka; Glen Izett, personal communication). The ash was involved (dragged) in the faulting, indicating that the event is post 740 ka. Displacement figures could not be obtained because no deposit was traceable across the fault. The fault strikes N 30° E, and dips 82° W. A very white carbonate gouge is present between the limestone and the basalt. A small channel has been eroded across the top of the main fault, and has subsequently filled with Holocene colluvium. The material in the channel is apparently intact, indicating that no movement has occurred in Holocene time.
Figure 17. Sketch of fault at the Hansel Valley exit roadcut. Paleozoic bedrock has been shattered and altered, and is in fault contact with Tertiary basalts. No beds were traceable across the fault, hence no measurements of offset were possible.
OVERVIEW OF NEOTECTONIC PATTERNS

The fault scarps on the northeast margin of the valley are the result of several events (based on surface offsets). The most recent faulting in the Bonneville delta in the north end of the valley occurred shortly after or about the same time as the decline of the water from the Bonneville Lake cycle highstand. The most recent movement on the fault scarp on the pre-Bonneville alluvial fan was before the formation of the Bonneville shoreline.

Results of this investigation indicate that the northwest margin has no late Quaternary surface ruptures, although morphology of the range-front appears youthful. No faulting was found which post-dates the formation of the Bonneville shoreline in this area, with the possible exception of the scarp found by the MIT scientists, which was not verified.

Recurrent movement along the southwestern margin fault indicates that it has formed a true tectonic scarp, and is capable of generating surface-faulting earthquakes. Richins (1979) inferred from focal mechanisms the presence of a fault plane under the Hansel Mountains, striking N 15° E, and dipping 55° W. This plane may be coincidental with a fault bounding the west side of the hill south of the Hansel Mountains, north of the West Gully. His study also indicated local east-west extension, which accounts for the north-south trend of the faults, including the 1934 scarp.
Evidence gathered from West Gully and the 1934 event scarp indicates faulting occurred: 1) after Little Valley time; 2) after the Bonneville transgression (probably two events); and 3) in the Holocene (1934). Faulting in the Little Valley sediments was in discrete planes (some fractures had no displacement) indicating that the sediments were already compacted, however, the faults were truncated later by the Bonneville transgression. This would place the time of faulting after Oxygen Isotope Stage 6, but before Stage 2. At least two of the four events occurred during deep-lake cycles, as is evidenced by the convoluted layers of lake bottom silt. It is postulated that the increased load on the crust after the lake receded induced tectonic activity.

First order leveling data from the railroad measured in 1911, 1934, and 1953 at the southern end of Hansel Valley suggests that the 1934 scarp is an antithetic feature to a west dipping fault in the southeast portion of the valley (Bucknam, 1978). This conclusion may be supported by the bedrock outcrop farther north in the center of the valley in the vicinity of Section 23, T. 12 N., R. 7 W. (Fig. 2, d2). Evidence also exists that refutes this conclusion. If there is a west dipping fault east of the 1934 scarp, it has no surface exposure or relief. Also, the railroad grade that was surveyed is about 2 miles south of the 1934 rupture in an area where the only down-to-the-
West scarp was located. It is probable that if the survey had been located farther north in the vicinity of the 1934 event, the opposite or down to the east measurements would have been made. Sam Harding (1985, personal communication) working with the U. S. Geological Survey on a seismic profile of the southern end of Hansel Valley, found no sign of a buried fault block.

The presence of bedrock in the middle of the valley is indicative of a more complex bedrock structure than expected, when considering a simple graben valley. It is possible that other faults are present away from the edges of the valley. If so, the faults closest to the mountain front are the most active (in the recent past) on the east side of the valley (Fig. 5, faults a₁, a₂, and a₃). On the southwestern margin, however, Holocene faulting is more predominant away from the mountain front (Fig. 5, fault c₁ and c₂).

North-dipping fine-grained Tertiary Salt Lake deposits encountered in Hansel Valley Wash, consisting of silt and clay, which would probably have been horizontal when deposited, were deposited intercalated with conglomerates, suggesting tilting after deposition. Little Valley sediments deposited in the same area are nearly horizontal, indicating that faulting and accompanying tilting had occurred prior to the Little Valley cycle.
QUATERNARY HISTORY OF HANSEL VALLEY, UTAH

PRE-QUATERNARY HISTORY

The pre-Quaternary history of the Hansel Valley area has not been studied in detail, mainly because deposits underlying Pleistocene units are poorly exposed. Deposits stratigraphically below the Little Valley lake cycle are usually given a Tertiary age classification, with the exception of the pre-Bonneville alluvial fans which have lake shore features inscribed on them. In the Jordan Narrows and Oquirrh Foothills area south of the Great Salt Lake, Slentz (1955), noted that the Salt Lake Group sediments were being deposited as late as the upper Pliocene, and that active faulting was occurring at this time. Eardley (1955) pointed out that there was major block faulting in the Morgan and Cache Valleys and in the Traverse and Oquirrh Mountains of north central Utah during the late Tertiary, and that fanglomerates ceased to be deposited and pedimentation started in the Pleistocene. Alluvial fans then grew on the pediments at the onset of the Pleistocene glacial lakes (Blackwelder, 1948). While no absolute dates were obtained from pre-Quaternary units within Hansel Valley, a geologic history similar to that of the southern valleys is inferred.
QUATERNARY HISTORY

In the early Quaternary Hansel Valley probably resembled its present configuration, but lacked the pluvial lake deposits and fault scarps. Certain faulting events along the margins have had some effect on the landscape, lowering the valley relative to the surrounding mountains, but probably not so significant as to make the area unrecognizable. The onset of the lacustrine cycles, which added sediments to the valley and etched shorelines into the walls, presented the major geomorphic changes in Hansel Valley and the Bonneville Basin in general.

Previous Interpretations Of Lake Bonneville History

Several interpretations of the history of Lake Bonneville have been made (see previous work). The conclusion drawn by most investigators is that three major lacustrine cycles occurred: the Little Valley cycle; the Bonneville Lake cycle which is continuous with the Provo shoreline sediments; and post-Provo or Gilbert levels. Scott (1983) suggested the term Bonneville cycle (pre-26 ka until about 11 ka) be renamed the Jordan Valley Lake cycle, but later Scott and others (1983) reverted back to the Bonneville designation.
Lacustrine fluctuations prior to the Bonneville cycle were noted by Bissell (1969), Morrison (1965), and Crittenden (1963). No dates are given and with the possible exception of Morrison (1965), few descriptions were made as to colors or textures of the sediments.

The overall lake history is shown in Fig. 6, and major lake levels are noted (adapted from Currey and Oviatt, 1985). By about 16 ka, the Bonneville Lake reached the Zenda threshold in southeastern Idaho, elevation about 1555 m (5100 feet) (Curry, and others, 1984). Scott (1983) estimates that the lake maintained this level for over 1000 years, long enough to amass the copious gravel deposits found in Hansel Valley and elsewhere in the Bonneville Basin, and to carve benches over 10 m wide in bedrock. The maximum lake surface area covered about 54,000 km² (Currey and Oviatt, 1985). The Zenda threshold failed about 15,000 years ago, and the catastrophic Bonneville flood ensued (Scott, 1983). The lake dropped about 100 m and stabilized at the Provo Lake level with the threshold controlled by bedrock at Red Rock Pass, southeastern Idaho.

Several authors prior to Scott (1983) postulated on two Provo age lakes, the Provo I and Provo II (Bissell, 1969, Broecker and Kaufman, 1965). This division was based on the possible development of a soil on thin sediments seen in beach gravels. This soil, which was not noted in
Hansel Valley, was possibly a reactivation surface as described by McCabe and Jones (1977).

The water continued to retreat and reached a low of less than 1281 m (4200 feet) by about 11,000 years B.P. (Currey and Oviatt, 1985). The water then returned to about 1296 m (4250 feet) where the Gilbert shoreline was occupied for somewhat less than 1000 years, and the lake has not been above this elevation since that time (Scott, 1983).

Lake Bonneville History In Hansel Valley

The best evidence found in Hansel Valley for the fluctuations of Lake Bonneville was found in the West Gully (Fig. 5 and Plate 2). The stratigraphic column (Fig. 5) was compiled from exposures in this gully.

The Little Valley Lake cycle probably reached a maximum about 80 m below the Bonneville shoreline (Scott, 1983). This level would have an elevation of approximately 1562 m (5120 feet) in the Hansel Valley area. This lake cycle has been previously correlated with Oxygen Isotope Stage 6 (Fig. 5; 138 ka). A major unconformity overlies the Little Valley cycle silts. This unconformity represents possibly up to 30,000 years of desiccation of the Bonneville basin, and may correlate stratigraphically with Morrison's "diastem and local alluvium > 4265 ft alt" (Morrison, 1965, p. 16).
The sediments above the unconformity (units 2 and 3, Fig. 5) represent a previously undescribed episode in the history of Lake Bonneville. This cycle, informally termed the Hansel Valley cycle, may represent what were previously described as Alpine sediments. Scott (1979) indicates that much of the sediments previously mapped as Alpine by various authors are probably much younger. The elevation of the shoreline of the Hansel Valley cycle has not been determined, but is probably not above 1342 m (4400 feet) elevation. Oviatt and others (1985) cite evidence for a lake cycle of similar age and extent, which they refer to as the Cutler Dam cycle.

Two TL dates taken from the Hansel Valley cycle sediments reveal dates of 82 ka and 76 ka. These dates are from uncontaminated sediments, not mixed with older or younger deposits, and are considered reliable, and correlate to late Oxygen Isotope Stage 5. Ostracode taxa also support the conclusions of a low stand lake (Appendix B). It is possible that these Hansel Valley deposits correlate to Morrison's (1965, p. 20) "Intra-Alpine Diastems".

Above the deposits of the Hansel Valley cycle is another unconformity, representing a recession of the lake. The following 30,000 to 35,000 years was probably a time of aridity, with smaller fluctuations of the lake possible, but limited in extent. No soils were found at the
unconformity. This absence may be attributed to limited exposures, and/or the intense eroding capability of the subsequent Bonneville Lake transgression.

The date of the transgression of Lake Bonneville is unanimous among those studying lacustrine cycles. Approximately 32 ka, the climate had changed significantly enough to allow the filling of the Bonneville Basin (Currey and Oviatt, 1985, Fig. 6). But perhaps more significant, was the diversion of the Bear River into the Bonneville Basin at Cache Valley at about that same time (Bright, 1963). The subsurface evidence for the filling and transgressing water is a conformable stack of facies changes, from transgressive beach gravels through laminated silts, deposited as the lake rose. This transgression was undoubtedly slower and/or of higher energy than the two previous regressions, as thick beach deposits of large cobbles and gravels indicate a high energy environment, not present in the regressive deposits. The Hansel Valley cycle sediments below the transgressive gravels are absent in some places possibly due the intense eroding power of the rising water.

The Stansbury shoreline, with an elevation approximately 1373 m (4500 feet) above sea level, is not everywhere present in Hansel Valley. The evidence left by this halt in the transgression of the Bonneville Lake cycle has been significantly weathered in places so as to not be
recognizable, and was not delineated on the map which accompanies this report (Plate 1). The lake bottom sediments reveal ostracodes typical of an alkaline poor, rising lake (Fig. 5).

The sediments above the transgressive gravels yielded the only material suitable for $^{14}$C and amino acid racemization dating. These dates (Fig. 5) support the interpretations of Scott (1983) for the ages of deep water in Lake Bonneville, as do the ostracode assemblages. This lake cycle is correlative with Oxygen Isotope Stage 2 (Fig. 5).

Apparently, the transgression was halted more than once. Bay mouth bars and spits, correlative across Hansel Valley, are located at approximately 1495 m (4900 feet), 1525 m (5000 feet), and 1562 m (5120 feet) elevation. It is possible that the 1525 m (5000 feet) deposits are the remnants of the Keg Mountain oscillation described by Currey and Oviatt (1985), but no subsurface exposures were found to verify this. It is also unclear if the halts in the transgression were consecutive or if they are the result of oscillations. Gilbert (Hunt, 1982) noted many bars and spits in the Bonneville transgressive deposits, but attributed them to a combination of currents and material source. Charles G. Oviatt (Personal communication, 1985) agreed with Gilbert's conclusions. The evidence in Hansel Valley is somewhat contradictory, as
the tops of these bars and spits are correlative across the valley. If they were solely the result of currents and materials, the deposits would not be expected to correlate in various areas, as these do. They are probably the result of both a halt in the transgression and a material source and currents.

The Bonneville shoreline was controlled by the Zenda threshold at 1552 m (5092 feet) (Currey and Oviatt, 1985). In the Hansel Valley area, the Bonneville shoreline reaches an elevation of 1586 m (5200 feet). The average rebound (in the center of Hansel Valley) is about 33 m (108 feet). This is in agreement with the measurements of Crittenden (1963) for the differences in the shoreline elevation due to isostatic rebound. The shorelines in Hansel Valley have about 1 m per km (5 feet per mile) of isostatic rebound in a north-to-south direction. The sediments between the Provo shoreline and the Bonneville shoreline consist of relatively fine grained shore facies deposits, which is supporting evidence for the Bonneville flood theory, as no large gravel deposits were found. Also, no regressive shorelines are visible between the Bonneville and Provo shoreline. The lake maintained a relative constant elevation, about 1470 m (4820 feet) in Hansel Valley, for approximately 1500 to 2000 years, until about 14 ka (Currey and Oviatt, 1985). The regression from the Provo shoreline
was a gradual process, and etched numerous shorelines in the bottom sediments deposited during higher lake stands.

The historic level of the Great Salt Lake has had little geomorphic effect on Hansel Valley, with lake levels not exceeding 1285 m (4212 feet) elevation. With the exception of several small surface ruptures resulting from earthquakes, and the accumulation of material on alluvial fans, the landscape has changed little since the regression of Lake Bonneville.
REFERENCES


Bissell, H. J., 1969, Bonneville, an ice age lake: Department of Geology, Brigham Young University, Provo, Utah, 66 p.

Blackwelder, Eliot, 1948, The Great Basin, with emphasis on glacial and postglacial times, part 1, the geological background: Bulletin of the University of Utah, v. X, no. 7, p. 3-16.


Scott, W. E., 1979, New interpretations of Lake Bonneville stratigraphy and their significance for studies of earthquake-hazard assessment along the Wasatch Front: Manuscript submitted for the Conference on Earthquake Hazards along the Wasatch Front and in the Reno-Carson City Area July 30- August 1, 1979, Alta, Utah, 28 p.


Wang, Yunshuen, 1985, Petrology and mineralogy of Tertiary(?) volcanic rocks of Snoville area, Utah, and Tertiary-Quaternary(?) volcanic rocks of Table Mountain and Holbrook areas, Idaho (M. S. thesis): Logan, Utah, Utah State University, 83 p.


APPENDICES
APPENDIX A: RESULTS OF SIEVE ANALYSIS

EXPLANATION OF SIEVE DATA HISTOGRAMS

The following histograms show plots of weight % sample versus size of constituents (phi). Weights are divided into increments of 5%. Size intervals are plotted by 1/2 phi unit. Data in the window on each graph is explained in the appendix table.

Phi intervals that are not contiguous represent fractions not divided into 1/2 phi units, but represent whole phi units. These units represent roughly twice as much sample per unit of measurement. The end columns on the graph represent remaining sample. In order to calculate data for statistical parameters, cumulative frequency charts were constructed, with data extended to 14 phi and 100% weight on the right side of the graph, and to 0% weight on the left side.
# Sieve Analysis Tables

<table>
<thead>
<tr>
<th>UNIT SAMPLED</th>
<th>MODE</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mo</td>
<td>Mz</td>
<td>G</td>
<td>I</td>
<td>Sk</td>
<td>K</td>
<td>K'</td>
</tr>
<tr>
<td>11</td>
<td>4.20</td>
<td>4.90</td>
<td>1.45</td>
<td>1.80</td>
<td>0.39</td>
<td>1.52</td>
<td>0.60</td>
</tr>
<tr>
<td>9</td>
<td>4.75</td>
<td>6.08</td>
<td>1.53</td>
<td>1.69</td>
<td>0.51</td>
<td>1.44</td>
<td>0.59</td>
</tr>
<tr>
<td>7a</td>
<td>4.75</td>
<td>5.77</td>
<td>1.75</td>
<td>1.94</td>
<td>0.83</td>
<td>1.69</td>
<td>0.63</td>
</tr>
<tr>
<td>7b</td>
<td>4.25</td>
<td>5.72</td>
<td>2.40</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>6</td>
<td>5.25</td>
<td>3.77</td>
<td>2.60</td>
<td>2.90</td>
<td>-0.40</td>
<td>1.65</td>
<td>0.62</td>
</tr>
<tr>
<td>5</td>
<td>4.75</td>
<td>6.23</td>
<td>2.05</td>
<td>2.36</td>
<td>0.53</td>
<td>1.80</td>
<td>0.64</td>
</tr>
<tr>
<td>4</td>
<td>-3.50</td>
<td>-2.67</td>
<td>1.65</td>
<td>2.08</td>
<td>-1.34</td>
<td>2.18</td>
<td>0.69</td>
</tr>
<tr>
<td>3</td>
<td>4.50</td>
<td>5.52</td>
<td>1.83</td>
<td>2.26</td>
<td>0.47</td>
<td>1.78</td>
<td>0.64</td>
</tr>
<tr>
<td>2</td>
<td>4.50/7.50</td>
<td>6.15</td>
<td>1.43</td>
<td>1.23</td>
<td>0.03</td>
<td>0.62</td>
<td>0.38</td>
</tr>
<tr>
<td>1</td>
<td>4.25</td>
<td>6.22</td>
<td>2.13</td>
<td>2.27</td>
<td>0.58</td>
<td>1.19</td>
<td>0.54</td>
</tr>
</tbody>
</table>

* Not Calculated, 5% weight data not available.

1. All sieve analysis methods, procedures, and calculations are from: Folk, R. L., 1974, Petrology of sedimentary rocks: Hemphill Publishing Company, Drawer M. University Station, Austin, Texas, 159 p.

2. Unit sample numbers refer to figure 5 and plate 2.

3. MODE: Most frequently-occurring particle diameter. Calculated as the steepest portion of the cumulative graph.
$^3$Mz (Folk): Graphic Mean, graphic measure for determining overall size.

$$Mz = (\bar{\phi}_{16} + \bar{\phi}_{50} + \bar{\phi}_{84}) / 3$$

$^4\overline{\sigma_G}$: Graphic Standard Deviation, similar to statistical standard deviation.

$$\overline{\sigma_G} = (\bar{\phi}_{84} - \bar{\phi}_{16}) / 2$$

$^5\overline{\sigma_I}$: Inclusive Graphic Standard Deviation,

$$\overline{\sigma_I} = \frac{\bar{\phi}_{84} - \bar{\phi}_{16}}{4} + \frac{\bar{\phi}_{95} - \bar{\phi}_{5}}{6.6}$$

$\overline{\sigma_I}$ under

- .35 , very well sorted
- .35 - .50 , well sorted
- .50 - .71 , moderately well sorted
- .71 - 1.0 , moderately sorted
- 1.0 - 2.0 , poorly sorted
- 2.0 - 4.0 , very poorly sorted
- over 4.0 , extremely poorly sorted

$^6Sk_I$: Inclusive Graphic Skewness.

$$Sk_I = \frac{\bar{\phi}_{16} + \bar{\phi}_{84} - (2\cdot\bar{\phi}_{50})}{2(\bar{\phi}_{84} - \bar{\phi}_{16})} + \frac{\bar{\phi}_{5} + \bar{\phi}_{95} - (2\cdot\bar{\phi}_{50})}{2(\bar{\phi}_{95} - \bar{\phi}_{5})}$$
Symmetrical curves have Sk, = 0.00, those with excess fine material have positive skewness, those with excess coarse material have negative skewness.

Verbal Limits:

+1.00 to +0.30 strongly fine-skewed  
+0.30 to +0.10 fine-skewed  
+0.10 to -0.10 near-symmetrical  
-0.10 to -0.30 coarse-skewed  
-0.30 to -1.00 strongly coarse-skewed

$K_G$: Graphic Kurtosis, calculates peakedness, as compared to the normal probability curve.

$$K_G = \frac{\bar{\phi} - \bar{\phi}_5}{2.44 (\bar{\phi}_75 - \bar{\phi}_{25})}$$

$K_G = > 1.00$ leptokurtic, strongly peaked

$K_G = < 1.00$ platykurtic, weakly peaked

$K_G = 1.00$ normal curve

Verbal Limits:

< 0.67 very platykurtic  
0.67 to 0.90 platykurtic  
0.90 to 1.11 mesokurtic  
1.11 to 1.50 leptokurtic  
1.51 to 3.00 very leptokurtic  
> 3.00 extremely leptokurtic

Mathmatical Limits: 0.41 to infinity. Most sediments range from 0.60 to 5.00.
$K'_G$: Transformed Kurtosis.

$$K'_G = \frac{K_G}{1 + K_G}$$

Normal curves = 0.50, most sediments range from 0.40 to 0.65.
Unit 1

Mode: 4.25
G. Mean: 6.22
Sorting: 2.27
Skewness: 0.58
Kurtosis: 1.19

Grain Size (Phi)
Unit 2

Mode: 4.50
7.50
G. Mean: 6.15
Sorting: 1.23
Skewness: 0.03
Kurtosis: 0.62

Grain Size (Phi)
Unit 3

Mode: 4.50
G. Mean: 5.52
Sorting: 2.26
Skewness: 0.47
Kurtosis: 1.78

Grain Size (Phi)
Unit 4

- Mode: -3.50
- G. Mean: -2.67
- Sorting: 2.08
- Skewness: -1.34
- Kurtosis: 2.18

Grain Size (Phi)
Unit 5

Mode: 4.75
G. Mean: 6.23
Sorting: 2.36
Skewness: 0.53
Kurtosis: 1.80
Unit 6

Mode: 5.25
G. Mean: 3.77
Sorting: 2.90
Skewness: -0.40
Kurtosis: 1.65

Grain Size (Phi)
Unit 7b

Mode: 4.25
G. Mean: 5.72
Sorting: --
Skewness: --
Kurtosis: --
Unit 7a

Mode: 4.75
Mean: 5.77
Sorting: 1.94
Skewness: 0.83
Kurtosis: 1.69

Grain Size (Phi)
Unit 9

Mode: 4.75
G. Mean: 6.08
Sorting: 1.69
Skewness: 0.51
Kurtosis: 1.44

Grain Size (Phi)
Unit 11

Mode: 4.20
G. Mean: 4.90
Sorting: 1.80
Skewness: 0.39
Kurtosis: 1.52

Grain Size (Phi)
APPENDIX B: RESULTS OF OSTRACODE IDENTIFICATION
The following graph lists the correlation of map units described in the text with the sample numbers discussed by Mr. Richard M. Forester. Figure 5 in the text shows the relative stratigraphic position of the sampled units.

<table>
<thead>
<tr>
<th>SAMPLE NUMBER</th>
<th>UNIT IN FIGURE 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>9</td>
</tr>
<tr>
<td>42</td>
<td>7</td>
</tr>
<tr>
<td>50</td>
<td>5</td>
</tr>
<tr>
<td>21</td>
<td>3</td>
</tr>
<tr>
<td>20</td>
<td>2</td>
</tr>
<tr>
<td>10</td>
<td>1</td>
</tr>
</tbody>
</table>
Dr. James McCalpin  
Department of Geology  
Utah State University  
Logan, Utah 84322

Dear Jim:

I've enclosed a list of the ostracode taxa I found in your samples and a brief biostratigraphic-paleoenvironmental interpretation for each sample. As I noted in our phone conversation, I basically agree with all of your age and environmental calls, however, both of our interpretations assume stratigraphic order and continuity. That is, for example, the ostracodes show that sample 10 and 42 are big lakes and assumes 10 is about 150k years old due to stratigraphic position, and correlation to McCoy's Little Valley study. Still older pluvials may be quite similar to that Little Valley event and this would throw my correlation off. I've also enclosed a reprint on the core study of the last lake cycle. If you have questions, please feel free to write or call.

Best regards,

[Signature]

Richard M. Forester

Enclosures
You commented in one of our phone conversations that you believed, based on your fieldwork, that the stratigraphic order of these samples (10 oldest and 40 youngest) was well established, which is important because this section exhibits two pluvials separated by an interpluvial. Finding pluvial interpluvial pluvial sequences in outcrop is rare.

Sample 10 contains an ostracode assemblage that is correlative with one I examined from sediments identified by Bill McCoy as being part of the older Little Valley pluvial. The ostracodes suggest that this is a large lake because of the presence of taxa like C. sp. caudata type, which live in both the littoral and profundal areas of lakes, but prefer profundal areas and because in the general Great Salt Lake Basin "high stand" lake phases are alkaline rich "runoff" waters whereas low stands are alkaline poor "groundwater" water. The presence of Limnocythere sappamensis and L. ceriotuberosa indicate this is alkaline rich water. The presence of rare L. staplini and L. beaconsensis indicate alkaline poor water is entering the lake near this site and most probably this alkaline poor water is from marginal lacustrine groundwater discharge into the lake.

Sample 20 contains a quite different ostracode assemblage than sample 10. Heterocycpris n. sp. is a taxon that is largely restricted to groundwater discharge environments and Candona rawsoni, L. staplini and Ilyocypris bradyii suggest this is alkaline poor water. The simplest interpretation for this sample is that the central lake level has fallen and this is the marginal lacustrine groundwater environment.

Sample 21 and 50

Sample 21 contains groundwater discharge and alkaline poor taxa that suggest "low stand" central lakes, which implies this is the interpluvial. Sample 50 contains no groundwater discharge taxa, but does contain an alkaline poor species suggesting lake level is rising, but as yet is not alkaline rich. This type of lake is recognized in the enclosed reprint as the first step in the early stage of a pluvial phase, part of unit IIIE. We dated this event as starting 25k years ago in the cores, but Jack Oviatt has dated outcrop ostracode data that suggests this could be as old as 40 or 45k years ago. Perhaps this event is time transgressive and is seen first on the flanks of the basin and last in the center of the basin when the brine is dilute enough to have ostracodes.

Sample 42 contains a profundal dominated alkaline loving ostracode assemblage that is correlative with the IIIb assemblage defined in figure 4 of the enclosed reprint. This should be the lake which is at the Bonneville shoreline and based on the core study we believe is roughly 15.5 to 17k years ago.

Sample 40 contains a mixture of alkaline rich and poor ostracodes, but the alkaline poor forms dominate and many of the alkaline rich forms are poorly preserved and probably reworked. This suggests the lake is regressing either due to evaporative fall from the Provo shoreline or due to the catastrophic fall from Bonneville. The latter two events are roughly dated at 14 to 15 k years ago.
The timing and environmental interpretations for this sample series is strongly dependent upon both the stratigraphic order and the stratigraphic continuity you've illustrated in your composite section. Based on material I've examined for cores in this basin these pluvial interpluvial events have been repeated an unknown number of times during the Quaternary and whereas each one is different they have a broadly similar group of ostracodes.
Jim McCalpin Hansel Valley samples ostracode taxa

Smpl 10

- *Candona* sp caudata type
- *Candona* decora?
- *Limnocythere ceriotuberosa*
- *Limnocythere sappaensis* common
- *Limnocythere staplini* rare
- *Limnocythere n. sp.* rare
- *Cyprideis* sp juveniles only

Smpl 20

- *Candona rawsoni*
- *Ilyocypris bradyii*
- *Heterocypris* n. sp.
- *Limnocythere n. sp.* 2 abundant
- *Limnocythere staplini* common

Smpl 21

- *Limnocythere staplini*
- *Heterocypris* n. sp. rare
- rootlet? molds

Smpl 50

- *Limnocythere staplini*

Smpl 42

- *Candona* spp from enclosed reprint species in fig. 4 col. C,D,E,F
- *Cytherissa lacustris*
- *Limnocythere ceriotuberosa*
- *Limnocythere staplini* rare
- *Limnocythere itasca* rare

Smpl 40

- *Candona casta*cuaro sensu Delorme
- *Candona* spp from reprint fig. 4 col. C,D - reworked
- *Candona caudata*
- *Limnocythere ceriotuberosa*
- *Limnocythere sappaensis*
- *Limnocythere friabilis*?
- rootlet? molds-
APPENDIX C: RESULTS OF SAMPLES SENT FOR ABSOLUTE DATING.
<table>
<thead>
<tr>
<th>STRATIGRAPHIC UNIT</th>
<th>THERMOLUMINESCENCE</th>
<th>CARBON 14</th>
<th>AMINO ACID RACEMIZATION</th>
<th>OXYGEN ISOTOPIC STAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1) Alpha Analytic Inc. sample # (yr. B.P.)</td>
<td>(2) Beta Analytic Inc. sample # (yr. B.P.)</td>
<td>(3) INSTAAR (Univ. of Colo.) sample # (yr. B.P.)</td>
<td>(4)</td>
</tr>
<tr>
<td>upper 9 laminted silt</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>upper 8 convoluted silt</td>
<td>1949 13,000</td>
<td>(11,700 +/- 1,100)</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>lower 7 laminted silt</td>
<td></td>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>lower 6 convoluted silt</td>
<td>1948 16,000</td>
<td>12040 15,450 +/- 650</td>
<td>ARL-4391 +/- 21,000</td>
<td>2</td>
</tr>
<tr>
<td>brown 5 laminted silt</td>
<td></td>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>beach 4 gravel</td>
<td></td>
<td></td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>green 3 silt</td>
<td>1947 82,000</td>
<td>(67,000 +/- 3,000)</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>brown 2 silt</td>
<td>1946 76,000</td>
<td>(65,000 +/- 4,200)</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>compact 1 silt</td>
<td>2098 138,000</td>
<td>(115,000 +/- 17,500)</td>
<td></td>
<td>6</td>
</tr>
</tbody>
</table>
EXPLANATION

1  ALPHA ANALYTIC INC.
   University Branch
   P.O. Box 248113
   Coral Gables, Florida 33124

2  BETA ANALYTIC INC.
   University Branch
   P.O. Box 248113
   Coral Gables, Florida 33124

3  AMINO ACID LABORATORY
   INSTAAR
   University of Colorado
   Boulder, Colorado

4  Bowen, D. Q., 1978, Quaternary geology, a
   stratigraphic framework for multidisciplinary
   work: Oxford-New York-Toronto-Sydney-Paris-
   Frankfurt, Pergamon Pess, 221 p.

   Data corrected to compensate for compaction and
   fluctuations in ground water over the burial
   history of the sediments. Dates were originally
   reported on as-recvieved moisture contents and are
   given in parentheses. For a complete discussion
   see:

   McCalpin, James, 1986, Thermoluminescence (TL)
   dating in seismic hazard evaluations: an example
   from the Bonneville Basin, Utah: Proceedings of
   the 22nd Symposium on Engineering Geology and
   Soils Engineering, p. 156-176.