Quaternary Geology and Tectonics
of the
Waucoba Wash 15-Minute Quadrangle
Saline Valley, Inyo County, California

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science

by

Peg Ann O'Malley

August 1980
The thesis of Peg Ann O'Malley is approved:

[Signature]

Thesis Advisor

[Signature]

Department Chairman

[Signature]

Dean, Graduate School

University of Nevada

Reno

August 1980
ACKNOWLEDGEMENTS

Field assistance was provided by Jim Stroh, Chris Sanders, Steve Harlan and Chantal Eguiluz. To these people go my thanks. Helpful discussions with Drs. D. Burton Slemmons, Jonathan O. Davis and Jim Stroh as well as technical advice from Chris Sanders aided immeasurably in the completion of this work. Field consultation with Jonathan Davis and Burt Slemmons, both in the air and on the ground, was most enlightening.

Special thanks to Bill Gilmore and Jim Morrison of the Bishop Office of the Bureau of Land Management for their part in helping this work go more smoothly, to Cady Johnson for the use of his library, to John Zellmer for use of his aerial photographs and references, to the Basque Studies Center staff of the University of Nevada-Reno for use of their office facilities, and to the Mickels family of Mazourka Canyon for their continuing hospitality.

My thesis committee consists of Drs. D. Burton Slemmons, Jonathan O. Davis, Malcolm Hibbard, and Frederick F. Peterson. Their professional guidance and editorial suggestions and criticisms concerning this work have helped improve its overall quality.
ABSTRACT

Saline Valley occupies a structural depression sometimes described as a rhombochasm. Analysis of faults and shear zones shows the area dominated by a conjugate fracture set; right-oblique normal offset on northwest trends, left-oblique normal offset on northeast trends. Fault orientation is compatible with regional $\sigma_1$ of N10°E proposed by Wright (1976). Saline Valley lies within an area of right-oblique extension (Hamilton and Myers, 1966).

The eastern Inyo range front seems to buttress against westward extension of the tension-gash system of the Saline and Last Chance-Panamint Ranges. Northeast-trending faults of the latter system may extend across the valley, displacing some Inyo range front fans. Distortion of fault trends near the Inyo front suggests influence of drag related to right-lateral shear.

Saline Valley is not now experiencing tectonic activity and this may represent a seismic gap.
# TABLE OF CONTENTS

## CHAPTER 1

Introduction ......................................... 1  
Geographic setting .................................. 1  
Climate .................................................. 1  
Structural overview .................................. 3  
Seismicity ............................................... 5  
Statement of problem .................................. 6  
Methods of analysis .................................. 7  
  Lineament analysis ................................ 7  
  Fault scarp profiling ............................. 7  
  Modeling ............................................. 8  
  Special problems ................................... 8  
Previous work ......................................... 9  

## CHAPTER 2

Results of analysis ................................ 11  
Lineament analysis ................................ 11  
  Waucoba Wash 15-minute quadrangle ............ 11  
  Death Valley and Goldfield 1:250,000-scale quadrangles 13  
Surficial analysis .................................... 16  
Structural analysis .................................. 20  
  Saline Range ....................................... 20  
    Summary .......................................... 20  
    Volcanic rocks of the Saline Range ......... 21  
    Onset of late Cenozoic volcanism ........... 24  
    Field evidence .................................. 26  
    Overview ......................................... 26  
    Big Scarp ......................................... 27  
      Alluvial unit Qoa₁ .............................. 27  
      Alluvial unit Qoa₂ .............................. 30  
      Geomorphology of the upper surface of Big Scarp 32  
      Local tectonics ................................ 34
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fault scarp profiling</td>
<td>36</td>
</tr>
<tr>
<td>Locations 11 and 12, central graben area</td>
<td>41</td>
</tr>
<tr>
<td>Location 20</td>
<td>43</td>
</tr>
<tr>
<td>Locations 13 and 17, northern boundary scarp</td>
<td>46</td>
</tr>
<tr>
<td>Playa</td>
<td>55</td>
</tr>
<tr>
<td>Location 29</td>
<td>56</td>
</tr>
<tr>
<td>Location 31</td>
<td>59</td>
</tr>
<tr>
<td>Other Northeast-trending faults</td>
<td>59</td>
</tr>
<tr>
<td>Cuesta</td>
<td>59</td>
</tr>
<tr>
<td>North End</td>
<td>67</td>
</tr>
<tr>
<td>Location 38</td>
<td>69</td>
</tr>
<tr>
<td>Location 40</td>
<td>71</td>
</tr>
<tr>
<td>Locations 44 and 45</td>
<td>72</td>
</tr>
<tr>
<td>Location 46</td>
<td>72</td>
</tr>
<tr>
<td>Location 47</td>
<td>74</td>
</tr>
<tr>
<td>Location 48</td>
<td>77</td>
</tr>
<tr>
<td>Location 49</td>
<td>78</td>
</tr>
<tr>
<td>Regression Analysis</td>
<td>82</td>
</tr>
<tr>
<td>Eastern Inyo frontal fault zone</td>
<td>93</td>
</tr>
<tr>
<td>Summary</td>
<td>93</td>
</tr>
<tr>
<td>Red Fan</td>
<td>98</td>
</tr>
<tr>
<td>Qof$_1$</td>
<td>102</td>
</tr>
<tr>
<td>Qof$_{2a}$, upper terrace</td>
<td>103</td>
</tr>
<tr>
<td>Qof$_{2b}$, lower terrace</td>
<td>104</td>
</tr>
<tr>
<td>Age assessment and paleoclimatic effects</td>
<td>109</td>
</tr>
<tr>
<td>Paiute Canyon</td>
<td>114</td>
</tr>
<tr>
<td>McElvo Canyon</td>
<td>116</td>
</tr>
<tr>
<td>Spring Canyon</td>
<td>117</td>
</tr>
<tr>
<td>Craig Canyon</td>
<td>118</td>
</tr>
<tr>
<td>Nelson Range</td>
<td>120</td>
</tr>
<tr>
<td>Stereographic analysis</td>
<td>121</td>
</tr>
<tr>
<td>Chapter Title</td>
<td>Page</td>
</tr>
<tr>
<td>-------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>Structural summary and conclusions</td>
<td>124</td>
</tr>
<tr>
<td>REFERENCES</td>
<td>132</td>
</tr>
<tr>
<td>PERSONAL COMMUNICATION</td>
<td>138</td>
</tr>
</tbody>
</table>
TABLE OF FIGURES

<table>
<thead>
<tr>
<th>FIGURE</th>
<th>DESCRIPTION</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Location map of the Saline Valley region</td>
<td>2</td>
</tr>
<tr>
<td>2.</td>
<td>Pull-apart model for the Death Valley region (after Burchfiel and Stewart, 1966; Hill and Troxel, 1966)</td>
<td>4</td>
</tr>
<tr>
<td>3.</td>
<td>Curved scarp at the south end of Saline Valley</td>
<td>15</td>
</tr>
<tr>
<td>4.</td>
<td>Western boundary of the Saline Range</td>
<td>22</td>
</tr>
<tr>
<td>5.</td>
<td>Eastern boundary of the Saline Range near Eureka Valley</td>
<td>22</td>
</tr>
<tr>
<td>6.</td>
<td>Aerial photograph of the Big Scarp locality</td>
<td>28</td>
</tr>
<tr>
<td>7.</td>
<td>Alluvial unit Qoa(^1) at Big Scarp locality</td>
<td>31</td>
</tr>
<tr>
<td>8.</td>
<td>Alluvial unit Qoa(^2) at Big Scarp locality</td>
<td>31</td>
</tr>
<tr>
<td>9.</td>
<td>Alluvial surface north of the northern boundary scarp, Big Scarp locality</td>
<td>33</td>
</tr>
<tr>
<td>10.</td>
<td>Plot of scarp age vs. maximum slope angle (after Wallace, 1977)</td>
<td>39</td>
</tr>
<tr>
<td>11.</td>
<td>Fault scarp profile 11, Big Scarp locality</td>
<td>42</td>
</tr>
<tr>
<td>12.</td>
<td>Fault scarp profile 12, Big Scarp locality</td>
<td>42</td>
</tr>
<tr>
<td>13.</td>
<td>Fault scarp at location 20, Big Scarp locality</td>
<td>45</td>
</tr>
<tr>
<td>14.</td>
<td>Fault scarp profile 20, Big Scarp locality</td>
<td>45</td>
</tr>
<tr>
<td>15.</td>
<td>Fault scarp profile 13, Big Scarp locality</td>
<td>47</td>
</tr>
<tr>
<td>16.</td>
<td>Photograph of offset carbonate horizons at arroyo near location 13, Big Scarp locality</td>
<td>50</td>
</tr>
<tr>
<td>17.</td>
<td>Fault scarp profile 17, Big Scarp locality</td>
<td>52</td>
</tr>
<tr>
<td>18.</td>
<td>Photograph looking north from Big Scarp to Playa locality over the Qoa(^2) surface</td>
<td>57</td>
</tr>
<tr>
<td>19.</td>
<td>Fault scarp profile 29, Playa locality</td>
<td>58</td>
</tr>
<tr>
<td>20.</td>
<td>Photograph of scarp at location 29</td>
<td>60</td>
</tr>
<tr>
<td>21.</td>
<td>Fault scarp profile 31, Playa locality</td>
<td>60</td>
</tr>
<tr>
<td>22.</td>
<td>Photograph of Cuesta locality from the north</td>
<td>62</td>
</tr>
<tr>
<td>23.</td>
<td>Photograph of fault at location 2, Cuesta locality</td>
<td>64</td>
</tr>
<tr>
<td>24.</td>
<td>Photograph looking ESE from Paiute Canyon to Dry Wash</td>
<td>68</td>
</tr>
<tr>
<td>25.</td>
<td>Photograph of North End scarps</td>
<td>68</td>
</tr>
<tr>
<td>26.</td>
<td>Fault scarp profile 28, North End locality</td>
<td>70</td>
</tr>
<tr>
<td>Page</td>
<td>Image/Text Description</td>
<td></td>
</tr>
<tr>
<td>------</td>
<td>------------------------</td>
<td></td>
</tr>
<tr>
<td>27.</td>
<td>Photograph of varnished desert pavement surface near location 45, North End locality</td>
<td></td>
</tr>
<tr>
<td>28.</td>
<td>Fault scarp profile 46, North End locality</td>
<td></td>
</tr>
<tr>
<td>29.</td>
<td>Fault scarp profiles 47a and 47b, North End locality</td>
<td></td>
</tr>
<tr>
<td>30.</td>
<td>Photograph of splayed fault with terrace, location 47a, North End locality</td>
<td></td>
</tr>
<tr>
<td>31.</td>
<td>Fault scarp profile 48, North End locality</td>
<td></td>
</tr>
<tr>
<td>32.</td>
<td>Fault scarp profile 49, North End locality</td>
<td></td>
</tr>
<tr>
<td>33.</td>
<td>Photograph of natural levee along profile 49, North End locality</td>
<td></td>
</tr>
<tr>
<td>34.</td>
<td>Regression curve of scarp height vs. slope angle for profile 49, North End locality</td>
<td></td>
</tr>
<tr>
<td>35.</td>
<td>Plot of other North End scarp data on &quot;isochron&quot; of profile 49</td>
<td></td>
</tr>
<tr>
<td>36.</td>
<td>Plot of North End scarps on straight-line &quot;isochron&quot; developed for profile 49</td>
<td></td>
</tr>
<tr>
<td>37.</td>
<td>Regression curve for scarp height vs. slope angle for North End locality</td>
<td></td>
</tr>
<tr>
<td>38.</td>
<td>Regression curve for scarp height vs. slope angle for Big Scarp locality</td>
<td></td>
</tr>
<tr>
<td>39.</td>
<td>Regression curve for scarp height vs. slope angle for Playa locality</td>
<td></td>
</tr>
<tr>
<td>40.</td>
<td>Regression curves for all scarp data</td>
<td></td>
</tr>
<tr>
<td>41.</td>
<td>Regression curves for scarps in the Saline Valley area plotted with Bucknam and Anderson (1979) scarp data</td>
<td></td>
</tr>
<tr>
<td>42.</td>
<td>Modified stratigraphic column for the Waucoba Wash quadrangle</td>
<td></td>
</tr>
<tr>
<td>43.</td>
<td>Photograph of the Red Fan locality as seen from the east</td>
<td></td>
</tr>
<tr>
<td>44.</td>
<td>Photograph of antithetically tilted Qof1 fault block</td>
<td></td>
</tr>
<tr>
<td>45.</td>
<td>Schematic cross section of Qof1 and Qof2 units within the Red Fan locality</td>
<td></td>
</tr>
<tr>
<td>46.</td>
<td>Detailed map of Qof1 and Qof2 at Red Fan locality</td>
<td></td>
</tr>
<tr>
<td>47.</td>
<td>Photograph of colluvial cone, Qoc, at the Red Fan locality</td>
<td></td>
</tr>
<tr>
<td>48.</td>
<td>Photograph of oxidized zone at Qoc-bedrock contact, Red Fan locality</td>
<td></td>
</tr>
<tr>
<td>Page</td>
<td>Description</td>
<td></td>
</tr>
<tr>
<td>------</td>
<td>-------------</td>
<td></td>
</tr>
<tr>
<td>49.</td>
<td>Photograph of offset in basalts at Paiute Canyon and color altered zone of Qoala</td>
<td></td>
</tr>
<tr>
<td>50.</td>
<td>Photograph of offset iron-stained horizon at location 37, Spring Canyon locality</td>
<td></td>
</tr>
<tr>
<td>51.</td>
<td>Stereographic projection of poles of joint and shear planes and rake of slickensides</td>
<td></td>
</tr>
<tr>
<td>52.</td>
<td>Orientation of $\sigma_1$ and resulting principal shears in pre- and post-13 m.y. time and structure of Saline Valley as related to these shears</td>
<td></td>
</tr>
</tbody>
</table>
PLATES

All plates are in back pocket.

1. Lineament analysis of the Waucoba Wash 15-minute quadrangle
2. Lineament analysis of a portion of the Goldfield and Death Valley 1:250,000-scale quadrangles
3. Location map of sample and observation localities
4. Moody and Hill (1956) structural model of the Goldfield and Death Valley regions
5. Structural interpretation of lineaments of a portion of the Goldfield and Death Valley 1:250,000-scale quadrangles based on a drag-curved fault model
TABLES

1. Geomorphic features of faults by slip-type and ranked in approximate frequency of occurrence in active fault zones (Slemmons, 1977). 139

2. Scarp groupings according to estimated age for the Saline Valley area. 141
CHAPTER 1
Introduction

Geographic Setting

Saline Valley, of which Waucoba Wash 15-minute quadrangle constitutes the northern half, has an overall relief of 3061 meters (10,042 feet) and a topographic closure of 1200 m (4000 ft), exceeded by fault controlled troughs elsewhere in the world by the Turfan depression of Sinkiang and Lakes Baikal and Tanganyika (Hamilton and Myers, 1966). Boundaries of Saline Valley include the Inyo Mountains to the west, the Nelson Range to the south, the Panamint and Last Chance Ranges to the east and the Saline Range to the north (fig. 1). The valley lies near the western margin of the Basin and Range province in a region characterized by high uplift rates within mountain ranges, considerable topographic relief, and late Tertiary and Quaternary volcanism of the basalt-rhyolite bimodal type.

Climate

The climate of Saline Valley is similar to that of Death Valley to the east. Rainfall is sparse and seasonal, most occurring from November to April and the remainder coming in the form of summer thunderstorms. Average annual precipitation is about 7.5 cm (3 in) and years with no rain falling on the valley floor are common (Zellmer, 1980). Summer temperatures are high and average about 40°C (105°F) (Wardlaw, 1979) with extremes of 49°C (120°F) unofficially
Figure 1. Location map of the Saline Valley region. Shaded area indicates location of the Waucoba Wash 15-minute quadrangle.
reported. Winter temperatures are mild and average about 7° to 10°C (45° to 50°F) on the valley floor. Frost is rare at lower elevations and the winter snowline is usually above 1525 m (5000 ft), heavy snow occurring along the crest of the Inyo Mountains (Zellmer, 1980).

Structural Overview

The regional location of Saline Valley is significant because it lies within a transition zone between the Basin and Range province to the east and north of the Walker Lane and the continental border province of predominantly right-lateral shear between the Pacific margin and the Sierra Nevada. Position of the valley to the north of the Garlock fault includes it within the crustal region described by Davis and Burchfiel (1973) as undergoing active spreading, with the Garlock fault marking the transform boundary between this area and the relatively quiescent tectonic blocks of the Mojave and southern Nevada regions. Interpretations with regard to the western migration of the Sierra Nevada block affect the Saline Valley area because of its close proximity to and geologic affinities with the Sierra Nevada-Owens Valley regions (Wright, 1976; Rest and Hamblin, 1978).

The outline of the alluviated valley has a rhombic shape and it has been suggested by some authors that Saline Valley is a rhombochasm, formed by the pull-apart of crustal blocks in response to a pervasive right-lateral regional shear (Lombardi, 1963, 1964; Babcock, 1974; Zellmer, 1980).
Figure 2.

(a) Tectonic sketch map of the Death Valley region (after Hill and Troxel, 1966).

(b) Diagrammatic map showing interpretation of strike-slip movement affecting area of tension, Death Valley, California (after Burchfiel and Stewart, 1966).
Burchfiel and Stewart (1966) have proposed a similar model for the Death Valley region (fig. 2).

Within this regional framework, Saline Valley seems to be a piece of a much larger block and should be discussed generally as part of that block. Between the Inyo Mountains to the west and the Grapevine Mountains to the east are a series of northeast-trending basins and ranges. Although rocks within these ranges vary in age from Precambrian to Cenozoic (McAllister, 1956; Ross, 1967b; Burchfiel, 1969), all are affected by a system of northeast-trending normal faults which divide the major ranges into a series of tilted blocks. Hamilton and Myers (1966) refer to this region as a "tension-gash" system. Intervening areas of alluvium mark the separation of these blocks. A zone of right-lateral shear with a significant dip-slip component occurs along the eastern flanks of the Inyo Mountains and Nelson Range which lie on the west and southwest borders of the valley, respectively (McAllister, 1956; Ross, 1967b). This right-lateral shear reflects the regional stress pattern that controls much of the structure within the local area.

Seismicity

A compilation of epicenters within the western United States (Smith, 1978) for the years 1950 through 1976 shows the Saline Valley area to be one of relative seismic quiescence. Only four epicenters were located in the valley over this 26-year timespan, the area apparently representing a
modern seismic gap surrounded by the seismically active Garlock, Sierra Nevada-Owens Valley, Death Valley-Furnace Creek, and southern Nevada fault provinces. Bias in the data base to the side of fewer recorded earthquakes is probable due to the location of the study area on the fringe of the Cal Tech, Berkeley and University of Nevada - Reno seismograph nets (A. Ryall, personal communication, 1980). Given the anomalously high incidence of seismic activity peripheral to the area, however, it seems unlikely that the entire gap is a phenomenon of insufficient instrumentation.

Statement of Problem

The Saline Valley area has a number of topographic and geologic peculiarities which beg explanation. Those problems of particular interest to the author are:

1. nature of motion of the Inyo Mountains-Nelson Range blocks, relative to the Saline depression;
2. nature of motion of the Saline Range and Last Chance-Panamint Range block(s) and relative timing of faulting events;
3. type of deformation present within crustal blocks involved in formation of Saline Valley and the possible relationship of this deformation to regional stress patterns;
4. possible effects of Quaternary stress distribution on older Cenozoic and pre-Cenozoic structures.
Methods of Analysis

A number of techniques have been combined in the analysis of structures within and encompassing the Waucoba Wash 15-minute quadrangle.

Lineament Analysis

Lineament analysis, based on criteria developed by Slemmons (1969, 1977) and outlined in Table 1, was applied to black-and-white aerial photographs at scales of approximately 1:30,000 and 1:50,000; color aerial photographs at a scale of about 1:21,000, the 15-minute topographic quadrangle of Waucoba Wash and 1:250,000-scale topographic maps of portions of the Death Valley and Goldfield quadrangles. Integration of these analyses with available published data as well as field truth verification by Drs. D. Burton Slemmons and Jonathan O. Davis comprised a portion of the study.

Fault Scarp Profiling

In accordance with techniques developed by Wallace (1977), fault scarps were located in the field, profiles made to determine slope angles, and scarp heights measured. In addition, notes were compiled on the nature of the surfaces offset by faults in an attempt to quantify their relative ages. A Brunton compass was utilized to measure scarp slope angles and a 2-meter pole was used to delineate portions of the slope to be measured. A 50-meter tape was laid along the profile to be measured and the pole was placed
next to the tape. Measurements were taken in 2-meter increments except where rapid change in slope angle indicated the advantage of smaller units. Care was taken to avoid, whenever possible, any rocks or slope aberrations which showed no evidence of having tectonic origin. Scarp slopes which are profiled are not affected by runoff scouring at their bases.

A Brunton compass was set on the pole after positioning along the profile and the slope angle read and recorded to the nearest half-degree. Profiles were drawn by hand at a scale of 1:1 using slope angles and linear distances recorded in the field.

Modeling

Several tectonic models were examined and tested in light of field data. The models of Lombardi (1963, 1964), Babcock (1974) and Zellmer (1980) were evaluated for their evidence and interpretations as well as models for the Death Valley region (Burchfiel and Stewart, 1966; Hill and Troxel, 1966).

An alternative model to those mentioned above was developed, tested, and refined to account for fault and shear plane trends and offsets.

Special Problems

The difficulties involved in dating surfaces of Quaternary age are a major obstacle to this study. A reliable technique applicable in most regions for Quaternary chron-
ology involves the use of degree of soil horizonation as a criterion for age assignment. This method was not employed in this study since horizonation useful for age determination was not observed. A detailed analysis of soils of the region was outside the scope of this work.

Other techniques which are potentially helpful in determining chronology of surfaces are discussed in the literature. Foremost of these include:

1. fault scarp profiling;
2. radiometric dating methods;
3. paleoclimatic effects and fanhead trenching; geomorphological age indicators.

Fault scarp profiling and other geomorphological age indicators are discussed in some detail and some applications of radiocisotopes are indicated. Desert varnish is also used as an indicator of relative age.

Previous work

The Saline Valley area is mapped in some detail by a number of workers with the U. S. Geological Survey. A regional geologic map of the Death Valley area was compiled by Jennings (1973) and by Steitz and Stinson (1973). Mapping at the 15-minute scale has been completed for the Waucoba Wash quadrangle (Ross, 1967b), the Ubehebe Peak quadrangle (McAllister, 1956) and the Dry Mountain quadrangle (Burchfiel, 1969). McAllister (1955) also presents the geology and mineral deposits of the Ubehebe Peak quadrangle.
in a separate report. Ross (1965, 1967a, 1970) mapped the general geology of the Inyo Mountains area, described the petrology of three granitic bodies within the Inyo Mountains, and also the volcanic rocks of the Saline Range.

The geology of the Cerro Gordo mining district, Inyo Mountains, was mapped and described by Merriam (1963). Lombardi (1963, 1964) compiled a map which includes new fault data as part of a study of saline deposits within the valley and presents an abstract on deformation in Saline Valley as related to regional deformation in the western United States. Gale (1912) and Hardie (1968) also studied evaporite deposits in Saline Valley.

Geophysical work includes a gravity survey of the Death Valley 1:250,000-scale quadrangle by Mabey (1963) and Chapman and others (1971) as well as peripheral gravity work by Pakiser and Kane (1965) and Pakiser, Kane and Jackson (1964) in the Owens Valley.

A soil survey of Saline Valley by the U. S. Bureau of Land Management (1979) is also available. Zellmer (1980) completed a Ph.D. dissertation on the southern half of Saline Valley that is within the Ubehebe Peak and New York Butte quadrangles.
CHAPTER 2
RESULTS OF ANALYSIS

Lineament Analysis

Waucoba Wash 15-minute Quadrangle

The Waucoba Wash 15-minute quadrangle is examined for lineaments of possible structural significance using the topographic base of the U. S. Geological Survey (1951), black-and-white aerial photographs of the U. S. Geological Survey at an approximate scale of 1:50,000 and of the U. S. Naval Ordnance Test Station at an approximate scale of 1:30,000, and color aerial photographs of excellent quality at a scale of 1:21,000 provided by the U. S. Bureau of Land Management. In a preliminary study undertaken by the author in fall of 1978, a large number of lineaments were described without field verification from both topographic and aerial photographic interpretation. Later investigations have confirmed some of these features as faults or probable faults while others are not evident on the ground. A compilation of these lineaments is shown on Plate 1.

Analysis of the trends represented by lineaments in this quadrangle in light of potential tectonic relationships suggests two possibilities:

1. The northeast-trending lineaments represent Riedel shears to a right-lateral zone of relative offset. This zone is bounded by the Grapevine-Funeral Mountains in Death Valley to the east and the
Inyo Mountains to the west. Developing P-shears within this system are represented by the northwest-trending eastern Inyo Mountains frontal fault zone and the Death Valley-Furnace Creek fault zone. This model is developed on ideas proposed by Tchalenko (1970). For this model to work, the northeast-trending faults must show right-lateral offset.

2. The northeast-trending lineaments represent one-half of a conjugate fracture system, the other half represented by a prominent N10°W to N17°W-trending system, subparallel but somewhat oblique to the N25°W orientation of the eastern Inyo Mountain front. This fracture system would develop in response to a \( \sigma_1 \) with a N10°E-S10°W orientation, compatible with relative Pacific-North America plate motions. The N80°W extensional direction (\( \sigma_3 \)) yields a significant dip-slip component to the stress regime along the Inyo front and is in accord with models based on field evidence by Gilluly (1963), Thompson (1966), Hamilton and Myers (1966), Stewart (1971), Thompson and Burke (1974) and Wright (1976, 1977). The fracture sets indicated in this analysis have been locally mobilized by crustal stress to accommodate deformation through faulting.
In order for option 2 above to be a viable model, northeast-trending faults should exhibit left-lateral or left-oblique offset.

A third dominant set of lineaments has an approximate N60°W orientation. This is somewhat anomalous to other trends within Saline Valley but is compatible with the major fault zone associated with the Nelson Range front at the south end of the valley. This trend may reflect the overprint of an older structure which pre-dates late Cenozoic tectonic patterns within the area.

Death Valley and Goldfield 1:250,000-scale Quadrangles

The regional relationship of geologic structures must be considered in any study of Saline Valley. In the past, structural and geologic interpretations have attempted to define the valley as an entity in itself, modelling it in a manner similar to adjacent areas such as Death Valley. As Hamilton and Myers (1966) have indicated, Saline Valley must be considered as an integral part of the tectonic picture of the entire boundary zone between the Sierra Nevada and the Walker Lane, the transition zone between Basin and Range and the continental border province west of the Sierra Nevada which is dominated by right-lateral shear.

Portions of the Death Valley and Goldfield 1:250,000-scale topographic quadrangles have been analyzed for lineaments which may reflect the boundaries of and deformation patterns within structural units. The region as a whole
shows two dominant trends: one of northwesterly orientation, roughly parallel to the Walker Lane, San Andreas, Owens Valley and Death Valley-Furnace Creek fault systems; the other of northeasterly orientation and generally parallel to Basin and Range frontal fault trends to the north and east of the Walker Lane (Plate 2).

Regional patterns have local distortion which may indicate drag deformation in response to right-slip along major fault zones. This is particularly evident in the southern end of Saline Valley where both northeast and northwest-trending lineaments bend. In this region, northeast-trending zones exhibit increasingly easterly orientations and northwest-trending zones become more northerly. This observation is corroborated by aerial reconnaissance (fig. 3).

The added potential for rotation of crustal blocks caught between major shear zones has been explored by Luyendyk and others (1980) in a regional synthesis of structures south and west of the Garlock fault. Although the concept is intriguing and may be applicable to describe minor fragments of crust within the region, a structural model based on clockwise rotations of discrete blocks of major proportions within the Saline Valley area and the Waucoba Wash quadrangle in particular is not compatible with field evidence.
Figure 3. Curved scarp at the south end of Saline Valley. Note scarp offsetting alluvium on pediment surface at the base of the Nelson Range.
Surficial Analysis

Field evidence collected during this study indicates that Saline Valley contains many faults which offset alluvium of Quaternary age. Faults which were examined in alluvium and colluvium of the Waucoba Wash quadrangle were confined to outcrops of a certain morphological type. Only those surfaces which show a greater degree of rock weathering and desert varnish development and which are not presently undergoing deposition are observed to show fault offset. Rock weathering and desert varnish development were evaluated with consideration for the effects of substrate, principally how rocks of varying lithologies within the unit will alter its weathering characteristics.

Field work attempted to assess the degree of weathering and varnish development on rocks within individual alluvium units offset by faults whose scarps were profiled. Mapping of alluvium was done through use of black-and-white aerial photographs and color aerial photographs described above. Where possible, alluvium units were field checked and cross-cutting relationships noted.

In general, development of desert varnish on alluvium surfaces was a major factor in relative age assignment. For a given fan complex with a relatively uniform sediment source over an extended period of time, the darkness of the varnish surface seems to correlate directly with the relative age
of the sediment. This assessment is corroborated by cross-cutting relationships.

As Engel and Sharp (1958) have noted, development of desert varnish appears to be highly dependent on local conditions. They cite an example from the Mojave region of southern California in which well-varnished stones with a good ground-line varnish band and orange-brown bottom coating were observed firmly seated in the bed of a graded roadway constructed in 1931. They comment that conditions for varnish formation in this location may have been ideal since abundant manganese and iron are available in adjacent soils and the topographic situation is fairly stable. Other authors cite situations in which climate differences appear great enough to be major sources of variation between sites. In these instances, the connecting link does not appear to be time-related but rather to be dependent on some other factor such as lithology, local setting, geochemical relations, and climate. Seltzer (1952) states that varnish formation may take as little as 500 years, Klute and Krasser (1940) studied varnished stones on surfaces of Alpine moraines with ages of 40 to 80 years, and Engel and Sharp (1958) indicate varnish formation at the location cited above at only 25 years.

For these reasons it was considered impractical to make assumptions with respect to age correlations between alluvium units solely on the strength of observations of varnish development. While it serves as a useful tool for work within a given fan complex, varnish could not be regar-
ded as an absolute age indicator. Knauss and Ku (1980) have recently completed investigations of the possibility of using uranium series dating of varnish as a technique for absolute determination of surface age. The results of their research are encouraging and may be applicable to studies such as this one at a later date.

Deterioration of varnished surfaces was apparent in several areas within the quadrangle, the degree of which seems to bear relationship to lithology and to climate. Alluvium which is derived from a granitic source area or which contains abundant clastic debris of granitic lithologies will show a greater degree of deterioration of varnish. This is evident in the Cuesta locality and Paiute Canyon (Plate 3) where physical competence of the granitic rocks is low due to chemical weathering along extensive joints in bedrock. Varnish surfaces on this type of rock show patchiness related to the disintegration of the underlying rock. Similar observations of varnish deterioration on alluvium in the western Mojave desert have been made by Engel and Sharp (1958) and on stones of an alpine glacial moraine by Beschel (1957).

Disintegration of granitic rocks takes place in shells with a thickness of about 3 to 5 mm. Much of the erosion of the varnish layer seems to be confined to this surface weathering rind. Newly exposed surfaces do not show development of varnish. Overall varnish development on surfaces in alluvium of low mafic composition, and especially those
sediments reflecting a dominantly granitic parent terrain, is significantly less than on adjacent younger surfaces which have developed on alluvium of mixed lithologies.

It can be argued that erosion of varnished surfaces reflects the Holocene environment on the basis that exposed surfaces in some locations show varnish degeneration and no modern varnish development. For reasons cited above, inhibition of varnish development on these surfaces may reflect a source/substrate effect rather than climatological and temporal parameters. Engel and Sharp (1958) define what they consider to be ideal climatological conditions for varnish development as an average of 10 cm (4 in) precipitation and a mean temperature from 16° to 18°C (60° to 65°F). This is within the range of temperature and precipitation which could be expected for Saline Valley, based on records kept for the Death Valley region which is environmentally similar (Wardlaw, 1979). It would appear that Saline Valley is in a period of favorable conditions for varnish development.
Structural Analysis

Saline Range

Summary

The Saline Range consists of a dominantly northeast-trending series of tilted blocks separated by northeast-trending faults with a left-oblique normal offset. The orientation of cross faults to these fractures suggest a conjugate trend, although no actual measurements of offset were obtained.

The left-lateral component of slip is observed in alluvial units disrupted by faults with a northeast trend at the North End location of the study area (Plate 3). Natural levees within older alluvium cut by faults are consistently offset in a left-lateral sense as well as showing a dip-slip offset. The latter is shown by scarp profiles. Most alluvial profiles within the valley reflect this trend of offset with the exception of those adjacent to the eastern Inyo Range front at the Red Fan location (Plate 3).

Because of the subdued geomorphic expression of many of the channel features on older alluvium surfaces, precise location of levees and their crests was often difficult and old channels are frequently obscure. In addition, not all scarps are crosscut by geomorphic features identifiable on both upthrown and downthrown blocks.

In addition to the left-slip component, a significant dip-slip offset is observed, the largest occurring in allu-
vium associated with shallow bedrock faults. Faults within
the Saline Range show tension along an axis compatible with
the N80°W tensional axis proposed by Wright (1976, 1977) for
the region. The range itself consists of a series of tilted
blocks in mainly volcanic rock (Ross, 1967b, 1970) which
increase in elevation in a northeasterly direction within
the Waucoba Wash quadrangle. The Saline Range ramps steeply
towards Eureka Valley on the east and Saline Valley on the
west from a crest at an approximate elevation of 1980 to
2040 m (6500 to 6700 ft) (figs. 4 and 5). The gross appear­
ance of the Saline Range is a large uparched or elongate
domal structure with draping formations slumping at its
flanks.

Volcanic Rocks of the Saline Range

Ross (1967b, 1970) mapped and described the volcanic
rocks of the Saline Range within the Waucoba Wash quadran­
gle. He determined these rocks to have a thickness of more
than 300 m (1000 ft) based on observations of faulted sec­
tions with thicknesses of over 180 m (600 ft) exposed along
scarps. Although these rocks would be field classified as
basalts, their compositions are not typical of basalt and
they are better described as trachyandesites (Ross, 1970).
Analysis of the Saline Range cap rocks determined them to
be high in alkalis and low in magnesium in comparison with
other rocks of similar silica content (Ross, 1970). For
simplicity, Ross' (1970) field classification of mafic
Figure 4. Western boundary of the Saline Range. Note ramping of basalts beneath the valley fill to the west.

Figure 5. Eastern boundary of the Saline Range near Eureka Valley. Note domal shape of range and ramping of basalts eastward toward the valley floor.
extrusive rocks as "basalt" will be used here, without quotations.

Saline Range extrusive rocks appear in field observation to be variable in composition with abundant tuffaceous units interlayered with denser more mafic flow rocks. Ross (1970) notes that while the actual cap rocks consist of basalt, the underlying rocks compositionally reflect a more felsic to intermediate trend where they are exposed. Surface exposure of these latter units is somewhat limited in comparison to the voluminous basalts but areal extent of felsic to intermediate composition rocks beneath the basalt cap is probably considerable. Within the Dry Mountain 15-minute quadrangle of Burchfiel (1969) a thick sequence of bedded tuffs and rhyolites is exposed in the northwestern quadrant along the eastern boundary zone of the Saline Range.

Eruptive centers within the basalts are defined by circular outcrops of highly vesicular to scoriaceous basalt and cinder which have a distinctive red coloration. It is probable that cinder cones once occupied all of these sites, as remnants of cones can be seen at several locations, most notably to the east of Lower Warm Spring and Palm Spring at the southeastern edge of the Waucoba Wash quadrangle.

Ross (1970) comments that the northeast-trending fracture system which currently offsets the rocks of the Saline Range into a series of tilted blocks is closely associated with large tongues of volcanic rock. He feels that the fracture system initially served as a zone along which the
volcanic rocks were extruded and which has remained active as a locus of major tectonism within the valley.

Recent investigations within the Saline Range indicate that some relief existed in the area prior to the extrusion of the lowermost exposures of basalt (James M. Stroh, 1980, personal communication). Uplift within the Saline Range and/or downdropping of the Saline Valley block has produced overall relief of approximately 740 m (5700 ft). Much of the development of the valley itself appears to have occurred in the time elapsed since igneous extrusive activity ceased. Three potassium-argon ages were determined on caprock flows within the Saline Range, of which two may be considered reliable (Ross, 1970). Whole rock determinations for samples 14 and P-158 yield essentially the same ages; 3.0 ± 1.2 million years (m.y.) and 2.8 ± 0.5 m.y., respectively. In addition, a potassium feldspar analysis gives an age in a similar range of 3.5 ± 0.1 m.y. (Ross, 1970).

Onset of Late Cenozoic Tectonism

The southern California region underwent a radical change in tectonic processes about 5 m.y. ago with the opening of the Gulf of California and an eastward shift in the active plate margin of North America from a position west to one east of the Baja California peninsula (Atwater, 1970; Suppe, 1970). The San Andreas fault broke along a new inland trace to connect with the boundary along the Baja peninsula (Atwater, 1970). Timing of this event appears to coincide with renewed tectonic activity throughout the
southern California region. The Mendocino triple junction impinged upon the coast at the latitude of the study area approximately 13 m.y. ago (inferred from Atwater, 1970), marking the switch from a compressional, subduction-related regime to one in which plate motions involved a dominant right-lateral shearing component. Ekren and others (1968) report a shift to north-trending normal faults from Cenozoic normal faults of other trends in southern Nye County which occurred about 14 m.y. ago, corresponding to this shear field reorientation. The shearing component was confined to the continental borderland until the opening of the Gulf of California and shift of the San Andreas to its present location 5 m.y. ago. Movement of the locus of plate interaction inland of the coast would have placed increased stress on the continental interior, shifting the concentration of shearing of the plate margin inland. Wright (1976) comments that most dip-slip displacement along variously oriented range-bounding faults has occurred in the past 3 to 4 m.y. Prior to inception of this episode of dip-slip offset, the region exhibited a low relief and was discontinuously blanketed by extrusive igneous rocks of the basalt-rhyolite association which are also from 3 to 4 m.y. old (Wright, 1977). This model fits the Saline Range and Saline Valley region well.

Westward migration of the Sierra Nevada block as proposed by Davis and Burchfiel (1973) and Wright (1976) in the zone to the north of the Garlock fault provides a mechanism for the tensional component imparted to the region.
(Wright, 1976, 1977). The cause of this westward migration has been discussed by Best and Hamblin (1978) as possibly reflecting a rafting of the Sierra Nevada batholith westward by convection of mantle material against its keel.

Field Evidence

Overview

The western boundary of the Saline Range within the Waucoba Wash quadrangle consists of a series of tilted, fault-bounded northeast-trending blocks which ramp westward into the Saline depression. Dips on the surfaces of volcanic cap rocks in the range generally reflect dip slope tilting of discrete blocks in response to local uplift and regional extension. Marginal to the Saline depression, dips increase valleyward and orient in a more westerly trend. The appearance of the range locally is that of a "megaslump" in which surfaces of volcanic rocks show a westerly plunge and in places show valleyward rotation. Work associated with this thesis was concentrated within alluvium which overlies the Saline Range bedrock and which more directly reflects tectonics within the valley during Quaternary time. Two areas are chosen for study which are closely associated with the Saline Range itself, based on their accessibility and occurrence of fault scarps within alluvium. These have been designated as Big Scarp and Playa locations (Plate 3). Other faults of northeasterly trend will be discussed in the following section.
Big Scarp

The Big Scarp locality lies in sections 8, 9, 10, 15, 16 and 17, T13S, R38E in the lower third of the Waucoba Wash quadrangle (Plate 3). The salient feature of this area is the long, high scarp developed in both alluvium and basalt bedrock which trends over 8.5 km (5 mi) northeasterly and ramps downward about 150 m (500 ft) in elevation to the southwest (fig. 6). The basalt surface is highly irregular with a vesicular top and representative dip and strike are difficult to obtain. One surface at location 21 (Plate 3) has a strike of N20°E with a 55°NW dip. To the northeast of this location, Ross (1967b) records a N30°E 30°NW strike and dip, and these values seem fairly consistent. This large scarp, the northern boundary scarp, faces south and defines that boundary of a complex graben, the southern limit of which is a topographically lower north-facing scarp which also exhibits bedrock offset. The graben between these two scarps contains a number of smaller fault scarps which offset alluvium and which seem to reflect the response of surficial materials to subsurface dislocations of bedrock.

Alluvial Unit Qoa

The main south-facing scarp shows a number of features which indicate progressive tilting of the faulted block with time. A distinct angular unconformity exists within alluvium exposed in the scarp, separating two lithologically distinct units. Alluvial unit Qoa both overlies and occurs between flows of basalt along Big Scarp near location 21.
Figure 6. Aerial photograph of the Big Scarp locality.
Qoa is alluvial material dominated by granitic clastics derived from the drainage of the Paiute Canyon area. Rocks of the Paiute Monument pluton within Paiute Canyon are coarse-grained quartz monzonites with distinctive, large (up to 20 mm across), well-formed (megascopically euhedral) pink potassium feldspar phenocrysts which give the rock a distinctive porphyritic texture. Mafic minerals in this unit are often chloritized and whole rock epidotization is locally common, the pink potassium feldspar standing out in striking contrast. Paiute Monument quartz monzonite rocks constitute about 99% of the total alluvium in the lower portions of the unit with occasional quartzite (both light and dark colored) and basalt clasts occurring throughout the section. The basalt is probably derived from slope wash off adjacent basalt bedrock, or from basalts cropping out in Paiute Canyon to the northwest. The quartzites may be derived from limited outcrops of Cambrian units in the watershed of Paiute Canyon. Qoa has a distinctly bimodal size distribution, as might be expected of sediment derived from the weathering of granitic outcrops (Mabbutt, 1977). Boulders (greater than 256 mm diameter) are frequent, many with diameters of 2 meters or more, but most are within the 1 to 2 meter range (fig. 7). Cobbles (64 - 256 mm) are common and represent about 50% of the unit. The sand to small pebble size fraction (0.2 to about 16 mm) is also common and occurs as lenses and interfillings between the larger boulders and cobbles.
bles.

A slight composition change in Qoa\textsubscript{1} upward and westward in the section reflects an increase in rocks of non-granitic lithologies such as quartzites, marbles, limestones and dolomites, and hornfelses. This probably marks the influx of alluvium from the north in a time when faulting was disrupting the drainage of Paiute Canyon and southward tilting of the valley was making conditions favorable to a more southerly drainage direction for areas in the north end of the valley. Continuity of Qoa\textsubscript{1} across the width of the valley below the unconformity suggests that the drainage of Waucoba Wash did not flow south across this portion of the valley during the time of Qoa\textsubscript{1} deposition.

Alluvial Unit Qoa\textsubscript{2}

Alluvial unit Qoa\textsubscript{2} which overlies Qoa\textsubscript{1} lies on an angular unconformity. The contact between the two units is regressive to the east. Qoa\textsubscript{2} does not seem to be as greatly as inclined as Qoa\textsubscript{1} which has a 5° dip in a N42°W direction, measured on a sand lens. Clast lithology of Qoa\textsubscript{2} differs from Qoa\textsubscript{1} with abundant quartzite, limestone, marble and hornfels in addition to some granitic rocks. Qoa\textsubscript{2} is better sorted than Qoa\textsubscript{1} and most particles are in the pebble to cobble size range (fig. 8). Interstitial lenses are of silt to fine sand and are much finer than interstitial sediments in Qoa\textsubscript{1}. It is inferred from the above that the source of Qoa\textsubscript{2} is more distant from Big Scarp than that of Qoa\textsubscript{1} which is known.
Figure 7. Alluvial unit $\text{Qoa}_1$ at Big Scarp locality.

Figure 8. Alluvial unit $\text{Qoa}_2$ at Big Scarp locality.
The abrupt change in alluvial lithology from \( Q_oa_1 \) to \( Q_oa_2 \) at this location has several possible causes:

1. the granitic source of \( Q_oa_1 \) was depleted;
2. the channel of the main wash was in some way altered, as described above in the previous heading;
3. the granitic source of \( Q_oa_1 \) was isolated due to tectonic uplift.

Alternatives (2) and (3) will be discussed below. It is unlikely that (1) provides the answer since the Paiute Canyon drainage currently supplies granitic sediment of the type described to the Waucoba Wash system.

Geomorphology of the upper surface of Big Scarp

Geomorphic evolution of the tilted land surface is evident in features seen both from the air and from the ground. The easternmost surface of the upthrown block to the north of the major scarp at the Big Scarp location shows subdued relief with few drainage channels except for those of large cross sectional area. Channels show a distinctly rounded appearance with low, sloping gully walls and moderately even channel bottoms. Pavements developed on these surfaces are smooth and regular. In a progressively westward direction, the pavement becomes rougher and channels increase in number and drainage complexity (fig. 9). Channel bottoms are increasingly irregular and gully walls steeper to the west. Major active channels within the modern drainage of Waucoba
Figure 9. Alluvial surface north of the northern boundary scarp, Big Scarp locality. Note westward younging of geomorphic features.
Wash have wide bottoms which are somewhat terraced, which contain a variety of sedimentary environments, and which contain abundant clastic debris of varying sizes, often occurring in zones due to levee formation and bank overflow. Gully walls are nearly vertical and often overhang where undercut by ephemeral stream flow.

Local Tectonics

The distinct lithological shift in rock type included in Big Scarp alluvial units Qoa\(_1\) and Qoa\(_2\) may hold tectonic implications. Paiute Canyon to the north and west of the Big Scarp locality opens on to a large fan with a surficial appearance and sediment lithology which set it apart from other fans in the area. The Paiute Canyon watershed drains an area dominated almost exclusively by granitic rocks of the Paiute Monument pluton, described earlier. Near the mouth of Paiute Canyon, basalts locally intrude these granitic rocks and may provide a limited source of basaltic alluvial clasts. In addition, epidotization of all but the large pink potassium feldspar phenocrysts in some areas within the canyon produces a distinctive source of marker clasts. The area from which Qoa\(_1\) was derived is clearly Paiute Canyon. At some time after the basalt extrusion, uplift along the fault marking the northern boundary of Big Scarp caused a gradual westward shift in the locus of deposition of Qoa\(_1\). This shift can be seen in (a) the increase in irregularity of the Qoa\(_1\) surface to the west,
(b) increase in number of channels and steepness of channel walls westward and in preservation of smaller channels, and (c) slight composition change in Qoa₁ upward and westward in the section, described above.

Uplift of Big Scarp can account for the westward shift in Qoa₁ deposition but cannot account for the angular unconformity between Qoa₁ and Qoa₂ nor for the corresponding change in sediment source. For an explanation of these phenomena, data from the Cuesta locality will be considered in a later section. Briefly, it may be that the uplift of the Cuesta block eventually diverted the distributary channels of the Paiute Canyon fan complex to a region south and west of its former drainage. This southward and westward tilting of the valley floor can also explain influx of Qoa₂ material from the north. As described above, the first appearance of Qoa₂ in the stratigraphic section marks the establishment of the modern drainage of Waucoba Wash which does not seem to have existed prior to this time.

Diversion of the Paiute Canyon fan drainage caused isolation of the old fan surface from active deposition and it has since become an area in which deflation by wind and physical and chemical breakdown of stones at the surface have combined to produce a remarkably smooth and even-textured pavement, dominated by gruss and scattered boulders.
Fault Scarp Profiling

Scarp profiles along the northern boundary scarp at the Big Scarp locality provide additional evidence for repeated offset along the principal fault of the northern boundary zone. Profiles 13 and 17 and observations at locations 14 and 15 (Plate 3) support the hypothesis that uplift of the basalts and their alluvial cover has been progressive and episodic, the hinge of uplift lying to the west beneath the alluvial cover of the Saline depression. Distinct bevels across the scarp profiles indicate multiple movements along the fault in a dip-slip sense.

Beginning at location 13, the westernmost profile across the northern boundary scarp, two bevels are evident. Locations 14 and 15 are progressively east of location 13 along the northern boundary scarp. At location 14, three bevels seem to occur along the scarp whereas at location 15 the number of bevels has increased to four. No profiles were measured in these latter two locations.

Profile 17 is near a bend in the northern boundary scarp. The section includes both $Qoa_1$ and $Qoa_2$ units. Considerable slope wash has accumulated at the base of the scarp and obscures the lowermost portion, accounting for the first obvious negative change in slope. Seven bevels are present, four of which suggest a tectonic origin.

To the south of the northern boundary scarp are a number of lower scarps which offset alluvium. In no place are these scarps observed to offset bedrock. Bedrock can be
inferred to lie at shallow depth within this zone on the basis of data presented in the regional Bouguer gravity survey of Mabey (1963) and Chapman and others (1971) for the Death Valley region, as well as from observations of surficial outcrop trends and their westward projections. Faults which affect alluvium within this area seem to be reflecting dislocations in bedrock at relatively shallow depth and surficial adjustments of alluvium to those dislocations.

Scarps in alluvium are identifiable on the ground by their linearity and also by the fact that many trend perpendicular to channels associated with the dominant drainage trends for the area. Lag deposits are also characteristic of surfaces in faulted alluvium and occur on the crests of scarps. The finer material is removed by wind and slope wash, concentrating the larger clastic fraction on the upthrown block. Faulted surfaces are characterized by well-developed pebble pavements. Desert varnish coats clastic material at the surface and many rocks are ventifacts. Most alluvium involved in surface faulting is Qoa2.

Quantitative basis for observations was provided through profiling of scarps, accomplished through use of a technique modified from Wallace (1977) and described above. A Brunton compass was employed to measure slope angle rather than an Abney level, but otherwise the procedure was the same. Several profiles were made of segments of the major northern boundary scarp as well as less conspicuous scarps
in alluvium within the graben to the south. Sites were selected to present, as much as possible, a representative sample of scarp features within the area which would give evidence of its tectonic history. A problem in interpretation of this data centers on how alluvial units degrade in response to surficial processes. The Wallace scarp profiling techniques are designed to determine scarp age through correlations with scarp slope angle and projections of systematic scarp degradation through time. Wallace (1977) admits that many variables are involved in determining rates of slope degradation, assuming that a scarp is developed which initially has a free face. He presents curves for both colluvial material and bedrock but cautions that colluvium can be highly variable (fig. 10). Factors such as degree of induration, particle size range, vegetative cover, hydrologic relationships, bedding characteristics, climate, initial slope angle and resistance of particles of varying lithologies to physical and chemical deterioration will play a large part in the ability of a slope to withstand erosion. In addition, scarp height is critical to the rate of slope degradation. Both Wallace (1977) and Bucknam and Anderson (1979) comment on the importance of scarp height considerations as well as those of slope angle in determining scarp age. However, Wallace fails to address this variable in derivation of his graphs.

Bucknam and Anderson (1979) derive an equation for use with 3 meter high scarps in three selected localities in
Figure 10. Plot of scarp age vs. maximum slope angle (after Wallace, 1977).
Utah. Scarp slope angle, $\theta$, equals $-8.5 \log T + 52.5$, where $T =$ time in years. Thus, given slope angle, approximate age can be calculated. The equation provides good correlation with Wallace projections for the same scarps and scarps in this study area. Use of the equation in this manner was not implied by Bucknam and Anderson (1979), however, and the reader is urged to use extreme caution and skepticism in reviewing age data presented. The Bucknam and Anderson (1979) equation (hereafter referred to as B&A equation) is used simply to give a more precise number to Wallace projections. It is not intended to be absolute but may provide a general indication of age and possibly of recurrence interval.

It will be noted that several of the scarps discussed in this paper contain bevels which are not necessarily the result of the faulting which has occurred episodically at the same location through time. Rather, faults which contain splays that separate and coalesce often give the appearance of tectonic beveling but the bevels may indicate events which are contemporaneous.

Slope degradation is a logarithmic function with respect to scarp age and small changes in the lower slope angles produce large variations in derived scarp age, by either Wallace or B&A methods. Lower slope angles are usually associated with scarps of lesser height and care must be taken in evaluation of this data.
Additionally, Wallace (1977) and Bucknam and Anderson (1979) develop curves and equations for use with profiles derived in regions with significantly different climatic conditions than the study area. Climate would have a noticeable effect on rates of slope degradation and slope angle modification.

Locations 11 and 12, central graben area

At locations 11 and 12, two scarps of comparable height are profiled and observed to cut alluvium of similar surface. The geomorphic development of alluvium surfaces at these two locations is essentially identical. Desert varnish coatings on surface rocks have the same color and surfaces have the same degree of pavement development as reflected in the coarseness and tightness of the surface. It can be suggested that the alluvium at these two localities is the same age.

Profile 11 is of a scarp with a height of 2.4 m (7.9 ft) and a total length from crest to base of 12 m (40 ft). The scarp faces north. The scarp slope shows no evidence of beveling and strongly suggests a single phase of offset (fig. 11). The maximum slope angle on this scarp is 13° and is measured on a wash-dominated slope. The crest of the scarp is rounded and trenching of the scarp face uncovered pebbles and cobbles embedded in a layer of fine silt to sand which continued to a depth of about 20 cm (8 in). Using curves presented by Wallace (1977; fig. 10, this paper),
Figure 11. Fault scarp profile 11, Big Scarp locality. (Notches mark ends of measured slope segments, slope angles are shown between notches. Arrow indicates beginning of profile.)

Figure 12. Fault scarp profile 12, Big Scarp locality. (X = change in slope direction.)
this slope represents a surface with an approximate age of slightly greater than $10^5$ years. The B&A equation yields an age of 44,000 years, which is younger than the Wallace age by about an order of magnitude.

Profile 12 extends 17 m (56 ft) from crest to base of the scarp and shows a scarp height of 1.36 m (4.5 ft). The scarp faces north. Once again, the scarp slope shows no indication of beveling, suggesting only a single faulting event (fig. 12). The maximum slope angle measured along this profile is 12° which gives a Wallace age of $10^5$+ years and a B&A age of 58,000 years. The faulted surface and sub­strate is the same as in profile 11 and the scarp morphology is similar to the former, with a rounded crest and wash­dominated slope. It is possible that these two scarps re­present offsets produced in the same tectonic event. A differ­ence of only 1 m in scarp height could account for a more rapid degradation of the slope in profile 12 and resulting lower maximum slope angle. This illustrates how a 1° differ­ence in slope which is possibly related to initial scarp height or initial slope angle can cause a 14,000 year differ­ence in inferred age.

Location 20

Near the northern boundary scarp at location 20 a scarp is cross-cut by an arroyo. Measurement of the fault plane separating alluvial units was possible within the cross section exposed by the channel cut. Dip of the fault plane
is approximately 65° to the south and strike of the scarp is about N80°E at this location. The scarp crest is quite rounded, as are many in this area (fig. 13). Degradation of the scarp slope is not as great as in profiles 11 and 12 and the slope is both debris and wash controlled. Two bevels are suggested in the profile, making this scarp unique. Within the graben area of faulted alluvium at the Big Scarp locality, only profile 20 shows evidence of multiple offset (fig. 14). Its proximity to the northern boundary scarp which shows evidence of at least four fault events may account for this reactivation.

Faulted alluvium at location 20 is of Qoa₂. Granitic clasts are rare to sparse in both the upthrown and downthrown blocks. The upthrown block contains approximately 25% granitic rocks while the downthrown block contains 5% or less. Most of the coarse clastics in the southern downthrown block is quartzite with subordinate hornfels, metasedimentary material and minor carbonate. The upthrown northern block contains more abundant granitic rocks plus quartzites, hornfels and less than 1% carbonate. The source area for both units seems to be from the west to northwest because neither unit contains what could be verified as volcanic rocks of the Saline Range. Overall scarp height at location 20 is 2.2 m (7.2 ft) and this can be broken into two bevels of 0.7 m (2.3 ft) and 1.5 m (4.9 ft), indicated as segments 20a and 20b, respectively. Slope measurements along section
Figure 13. Fault scarp at location 20, Big Scarp locality.

Figure 14. Fault scarp profile 20, Big Scarp locality.
20a of the scarp profile show a maximum angle of 10° which translates to a Wallace age of \(10^6\) years and a B&A age of 100,000 years. The maximum slope at section 20b is considerably steeper and measures 19°, giving a fair correlation between a Wallace age of \(10^4\) years and a B&A age of 8700 years. The recurrence interval for faulting along this scarp is on the order of 90,000 years, given these age assumptions. For the area as a whole, this figure seems unreasonable but considering that this scarp is developed within an alluvium-dominated graven bounded by faulted bedrock it is possible that fractures within the alluvium may reactivate in different patterns for each faulting event.

Locations 13 and 17, northern boundary scarp

Profiles 13 and 17 cross sections of the northern boundary scarp. Volcanic bedrock is believed to down-ramp westward beneath the alluvial cover at shallow depth along this scarp and can be seen dipping westerly in outcrop at its eastern margin adjacent to the Saline Range uplift.

Profile 13 is near the westernmost surficial expression of the northern boundary scarp (fig. 15). Two bevels, scarp segments 13a and 13b, are recorded and correspond to maximum slope angles of 14.5° and 38°, respectively. Slopes in the alluvium uplifted along the scarp at location 13 are developed in \(\text{Qoa}_2\). Induration of this unit is moderate to good with alluvium consisting almost entirely of pebble to cobble sized clasts. Lenses of material in the silt to sand size
20a of the scarp profile show a maximum angle of 10° which translates to a Wallace age of 10^6 years and a B&A age of 100,000 years. The maximum slope at section 20b is considerably steeper and measures 19°, giving a fair correlation between a Wallace age of 10^4 years and a B&A age of 8700 years. The recurrence interval for faulting along this scarp is on the order of 90,000 years, given these age assumptions. For the area as a whole, this figure seems unreasonable but considering that this scarp is developed within an alluvium-dominated graven bounded by faulted bedrock it is possible that fractures within the alluvium may reactivate in different patterns for each faulting event.

Locations 13 and 17, northern boundary scarp

Profiles 13 and 17 cross sections of the northern boundary scarp. Volcanic bedrock is believed to down-ramp westward beneath the alluvial cover at shallow depth along this scarp and can be seen dipping westerly in outcrop at its eastern margin adjacent to the Saline Range uplift.

Profile 13 is near the westernmost surficial expression of the northern boundary scarp (fig. 15). Two bevels, scarp segments 13a and 13b, are recorded and correspond to maximum slope angles of 14.5° and 38°, respectively. Slopes in the alluvium uplifted along the scarp at location 13 are developed in Qoa_2. Induration of this unit is moderate to good with alluvium consisting almost entirely of pebble to cobble sized clasts. Lenses of material in the silt to sand size
Figure 15. Fault scarp profile 13, Big Scarp locality.
range occur only rarely in the section. A large arroyo crosses perpendicular to the scarp at this location and channel walls are observed to hold a vertical to overhanging face. This may be due in part to channel wall cementation by carbonate (Lattman, 1973).

Within the arroyo, two calcium carbonate-rich horizons are developed in alluvium of the arroyo wall. These calcium carbonate layers consist of coatings of larger rocks and cementation of finer material. Carbonate horizonation is distinctive because of the lighter color imparted to the cemented alluvium and the prominent rinds on the larger pebble to cobble sized clasts. Lattman (1973) and Cooley and others (1973a, 1973b) have described this type of carbonate accumulation as "gully bottom cementation". The deposit described by Lattman (1973) is limited in lateral extent beyond the immediate arroyo walls. The deposition of calcium carbonate occurs when carbonate-charged waters flow through the arroyo during episodic flooding. Deposits thus are accumulated in a narrow zone close to the gully bottom. It was not determined that these deposits fit all of Lattman's criteria. Attempts to excavate the channel wall with an ice axe and with a hammer and chisel proved inadequate due to the extreme resistance of the deposit.

Uplift of the land surface through faulting will lower the baselevel of the arroyo and subsequent nickpoint migration will scour a new stream bottom below the level of the former one, leaving it perched and isolated. If the stream
bottom is well-defined by a carbonate deposit such as the one described above, the gully wall will be marked by a line of carbonate after nickpoint retreat.

The lower of the two carbonate horizons described earlier within the arroyo walls at location 13 corresponds to the nickpoint presumed to be derived from the last major fault movement. Height of the lower carbonate horizon above the modern gully bottom is about 60 cm (2 ft). This lower horizon is extremely well cemented, locally contains relatively pure carbonate, and dominates a pebble layer in unit Qoa₂ composed principally of granitics, some limestones and marbles, quartzite and hornfels. The carbonate layer has an average thickness of only 2 cm (0.8 in). Carbonate coatings have a thickness of several millimeters and cover entire rocks, not only their bottoms.

The upper carbonate horizon is approximately 2 m (6.6 ft) above the modern gully bottom and consists of a less indurated zone of cementation confined to the bottoms of larger size rocks. Alluvium within this zone is somewhat coarser than the lower unit previously described but contains the same Qoa₂ compositional range. Separation of these two horizons of carbonate is about 140 cm (4.6 ft) (fig. 16). These two carbonate layers correspond to the two major bevels evident in the scarp profile and represent two periods of fault offset. The correlation is striking, with the separation between the first and second bevel on the profile measured at 1.4 m (140 cm). Carbonate cementa-
Figure 16. Photograph of offset carbonate horizons at arroyo near location 13, Big Scarp locality.
tion above the upper horizon was not observed.

The smaller size and range in size of rocks of Qoa<sub>2</sub> exposed in the scarp and arroyo indicates a more distant source than that of Qoa<sub>1</sub> exposed in profile 17 to the east. Slope angles for this profile indicate a Wallace age of 10<sup>4</sup> years and a B&A age of 29,500 years for section 13a and a Wallace age of less than 10<sup>2</sup> years and a B&A age of only 50 years for section 13b. The latter age is anomalously young when compared to other scarps in the study area. Proximity of profile 13 to the arroyo and possible influence of carbonate infiltration may be affecting the stability of slopes.

Profile 17 is located east of profile 13 along the northern boundary scarp and represents a portion of the scarp showing a larger number of offsets, as indicated by bevels (fig. 17). Profile 17 also contains the angular unconformity separating units Qoa<sub>1</sub> and Qoa<sub>2</sub>. The scarp has been segmented into seven sections, not all of which are necessarily representative of fault-related bevels. Section 17a has been further subdivided into two sections, 17a<sub>1</sub> and 17a<sub>2</sub>. A 5° change in slope between these two sections suggests that the upper bevel could be an ancient scarp rather than erosional reounding of the crest. The height of the slope at 17a<sub>1</sub> is 0.4 m (1.3 ft) and the maximum angle of slope is 8°, yielding a Wallace age of 10<sup>6</sup> years and a B&A age of 149,500 years. Slope 17a<sub>2</sub> increases to a maximum angle of 15° with a height of 2.9 m (9.5 ft). Ages for 17a<sub>2</sub> are 10<sup>5</sup> (Wallace, 1977) and 22,500 (Bucknam and Anderson,
Figure 17. Fault scarp profile 17, Big Scarp locality.
1979) years.

The lower portion of profile 17 consists of five segments. Segments 17b, 17c and 17d reflect a steepening trend in the slope toward the base and are likely representative of fault-related beveling. Segments 17e and 17f at the base of the scarp are on slopes complicated by wash slope accumulations and ages derived from this region of the profile are probably not indicative of age of fault movement. A total of 5.4 m (17.7 ft) of offset is indicated for the lower portion of the scarp if segments 17e and 17f are taken collectively, suggesting that the most recent movement may have been large.

Slope angles in section 17b were developed in Qoa$_2$ and show a maximum inclination of 22° and a bevel height of 2.9 m (9.5 ft). This gives a Wallace age of slightly more than $10^3$ years and a B&A age of 4000 years, marking the beginning of what may be interpreted as Holocene movement along the scarp. Section 17c is an anomalous slope extending for 0.8 m (2.6 ft) in height and having an inclination of 26°. This may be the upper portion of section 17d but also may represent an offset along the main scarp of a smaller magnitude than other offsets whose heights cluster around 2.5 to 3.5 m (8.2 to 11.5 ft). The Wallace age for this segment is $10^3$ years and the B&A age is 1300 years, yielding good correlation.

Between sections 17c and 17d lies the unconformity separating units Qoa$_1$ and Qoa$_2$. The bevel in the slope is
marked by a change in both the coloration of the units and their lithologies. Section 17d has a very steep slope developed in the granitic alluvial unit Qoa\textsubscript{1} which has a characteristic bimodal size range dominated by cobbles to boulders and fine to coarse sand. Material of an intermediate size is subordinate. Differences in response of Qoa\textsubscript{1} and Qoa\textsubscript{2} to weathering may affect the nature of the slopes developed on scarps offsetting these materials. For this reason, it is suggested that section 17c be included with 17d.

Slope measurements in Qoa\textsubscript{1} are difficult because of the bouldery nature of the unit and the irregularity of the slope in response to the substrate. A maximum slope angle of 31° was measured, corresponding to scarp height of 3.2 m (10.5 ft). Inclusion of section 17c raises the height to 4 meters (13 ft). In order to standardize the slope angle with the substrate, the 26° slope angle measured and approximate ages derived in section 17c will be used for the entire 4 m segment.

Scarp segments 17e and 17f lie within the debris and wash dominated portion of the scarp and the slope angle measured reflects debris accumulation at the base of the scarp. Calculations of ages for this section of the scarp are therefore not representative of the true age and will be significantly older. Segment 17e lies within the debris slope and has an overall height of 3.6 m (11.8 ft), as well as can be ascertained. Maximum slope angle measured for this segment is 23.5°. A Wallace age of 10^3 years and a B&A age of 2600
years were calculated but are not representative. The relative youth of this scarp segment is indicated, however, considering that this young age is derived from debris slope measurements.

Attempt to obtain a strike-slip component for these faults did not prove to be particularly successful. One observation of an apparent offset of an older channel across a scarp in the graben area was made by Dr. D. Burton Slemmons during field checking of the thesis area. An indication of left-lateral offset was noted in a displaced drainage. Additional work in the area did not locate other indications of lateral offset.

Playa

The Playa locality lies adjacent to the western border of the Saline Range and contains a small rhomb-shaped ephemeral lake surrounded by faulted blocks of basalt bedrock (Plate 3). Scarps in alluvial material profiled at locations 29 and 31 have a geomorphic expression that suggests greater age than those in other areas sampled. Crests of scarps are quite rounded and even a relatively high scarp of 3.0 m (9.8 ft) shows a maximum slope angle of only 15.5°, statistically less than in any other area. Alluvial material exposed at the surface and within arroyo walls is representative of the typical clastic assemblage associated with bedrock units in the drainage of Waucoba Wash. White quartzites are especially common as well as granitic clasts which suggest an origin in the Papoose Flat pluton. Poorly devel-
opied imbrication of pebbles at location 32 indicates a paleo-
current direction toward the east-southeast, in an area
presently draining northward toward the playa. Formation of
the playa in its current expression therefore has occurred
since the development of the alluvial surface to its south.

Alluvium at location 28 was found to closely resemble
Qoa at Big Scarp location 17 to the south and aerial photo-
graphs show it to form a continuous surface between those
two localities (fig. 18). The appearance of advanced age
of this alluvial surface is supported by darkly varnished
and well-developed ventifacts. The quartzites and volcanic
rocks are both polished and grooved by wind action. Carbon­
ate rocks show well-developed solution etching with sharp
spikes on their lower surfaces. The crests of scarps in
this area show a high degree of rounding and even low scarps
have lag deposits of cobble to small boulder sized material.

Location 29

A profile was measured across a 3.6 m (11.8 ft) north­
facing scarp in this location which has what seems to be a
break in slope corresponding to a tectonic-related bevel
(fig. 19). The maximum slope angle for profile 29a along
the upper 0.6 m (2 ft) of the scarp is 6° and 15.5° for pro­
file 29b, the lower 3.0 m (9.8 ft). Using Wallace (1977)
criteria for evaluation of scarp age, the upper bevel has an
apparent age of 10^7 years and is the oldest scarp measured
within the study area. The B&A equation (1979) gives an age
of about 300,000 years. Profile 29b is on an anomalous scarp
Figure 18. Photograph looking north from Big Scarp to Playa locality over the Qoa₂ surface. Note continuity of surface between these two areas.
Figure 19. Fault scarp profile 29, Playa locality.
with a maximum slope angle only half that of scarps having comparable height in other areas. A Wallace age of $10^5$ years is calculated for this scarp and a B&A age of 22,500 years. Observations of geomorphic expression within the area mentioned above support the indications given by scarp height/maximum slope angle relationships, that this is an old feature relative to others in the study area. Figure 20 shows the appearance of this scarp in the field.

Location 31

The scarp profiled in location 31 is south-facing and shows a single offset (fig. 21). Scarp height is 1.0 m (3.3 ft) and maximum slope angle is 12.5°. The Wallace age derived for the scarp is about $10^6$ years and the B&A age is about 55,000 years. This scarp is tentatively classified with scarps in other areas within the quadrangle that have approximate ages of less than 100,000 years but greater than about 20,000 years (Table 2 shows this classification).

No scarps in the Playa location seem to be of Holocene age.

Other Northeast-trending Faults

Three locations studied within Saline Valley show additional evidence of northeast-trending faults which offset alluvium. These areas are shown on Plate 3 and are designated as the Cuesta, North End and Spring Canyon localities.

Cuesta

The Cuesta locality includes sections 1, 6 and 12,
Figure 20. Photograph of scarp at location 29.

![Photograph of scarp at location 29](image)

Figure 21. Fault scarp profile 31, playa locality.
T13S, R38E and section 6, T13S, R37E. Hill 2215, located in the NW 1/4, NE 1/4, section 6, T13S, R38E displays a series of stepped surfaces within the alluvium which is uplifted and exposed in the landform (fig. 22). At location 1, an arroyo trending approximately N5°W on the east side of Hill 2215 exhibits bedding within its walls which dips 25° northeasterly and strikes N40°E. The large boulders of granite contained within this alluvium are of the Paiute Monument type with large (about 20 mm across), well-formed phenocrysts of potassium feldspar. Material constituting the older alluvium within Hill 2215 is of the Paiute Monument source. Current gradients measured in alluvium within modern stream bottoms in this area are 3 1/2° to the south and southeast. It seems that the older alluvium of Hill 2215 has had a reversal of gradient, probably through back rotation of the block which contains it with respect to the eastern Inyo frontal fault zone.

A minimum of 25° of eastward rotation would serve to restore a paleogr gradient of 0° to the alluvium within the faulted block. To restore a more realistic gradient in a downvalley direction from the source area in Paiute Canyon, it would be necessary to rotate the alluvial block 30° to 35°, west side up.

A fault which intersects the eastern front of Hill 2215 at location 2 has a strike of N14°W and a dip of approximately 80°NE. This fault separates older alluvium to the east from a basalt unit to the west. The basalt stratigra-
Figure 22. Photograph of Cuesta locality from the north.
phically overlies the alluvium and the fault thus has an apparent reverse slip (fig. 23). The trend of the fault is parallel to that of the Inyo Mountain front. The fault, described at locations 2 and 6, is offset vertically along a scarp on the eastern flank of Hill 2215.

One interpretation of this apparent reverse offset relies on tectonic rotation of this block. If it is assumed that the fault pre-dates the normal fault which fronts the cuesta to the east and had an initial normal-slip offset, then a $25^\circ$ east rotation of the block containing the fault will restore its dip to $75^\circ$NW. A $30^\circ$ rotation will produce a dip of $70^\circ$NW. Normal faulting with these dips would be compatible with the range in dip angle predicted for Basin and Range-type extensional tectonics (Wallace, 1977). A second interpretation is that the fault has a primary reverse offset and post-dates or is contemporaneous with the cuesta-bounding fault to the east. In this case, the fault would not have been affected by subsequent rotation. The author favors the first interpretation.

The maximum age of faulting both at the eastern cuesta boundary and at locations 2 and 6 is limited by the age of the offset rock units. Alluvium of the Qoa$_1$ type is the youngest unit at these localities and both overlies and occurs between volcanic units with an inferred Plio-Pleistocene age (Ross, 1970). The granitic boulders present within Qoa$_1$ show the development of pronounced weathering rinds with
Figure 23. Photograph of fault at location 2, Cuesta locality. East side is to left of photo.
accompanying exfoliation. Surfaces of boulders are broken by light to moderate finger pressure and potassium feldspar phenocrystals stand out in positive relief. Calcium carbonate locally fills fissures within the alluvium and coats individual cobbles and boulders. The overall appearance suggests great age, no doubt enhanced by prior alteration of source rocks in Paiute Canyon.

It is implied that tilting of the Cuesta block has been progressive. Bedding in the younger channel fill shows less back rotation than that in $\text{Qoa}_1$. Further evidence of back rotation of the Cuesta block is seen at location 4. Here an outcrop of younger alluvium, representing a remnant of channel fill from the adjacent tributary canyon, is plastered to the north canyon wall against $\text{Qoa}_1$. No matching alluvium appears on the south side of the wash and the striking mismatch in sediment size emphasizes the difference between this younger terrace fill and $\text{Qoa}_1$. The terrace material is finer grained, has thinner bedding laminae, and a greater degree of sorting in comparison with the poorer sorting, coarser texture, greater angularity and less well-defined bedding of $\text{Qoa}_1$. Dips on bedding in the younger channel deposit are $5^\circ\text{NNW}$ with a strike of approximately $\text{N10}^\circ\text{E}$. Correction of this NNW dip to correspond to modern SSE drainage gives an approximate $8^\circ$ southerly rotation.

The Cuesta locality is important for its inferred effect on depositional trends to the south and east, particularly in the Big Scarp locality. $\text{Qoa}_1$ at the Cuesta site
occurs both above and below basalt units, presumably related to flows in Paiute Canyon to the west but possibly related to Saline Range volcanism to the east. Deposition of Qoa₁ toward the east therefore occurred prior to, contemporaneous with, and after the extrusion of basalt in this area and at the Big Scarp locality. Faulting which effected the uplift of the Cuesta block appears to post-date at least some of the tectonic activity to the east at Big Scarp. A major northwestward tilt of the Cuesta block caused a southerly deflection of the drainage of Paiute Canyon, effectively removing that locality as a source of sediment for points to the east.

Qoa₁ can be seen to overlie Plio-Pleistocene basalt in the Big Scarp locality to a thickness of about 20 m (60 ft) and approximately 30 m (100 ft) in some localities where channels allow observation of a partial section. In addition, Qoa₁ crops out in patches atop basalt to the east beyond the northern boundary scarp. The inference is that deposition of Qoa₁ from the Paiute Canyon source continued in the Big Scarp locality well after the time of major basalt eruptions. Initiation of uplift within the Saline Range gradually shifted the locus of deposition of this unit westward. The angular unconformity between Qoa₁ and the younger Qoa₂ in profile section 17 c,d of the Big Scarp locality marks the major uplift of the Cuesta block and diversion of Paiute Canyon drainage to the south. The age of the bevel at Big Scarp location 17b, the next older bevel which lies
entirely within $Q_o a_2$, is 4000 years using the B&A equation. Profile section 17 c,d has an approximate age of $10^3$ years (Wallace, 1977) or 1300 years (Bucknam and Anderson, 1979). It would appear the Cuesta block faulting occurred contemporaneous with or later than Saline Range-related uplift, possibly allowing a spill-over of $Q_o a_1$ material into the Big Scarp area until northwestward rotation of the block during the Holocene created an insurmountable gradient (fig. 24).

North End

Scarps studied in the North End locality (plate 3) are situated in sections 23, 24, 25 and 26, T12S, R37E. As in the Big Scarp area, North End scarps offset only alluvium displaying a well-developed pavement surface with dark varnish coatings (fig. 25). Alluvium consists of sedimentary, meta-sedimentary and igneous extrusive rocks common in the modern Waucoba Wash. Source area for this sediment is difficult to determine on the basis of lithology alone. Rocks in the drainages to the north of Paiute Canyon consist of a variety of Paleozoic sedimentary types as well as igneous rocks of the Papoose Flat pluton. Lithologically alluvium in this area is extremely heterogeneous and contains quartzite, limestone, dolomite, marble, hornfels, shale and minor granitic rocks. Much of the faulted sediment probably represents alluvium derived from drainages to the south of and including Lead Canyon and those to the north of Paiute Canyon within the Waucoba Wash drainage.
Figure 24. Photograph looking ESE from Paiute Canyon to Dry Wash. Cuesta and Big Scarp localities are in distance.

Figure 25. Photograph of North End scarps.
Active washes and surfaces with lighter desert varnish coloration are not affected by fault offset. Scarps in the North End locality provided evidence of left-slip compatible with a model of conjugate faulting with a $\sigma_1$ in a N10°E orientation, the conjugate set represented by faults of the eastern Inyo frontal fault system. Left-slip was observed in offset geomorphic features such as channels and, in particular, natural levees. Location of matching geomorphic features on both upthrown and downthrown blocks was difficult and not all scarp localities yielded information of this nature.

Tentative age dating by the Wallace (1977) profiling method and regression analysis using the Bucknam and Anderson (1979) approach shows that North End contains 11 scarps falling within the "Holocene" and "Latest Pleistocene" groupings (refer to Table 2). Most scarps in this area offset alluvium of the same age, mainly what appears to be the oldest surface. Scarp profile 47 stands out statistically as potentially younger than other North End scarps, based on its scarp height/slope angle relationship and its offset of younger alluvium.

Location 38

A profile across the scarp at location 38 is presented in figure 26. The maximum slope angle on the east-southeast facing scarp measures 26 1/2° and the overall scarp height is 3.6 m (11.8 ft). Left-slip offset of 2 to 2.5 m (6.6 to
can be observed on channel and debris on either side of the scarps. The slip-rip is north-south oriented above at an elevation of approximately 4 m (13 ft). This scarp was noted for its youthful appearance with very slight debris accumulation at its base and moderately steep slope.

Both Wallace (1977) and Hocquen and Anderson (1979) evaluations of scarp age for this profile give very similar values. These are 2000 and 1550 years, respectively, with a maximum error of 50 years.

Figure 26. Fault scarp profile 38, North End locality.

Left-slip failure is suggested in displacement of major drainages across the scarps. The scarp profile dips to the right with the transition marked by a change in the direction of lateral offsets perpendicularly.
8.2 ft) can be observed on channels and levees to either side of the scarp. The dip-slip to strike-slip ratio is thus 1.8:1 to 1.44:1 at this location. The net oblique slip is approximately 4 m (13 ft). This scarp was noted for its youthful appearance with very slight debris accumulation at its base and moderately steep slope.

Both Wallace (1977) and Bucknam and Anderson (1979) evaluations of scarp age for this profile give very young values. These are $10^3$ and 1150 years, respectively, well within the Holocene.

**Location 40**

The south-facing scarp at this location shows two bevels and has an overall height of 5.1 m (16.7 ft). The most recent movement of 3.5 m (11.5 ft) is recorded on the lower bevel and the maximum slope angle here is 30°. The upper bevel has a height of 1.6 m (5.25 ft) and a maximum slope angle of 15°. No profile was taken at this location. Left-slip offset is suggested in displacement of major drainages across the scarp. The downthrown block has been modified by slope wash and incision. Good measurements of lateral offset were not possible.

On the basis of the steep slope angle preserved in the lower bevel of the scarp, a Wallace age of about $10^2$ years and a B&A age estimate of 500 years are obtained. This age places the lower portion of the fault in a group with other potentially Holocene faults (Table 2). The upper bevel gives Wallace and B&A ages of $10^5$ and approximately 25,000
years, respectively.

Locations 44 and 45

This is the same south-facing scarp which will be discussed at location 47. At location 44, the scarp has an overall height of 3.9 m (12.8 ft) and probably reflects a single event because no bevels are evident. The surface in this location seems old with much chemical disintegration of carbonates and granitic rocks weathering to gruiss. Quartzites are highly etched and coatings of desert varnish are very dark (fig. 27). The scarp was observed principally for evidence of lateral offset. Near a cross-cutting modern arroyo at location 45, the scarp intersects a stone line which is probably a relict levee. The crest of the stone line is broad and the line itself is irregular and somewhat sinuous. Ascertaining amount of offset on this line along the scarp is difficult but sense of offset is left-slip. The amount of offset is large considering the height of the scarp and is about 3 m (9.8 ft). This gives a dip-slip to strike-slip ratio of 1.3:1. Net oblique slip along this portion of the scarp is about 5 meters (16 ft).

An adjacent small drainage suggests an offset of about 1 meter (3.3 ft). Detailed profiling could reveal this scarp to represent more than one phase of vertical offset.

Location 46

A profile of this south-facing scarp is shown in figure 28. Overall scarp height is 3.4 meters with a maximum
Figure 27. Photograph of varnished desert pavement surface near location 45, North End locality.
slope angle of 28°, giving a Wallace age of 102 years and a B&A age of 760 years. The scarp is of probable Holocene age. A prominent nickpoint can be seen migrating up the main wash not far from the scarp face and there is the hint of another nickpoint in an adjacent small gully. The position of the major nickpoint in relation to the scarp face suggests that the uplift event was fairly recent because migration and degradation of the nickpoint is not advanced. The position of the nickpoint is now controlled by two small boulders which are lodged in the channel and may be preventing its more rapid upstream migration.

Location 47

This is a complex scarp locally containing two splays. Two profiles have been made in an attempt to record the nature of this scarp as two separate splays and also as a single scarp (figs. 29a and 29b). The limitations of the scarp height/scarp slope angle relationship to age dating become apparent because the scarp in both its single and compound aspect was formed at a single time. The two sections give significantly different ages for movement.

Profile 47a crosses the scarp at a point which displays two fault splays separated by a narrow terrace (fig. 30). The two fault branches have similar scarp heights and somewhat similar maximum slope angles. The upper branch, 47a1, has the steeper maximum slope angle of 26° and a scarp height of 2.0 m (6.6 ft). This gives a Wallace approximate
Figure 28. Fault scarp profile 46, North End locality.

Figure 29. Fault scarp profiles 47a and 47b, North End locality.
Figure 30. Photograph of splayed fault with terrace, location 47a, North End locality.
age of $10^2+$ years and a B&A age of about 1300 years. The lower branch, 47a$_2$, has a scarp height of 2.7 m (8.9 ft) and a maximum slope angle of 20°, which gives a Wallace age of $10^3$ years and a B&A age of 5100 years.

Profile 47b lies to the east of 47a and crosses the scarp at a point where the two branch faults coalesce to form a slope unbroken by terraces. Two bevels are evident in the profile, 47b$_1$ representing the upper and 47b$_2$ the lower bevel. Segment 47b$_1$ has a height of 1 meter and a maximum slope angle of 18°, giving a Wallace age of $10^4$ years and a B&A age of approximately 11,450 years. Segment 47b$_2$ has a height of 3.4 meters and a maximum slope angle of 32.5°. This portion of the scarp has young Wallace and B&A ages of $10^2+$ and 225 years, respectively.

The discrepancy in age calculations for these two segments of the same scarp can be explained with the assumption that either (a) the scarp broke at significantly different times at the sites of the two profiles, or (b) that slope modification is anomalous because of the complex nature of the scarp and the differing scarp heights of coalesced sections. In any event, it appears that both breaks within this zone are "Holocene" in age, using criteria available for analysis.

Location 48

Profile 48 lies along the eastern limb of a scarp also profiled at location 46 (fig. 31). The scarp ramps downward to the east and becomes more subdued. As in the scarp pro-
filed at location 47, this scarp shows an anomalous age rela-
tionship between its eastern and western segments, most
likely related to degradation characteristics of scarps of
varying heights. The scarp is probably representative of a
single faulting event with an offset in this location of 1.4
meters (4.6 ft) and a maximum slope angle of 17°. It is
conceivable that this scarp can be subdivided into two bevels
with heights of 1.0 and 0.4 meters and maximum slope angles
of 12° and 17°, respectively. Using a cumulative offset of
1.4 m gives a Wallace age of $10^4$ years and a B&A age of
15,000 years. This is significantly older than the same
scarp dated at 760 years at location 46. Taken individually,
scarp segments 48a and 48b give Wallace ages of $10^6$– and $10^4$+
years and B&A age approximations of 70,000 and 15,000 years,
respectively. Obviously, scarp height is a critical factor
to be reckoned with in determining rates of slope degrada-
tion.

Location 49

A long profile along one side of an uplifted, abandoned
channel with a prominent set of natural levees was made in
an attempt to document a number of faults that offset the
older alluvial surface (fig. 32). The profile has a length
of 138 m and intersects four major scarps, one of which
(49d₁d₂) contains a splayed fault similar to that in loca-
tion 47a. Structures represented in the profile include a
small complex graben broken by numerous scarplets, many
with displacements sufficiently small to make them difficult
Figure 31. Fault scarp profile 48, North End locality.

Figure 32. Fault scarp profile 49, North End locality.
to assess with regard to their age. Slope angles on some of these minor scarplets are only a degree or two.

The alluvium surface broken by this series of scarps is among the oldest in the area. This assessment is made on the basis of varnish and pavement development, sandblasting of clasts exposed at the surface, weathering of susceptible lithologies such as rocks of granitic and carbonate composition, and the subdued relief evident on aerial photographs and reconnaissance (fig. 33). Only the old surface is offset by faults and scarps do not extend to intersect younger channel fill to the west nor a topographically lower alluvium surface to the east which has a similar degree of varnish development but otherwise appears geomorphically younger.

On the basis of these observations, faulting along profile 49 probably represents either a single event or events over a short period of time. Calculations of age for this zone fall between 6700 and 131,000 years (Bucknam and Anderson, 1979) and $10^4$ and $10^6$ years (Wallace, 1977), a significant spread. As in profile 48, initial scarp height and initial scarp angle seem to be the most important factors in determining evolution of slope angle and rates of scarp degradation.

The range in profiled scarp heights and maximum slope angles within this graben complex is 0.7 to 2.2 meters (2.3 to 7.2 ft) and 9° to 20°, respectively, with several scarplets of heights less than 0.5 m (1.6 ft) and slope angles of
Figure 33. Photograph of natural levee along profile 49, North End locality.
Regression Analysis

Regression is defined in the Merriam-Webster dictionary (1970) as the amount by which the conditional expectation of one of two correlated variables is closer to the mean of its set than are given values of the second to the mean of its set. Bucknam and Anderson (1979) utilize regression of scarp slope angle on the logarithm of scarp height for data from various Utah localities to provide statistical evidence for a regular relationship between scarp height and slope angle. They determine that scarp height can be used as an independent variable when correlated with slope angles for determining approximate ages of scarp surfaces. They conclude that initial slope angle is not likely to affect the outcome of age determinations of scarps older than several thousands of years because slopes tend to degrade rapidly to the angle of repose and retreat more slowly thereafter. Thus, for scarps of a given height, a regular decrease in slope angle relationships may provide a quantitative method for age determination of scarps (Bucknam and Anderson, 1979).

Scarp profiling data from this study was analyzed by standard regression with scarp height plotted against the logarithm of slope angle, with the axes reversed from the plots of Bucknam and Anderson (1979). Graphs are compiled on linear x and y coordinates. An idea which was tested along profile 49 was to ascertain the degree of correlation of
slope angle with scarp height along a profile which suggests a single tectonic event producing a series of faults.

A plot of scarp height versus maximum slope angle for scarps along profile 49 gives a fairly smooth regression curve with an r value of 0.895 (fig. 34). Assuming that all scarps result from a time-constrained seismic event or events, the resulting curve may represent an isochron. A plot of other scarps in the North End location on this "isochron" does not give particularly encouraging results (fig. 35). A linear trend is strongly suggested by the data array. Geologic processes are logarithmic, not linear, functions. Rates of slope degradation, as pointed by Wallace (1977) and Bucknam and Anderson (1979), are initially rapid but decrease with time as slope angles flatten and angle of repose is achieved. The straight-line curve generated for profile 49 and fit to other North End profiles shows slope angle to be a linear function of scarp height (fig. 36). This relationship implies that slope angle is less a function of degradation of the scarp face with time than it is a function of the initial slope angle developed at the time of faulting. Initial slope angle would be closely related to initial scarp height, scarps showing greater initial offset having steeper slope angles.

Regression curves are presented for other localities within the study area. Figure 36 shows a curve for North End data points, Big Scarp is shown in figure 38, and Playa in figure 39. The Playa locality has so few data points
that a statistical analysis of the area seems inappropriate. However, in comparison to other scarps in areas studied, the Playa data plots consistently "older" with Big Scarp and North End curves following trends which suggest "younger" and mutually similar chronologies (fig. 40). Data for the Fish Springs, Drum Mountains, Panguitch, and Scipio sites of Bucknam and Anderson are shown along with curves for the three areas studied in Saline Valley (fig. 41). Both Drum Mountains and Fish Springs scarps are believed to be Holocene (Bucknam and Anderson, 1979), those of Drum Mountains having ages of about 12,000 years and Fish Springs on the order of a few thousands of years. Scipio scarps are also very young and have approximate ages of a few thousands of years. Correspondingly, North End scarps plot the youngest of the three areas overall and appear almost coincident with the Scipio curve in slope and placement.

Big Scarp can be subdivided into two groups of scarps and plotted separately as well as in a single group. When this is done, Big Scarp curves show diverse age relationships with the upper curve falling on the "young" side of North End and the lower curve falling on the "old" side of Playa. The Playa locality plots consistently older than either of the other two groups taken as a whole.
PROFILE 49

<table>
<thead>
<tr>
<th>Profile</th>
<th>Slope Angle (°)</th>
<th>Log Slope Angle (X)</th>
<th>Scarp Height (m) (Y)</th>
<th>Y^2</th>
<th>X^2</th>
<th>XY</th>
<th>Y</th>
<th>X</th>
</tr>
</thead>
<tbody>
<tr>
<td>49a₁</td>
<td>14</td>
<td>1.15</td>
<td>1.8</td>
<td>1.31</td>
<td>3.24</td>
<td>2.06</td>
<td>1.42</td>
<td>1.15</td>
</tr>
<tr>
<td>49a₂</td>
<td>20</td>
<td>1.30</td>
<td>2.2</td>
<td>1.69</td>
<td>4.84</td>
<td>2.86</td>
<td></td>
<td></td>
</tr>
<tr>
<td>49b</td>
<td>9</td>
<td>0.95</td>
<td>0.7</td>
<td>0.91</td>
<td>0.49</td>
<td>0.67</td>
<td></td>
<td></td>
</tr>
<tr>
<td>49c</td>
<td>10</td>
<td>1.0</td>
<td>0.8</td>
<td>1.0</td>
<td>0.64</td>
<td>0.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>49d₁</td>
<td>20</td>
<td>1.30</td>
<td>1.6</td>
<td>1.69</td>
<td>2.56</td>
<td>2.08</td>
<td></td>
<td></td>
</tr>
<tr>
<td>49d₂</td>
<td>15</td>
<td>1.18</td>
<td>1.4</td>
<td>1.38</td>
<td>1.96</td>
<td>1.65</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

n = 6
m = 3.62
b = -2.74
regression line: \( y = 3.62 \log x - 2.74 \)
\( r = 0.894 \)

Figure 34. Regression curve of scarp height vs. slope angle for profile 49, North End locality.
Figure 35. Plot of other North End scarp data on "isochron" of profile 49.
Figure 36. Plot of North End scarps on straight-line "isochron" developed for profile 49.
### North End Slope Profile Angle Scarp Log Slope Height (m) Angle (°)

<table>
<thead>
<tr>
<th>Profile</th>
<th>Slope Angle</th>
<th>Log Slope Angle</th>
<th>Scarp Height</th>
<th>X²</th>
<th>Y²</th>
<th>XY</th>
<th>Y</th>
<th>X</th>
</tr>
</thead>
<tbody>
<tr>
<td>38</td>
<td>26.5°</td>
<td>1.42</td>
<td>3.6</td>
<td>2.03</td>
<td>12.96</td>
<td>5.12</td>
<td>2.07</td>
<td>1.28</td>
</tr>
<tr>
<td>40a</td>
<td>15°</td>
<td>1.18</td>
<td>1.6</td>
<td>1.38</td>
<td>2.56</td>
<td>1.88</td>
<td></td>
<td></td>
</tr>
<tr>
<td>40b</td>
<td>30°</td>
<td>1.48</td>
<td>3.5</td>
<td>2.18</td>
<td>12.25</td>
<td>5.17</td>
<td></td>
<td></td>
</tr>
<tr>
<td>46</td>
<td>28°</td>
<td>1.45</td>
<td>3.4</td>
<td>2.09</td>
<td>11.56</td>
<td>4.92</td>
<td></td>
<td></td>
</tr>
<tr>
<td>47a₁</td>
<td>26°</td>
<td>1.42</td>
<td>2.0</td>
<td>2.00</td>
<td>4.00</td>
<td>2.83</td>
<td></td>
<td></td>
</tr>
<tr>
<td>47a₂</td>
<td>21°</td>
<td>1.32</td>
<td>2.7</td>
<td>1.75</td>
<td>7.29</td>
<td>3.57</td>
<td></td>
<td></td>
</tr>
<tr>
<td>47b₁</td>
<td>18°</td>
<td>1.26</td>
<td>1.0</td>
<td>1.58</td>
<td>1.0</td>
<td>1.26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>47b₂</td>
<td>32.5°</td>
<td>1.51</td>
<td>3.4</td>
<td>2.29</td>
<td>11.56</td>
<td>5.14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>48a,b</td>
<td>17°</td>
<td>1.23</td>
<td>1.4</td>
<td>1.51</td>
<td>1.96</td>
<td>1.72</td>
<td></td>
<td></td>
</tr>
<tr>
<td>49a₁</td>
<td>14°</td>
<td>1.15</td>
<td>1.8</td>
<td>1.31</td>
<td>3.24</td>
<td>2.06</td>
<td></td>
<td></td>
</tr>
<tr>
<td>49a₂</td>
<td>20°</td>
<td>1.30</td>
<td>2.2</td>
<td>1.69</td>
<td>4.84</td>
<td>2.86</td>
<td></td>
<td></td>
</tr>
<tr>
<td>49b</td>
<td>9°</td>
<td>0.95</td>
<td>0.7</td>
<td>0.91</td>
<td>0.49</td>
<td>0.67</td>
<td></td>
<td></td>
</tr>
<tr>
<td>49c</td>
<td>10°</td>
<td>1.00</td>
<td>0.8</td>
<td>1.00</td>
<td>0.64</td>
<td>0.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>49d₁</td>
<td>20°</td>
<td>1.30</td>
<td>1.6</td>
<td>1.69</td>
<td>2.56</td>
<td>2.08</td>
<td></td>
<td></td>
</tr>
<tr>
<td>49d₂</td>
<td>15°</td>
<td>1.18</td>
<td>1.4</td>
<td>1.38</td>
<td>1.96</td>
<td>1.65</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\[ n = 15 \]
\[ m = 5.30 \]
\[ b = -4.69 \]

Regression line: \[ y = 5.30 \log x - 4.69 \]
\[ r = 0.985 \]

**Figure 37.** Regression curve for scarp height vs. slope angle for North End locality.
<table>
<thead>
<tr>
<th>Profile</th>
<th>Slope Angle</th>
<th>Log Slope Angle (X)</th>
<th>Scarp Height (m) (Y)</th>
<th>$x^2$</th>
<th>$y^2$</th>
<th>XY</th>
<th>Y</th>
<th>X</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>13°</td>
<td>1.11</td>
<td>2.4</td>
<td>1.24</td>
<td>5.76</td>
<td>2.66</td>
<td>2.08</td>
<td>1.21</td>
</tr>
<tr>
<td>12</td>
<td>12°</td>
<td>1.08</td>
<td>1.4</td>
<td>1.17</td>
<td>1.96</td>
<td>1.51</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13a</td>
<td>14.5°</td>
<td>1.16</td>
<td>2.1</td>
<td>1.35</td>
<td>4.41</td>
<td>2.44</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13b</td>
<td>38°</td>
<td>1.58</td>
<td>3.5</td>
<td>2.5</td>
<td>12.25</td>
<td>5.53</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17a₁</td>
<td>8°</td>
<td>0.9</td>
<td>0.4</td>
<td>0.81</td>
<td>0.16</td>
<td>0.36</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17a₂</td>
<td>15.5°</td>
<td>1.19</td>
<td>1.9</td>
<td>1.42</td>
<td>3.61</td>
<td>2.26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17b</td>
<td>22°</td>
<td>1.34</td>
<td>2.9</td>
<td>1.8</td>
<td>8.41</td>
<td>3.89</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17c,d</td>
<td>26°</td>
<td>1.41</td>
<td>4.0</td>
<td>1.99</td>
<td>16.0</td>
<td>5.64</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20a</td>
<td>10°</td>
<td>1.0</td>
<td>0.7</td>
<td>1.0</td>
<td>0.49</td>
<td>0.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20b</td>
<td>19°</td>
<td>1.28</td>
<td>1.5</td>
<td>1.64</td>
<td>2.25</td>
<td>1.92</td>
<td></td>
<td></td>
</tr>
<tr>
<td>n = 10</td>
<td></td>
<td>12.05</td>
<td>20.8</td>
<td>14.92</td>
<td>55.3</td>
<td>26.91</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

m = 4.62

b = -3.51

regression line: $y = 4.62 \log x - 3.51$

r = 0.95

Figure 38. Regression curve for scarp height vs. slope angle for Big Scarp locality.
<table>
<thead>
<tr>
<th>Profile</th>
<th>Slope Angle</th>
<th>Log Slope Angle (X)</th>
<th>Scarp Height (m) (Y)</th>
<th>$X^2$</th>
<th>$Y^2$</th>
<th>XY</th>
<th>$\bar{Y}$</th>
<th>$\bar{X}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>29a</td>
<td>6°</td>
<td>0.78</td>
<td>0.6</td>
<td>0.61</td>
<td>0.36</td>
<td>0.47</td>
<td>1.53</td>
<td>1.02</td>
</tr>
<tr>
<td>29b</td>
<td>15.5°</td>
<td>1.19</td>
<td>3.0</td>
<td>1.42</td>
<td>9.0</td>
<td>3.57</td>
<td></td>
<td></td>
</tr>
<tr>
<td>31</td>
<td>12.5°</td>
<td>1.10</td>
<td>1.0</td>
<td>1.21</td>
<td>1.0</td>
<td>1.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>n = 3</td>
<td></td>
<td>3.07</td>
<td>4.6</td>
<td>3.23</td>
<td>10.36</td>
<td>5.14</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$m = 4.87$
$b = -3.43$

Regression line: $y = 4.87 \log x - 3.43$
$r = 0.76$

Figure 39. Regression curve for scarp height vs. slope angle for Playa locality.

![Figure 39. Regression curve for scarp height vs. slope angle for Playa locality.](image)
Figure 40. Regression curves for all scarp data.
Figure 41. Regression curves for scarps in the Saline Valley area plotted with Bucknam and Anderson (1979) scarp data.
Eastern Inyo Frontal Fault Zone

Summary

The Inyo Mountains form the western boundary of Saline Valley and mark the region within the study area exhibiting maximum relief and greatest lithologic variety. Rocks of the range are: sedimentary and metasedimentary rocks ranging in age from pre-Cambrian to Permian; Mesozoic intrusive rocks comprising three major plutons of quartz monzonite to granodiorite composition, associated with the period of emplacement of the Sierra Nevada batholith; and Plio-Pleistocene volcanic rocks of the types described in the Saline Range. The volcanic rocks are only locally widespread within the Waucoba Wash quadrangle but constitute a sizeable surficial exposure to the south in the Lee Flat area as well as within the Coso Range (Lombardi, 1963; Ross, 1965, 1967b; Duffield and Bacon, 1977). A modified stratigraphic column of sedimentary and metasedimentary rocks of the Waucoba Wash quadrangle is shown in figure 42.

Uplift of the Inyo Mountains can be related temporally and tectonically to the Sierra Nevada, the next major range to the west which forms the regional boundary for Basin and Range-type faulting (Hamilton and Myers, 1966; Bachman, 1978). Matthes (1930) and Christensen (1966) indicate that prior to late Cenozoic time the ancestral Sierra Nevada had an elevation of about 2100 m (6900 ft) and was more subdued than today. Evidence within the Saline Valley area discussed in this section also points to an ancestral Inyo Mountain range
Figure 42. Modified stratigraphic column for the Waucoba Wash quadrangle (after Ross, 1967b).
existing prior to Plio-Pleistocene time.

Since Plio-Pleistocene time (1.8 to 3.4 m.y. ago), the Sierra Nevada escarpment was formed, first by downwarp flexure and later by faulting, accompanied by volcanism (Putnam, 1960; Axelrod, 1962; Christensen, 1966; Curry, 1971; Bachman, 1978). Bachman (1978) places the uplift of the White-Inyo Mountains about 2.3 to 2.43 m.y. ago, after the impoundment of Waucobi Lake and equal in age to the oldest Waucobi lake beds. The White-Inyo block was uplifted as much as 2300 m (about 7500 ft) with respect to the Owens Valley during this time. It is considered reasonable to assume at least the same magnitude of relative uplift of the Inyo Mountains with respect to the Saline Valley depression. Given the 2100 m (6900 ft) initial height proposed for the Sierra Nevada-Inyo block prior to most recent uplift, a total of 4400 m (14,500 ft) of structural relief should be present.

Interpretations of data gathered by geophysical surveys of the Saline depression (Mabey, 1963; Chapman and others, 1971) indicate a sedimentary fill with a maximum thickness of 610 m (2000 ft) to 915 m (3000 ft) overlying basement rocks within the western portion of the valley. Added to the approximately 3050 m (10,000 ft) of modern topographic relief, this gives a total of about 3650 m (12,000 ft) to 3950 m (13,000 ft) of structural relief between the Inyo Mountains and the Saline Valley depression. Of this relief, 2300 m (7550 ft) may represent fault offset within the past 2.3 to 2.43 m.y. (Bachman, 1978), an uplift rate of about
Geomorphically, the eastern Inyo Mountain front appears to be extremely young. Modern fan development in the northern half of the range within the Waucoba Wash quadrangle is in a youthful stage with many fans existing as distinct depositional landforms rather than as a piedmont apron.

Southward along the range front, fans become more extensive and finally comprise a piedmont-like surface along the Nelson Range front. This southern piedmont is likely to represent a pediment, at least in part, as is indicated by a number of inselbergs along its surface as well as by the anomalous gravity gradient within the area. The latter indicates only a few hundred feet of Cenozoic fill in contact with bedrock in this region (Mabey, 1963; Chapman and others, 1971). Whether the surface represents an advanced erosional pediment or a veneered downfaulted block cannot now be answered.

Disregarding bedrock complications, progressive fan enlargement southeastward along the eastern Inyo front suggests that the northern portions of that rangefront may be experiencing more rapid uplift rates and/or northern fans are being overwhelmed and restricted by westward tilting of the Saline Valley floor and encroachment of sediment from the main part of Waucoba Wash. An analogous situation exists to the east in Death Valley where fans on the eastern margin of that depression are kept small by eastward tilting of the valley floor and burial of fan material by sediment of the
valley fill (Denny, 1965; Hunt and Mabey, 1966).

In order to determine the nature of most recent tectonic motions along the eastern Inyo front, bedrock surfaces in several canyons were examined for evidence of slickensides, preferably those in which grooved surfaces could give evidence of relative last motions of the respective faulted blocks in the manner described by Billings (1972, p. 201). McElvoy Canyon and Spring Canyon locations within the Waucoba Wash quadrangle (Plate 3) and Craig Canyon in the New York Butte quadrangle to the south gave data of the type sought. In addition, offset of a natural levee in alluvium at the Red Fan location (Plate 3) provided quantifiable data. A joint set in bedrock within the Nelson Range is also included in fault analysis of this region but data are probably inconclusive due to questions about the origin of these joint structures.

Paiute Canyon yielded information on the nature of the eastern Inyo Mountains front prior to and during basalt eruption, corroborating many of the comments made by earlier workers on the tectonic history of the region and summarized above.

Analyses of faults lying within the northwest-trending system of the eastern Inyo frontal zone do not include scarp profiles and are based on observations of scarp height, maximum slope angle, beveling of scarp slopes and lateral offset of identifiable geomorphic features. All faults found in this study showing right-lateral offset occur along this
northwest-trending shear system.

Red Fan

Situated at the mouth of McElvoy Canyon (Plate 3), the Red Fan locality is distinctive for the large, red-hued alluvial fan which has been cut and offset by faults (fig. 43). These faults are related to the northwest-trending set of the conjugate pair which dominates the Saline Valley region. Four measurements of right-slip were obtained on a natural levee which is crossed by a fault near location 7. Three measurements indicate right-slip of 2.5 m (8 ft) and a fourth gives an offset of 3.6 m (12 ft). Measurements are made on offset of the levee crest which is easily identified by the ridge of boulder size material forming the highest point on the landform. Cumulative vertical offset across the scarp is approximately 4.9 m (16 ft) on a surface which shows at least two bevels, indicating two periods of fault movement on the same zone. The lower bevel, representing the most recent faulting event, has a vertical offset of about 3 meters (10 ft) while the upper bevel gives an offset of 1.8 m (6 ft). Both sides of the levee show similar offset. The uniformity of the 2.5 m lateral offsets measured in three locations on the same landform make the figure an appealing one to use in structural analysis.

Taking the 4.9 m cumulative value of vertical offset and the 2.5 m value for lateral offset, a new right-oblique offset of 5.5 m (18 ft) can be calculated on a N23°W-trending fault, probably during two episodes of activity. The
Figure 43. Photograph of the Red Fan locality as seen from the east.
Red Fan complex has experienced faulting of an antithetic nature as evidenced in scarps in older colluvial material \((Q_{of1})\), the scarps generally having slopes of \(25^\circ\) to \(27^\circ\) in a westerly direction and reflecting a strong tensional or pull-apart component. The older \(Q_{of1}\) fan surface, characterized by the darkest and thickest varnish coatings on the coarser clastic fragments, gives strong indication that it has been steepened with respect to more recent fan surfaces, designated \(Q_{of2}\). The \(Q_{of2}\) fan material which is presently being entrenched by modern channels comprises the bulk of the landform and locally engulfs antithetically faulted and tilted fan fragments of \(Q_{of1}\) (fig. 44). Surfaces within unit \(Q_{of2}\) have an average gradient of \(5^\circ\) in an easterly direction. Easternmost surfaces on tilted \(Q_{of1}\) blocks have gradients of \(10^\circ\) easterly, corresponding to the dip-slope surface. Westerly segments of \(Q_{of1}\) have surface dips of \(12^\circ\) and those immediately adjacent to the Inyo front have surface dips of \(16^\circ\) toward the northeast.

The increase of \(6^\circ\) in surface dips on \(Q_{of1}\) toward the west could conceivably represent a fault-segmented normal fan profile. It seems more likely, however, that the \(Q_{of1}\) surface has been both faulted and rotated, portions of the unit being attached to the rising footwall block of the eastern Inyo frontal fault system, the remainder responding to motions of the headwall block (fig. 45).

An analogous situation exists on the west side of the
Figure 44. Photograph of antithetically tilted Qof\textsubscript{1} fault block (view is to the south).

Figure 45. Schematic cross section of Qof\textsubscript{1} and Qof\textsubscript{2} units within the Red Fan locality.
Inyo Mountains in the Plio-Pleistocene Waucobi lake beds. Bachman (1978) describes a 6° westward rotation of the Waucobi beds which he believes to represent response to a relative uplift of the Inyo and downdrop of the Owens Valley blocks. The Waucobi beds lie at the hinge of this motion and have been deformed as its product. Abrupt termination of these lake beds to the west is believed to represent fault truncation, the remainder of the Waucobi bed deposit lying beneath younger valley fill within the Owens Valley (Bachman, 1978).

It is possible that the Qof₂ surface had an initial dip within the range measured. This possibility was investigated. Representative colluvial units within Qof₁ and Qof₂ were examined for comparison of sediment size range. Both units were very similar in clast lithology, interstitial sediment and their size range. Cobble to boulder size material in particular showed a marked uniformity in size and frequency distribution. The Qof₁ material gave a subtle appearance of slightly coarser fabric but similarities far outweighed differences.

Qof₁

The Qof₁ fan surface on the northern levee has a varnish which is much darker and a pavement surface which is tighter than younger terrace surfaces to the south. Igneous rocks dominate the lithology, these derived from the Paiute Monument and heterogeneous Pat Keyes pluton in the adjacent drainage of McElvoy Canyon. In addition, characteristic
quartzite probably from the Lost Burro Formation occur in all detrital fan assemblages, as well as minor carbonate and pegmatitic material. The proportion of detritus of sedimentary origin within Qof$_1$ is somewhat greater than in Qof$_2$ but otherwise they are lithologically quite similar. Varnish is colored 2.5YR 5/6, the hue being more red than on younger Qof$_2$ surfaces.

Grain size distribution in Qof$_1$ is somewhat anomalous as the site investigated is affected by the presence of the levee. Boulders are slightly more abundant within the area sampled than in Qof$_2$. The larger fraction of Qof$_1$ pavement is as follows:

- Boulders and cobbles (2.20 cm) ~20%
- Cobbles (15 - 20 cm) ~20%
- Pebbles (1 - 4 cm) ~60%

Subsurface material consists of fine sand to silt with a light grey color, 2.5Y 7/2. No evidence of horizonation within the unit was observed.

Igneous rocks at the surface frequently show spheroidal weathering and rocks with large fractures are undergoing physical disintegration by splitting. Varnish exhibits patchiness on some light colored granitic boulders and seems to be in a state of deterioration.

Qof$_{2a}$, upper terrace

This is the highest and presumably the oldest terrace of the Qof$_2$ fan. The surface shows tight pavement of pebble to cobble-size rocks. Again, igneous rocks dominate the
lithology with about 98% of the detrital material in a 1.5 m$^2$ (16 ft$^2$) sample area having this lithology. A quartz diorite cobble was examined for varnish coloration since a representative varnished quartzite could not be found. The varnish on this rock was somewhat patchy and was darker on areas containing more abundant mafic minerals. The best and clearest color was obtained on feldspars and is a reddish yellow, 5YR 6/6.

The undersides of larger pebbles and cobbles with some degree of burial have an orange stain. Cobbles show some shattering but spheroidal weathering is not common. Most light colored granitic rocks show little, if any, varnish and degree of varnish appears to be dependent on mafic mineral content of the host rock.

Detrital size range of the pavement of Qof$^2_{2a}$ is as follows:

- **Boulders** (> 1 m) <1% (rare)
- **Boulders and cobbles** (20 cm) ~15%
- **Cobbles** (15 - 20 cm) ~15%
- **Pebbles** (1 - 4 cm) ~65%

The remainder is the finer-grained detrital fraction to granule size.

Subsurface material was the same as Qof$^1_1$ and constituted a light grey fine sand to silt, 2.5Y 7/2.

Qof$^2_{2b}$, lower terrace

This lower, and presumably younger, terrace within Qof$^2_2$ shows less varnish development than either of the two surfa-
ces described above. Debris on the terrace surface seems relatively fresh. Some clasts have rolled down from the upper Qof$_{2a}$ terrace and varnish coatings are more common near the juncture of these two surfaces. No spheroidal weathering occurs on surfaces of rocks in this unit.

The range of particle size and composition is identical to the upper Qof$_{2a}$ terrace. Lithology is principally granitic with an accessory assemblage of carbonate, quartzite and chert. Varnish is very light and the pavement surface less well-developed than on either of the other two surfaces examined. Subsurface fine-grained material is identical to Qof$_1$ and Qof$_{2a}$ in both size and coloration.

Figure 46 shows a detailed map of the units described above and their interrelationships.

The slope developed on a fan surface will depend on the range in size of sediment being transported and the viscosity of the transporting medium. Coarser sediment transported in a viscous medium such as a mudflow will not travel as far from the source and will build a surface of steeper gradient upon deposition than fine-grained sediment which is transported in water. Thus, debris flow deposits will build steeper landforms than alluvial deposits. Units Qof$_1$ and Qof$_2$ have the appearance of debris flow deposits. Larger rocks are generally separated from one another by interstitial sediments of much smaller grain size. Lenses of what appears to be alluvial sediment occur in exposures within the fanhead trench but these are not representative of
Figure 46. Detailed map of Qof₁ and Qof₂ at the Red Fan locality.
those that constitute the landform as a whole.

The surface established on $Qof_1$ has been shown to be about $6^\circ$ steeper overall than that on $Qof_2$. For a steeper fan surface to exist, sediment of $Qof_1$ must be much coarser than $Qof_2$. The cone of sediment of the $Qof_1$ fan would also have a smaller base than the modern fan if projected downward to the contemporary valley floor. As shown above, $Qof_1$ and $Qof_2$ have essentially the same sediment size range. It is more likely that $Qof_1$ has been steepened since its deposition.

An adjacent cone of colluvium ($Qoc$) at location 37 shows a varnished surface with color and thickness similar to $Qof_1$. $Qoc$, like $Qof_1$, has an oversteepened relationship with respect to younger colluvial material which overlaps it. The older colluvium has a slope of $37^\circ$ and occurs as an erosional remnant (fig. 47). Younger colluvium, the surface of which appears quite active, has a slope angle of $30^\circ$. The $7^\circ$ rotation of the colluvium $Qoc$ in a valleyward direction is correlative with the $6^\circ$ valleyward rotation of $Qof_1$ with respect to $Qof_2$. Younger colluvium has a finer grain size and some of the difference in slope angle may be related to this factor. $Qoc$ does not appear to be offset by the faults which offset $Qof_1$. $Qoc$ has been deposited over sheared and altered bedrock. Gypsum fracture fillings, salt efflorescence and iron oxide staining occur within this underlying unit and its mechanical competence is poor (fig. 48). Failure and downslope creep of $Qoc$ over the bedrock surface is considered
Figure 47. Photograph of colluvial cone, Qoc, at the Red Fan locality.

Figure 48. Photograph of oxidized zone at Qoc-bedrock contact, Red Fan locality.
likely in addition to the proposed tectonic rotation.

Qof\textsubscript{1} constitutes an eroded landform which, prior to its tectonic modification, was probably a fan much like the one presently occupying the base of the slope at the mouth of McElvoy Canyon. Rotation of the fan \(6^\circ\) to the west would bring its slopes into accord with modern gradients. Like the Qof\textsubscript{2} fan, the Qof\textsubscript{1} fan may have been deeply entrenched at its apex. Erosion by the modern stream has uncovered a thick section of Qof\textsubscript{2} within the fanhead trench. Thick accumulations of colluvium related to the Qof\textsubscript{2} landform are exposed in what are now a series of terraces within the gorge. Bedding attitudes within Qof\textsubscript{2} are consistent through the depth of the exposure. Scant evidence of faulting is present within Qof\textsubscript{2}.

Location 7 (illustrated in figure 44) shows what seems to be reactivation of a Qof\textsubscript{1} age fault and subsequent offset of Qof\textsubscript{2} sediments. The style of faulting has changed since the Qof\textsubscript{1} surfaces display offsets which are antithetic to the Inyo front and the Qof\textsubscript{2} surface shows horst and graben structure. It can be conjectured that the antithetic nature of the scarps in Qof\textsubscript{1} is due to rotation and valleyward sliding of faulted blocks in response to gravity effects. The sediments of Qof\textsubscript{2} are too young to have experienced this rotation to such a degree.

Age Assessment and Paleoclimatic Effects

In making assessment of ages of alluvial fan environments as sites in which faulting has taken place, one must
consider a number of factors. Geomorphology of alluvial fans is extremely complex and the fan itself is a landform which has experienced the opposing effects of both deposition and erosion (Lustig, 1965). The morphology of the fan at any point in time is affected by tectonics, climate, parent rock within the source area and its weathering characteristics, sediment size range, topography and the size of the drainage basin.

Some controversy seems to exist with regard to the effects of tectonics upon the system. The development of fanhead trenches is of particular concern to this study. Bull (1977), citing the pioneering work of Eckis (1928), concludes that in the period after tectonic uplift of a mountain range, the stream will continue to downcut within the mountains and will eventually cut below the altitude of the fan apex. This entrenchment of the fanhead can be permanent if its result causes the fanhead area to be removed as an area of potential deposition. If, however, the rate of uplift equals or exceeds the sum of the effects of downcutting and deposition, the fan deposits will continue to accumulate adjacent to the mountain front. If $\frac{\Delta u}{\Delta t}$ represents mountain front uplift, $\frac{\Delta w}{\Delta t}$ is stream channel downcutting, and $\frac{\Delta s}{\Delta t}$ represents fan deposition, this relationship can be expressed as:

$$\frac{\Delta u}{\Delta t} \geq \frac{\Delta w}{\Delta t} + \frac{\Delta s}{\Delta t}.$$ 

In this way, uplift in the mountain range can counteract the tendency for a fanhead to trench (Bull, 1977). Thus, rapid
uplift in a mountain system should be accompanied by active fan deposition. Fanhead trenching therefore signals uplift of the mountain front at a rate lower than stream channel downcutting and fan deposition and can represent adjustment of the fan to a new equilibrium after a period of rapid uplift. In this context, periods of relative stability which may occur between tectonic events may actually promote entrenchment of intermittent streams at the fanhead.

Bull (1968) comments that trenching of a fan near the apex can cause the locus of deposition to shift downfan. Elongation of the fan perpendicular to the mountain front will occur because deposition will be taking place only in the lower reaches of the landform where the fanhead trench intersects the fan surface (Ritter, 1979). Gradients produced in streambeds during periods of trenching will thus be flatter than those established during periods of active alluviation and drainages will be more channelized. Lustig (1965) proposes that every fan will exhibit a relict property which reflects a past environmental condition. The problem at hand requires that landforms be examined and interpreted for the information they may give on past and present tectonic environments. Considerations must be made for the fact that environmental conditions in the past may have been significantly different than those of the present.

Entrenchment represents an erosional process operating on a fundamentally depositional landform. This disequilibrium state is restricted to periods in which deposition of the
fan is affected by either climatic or tectonic disturbance. Ritter (1979) states that climate will affect the equilibrium condition of fans through disruption of the load-discharge balance in the rivers of the fan system. The present aridity of the southwestern United States has been interpreted by Lustig (1965) as being conducive to fan entrenchment. During periods of greater precipitation, vegetation on fan surfaces, and thus resistance of those surfaces to erosion, is increased. Frequent overflow of distributary channels under these conditions causes widespread aggradation (Ritter, 1979). During arid periods, such as the present, precipitation is local and infrequent and resulting debris flow events cause trenching of the unvegetated fan surface and a downstream shift in the locus of deposition. Ritter (1979) feels that arid climates promote a destructive phase in the developing fan morphology and that debris flows are the cause of entrenchment rather than following previously incised channels.

The implication for Saline Valley and the Red Fan locality in particular is that Qof 2 fan surfaces may have developed during a wetter climatic period than the present. The most recent period of significantly wetter climate was during the Pleistocene glacial epoch which ended approximately 10,000 years ago, marking the beginning of the Holocene.

A prominent terrace within the fanhead trench at location 7 lies 11 m (36.3 ft) above the modern stream channel and contains material of lithologic and textural similarity
to Qof₂ surfaces elsewhere in the fan complex and with the same slope gradient as those surfaces. Material of this terrace has been described above as Qof₂a. This terrace appears to be a remnant of a fill which occupied a channel developed by a previous stage of fanhead entrenchment which affected the initial Qof₂ fan. If this is so, the uppermost Qof₂ surface represents deposition not during the Tioga but during the Tahoe glacial period in the Sierra Nevada (Birkeland and others, 1970), providing that the surfaces present in this section are a complete sequence and no depositional events are missing. Subsequent trenching of Qof₁ during the interglacial which followed was later infilled by alluvium deposited during the Tioga glacial event. This later alluviation produced the lower Qof₂b terrace which has a height of 6.1 m (20 ft) above the modern channel. Using this model, the most recent trenching has taken place during the present interglacial.

Faulting affecting Qof₂ does not penetrate the alluvium of the terraces Qof₂a or Qof₂b. Thus, faulting is restricted to a period prior to 40,000 to 60,000 years B.P. This is an extremely arbitrary method of age determination because the correlations are tenuous. Corroboration of ages of faulting on these surfaces using the Wallace fault scarp profiling method is not applicable because of the extremely low relief across the scarp in Qof₂.
Paiute Canyon

Within Paiute Canyon (Plate 3), lowermost flow rocks probably about the same age as the Saline Range basalts overlie what appears to be a pediment. This erosional surface is developed on rocks of the Paiute Monument pluton and is thinly veneered with \( \text{Qoa}_1 \)-type alluvium (Tg of Ross, 1967).

\( \text{Qoa}_1 \) beneath the two basalt flows within this exposure at location 25 displays an alteration from the white to light cream characteristic of this unit in fresh outcrop to a distinctly pink color (fig. 49). These color horizons have a thickness of as much as 5 meters (about 16 ft) and may represent paleosols (J. Stroh, 1980, personal communication). It can also be argued that these horizons represent baked, oxidized zones associated with the overlying lavas. The relative thickness of the colored zones tends to put this latter concept in some doubt, particularly because the basalt flows are of similar thickness whereas the color horizons are not, the lower, older horizon having the greater thickness.

Development of pediment surfaces requires time. It has been estimated that pedimentation is currently a slow process, on the order of 0.1 to 0.2 cm/yr (Cooke and Warren, 1973). No actual measurement of mountain front retreat-pediment extension has actually been accomplished, however, and this figure is strictly a matter of educated speculation.

The pediment surface over which the lower basalt unit flowed extends at least 2.5 km (about 1.5 mi) west of the
Figure 49. Photograph of offset in basalts at Paiute Canyon locality and color altered zone in Qoa1.
modern range front within Paiute Canyon and may extend further. The hypothesis suggested by observations of the range of this pediment surface is that the Inyo block was a topographic high and experienced a period of relative stability for a significant time span prior to extrusion of the basalt and initiation of the modern epoch of uplift at the Plio-Pleistocene boundary. This supports statements by Bachman (1978). At 0.2 cm/yr, the observed pediment would require about 2 m.y. to develop. Should the color horizons prove to be soils, this would further support this hypothesis.

Basalt flows within the Paiute Canyon area are progressively offset with age, as indicated by stratigraphic position. Faulting caused significant offset of bedrock in the time spanned by periods of extrusive igneous activity. Tectonism and volcanism appear to have been concurrent during this period. Additional offset of both basalt flows at this location has occurred since the eruption of the younger flow.

McElvoy Canyon

Rocks near the mouth of McElvoy Canyon (Plate 3) are those of the Jurassic to Triassic Pat Keyes pluton of the Hunter Mountain quartz monzonite. These igneous rocks are extensively sheared and in places exhibit considerable alteration. Location of good slickensided surfaces on what are considered to be representative shear planes with regional significance is difficult. Four locations are selected which provide good exposures and two of these have grooved surfaces which are suitable for determination of the nature
of last slip. These four shear zones are designated S4 through S7.

Data recorded from these shear zones is presented below:

<table>
<thead>
<tr>
<th>Location</th>
<th>Shear Plane</th>
<th>Slickensides</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>S4</td>
<td>N10°W</td>
<td>55°E 68°</td>
<td>S65°E</td>
</tr>
<tr>
<td>S5</td>
<td>N70°E</td>
<td>65°W 4°</td>
<td>S72°W</td>
</tr>
<tr>
<td>S6</td>
<td>N10°W</td>
<td>66°E 19°</td>
<td>S17°E</td>
</tr>
<tr>
<td>S7</td>
<td>N10°W</td>
<td>34°W no slickensides</td>
<td>Major shear</td>
</tr>
</tbody>
</table>

Spring Canyon

Three observations have been made on slickensided surfaces which correspond to major shear zones in Spring Canyon (Plate 3). These zones are defined within the rocks of the Pat Keyes pluton of the Hunter Mountain quartz monzonite which in this location has been extensively sheared and altered, in places approaching the intensity of shearing common to some serpentinites. On a small scale, attitudes of shear planes at nearly any angle can be obtained. The three zones selected coincide with what are believed to be major throughgoing structures, related to regional stress rather than localized rock failure. The shear planes corresponding to these zones are designated S1, S2 and S3.
A last movement in a right-oblique normal sense would be compatible with these slickenside orientations as would a left-oblique reverse motion. However, only right-oblique will be compatible with regional stress field orientations, and observed normal-slip offsets along the eastern Inyo front.

In addition, alluvium of the Spring Canyon fan is offset by faults at location 37. A heavily oxidized zone has been offset approximately 30 cm in what appears to be reverse slip (fig. 50). Some strike-slip is probably also involved since a pebble layer to the west of the fault has no counterpart to the east. Amount and direction of strike-slip displacement were not possible to ascertain.

Strike of the fault plane is approximately N10°E with a dip of about 68°SE. This fault corresponds to a region to the north in which a small graben cuts the fan surface near the mouth of Spring Canyon (Plate 4). The anomalous reverse offset of this fault is probably the result of the behavior of unconsolidated material on the margin of a complex graben.

Craig Canyon

Located outside of the study area in the New York Butte 15-minute quadrangle, adjacent to section 35, T15S, R38E,
Figure 50. Photograph of offset iron-stained horizon at location 37, Spring Canyon locality. Note apparent reverse offset. Fault plane dips to the right (east).
Craig Canyon is the site in which a number of shear attitudes have been recorded. Shears in both granitic rocks of the Hunter Mountain stock and in Paleozoic sedimentary rocks were observed and the clearest attitudes recorded for comparison with those of canyons of the Waucoba Wash quadrangle. The best data were obtained on shear planes in the sedimentary rocks. Igneous rocks in this area are highly altered and locally mineralized. Shear zones were designated S8 through S13.

<table>
<thead>
<tr>
<th>Location</th>
<th>Shear Plane</th>
<th>Slickensides</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Strike</td>
<td>Dip</td>
<td>Rake</td>
</tr>
<tr>
<td>S8</td>
<td>N35°W</td>
<td>50°E</td>
<td>46°</td>
</tr>
<tr>
<td>S9</td>
<td>N25°W</td>
<td>34°E</td>
<td>74°</td>
</tr>
<tr>
<td>S10</td>
<td>N10°W</td>
<td>82°E</td>
<td>80°</td>
</tr>
<tr>
<td>S11</td>
<td>N07°W</td>
<td>83°E</td>
<td>55°</td>
</tr>
<tr>
<td>S12</td>
<td>N10°W</td>
<td>79°E</td>
<td>68°</td>
</tr>
<tr>
<td>S13a</td>
<td>N25°W</td>
<td>55°E</td>
<td>no slickensides</td>
</tr>
<tr>
<td>S13b</td>
<td>N15°W</td>
<td>68°W</td>
<td>no slickensides</td>
</tr>
</tbody>
</table>

Nelson Range

Three joint attitudes were obtained from granitic rocks of the Hunter Mountain stock in the Nelson Range near Grapevine Canyon. No slickenside observations were possible due to the highly altered nature of the bedrock. These joint sets have been designated J1, J2 and J3.
Location    | Strike   | Dip      
------------|----------|----------
J1          | N45°E    | 86°SE    
J2          | N13°W    | 78°SW    
J3          | N16°W    | 22°NE    

**Stereographic Analysis**

A stereographic plot of the poles of all shear planes and joints is given in figure 51. Open figures are poles of shears associated with right-oblique slip with the exception of triangle S5. The latter represents the only left-slip measurement in bedrock of the eastern Inyo front, confirmed by directed roughness of slickensided surfaces. Solid figures represent the rake of slickensides on fault planes.

Given a N20°W 60°NE idealized plane for northwest-trending normal faults and a N40°E 60°NW plane for northeast-trending normal faults resulting from the proposed orientation of σ₁ in a N10°E direction, all points but S3 fall within quadrants compatible with the proposed stress regime. S3 shows a deviation from the general N10°W to N18°W trend of the faults of the Inyo block in this area, however, which is probably within the range of flexure of a given fault zone. Few faults display straight, consistent trends throughout their lengths.

Rakes recorded on slickensides for all fault planes are consistent with proposed models of offset for those zones. Right-oblique normal offset is indicated for all zones except S5. The latter has an orientation which would suggest left-oblique slip and chatter marks produced on the slickensided
Figure 51. Stereographic projection of poles of joint and shear planes and rake of slickensides. Open symbols are poles of fault and shear planes; closed symbols (black) are plots of rake of slickensides on fault and shear planes.
surface confirm this.
CHAPTER 3

Structural Summary and Conclusions

In light of data presented above, the Tchalenko model of Riedel fracturing does not seem to apply to Saline Valley (Tchalenko, 1970). Rather, Saline Valley has been developed during the past 2.3 to 3.4 m.y. by fracture and deformation associated with the oblique tensional fragmentation of the far western Basin and Range (Hamilton and Myers, 1966). The northeast-trending faults to the east of the Saline depression which bound blocks ramping down southerly into the valley comprise what Hamilton and Myers (1966) refer to as a tension-gash system in a region undergoing both extension and right-lateral shear. The uplifted block of the White-Inyo Mountains to the west strikes northwestward and corresponds to the general trend of regional strike-slip faults. Orientation of the basins fits a model in which oblique extension, resulting from pull-apart of the ranges in a northwesterly direction, causes voids to be produced into which basin blocks collapse (Hamilton and Myers, 1966; Burchfiel and Stewart, 1966).

The fracture system so evident in the Saline Valley area appears to have been developed at a time prior to the current uplift of the Inyo range and downdrop of the Saline Valley block. The stress field reorientation which would have been conducive to the formation of fractures of the trends which dominate the Saline Valley region corresponds to the time in
which the Mendocino triple junction migrated north of this point, about 13 m.y. ago (Eckren and others, 1968; Atwater, 1970). Breakup of the Sierra Nevada-Owens Valley-White-Inyo Mountains block and development of the ranges and valleys of this area did not occur until much later, after the opening of the Gulf of California about 5 m.y. ago (Atwater, 1970) and probably coincident with much of the volcanism in the area which occurred about 3 to 4 m.y. ago (Wright, 1977). Right-lateral shear and oblique extension of the area (Hamilton and Myers, 1966; Burchfiel and Stewart, 1966; Davis and Burchfiel, 1973; Best and Hamblin, 1978) caused a foundering of the blocks of the Saline and Last Chance-Panamint Ranges as well as an apparent distortion of faults and shears within the Saline Valley block.

Curvature of faults can be observed in scarps in alluvium of the valley and is suggested in faults within the basalt bedrock of the Saline Range (Ross, 1967b). Northeast-trending scarps show a more easterly trend as they approach the eastern Inyo Mountain front. Lineament analysis of the Goldfield and Death Valley quadrangles suggests this trend (Plate 2) and mapping of faults within alluvium confirms many of these trends. To the north end of the eastern Inyo frontal fault zone, faults with a northwesterly orientation which figure so prominently in the boundary of the range front to the south become less continuous. The range front takes on a northerly to northeasterly trend and becomes fragmented, incorporating faults which have an orientation
suggestive of those of the Saline Range which experience left-oblique offset (Ross, 1967b). This suggests a zig-zag pattern of coalescing orthogonal fractures on conjugate fault sets (Slemmons, 1977).

Superimposing an idealized pattern of shears which would hypothetically develop in response to the N10°E principal stress orientation (Moody and Hill, 1956) suggests an interpretation of the two major fracture sets within the valley as primary first-order (1°) shears of a conjugate set. The Nelson Range front, given this model, would appear to be a second-order (2°) shear. Plate 5 shows this relationship.

An alternative interpretation which adds to the inferences of the Moody and Hill (1956) model is shown in Plate 6. Superimposed on the topographic map of a portion of the Goldfield-Death Valley regions, the model proposes a pattern of distortion within faults and shears of the region compatible with drag along a right-lateral shear couple of regional dimensions. In this model, the eastern Inyo Mountain front serves as the western boundary of a zone of oblique extension which includes the Saline, Last Chance, Panamint, and Cottonwood Ranges to the east. The eastern boundary of this region of tilting and foundering blocks lies within the Death Valley area and is possibly represented by the Death Valley-Furnace Creek fault system.

Faulting within alluvium of the Saline Valley depression has been shown to occur in discrete zones rather than in a
random pattern throughout the valley floor. These zones of faulted older alluvium coincide with the major valleys which intrude between spurs of basalt projecting into and ramping under the alluvial fill of Saline Valley. Coincidence of zones of fault-offset older alluvium in fans along the eastern Inyo front with these major northeast-trending corridors of faulting suggests an interrelationship, activity on one zone possibly causing renewal of activity on the conjugate at a point of intersection.

More important is the implication that northeast-trending fault systems continue past the immediate western margins of the Saline Range and may in fact continue beneath the alluvium of Saline Valley to the buttress of the Inyo Mountains. This tends to discount the speculation that Saline Valley is a "pull-apart" bounded on four sides by shear zones, a simple rhombochasm. Rather, it is suggested that Saline Valley forms a local depression to the east of which the uparching of the Saline Range-Last Chance-Panamint Range block is causing a draping and "mega-slumping" of bedrock both to the east and to the west (Wright and Troxel, 1971).

The enigmatic trend of the Nelson Range which forms the southern boundary of Saline Valley may reflect a fracture system which pre-dates the tectonic regime of the modern southwestern Basin and Range. Williams and others (1974), in their study of geologic features of the Death Valley area, map a fault zone of similar trend, the Sheephead
Fault Zone, which lies within the Black Mountains. They comment that this fault zone lies parallel with and close to the lines of facies change within that area, adjacent to the southern limit of the upper member of the Noonday Dolomite (Williams and others, 1974). It is believed that the abrupt facies and thickness change along this zone indicates that it was a throughgoing fault active in Cenozoic and earlier time (Williams and others, 1974).

A regime of compression dominated the Saline Valley-Death Valley region prior to 13 m.y. ago (Ekren and others, 1968; Atwater, 1970). The orientation of the principal stress axis, $\sigma_1$, of that time would have been aligned more east-westerly than the present. Fractures developed under this stress regime could become reactivated under a changed stress system and their imprint imposed on a conjugate system otherwise compatible with contemporary tectonics. It is the opinion of the author that the Nelson Range frontal fault represents such a structure. Figure 52 attempts to show these relationships.

Interpretations of fault scarp profiles using Wallace (1977) and Bucknam and Anderson (1979) techniques are not consistent with the bias of the author concerning age of faulting within Saline Valley. Graphic and statistical comparisons of fault scarps in Saline Valley with those studied in northern Nevada and Utah (Wallace, 1977; Bucknam and Anderson, 1979) suggest that many scarps in the study area are of Holocene age. All faults examined are mid- to late
Figure 52. Orientation of \( \sigma_1 \) and resulting principal shears in pre- and post-13 m.y. time and structure of Saline Valley as related to these shears. (a) Principal stress orientation during subduction-related compression prior to 13 m.y. ago. (b) Principal stress orientation from 13 m.y. to present. (c) Faults and shears in Saline Valley as a product of these two stress fields and their mobilization under the present stress regime.
Quaternary age as determined by analysis of scarp profiles. Confinement of faults to regions underlain by older alluvium, as determined by relative stage of development of desert varnish and pavement, degree of rounding and degradation of channel sides, number of channels preserved and size of channels preserved, presence of ventifacts and anomalous clastic constituency given modern sediment sources, suggests two possibilities:

1. Rates of tectonic and geomorphic evolution in Saline Valley are extremely rapid and most, if not all, unconsolidated valley fill is Holocene to latest Pleistocene age.

2. Saline Valley experiences a normal arid climate, channeling and arroyo cutting associated with modern drainage systems and fanhead trenching represent the magnitude of average Holocene deposition and erosion. Older alluvial surfaces within the valley and in fans are mid- to late Pleistocene age. Faulting preserved in older alluvium is most likely to represent an event within the late Pleistocene.

Given the latter hypothesis, the significance of the modern aseismic nature of Saline Valley takes on added meaning (Smith, 1978). Deformation in Saline Valley may be relatively slow and distributed over a wide zone of northeast-trending faults. Major crustal deformation is being accommodated by the Death Valley-Furnace Creek fault zone to the
east and the Owens Valley fault zone to the west, each of which is a relatively simple northwest-trending right-lateral shear.

Saline Valley seems more suited structurally to "soak up" deforming stresses because of its highly fragmented nature. Tectonic activity in the valley conceivably could be episodic with pulses of faulting activity interspersed with periods of quiescence which may be relatively long. Most recurrence intervals, as indicated by bevels on scarps showing bona fide multiple movements are on the order of several thousands of years. The current status of Saline Valley as a seismic gap may only be a prelude to a period of renewed activity at some time in the future.
REFERENCES


Williams, Eugene G., Wright, Lauren A. and Troxel, Bennie M., 1974, The Noonday Dolomite and equivalent stratigraphic units, southern Death Valley region, California: in Death Valley Region, California, Geol. Soc. Amer. Cordilleran Section Guidebook.

Wright, Lauren, 1976, Late Cenozoic fault patterns and stress fields in the Great Basin and westward displacement of the Sierra Nevada block: Geology, v. 4, p. 489-494.


PERSONAL COMMUNICATION

Ryall, Alan S., Director, Seismological Laboratory, University of Nevada, Reno, Reno, NV 89557.

Stroh, James M., Professor of Geology, The Evergreen State College, LAB I, Olympia, WA 98505.
### TABLE 1

Geomorphologic features of faults by slip-type and ranked in approximate frequency of occurrence in active fault zones (Slemmons, 1977).

<table>
<thead>
<tr>
<th>Approximate Rank</th>
<th>Geomorphic Feature</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>STRIKE-SLIP FAULTS</strong></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Scarp or eroded scarp</td>
</tr>
<tr>
<td>2</td>
<td>Bench</td>
</tr>
<tr>
<td>3</td>
<td>Linear drainage features—canyon, gully, swale, trench, trough, stream or valley</td>
</tr>
<tr>
<td>4</td>
<td>Depressions—pond, swamp, swampy depression, sag, playa, sag pond, swampy trench, rhomb-shaped depression</td>
</tr>
<tr>
<td>5</td>
<td>Lateral offset of stream or drainage channel</td>
</tr>
<tr>
<td>6</td>
<td>Fault gap, notch or saddle</td>
</tr>
<tr>
<td>7</td>
<td>Trench, wedge, rhomb or elongate rhomb depression</td>
</tr>
<tr>
<td>8</td>
<td>Offset ridgeline or hill</td>
</tr>
<tr>
<td>9</td>
<td>Deflected or diverted drainage channel, gully, gulch, stream or valley axis</td>
</tr>
<tr>
<td>10</td>
<td>Linear or elongate ridge, pressure ridge, bulge, buckle, termination bulge, transverse buckle</td>
</tr>
<tr>
<td>11</td>
<td>Trough</td>
</tr>
<tr>
<td>12</td>
<td>Ponded alluvium</td>
</tr>
<tr>
<td>13</td>
<td>Aligned notches and swales</td>
</tr>
<tr>
<td>14</td>
<td>Shutter ridge</td>
</tr>
<tr>
<td>15</td>
<td>Scarplet</td>
</tr>
<tr>
<td>16</td>
<td>Swale</td>
</tr>
<tr>
<td>17</td>
<td>Aligned vegetation, vegetation boundary or contrast</td>
</tr>
<tr>
<td>18</td>
<td>Aligned gullies, gulches, valleys and streams</td>
</tr>
<tr>
<td>19</td>
<td>Side-hill (or hillside) trench or trough</td>
</tr>
<tr>
<td>20</td>
<td>Spring, elongate spring, marsh, groundwater barrier</td>
</tr>
<tr>
<td>STRIKE-SLIP FAULTS (continued)</td>
<td></td>
</tr>
<tr>
<td>--------------------------------</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>Lineament (lithologic, topographic, altered or mineralized, soil contrast, <em>en echelon</em>, or Riedel</td>
</tr>
<tr>
<td>22</td>
<td>Fault valley, graben, rift, or rift valley</td>
</tr>
<tr>
<td>23</td>
<td>Fault trace</td>
</tr>
<tr>
<td>24</td>
<td>Fault path or pebbly path</td>
</tr>
<tr>
<td>25</td>
<td>Open Crack or fissure, <em>en echelon</em> fissures</td>
</tr>
<tr>
<td>26</td>
<td>Faceted ridge or spur, triangular facets</td>
</tr>
<tr>
<td>27</td>
<td>Alignment of springs or elongate spring alignments</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Unranked</th>
</tr>
</thead>
<tbody>
<tr>
<td>Riedel shears, <em>en echelon</em> fissures, scarps lineaments, P-shears, etc.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>NORMAL-SLIP FAULTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>6</td>
</tr>
<tr>
<td>7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>REVERSE-SLIP FAULTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>6</td>
</tr>
<tr>
<td>7</td>
</tr>
<tr>
<td>8</td>
</tr>
</tbody>
</table>
### TABLE 2

Scarp groupings according to estimated age for the Saline Valley area.

Conventions:
- **BS**: Big Scarp
- **RF**: Red Fan
- **NE**: North End
- **PL**: Playa

<table>
<thead>
<tr>
<th>Location</th>
<th>Max. Slope Angle</th>
<th>Scarp Height (m)</th>
<th>Wallace Age (yrs)</th>
<th>Bucknam &amp; Anderson Age (yrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GROUP I - HOLOCENE SCARPS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 RF</td>
<td>27°</td>
<td>3.0 m</td>
<td>$10^2$</td>
<td>900</td>
</tr>
<tr>
<td>13b BS</td>
<td>38°</td>
<td>3.5 m</td>
<td>$10^2$</td>
<td>50</td>
</tr>
<tr>
<td>17c,d BS</td>
<td>26°</td>
<td>4.0 m</td>
<td>$10^2$</td>
<td>1,300</td>
</tr>
<tr>
<td>38 NE</td>
<td>26.5°</td>
<td>3.6 m</td>
<td>$10^3$</td>
<td>1,150</td>
</tr>
<tr>
<td>40b NE</td>
<td>30°</td>
<td>3.5 m</td>
<td>$10^2$</td>
<td>500</td>
</tr>
<tr>
<td>46 NE</td>
<td>28°</td>
<td>3.4 m</td>
<td>$10^2$</td>
<td>760</td>
</tr>
<tr>
<td>47b₂ NE</td>
<td>32.5°</td>
<td>3.4 m</td>
<td>$10^2$</td>
<td>225</td>
</tr>
<tr>
<td>GROUP II - OLDER HOLOCENE SCARPS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17b BS</td>
<td>22°</td>
<td>2.9 m</td>
<td>$10^3$</td>
<td>4,000</td>
</tr>
<tr>
<td>47ₐ₂ NE</td>
<td>21°</td>
<td>2.7 m</td>
<td>$10^3$</td>
<td>5,100</td>
</tr>
<tr>
<td>49ₐ₂ NE</td>
<td>20°</td>
<td>2.2 m</td>
<td>$10^3$</td>
<td>6,700</td>
</tr>
<tr>
<td>GROUP III - LATEST PLEISTOCENE TO HOLOCENE SCARPS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20b BS</td>
<td>19°</td>
<td>1.5 m</td>
<td>$10^4$</td>
<td>8,700</td>
</tr>
<tr>
<td>47₁ NE</td>
<td>18°</td>
<td>1.0 m</td>
<td>$10^4$</td>
<td>11,450</td>
</tr>
<tr>
<td>4ₐ₂,b NE</td>
<td>17°</td>
<td>1.4 m</td>
<td>$10^4$</td>
<td>15,000</td>
</tr>
<tr>
<td>4ₐ₂,d₁ NE</td>
<td>20°</td>
<td>1.6 m</td>
<td>$10^4$</td>
<td>6,700</td>
</tr>
<tr>
<td>GROUP IV - LATE PLEISTOCENE SCARPS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11 BS</td>
<td>13°</td>
<td>2.4 m</td>
<td>$10^5$</td>
<td>44,000</td>
</tr>
<tr>
<td>12 BS</td>
<td>12°</td>
<td>1.4 m</td>
<td>$10^5$</td>
<td>58,000</td>
</tr>
<tr>
<td>13a BS</td>
<td>14.5°</td>
<td>2.1 m</td>
<td>$10^5$</td>
<td>29,500</td>
</tr>
<tr>
<td>17₁₂ BS</td>
<td>15.5°</td>
<td>1.9 m</td>
<td>$10^5$</td>
<td>22,500</td>
</tr>
<tr>
<td>31 PL</td>
<td>12.5°</td>
<td>1.0 m</td>
<td>$10^6$</td>
<td>55,000</td>
</tr>
<tr>
<td>40ₐ NE</td>
<td>15°</td>
<td>1.6 m</td>
<td>$10^5$</td>
<td>25,000</td>
</tr>
<tr>
<td>Location</td>
<td>Max. Slope Angle</td>
<td>Scarp Height</td>
<td>Wallace Age (yrs)</td>
<td>Bucknam &amp; Anderson Age (yrs)</td>
</tr>
<tr>
<td>----------</td>
<td>-----------------</td>
<td>--------------</td>
<td>-------------------</td>
<td>-------------------------------</td>
</tr>
<tr>
<td>GROUP IV - LATE PLEISTOCENE SCARPS (cont.)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>48a NE</td>
<td>12°</td>
<td>1.0 m</td>
<td>$10^6$</td>
<td>70,000</td>
</tr>
<tr>
<td>49a NE</td>
<td>14°</td>
<td>1.8 m</td>
<td>$10^5$</td>
<td>34,000</td>
</tr>
<tr>
<td>49d NE</td>
<td>15°</td>
<td>1.4 m</td>
<td>$10^5$</td>
<td>6,000</td>
</tr>
<tr>
<td>GROUP V - MID-PLEISTOCENE SCARPS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17a BS</td>
<td>8°</td>
<td>0.4 m</td>
<td>$10^6+$</td>
<td>172,000</td>
</tr>
<tr>
<td>20a BS</td>
<td>10°</td>
<td>0.7 m</td>
<td>$10^6$</td>
<td>100,000</td>
</tr>
<tr>
<td>29a PL</td>
<td>6°</td>
<td>0.6 m</td>
<td>$10^7$</td>
<td>295,000</td>
</tr>
<tr>
<td>49b NE</td>
<td>9°</td>
<td>0.7 m</td>
<td>$10^6$</td>
<td>131,000</td>
</tr>
<tr>
<td>49c NE</td>
<td>10°</td>
<td>0.8 m</td>
<td>$10^6$</td>
<td>100,000</td>
</tr>
<tr>
<td>GROUP VI - ANOMALOUS SCARPS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>29b PL</td>
<td>15.5°</td>
<td>3.0 m</td>
<td>$10^5$</td>
<td>22,500</td>
</tr>
<tr>
<td>47a NE</td>
<td>26°</td>
<td>2.0 m</td>
<td>$10^2$</td>
<td>1,300</td>
</tr>
</tbody>
</table>