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CENOZOIC STRATIGRAPHY AND EXTENSIONAL FAULTING IN THE SOUTHERN GABBS VALLEY RANGE, WEST-CENTRAL NEVADA

Rice University M.A. 1982

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CENOZOIC STRATIGRAPHY AND EXTENSIONAL FAULTING IN THE SOUTHERN GABBS VALLEY RANGE, WEST-CENTRAL NEVADA

by

Holly A. Dockery
RICE UNIVERSITY

CENOZOIC STRATIGRAPHY AND
EXTENSIONAL FAULTING IN THE
SOUTHERN GABBS VALLEY RANGE,
WEST-CENTRAL NEVADA

by

HOLLY A. DOCKERY

A THESIS SUBMITTED
IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE

MASTER OF ARTS

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HOUSTON, TEXAS

APRIL, 1982
ABSTRACT

In the southern Gabbs Valley Range of west-central Nevada, extensively deformed Mesozoic rocks form the basement for deposition of Cenozoic volcanic and sedimentary rocks which are in turn deformed by high-angle faults. The oldest Cenozoic unit is Singatse Formation of Oligocene age. This formation is a quartz latitic ash flow tuff which thickens to the southwest into a topographic depression. The Singatse is overlain by Miocene andesite breccia and flows. The andesite is the most abundant Cenozoic unit and is also observed to thicken to the southwest. Other rock units include: a restricted ash flow tuff overlying the andesite; a Pliocene basalt flow; and Miocene to Holocene sedimentary units composed of alluvial, fluvial, and lacustrine sediments.

Two major fault sets are observed: an east-west trending set and a north-northwest trending set. Both fault sets were active during the deposition of the Singatse Formation and continued to be active through the time of andesite deposition. The orientation of northwest trending andesite dikes suggest that the extension direction was oriented in a northeast-southwest direction during this time. Sometime after 17 myBP the extension direction changed to west-northwest,
resulting in the offset of the east-west faults by north-northwest faults. Basalts and sedimentary rocks were subsequently deposited on a faulted terrain resulting from north-northwest faults active in this stress field. Seismicity studies in the area indicate that extension in a west-northwest direction is operative to the present.
ACKNOWLEDGMENTS

I would like to thank my major advisor, John Oldow, for supplying the thesis topic and support for the first summer of field work and for his numerous critical reviews of the manuscript. I am also grateful to the other members of my committee, W.P. Leeman and H.G. Ave Lalleman, who also reviewed the thesis and made many valuable comments which were incorporated into the final draft. Thanks also go to Geri Martinez who typed part of the final copy. Javan Meinwald, Scott Bowen, and Frank Byers provided helpful discussions during the course of the study. Robyn Wright, Cleo Frangides, and Dave Matty furnished much appreciated moral support. Lastly, I want to thank my parents, Kenneth and Anabel Dockery, for their support and encouragement throughout my academic career.

Financial support for the second summer of the study came from the U.S.G.S., Menlo Park, California. Aid for the school year was acquired by the Financial Aid office at Rice University through H.E.W.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abstract</td>
<td>ii</td>
</tr>
<tr>
<td>Acknowledgements</td>
<td>iv</td>
</tr>
<tr>
<td>Table of Contents</td>
<td>v</td>
</tr>
<tr>
<td>List of Figures</td>
<td>vii</td>
</tr>
<tr>
<td>List of Plates</td>
<td>viii</td>
</tr>
<tr>
<td>Chapter I</td>
<td>9</td>
</tr>
<tr>
<td>Introduction</td>
<td>10</td>
</tr>
<tr>
<td>Regional Setting</td>
<td>14</td>
</tr>
<tr>
<td>Chapter II</td>
<td>18</td>
</tr>
<tr>
<td>Rock Units</td>
<td>19</td>
</tr>
<tr>
<td>Singatse Formation (Tv10)</td>
<td>26</td>
</tr>
<tr>
<td>Andesite (Tv11)</td>
<td>33</td>
</tr>
<tr>
<td>Unnamed Ash Flow (Tv13)</td>
<td>41</td>
</tr>
<tr>
<td>Basalt</td>
<td>44</td>
</tr>
<tr>
<td>Younger Sedimentary Deposits</td>
<td>46</td>
</tr>
<tr>
<td>Chapter III</td>
<td>50</td>
</tr>
<tr>
<td>Faults in the Southern Gabbs Valley Range</td>
<td>51</td>
</tr>
<tr>
<td>Chapter IV</td>
<td>61</td>
</tr>
</tbody>
</table>
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Fig.</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fig. 1</td>
<td>Map of the Basin and Range Province</td>
<td>11</td>
</tr>
<tr>
<td>Fig. 2</td>
<td>Location map</td>
<td>12</td>
</tr>
<tr>
<td>Fig. 3</td>
<td>Map showing other study areas referred to in this report</td>
<td>15</td>
</tr>
<tr>
<td>Fig. 4</td>
<td>Distribution of Mesozoic rocks</td>
<td>20</td>
</tr>
<tr>
<td>Fig. 5</td>
<td>Stratigraphic column</td>
<td>22</td>
</tr>
<tr>
<td>Fig. 6</td>
<td>Distribution of silicic ash flows in the Mina-Hawthorne region</td>
<td>23</td>
</tr>
<tr>
<td>Fig. 7</td>
<td>Modal mineralogy of the Singatse Formation (Tv10)</td>
<td>29</td>
</tr>
<tr>
<td>Fig. 8</td>
<td>Distribution of Singatse Formation</td>
<td>32</td>
</tr>
<tr>
<td>Fig. 9</td>
<td>Distribution of Andesite (Tv11)</td>
<td>35</td>
</tr>
<tr>
<td>Fig. 10</td>
<td>Distribution of Tv13</td>
<td>42</td>
</tr>
<tr>
<td>Fig. 11</td>
<td>Dips of beds in recent sediments (QTac)</td>
<td>48</td>
</tr>
<tr>
<td>Fig. 12</td>
<td>Distribution of QTa1</td>
<td>49</td>
</tr>
<tr>
<td>Fig. 13</td>
<td>Schematic cross-section across faults #I and #II showing faulting relationships</td>
<td>54</td>
</tr>
<tr>
<td>Fig. 14</td>
<td>Dike orientation in the study area</td>
<td>58</td>
</tr>
<tr>
<td>Fig. 15</td>
<td>Dike orientation in the Garfield Hills</td>
<td>59</td>
</tr>
</tbody>
</table>
LIST OF PLATES

Plate I  Mina 7 1/2" Quadrangle showing study area with all Cenozoic units and Faults #I, #II, #III, #IV, and #V ............on back cover
CHAPTER I
INTRODUCTION

The Gabbs Valley Range is located in the western Great Basin of the Basin and Range Province of western North America (Fig. 1). It is typical of the Basin and Range in that it is fault bounded and flanked by alluvial basins. However, the Gabbs Valley Range (Fig. 2) trends north-northwest, whereas most of the ranges in the Great Basin trend north-northeast. It lies within the Walker Lane physiographic subprovince (Locke, et al., 1940) which has been interpreted as a diffuse zone of right lateral shear (Stewart, 1967; Albers, 1967; Hardyman, 1978). According to this interpretation, long northwest trending faults with right-lateral strike-slip displacements are predicted. Within the study area, a complex system of east-west and north-northwest faults are observed and have displacements which are not compatible with the shear model. Thus, the shear model appears to be too simple to explain the observed fault patterns.

The southern terminus of the Gabbs Valley Range is defined by an east-west trending basin, informally designated the Upland Valley (Speed and Cogbill, 1979b), which separates the Gabbs Valley Range from the northern Pilot Mountains (Fig. 2). The Cenozoic rock units in the Gabbs Valley Range generally thicken to the south in the
FIGURE 2

Location map showing study area (shaded). Contours x1000 feet.
the Upland Valley whose paleoslope may be a direct response to faulting on its southern margin.

The thesis area covers approximately 30 square kilometers of the Mina 7 1/2" Quadrangle of Mineral County, west-central Nevada. It is centered on the western and southern portions of the Gabbs Valley Range (Fig. 2) northeast of the town of Mina and southeast of the town of Luning. Access of the area is very good via mining roads and stream valleys. The objectives of this study are: 1) to define a Cenozoic stratigraphy, 2) to correlate stratigraphic units mapped in the Gabbs Valley Range with those defined by other workers in surrounding ranges, and 3) to resolve the kinematics of Cenozoic faulting in this area.
REGIONAL SETTING

The Basin and Range has long been recognized as an area of regional extension resulting in normal block faulting (Gilluly, 1965; Hamilton and Myers, 1966; Atwater, 1970; and Coney, 1978). Originally it was assumed that stress directions had been more or less constant since the inception of extensional faulting (Hamilton and Myers, 1966; McKee, et al., 1970; Speed and Cogbill, 1979a). However, recent work, inclusive of this study, suggests that the extension direction in the Great Basin has varied locally and possibly on a regional scale during the Cenozoic (Anderson and Ekren, 1977 and Zoback and Thompson, 1978).

Zoback and Thompson (1978) present evidence for a 45° clockwise rotation of extension direction in northern Nevada (Fig. 3). Age of initiation of early rifting is determined to be between 17 and 14 m.y.B.P. (Miocene) on the basis of the radiometric dates of aligned NNW dikes which are referred to as the Northern Nevada Rift. The extension direction derived from the dikes is N68°E; which varies approximately 45° from the present extension direction based on geodetic strain, earthquakes, slip lines on faults, and chains of volcanic vents.

Anderson and Ekren (1977) also report that in eighteen localities in the southern Great Basin the extension directions as inferred from
fault and bedding attitudes are not compatible with the current
northwesterly stress direction. They state that post-Oligocene faults
occurring within present day ranges but with trends nonparallel to
the range bounding faults indicate an earlier northeast to east-
 northeast trending extension.

Less than 30 kilometers southwest of the study area (Fig. 3),
Speed and Cogbill (1979a) report the presence of an east-west trending
fault trough. They believe that it was formed in a field of N82°W
extension during the Oligocene which would indicate a consistent
direction operating from the Oligocene to the present. However, their
cross-section shows that most of the subsidence took place during
deposition of Oligocene tuff. Very little fault controlled relief
existed by the time of deposition of Miocene units. Although they did
not address this problem in their model, a change in orientation of
extension could have been responsible for a decrease in dip-slip
displacement and thus in the subsidence rate.

The Walker Lane was first recognized as a broad zone of
irregularly shaped ranges (Locke, et al., 1940). Later workers
(Stewart, et al., 1968, Albers, 1967) postulate the area to be a shear
zone where the ranges have been deformed by right-lateral strike-slip
movement along northwest-trending faults related to the San Andreas
fault system. In the Las Vegas shear zone (Fig. 3), thought by some
to be the southern extent of the Walker Lane, Stewart, et al. (1968) suggest that offsets of Paleozoic and Mesozoic sedimentary facies and thicknesses indicate 50 to 70 kilometers of right-lateral strike-slip or drag offset. North of the study area (Fig. 3) Hardyman (1979) proposed up to 48 kilometers of strike-slip movement along a 30 kilometer wide zone of the Walker Lane in the northern Gillis and Gabbs Valley Ranges. The displacement is based on offsets of inferred boundaries of Tertiary ash-flow tuff sheets. Several of the faults of this zone trend continuously into the study area where little or no strike-slip movement is reported (Oldow, et al., 1980). Speed and Cogbill (1979a) correctly suggest that in a field of uniform WNW extension, right lateral shear mechanisms are unnecessary to produce observed displacements on the faults in their area. However, Oldow, et al. (1980) show that, although most faults in the southern Gabbs Valley Range are compatible with a field of uniform extension, a zone of left-stepping en echelon faults exhibit some amount of right-lateral movement in excess of that explained by uniform extension. The displacement history of faults in the study area is critical to ascertain the nature of the motion that has occurred on the faults and to determine whether that motion is the result of right-lateral shear or that of variably oriented faults in a uniformly extending region.
CHAPTER II
ROCK UNITS

The Cenozoic rocks lie with angular unconformity on a basement of Mesozoic rocks consisting of marine sediments, volcanic, volcaniclastic, and intrusive rocks. The Mesozoic rocks are deformed in late Mesozoic by polyphase folds and thrust faults (Ferguson and Muller, 1949; Oldow, 1981; Speed, 1978). The Mesozoic succession is divided into three formations: massive dark gray limestone of the Upper Triassic Luning Formation; thin-bedded fossiliferous shale and limestone of the Triassic and Jurassic Sunrise-Gabbs Formation; and quartz-rich sandstone, limestone, and feldspar porphyry of the Jurassic and Cretaceous (?) Dunlap Formation. Intrusive rocks ranging in composition from granite to diorite truncate Mesozoic structures and are temporal correlatives of the Sierra Nevada batholithic complexes of late Middle to early Late Jurassic age (Ekren, et al., 1980). The outcrop pattern of Mesozoic rocks is shown in Fig. 4.

Previously undifferentiated Cenozoic rocks (Ferguson and Muller, 1949) lie predominately to the south of Mesozoic outcrops at lower elevations and range in age from Oligocene to Recent. They constitute a typical Great Basin assemblage of siliceous ash flow tuffs; intermediate to basic volcanic flows, breccias, and lahars all
cut by dikes and hypabyssal intrusions; and interstratified and overlying alluvial and fluvial sediments. Figure 5 shows the stratigraphic relationships of these rocks and Plate I shows the distribution of Cenozoic rocks discussed here.

The stratigraphically lowest Cenozoic unit exposed is a siliceous ash flow tuff (Tv10). It is correlative with the Oligocene Singatse Formation which was first described in the Yerington district (Fig. 3), 150 kilometers to the northwest (Proffett and Proffett, 1976). The Singatse tuff is one of the oldest and most areally extensive of nine major ash flow tuff sheets (Fig. 6) originating from a center located between Yerington and the northern Gabbs Valley Range (Ekren, et al., 1980). Only the upper part of the Singatse Formation is exposed in the southern Gabbs Valley Range where it was deposited on gentle topography underlain by pre-Tertiary rocks. In the study area it thickens to the southwest into a topographic depression in which the maximum observed thickness is 60 meters. The absolute thickness of the unit in the depression is unknown because the basal contact of the thickest sequence is not exposed.

Andesite breccias and flows (TV11) of mid-Miocene age unconformably overlie the Singatse Formation. They have a wide geographic distribution with the thickest exposed section (about 250 meters) occurring in the south-central area. Five hundred meters is
<table>
<thead>
<tr>
<th>AGE</th>
<th>NAME</th>
<th>THICKNESS</th>
<th>COLUMN</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>TERTIARY</td>
<td>SEDIMENTARY</td>
<td>25 m</td>
<td></td>
<td>Alluvial, fluvial, and lacustrine sediments.</td>
</tr>
<tr>
<td></td>
<td>ROCKS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>BASALT</td>
<td>25 m</td>
<td></td>
<td>Basalt flow with sparse feldspar phenocrysts.</td>
</tr>
<tr>
<td></td>
<td>SEDIMENTARY</td>
<td>25 m</td>
<td></td>
<td>Alluvial, fluvial, and lacustrine sediments.</td>
</tr>
<tr>
<td></td>
<td>ROCKS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>TV13</td>
<td>60 m</td>
<td></td>
<td>Ash flow tuff. Dominant phenocrysts; plagioclase and biotite.</td>
</tr>
<tr>
<td>MIocene</td>
<td>ANDESITE</td>
<td>500 m</td>
<td></td>
<td>Andesite breccia, flow, lahars, dikes, and hypabyssal deposits with occasional lenses of reworked volcanic material. Upper 250 meters stratified, lower 250 meters unstratified. Dominant phenocrysts: hornblende, plagioclase, and pyroxene.</td>
</tr>
<tr>
<td></td>
<td>(TV11)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MESOZOIC</td>
<td>SINGATSE FM.</td>
<td>60 m</td>
<td></td>
<td>Crystal-rich ash flow tuff quartz latitic in composition. Dominant phenocrysts: quartz, sanidine, biotite with some plagioclase and hornblende.</td>
</tr>
<tr>
<td></td>
<td>(TV10)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**FIGURE 5**

Tertiary stratigraphic column of rock units.
Inferred distributions of the Singatse Tuff, Guild Mine Member, Blue Sphinx Tuff, and the Hu-Pwi Rhyodacite thought to represent maximum original distribution of these units, study area is shaded (from Ekren, et al., 1980).
the minimum accumulated thickness estimated for the entire section of andesite which thickens to the southwest. Numerous internal unconformities exist indicating multiple extrusions.

An unnamed ash flow tuff (map unit Tvl3) unconformably overlies the andesites. Distribution is restricted to the extreme south-central area where it reaches a thickness of 60 meters. It is the lower part of a single cooling unit and has no internal unconformities. No temporal and compositional equivalents of Tvl3 are reported elsewhere in the Mina-Hawthorne region.

A basalt flow unit 25 meters thick is found one kilometer east of the study area unconformably overlying Tvl1. The age of the basalt is unknown but could be anywhere from lower Pliocene (Ross, 1961) to 2.8 my BP. (Speed and Cogbill, 1978). Basalt cropping out immediately north of the study area probably belongs to the same unit.

Sedimentary deposits ranging in age from late Miocene to Recent overlie the tuff and andesite units and are interstratified with the basalts. The sediments are composed primarily of gravels, stream deposits, and minor lacustrine rocks. The gravels are derived from pre-Tertiary and Tertiary rocks and attain a maximum thickness of 25 meters. The Tertiary sediments have been dissected during regional uplift resulting in linear ridges. Alluvial fan deposits typical of an uplifted arid region infill basins flanking the range. Fluvial deposits are primarily found in arroyos. Lacustrine sediments result
from water accumulation in a topographic depression at the southern end of the Gabbs Valley Range.
SINGATSE FORMATION (Tv10)

FORMATIONAL CHARACTERISTICS

The Singatse ash flow tuff (map unit Tv10) is an unwelded to moderately welded crystal-rich tuff. It laps onto and over topography formed by Mesozoic basement rocks along the northern and northeastern boundaries of the study area. Thickness ranges from a feather edge where onlapping Mesozoic rocks to a minimum total thickness of 60 meters (the basal contact is not exposed). The thickness and degree of compaction and welding increase to the southwest. The degree of compaction and welding is directly related to the thickness of an ash flow (Ross and Smith, 1961), indicating that thickening of the unit to the south may be attributed to deposition in a topographic declivity.

The color of the tuff ranges from pinkish gray to pink to white. Where more densely welded, Tv10 forms steep-sided cliffs and where more crystal-rich and less welded it forms low, rounded hills. It is a compound cooling unit composed of two flow units with essentially a single cooling gradient. Tv10 shows no lateral or vertical variations in modal mineralogy; a characteristic which is typical of the Singatse Formation reported elsewhere (Proffett and Proffett, 1976; Ekren, et al., 1980).
LITHOLOGY

Phenocrysts are euhedral to subhedral and include: shattered milky white feldspar up to 4 mm; clear, fractured quartz up to 6 mm; and biotite up to 4 mm. The groundmass in welded outcrops is glassy to perlitic and in unwelded outcrops has a sugary texture. Other constituents include: lithic fragments ranging in size from 1 mm to 20 cm and averaging about 1 cm; elongate ivory to white pumice; and black, streaky fiamme with axial ratios of as much as 25 to 1. Fiamme, pumice, and elongate minerals exhibit subparallel orientation perpendicular to the compaction direction and parallel to the paleoslope. Plunges of these linear features are predominately within 5° of horizontal but occasionally are found up to 55° from horizontal.

The non-matrix constituents of the tuff include lithic fragments (up to 5%) and phenocrysts of quartz (25-35%), plagioclase (20-40%), sanidine (10-25%), biotite (up to 5%), and hornblende (up to 2%). Quartz grains are slightly embayed and highly fractured. Plagioclase ranges in composition from An$_{25}$ to An$_{50}$ with an average of An$_{45}$ (measurements taken on 12 thin sections by A-normal method, Deer, et al., 1976) and shows normal and oscillatory zonation. Both plagioclase and sanidine have fluid and glass inclusions. Sanidine typically exhibits an arcuate fracture pattern. Feldspar commonly is altered along crystal faces and fractures to high birefringent clays.
Biotite is rimmed with and clouded by hematite resulting from alteration of fine magnetite dust, and it is bronze-colored in plane-polarized light. Lithic fragments, concentrated mainly in the lower part of the unit but found throughout, are composed of detrital shale, carbonate, and chert derived from Mesozoic rocks and plagioclase-rich volcanic rocks of unknown source. Amphiboles are pseudomorphically altered to opaque minerals. The groundmass consists mainly of glass shards and pumice, most of which exhibit axiolitic devitrification textures indicative of ash flow tuffs (Ross and Smith, 1961). Also present in the groundmass are small amounts of feldspar, opaque minerals, hematite, apatite, zircon, and rare pyroxene.

Figure 7 shows petrographic comparison between the Singatse Formation of the northern Gillis and Gabbs Valley Ranges and Tvl0 of the southern Gabbs Valley Range. The correlation of the top part of the Formation in the northern area with the southern area is very good. No other siliceous ash flow sheet reported by Ekren, et al. (1980) is observed to contain hornblende. The lack of lateral and vertical variations is also very typical of the Singatse Formation. A sample of Tvl0 from the northern Pilot Mountains has been identified in thin section as Singatse (Ekren et al., 1980). A date of 27 myBP was determined for Tvl0 in the northern Pilot Mountains (Marvin, et al., 1978). The Singatse Formation has been identified as a quartz
FIGURE 7

Petrographic correlation between the Singatse Tuff in the northern Gabbs Valley and Gillis Ranges and the southern Gabbs Valley Range. Modal mineralogy is shown for both the lower vitrophyre and the upper sections of the unit in the northern Gabbs Valley and Gillis Ranges. It is averaged throughout the unit in the southern Gabbs Valley Range where no vitrophyre is developed.
latite on the basis of chemical analyses (Proffett and Proffett, 1976).

DEPOSITIONAL SETTING

The Singatse Formation was deposited over gentle, uneven topography as exhibited by slightly plunging linear features and onlaps pre-Tertiary rocks. Compaction of ash flows increases as thickness of the flow becomes greater indicating that the increase in preserved section is depositional in origin. The source of the Singatse lies to the north (Ekren, et al., 1980); therefore the southerly increase in thickness observed in the southern Gabbs Valley Range is due to accumulation in a topographic depression rather than thickening towards the source.

Only the upper part of the formation, as defined by mineralogy, is found in the study area. The entire unit was deposited in a brief interval of time with no erosional breaks. Two possibilities exist: that only the upper part of the formation was deposited as far south as the southern Gabbs Valley Range, or that lower part of the unit was only deposited in the deeper part of the topographic depression such that only the upper part is seen onlapping the Mesozoic rocks. An outcrop of Singatse in the northern Pilot Mountains apparently represents the farthest southern extent of the ash flow. Figure 8
shows the distribution of the Singatse Formation in the study area.
FIGURE 8
Outcrop pattern of the Tvl0 (Singatase Tuff) in the study area.
LITHOLOGY

Ross (1961) described andesites in Mineral County as being primarily composed of agglomerates with minor flows. Phenocrysts reported in these rocks include hornblende, augite, and plagioclase. The groundmass is plagioclase or hyalopilite and composed almost entirely of plagioclase (oligoclase to labradorite in composition), with minor hornblende, augite, hypersthene, biotite, and olivine. The geochemical range in composition is reported as dacite to basalt with the most predominant variants being dacite to rhyodacite (Ross, 1961). Gilbert (1941) also described volcanic and volcaniclastic deposits in the Mono Lake, California region (west of Ross' area) as massive beds of brecciated hornblende andesite interbedded with conglomerates and tuff. Mineralogic and textural descriptions are similar to those of Ross. Nielsen (1965) describes rocks of intermediate composition in the Garfield Hills, the northeastern Pilot Mountains, and the southern Gabbs Valley Range as predominately "andesite breccia containing subordinate flows and ignimbrites cut by volcanic rocks".

Volumetrically the most abundant unit in the southern Gabbs Valley Range, Tvl1 is a heterolithic pile of breccias, flows, lahars,
hypabyssal intrusions, dikes, and occasional lenses of fluvially reworked material. The rock composition determined by modal mineralogy is predominately intermediate or andesitic. Distribution of Tvl1 in the study area is shown in Figure 9.

Tvl1 unconformably overlies the Mesozoic basement and Singatse tuff and fills depressions and channels. It is overlain locally by ash flow tuff (Tvl3), Pliocene basalt flows, QTac, and Qac. Age determinations for andesites occupying the same stratigraphic position in the Candelaria Hills are 15.7 myBP (Marvin et al., 1977), 17 myBP in the Excelsior Mountains (Marvin, et al., 1977) and 17.6 to 17.0 myBP for four samples in the northern Garfield Hills (Goodwin, unpublished data).

Thickness of the unit is extremely variable with the thickest continuous sections, reaching 250 m, located in the central and southcentral portions of the area. The unit thickens into a southwestward deepening depression. The minimum cumulative thickness estimated for the entire andesitic succession is about 500 m. This value is, however, a rough approximation due to extensive faulting, to the lack of marker beds, and to the lack of a complete section at any given locality. Nielson (1965) suggests a composite thickness of about 900 meters for andesites in and around the area, but no evidence for such a thick succession has been found in the present study.

The breccias are light gray on fresh surfaces and variegated in
Outcrop pattern of the Tull (Andesite) in the study area.
shades of green, brown, purple, and dark gray where altered. Outcrops of breccia weather to a lumpy appearance. Occasional lava flows interfinger with the breccias which are intruded by dikes and hypabyssal rocks. The flows and hypabyssal deposits are light gray when fresh, weather to brick red or dark gray and tend to form steep-sided hills with large scree slopes. The hypabyssal rocks are often characterized by columnar cooling joints. Some flows are observed to grade continuously upwards from ash-rich units to dense flow rock. In at least one instance, the ash-rich unit is moderately welded. Dike rocks are dark gray to black and usually perlitic. A few breccia deposits show normal graded bedding of clasts ranging in size from several meters to several centimeters in diameter. This configuration may suggest a mudflow or laharian origin (Schmincke, 1967).

In Tvl rocks from the southern Gabbs Valley Range, phenocrysts include hornblende, feldspar, and often pyroxene. These phenocrysts are euhedral to subhedral, up to one centimeter in length, averaging about 3 mm. Hornblende in the flow breccias sometimes is glomeroporphyritic. The breccias have clasts which are compositional equivalents of the matrix ranging in size from several mm up to 10 m. Weathering products of different rock types were also incorporated into the flow. On the southeastern border some of these included lithic fragments are clasts of olivine basalts which may be derived
from a pre-andesite basalt described by Nielsen (1963) in the northern Pilots. Flow rocks are often intercalated with the breccias and exhibit flow banding, alignment of elongate phenocrysts, and occasional flow folding.

Hypabyssal rocks occur in the northwest and northeast portions of the area and intrude other intermediate composition igneous rocks. They are identified by the absence of flow-banding or mineral alignment and by the presence of columnar cooling joints. The largest clasts of breccia are found in the area of the hypabyssal intrusions. Dike rocks, the fine-grained to glassy equivalents of the andesites, are also seen plugging vents.

Discontinuous fluvial units composed of lithic wackes and epiclastic beds with plane laminae and crossbeds occur intermittently between flows. Large blocks of petrified wood occur in some ash rich fluvial units. Replacement of wood by silica in such ash units is a typical result of groundwater enriched in silica derived from devitrification of volcanic glass (Williams, et al., 1954). The presence of trees indicates localized periods of quiescence and associated erosion between igneous events.

Plagioclase, hornblende, hypersthene, and augite are the dominant phenocrysts in the andesitic rocks. Plagioclase (35-75%) is usually twinned and shows oscillatory zonation, euhedral to subhedral, and has inclusions of opaques, glass, and apatite. Composition ranges from
andesine (An$_{40}$) to labradorite (An$_{70}$) with a mean of approximately
An$_{57}$ (measurements taken on 18 thin sections). Hornblende and
pyroxene occur in subequal amounts (5-15%) and often have rims of
magnetite and hematite. Both are euhedral to subhedral. Hornblende
usually has corroded cores and is altered to chlorite. The groundmass
is plagioclase to hyaloplilitic and composed of feldspar microlites,
opaques, pyroxene, biotite, and olivine.

Two subunits of Tvl1 are recognized based on the presence or
absence of stratification. The two units are separated geographically
by faults. Relations across the fault traces show these two subunits
are not time synchronous. The stratified section (Tvl1s) occurs in
the northwest corner of the thesis area and is recognized solely on
the basis of stratification occurring on the scale of four to five
meters in thickness. The unstratified section (Tvl1u) blankets the
remainder of the area and is characterized primarily by massive
bedding. Where stratification is observed in Tvl1u, it is laterally
discontinuous. Although the composition of both subunits is the same,
Tvl1s proves to be a useful stratigraphic horizon for interpretation
of timing along a major fault.

DEPOSITIONAL SETTING

Vertically and laterally Tvl1 is extremely varied reflecting
extrusion of volcanic rocks from multiple vents and differences in the nature of emplacement. It generally thins to the east (Meinwald, pers. comm., 1981) and to the north up paleotopographic slopes. Tvlulu thins abruptly over a north-northwest fault 1 kilometer east of the study area (Meinwald, 1982). Timing of fault displacements indicate that Tvlulu is older than Tvlul as will be discussed in the chapter on faulting. Localized areas of flow rock occur along the southcentral and southeastern boundary of the study area.

Dikes and hypabyssal intrusions (shown in northcentral area of Fig. 9) were probably the conduits from which Tvlul was extruded. Blocks of andesite flow breccia up to 10 meters in diameter are found close to hypabyssal conduits associated with faults. Because blocks of such large size are generally transported for very small distances (Sparks et al., 1978), the blocks suggest that the vent for the breccias was very close.

Mechanistically, deposition of the unstratified breccias of Tvlulu may be similar to pyroclastic flows modeled by Sparks, et al. (1978). Both the flows modeled by Sparks et al. (1978) and Tvlul are characterized by semi-rounded clasts floating in an ashlike matrix of the same composition and an absence of stratification. Pyroclastic flows are strongly influenced by topography and prefer to fill in low areas and channels as Tvlul seems to have done. Due to the tendency to
fill topographic depressions this lower part of a pyroclastic column
does not move great distances from the vent. For this reason the
source area for Tvlul probably lies close to the study area. The
direction of thickening, which also may be the direction to the
source, is to the southwest. In this case, the source area may be
related to conduits found west of Mina near the margin of the Garfield
Hills. If, at the time of andesite deposition, Soda Springs Valley
(Fig. 2) had undergone little or none of the extension observed today,
the conduits may have been closer. Alternately the source may be
buried underneath the alluvial fill of Soda Springs Valley. Andesite
flow rocks in the northern flank of the Upland Valley area may also
have originated from very localized fissures underlying the flows or
from a vent plugged by hypabyssal rocks postulated to exist to the
east of the area. The vent has been proposed on the basis of a thick
hypabyssal sequence (Meinwald, 1982). The flow rocks thicken in the
direction of that plug.

Between episodes of extrusion small stream channels formed,
reworking the underlying rock and depositing the epiclastic ash and
lithic wackes. Either periods of quiescence were long enough to allow
tree growth or kipukas were formed by channelling of the flows.
UNNAMED ASH FLOW TUFF (Tv13)

FORMATIONAL CHARACTERISTICS

An unnamed ash flow tuff, Tv13 overlies Tv11 unconformably and is only found to crop out in a small area near the south-central border of the map area (Figure 10); only QTg (gravel) directly overlies Tv13. Tv13 is comprised of a simple cooling unit of an ash flow tuff approximately 60 meters in thickness. The upper section exhibits compaction features in the form of elongate pumice. Few fiamme are observed and no vitrophyre is present. Downsection the compaction decreases in intensity and the ash becomes more vesicular and friable, leading to the hypothesis that Tv13 represents a portion of a cooling unit from which the uncompacted upper portion was eroded.

LITHOLOGY

Tv13 is buff to white with phenocrysts of milky white feldspar averaging 2 millimeters and ranging up to 5 millimeters in length, books of euhedral biotite averaging 1 millimeter in diameter, and small lithic fragments all in a light-colored sugary groundmass. In thin section Tv13 has a hyalopilitic texture. Phenocrysts include: 20% to 30% plagioclase (An40-50) which show oscillatory zonation and occasionally have corroded cores lined with hematite, up to 5% biotite
FIGURE 10

Outcrop pattern of Tvl3 (unnamed ash flow tuff) in the study area.
which exhibit occasional bent lamellae and slight alteration to hematite, 5% to 15% alkali feldspar, and clasts of plagioclase rich volcanics (2% to 5%). The groundmass is composed of strongly devitrified glass, feldspar microlites, opaques, and pyroxene.

No equivalents of Tvl3 presently are known to exist in the region and the source area is unknown. No ash flow tuff of this relative age and composition has been reported in the Mina-Hawthorne region.
BASALTS (QTb)

Dense dark gray to black rocks capping Table Mountain were given the field classification of basalt and probably are correlatives of similar rocks observed to locally overlie all other volcanic rocks throughout Mineral County. The flows reach 30 meters thickness in southern Mineral County (Ross, 1961) and are probably Pliocene in age (Ross, 1961; Silberman, et al., 1975; and Marvin, et al., 1977). Although some basalts to the south (dated at 3 to 4 m.y.b.p. by Marvin, et al., 1977) are associated with cinder cones (Speed and Cogbill, 1979), the absence of such features to the north suggests fissure-fed sources that possibly are localized along high-angle faults as suggested by Hardyman (1978) and as observed in the northern Gabbs Valley Range (Ekren, et al., 1980).

In outcrop, the lower contact of the basalt with Tvl1 is commonly obscured, but where exposed, the lower portion (1 meter) of the unit is brecciated, vesicular, and altered. The flow graded upward into a 15 meter thick section which is massive with well-developed cooling joints and occasional thin (0.5 centimeters) foliation. The top 10 meters of the section consists of vesicular and weathered to rounded blocks averaging a meter or more in diameter. In outcrop, the rock is aphanitic or has rare phenocrysts of plagioclase and commonly exhibits
a red coloration typical of mafic mineral alteration. In thin section, the sparse (0 to 5%) plagioclase phenocrysts range in composition from An$_{55}$ to An$_{70}$. They occur in a pliotaxitic groundmass composed almost entirely of feldspar microlites with minor percentage of hematite, glass, apatite, and pyroxene (?). Most samples have small vesicles and show alteration to chlorite, sericite, and hematite. Thin sections from samples taken across the entire sequence of basalt show no gross vertical variation in grain size or modal composition. To the north, the unit contains phenocrysts of hornblende and/or clinopyroxene (Ekren and Byers, 1978) and olivine bearing varieties occur to the south (Speed and Cogbill, 1979). Thus QTb is either characterized by lateral and/or vertical variations in lithology on a regional basis or by extrusion of a variety of mafic flows from multiple vents over a range in time.
YOUNG SEDIMENTARY DEPOSITS

The unit labeled QTg occurs as long linear ridges rising up to 25 meters above the alluvial valley fill. The ridges are composed of sand, gravel, cobbles, and boulders derived from Mesozoic and Cenozoic outcrops. These deposits extend into the major stream valleys and Soda Springs Valley following present-day drainage systems. The upper surfaces approximate a depositional plane established earlier in the history of the Great Basin. During subsequent uplift, stream action incised that terrace resulting in the current geomorphology. Similar dissected gravels have been observed by workers throughout this part of the Great Basin (Hardyman, 1979; Speed and Cogbill, 1979). One small outcrop of lacustrine deposits (Ts) is found associated with these gravels in the extreme southern part of the study area. Ts is overlain to the south by Tertiary gravels in angular unconformity, (pers. comm., J. Oldow, 1982) These deposits may be correlative with similar deposits found in the northern Pilot Mountains which were dated at 7.3 m.y.b.p. (Marvin, et al., 1977).

Unconsolidated to partially consolidated Quaternary alluvial sediments (Qac), derived from erosion of all pre-existing units, were deposited by small, ephemeral braided streams typical of an arid
region. Measurements taken in these deposits to the south of the Gabbs Valley Range give dips of 5° or less in random directions (Fig. 11). These dips are probably the result of deposition on a slightly irregular surface and probably do not indicate significant structural tilting. On the western border of the Gabbs Valley Range broad, gently sloping alluvial fans drape across the range front faults into the playa, filling the intermontane basin with an estimated hundreds of meters of alluvial fill (Meinwald, 1981). The distribution of Quaternary-Tertiary alluvium shown in Fig. 12.
FIGURE 11

Poles to bedding measured in recent sediments.
FIGURE 12

Outcrop pattern of Quaternary-Tertiary alluvium in the study area.
CHAPTER III
MORPHOLOGY

The prevalent fault orientations are east-west (ranging from east-northeast to east-southeast and north-northwest. The east-west faults are crosscut by the north-northwest trending fault set. Faults with short map traces also occur but have no apparent systematic trend or crosscutting relationships (Plate 1).

Two major east-west trending faults occur. The southernmost fault (I, Plate I) has a trace length of 3.5 kilometers and displaces Tivullu in each block. Tivullu is unstratified and no marker beds exist to indicate throw. The fault plane was located on the basis of aerial photography, linear array of breaks in slope, and gouge along those breaks. The northernmost fault (II, Plate I) gives a minimum throw of 330 meters down to the north. The map trace is 2.5 kilometers long and, at its western extent, fault II curves abruptly to the south attaining a north-south orientation and exhibits no displacement at its eastern end.

Two major north-northwest trending fault zones crosscut the east-west faults. The westernmost fault zone (III, Plate I) is traced along the range front through the entire length of the map area for about 6 kilometers. A gravity profile constructed by Meinwald (1982)
shows a smooth, gentle gradient indicating that faults within this zone are evenly spaced across Soda Springs valley and have uniform displacements. The gravity data produces a minimum total displacement of 800 meters across this zone forming Soda Springs Valley (Meinwald, 1982). The easternmost north-northwesterly fault zone (FIV, Plate I) has a map trace of 5 kilometers. To the north, fault FIV is a single fault which splays to the south in the study area. Throw along the splays ranges from 3 meters minimum of 30 meters. A single north-northwest fault (FV, Plate I) is downdropped to the east and has a map trace length of 2.5 kilometers. The minimum throw along fault FV is approximately 30 meters.

Faults of short trace length cross-cut neither long east-west nor north-northwest faults but are seen to cross-cut other short trace faults. Where observed, these faults exhibit throws from less than one meter up to about 10 meters. They display neither systematic cross-cutting relationships with one another, nor do they have a consistent trend.

**Timing**

The juxtaposition of Tvl0, Tvlu, and Tvl1s across fault FII and their inferred depositional relations indicate that they were deposited on a southerly dipping ramp and that fault FII was activated
after deposition of Tvllu and during or after deposition of Tvlls (Fig. 13) as discussed below. The ramp may have been the result of either a structural or topographic basin deepening to the south.

Two hundred and fifty meters of Tvlls is found north of fault #II. In places, Tvlls is deposited directly on Mesozoic rocks and Tv10. None is observed south of Fault #II. Tvllu directly overlies Tv10 south of Fault #II, but none is found in outcrop north of the fault.

The short time span for andesite deposition based on radiometric age dates and the lack of thick sedimentary deposits intercalated with the unit indicates the lack of long erosional periods between flows.

Therefore the discontinuous nature of the two subunits must be related to deposition and faulting rather than erosion. Given the fact that Tv10 thins to the north and that Tvlls is not found underlying Tvllu in the cliff face south of Fault #II, it may be surmised that Tvllu was first deposited partially filling the depression formed by the ramp. Tvlls was then deposited on top of Tvllu, lapping farther north onto the ramp. Tvllu would then underlie Tvlls at depth north of Fault #II, but would pinch out against the ramp, allowing Tvlls to lap directly onto the older rocks. In this case, although Tvllu would underlie Tvlls north of the fault, it might not be observed in outcrop due to insufficient erosion. Fault #II disrupted the ramp sometime after deposition of Tvllu. If the faulting had occurred
FIGURE 13

Schematic cross-section from north to south across faults #I and #II showing the basement ramp, the onlapping of Tvl0, Tvl1u, and Tvl1s. Also shown are the inferred relations across fault #II.
before or during deposition of Tvllu, it is probable that a thickened wedge of Tvllu would have accumulated on the downthrown side of the fault or erosion of the fault scarp would have produced a sedimentary unit on top of Tvll or in Tvllu north of the fault. Neither of these relationships is observed. Movement on the fault could have started any time after deposition of Tvllu. Absence of Tvlls south of the fault can be explained either by non-deposition or by subsequent erosion. If the fault was active during successive flows, the upthrown scarp could have restricted flow to the south. On the other hand, given a rate of uplift of 0.4mm/yr (calculated from fault activity in the Candelaria region, Speed and Cogbill, 1979a), 250 meters of Tvlls could easily have been stripped from the upthrown block.

The last movement on Fault V occurred synchronously with or after the Tvll. Only a small amount of Tvllu is found west of fault #V and there is no Tvlls. East of fault #V, only Tvlls is found. Therefore fault #V, like fault #II may have moved only after or during the deposition of Tvlls causing either restriction of its distribution; or Tvlls was eroded from the upthrown block. Because the angle formed by an extrapolated intersection of faults #II and #V is 65°, it can be argued that these faults constitute conjugate sets and they were active concurrently. The fact that the hypabyssal conduit from which
Tvlls was extruded occurs at the projected intersection of faults
might also indicate that the two faults were active simultaneously
allowing magma to rise along the line of intersection. The magma then
could have accumulated in the corner of a graben formed by faults #II
and #V.

There are no constraints for age of initiation of fault #I.
Juxtaposition of Tvllu on both sides indicate some movement has
occurred since the deposition of that unit.

Faults #III and #IV show no definitive relationships on which to
establish timing except that displacement has occurred since QTac was
deposited. There is little change in the thickness of Tv10 and Tv11
across faults #III and #IV. This would seem to indicate that most of
the dip-slip movement on these faults has occurred since deposition of
Tv11.

SENSE OF MOVEMENT

Before or around 17 myBP both east-west and some north-northwest
faults were active resulting in depositional control of Tv11. In the
present west-northwesterly oriented extension, east-west faults
predictably have large components of strike-slip displacement.
Generally, strike-slip faults tend to be relatively straight, thus the
abrupt bend on fault #II is then hard to accommodate if that fault has
predominantly strike-slip displacement as predicted in the present
stress regime. Also, the short trace of this fault and the fact that at its eastern end the displacement goes to zero does not allow for the existence of significant strike-slip motion in light of the large (330 meters) dip-slip component exhibited by the fault. Both of these observations indicate that fault #II has had a predominately dip-slip displacement history. At the same time, fault #V was possibly undergoing large amounts of dip-slip displacement. If these east-west and north-northwest faults were active during the same time period as conjugate sets, the extension direction called for would have a northeasterly orientation. This interpretation is supported by twelve andesite dikes with a composite length of about three kilometers which are found in the study area (Fig. 14). Their age is approximately 17 myBP and their average trend is N65°W. Because dikes are sensitive indicators of principal stress axes (Nakamura, 1977) the extension direction would be normal to their trend, or N25°E. Although it might be argued that these dikes are only indicative of a local stress field; dikes found in the northern Garfield Hills (approximately 40 kilometers west-northwest of the area) with a composite length of seven kilometers also have an average trend of about N65°W (Fig. 15). The presence of both dike swarms indicates that the northeasterly extension direction suggested by fault relations in the southern Gabbs Valley Range may exist on a relatively large scale at about 17 myBP.
FIGURE 14
Orientation of dikes in the study area. Length of line on the diagram indicates the length of the dike. Where more than one lies within $±2^\circ$, their trends are averaged and their lengths are added. Number at the end of a line indicates number of dikes added.
FIGURE 15

Orientation of dikes in the northern Garfield Hills. Length of line on the diagram indicates length of the dike. Where more than one lies within ±2°, their trends are averaged and their lengths added. The number at the end of a line indicated the number of dikes added in that line.
Sometime after 17 myBP the northeasterly extension direction had to rotate to the presently observed direction of N82°W (Speed and Cogbill, 1979a). Any movement on east-west faults would become predominately left-lateral strike-slip and movement on north-northwest faults would remain dominately dip-slip but the sense of strike-slip would reverse to right-lateral. Subsequent displacement on older north-northwest trending faults such as fault #V continued to downdrop and younger north-northwest faults, such as faults #III and #IV formed. This change in stress orientation and the resulting fault patterns probably occurred between 17 to 6 myBP when the rate of dip-slip displacement on the faults in the Candelaria trough (Speed and Cogbill, 1979a) changed.

In the framework of the Walker Lane as a right-lateral shear zone, faults #III and #IV should exhibit large components of right-lateral displacement. No evidence in the study area for such motion is seen. Continuation of pre-Tertiary structures across Soda Springs Valley allows only a few kilometers of strike-slip displacement (Oldow, 1978; Speed and Cogbill, 1979a). Note that if left-lateral movement, occurring along north-northwest trending faults during an older northeasterly extension, was followed by right-lateral movement along the same faults due to younger northwesterly extension, then the
apparent offset might be less than the actual total accumulated movement along the faults. The right-lateral strike-slip component of movement would have to be greater than the left-lateral component of motion in order to cause the observed right-lateral strike-slip motion.
SYNTHESIS

OLIGOCENE TO MID-MIOCENE

Voluminous silicic ash flow tuff sheets were extruded onto Mesozoic basement rocks which generally exhibit subdued topography. However, east-west trending fault troughs were being formed at two localities in western and central Nevada (Burke and McKee, 1979; Speed and Cogbill, 1979a) (Fig. 3) and possibly a third in the Upland Valley along the southern terminus of the Gabbs Valley Range. The east-west trending fault forming the Upland Valley may have caused thickening of a 27 my old tuff sheet to the south, away from its source. This would indicate an age of initiation for the east-west fault in the Upland Valley as 27 myBP or older. Approximately 10 my of erosion followed tuff deposition.

MID-MIOCENE TO PLIOCENE

Andesite flows and volcanioclastic rocks, from 17.5 to 15 my in age erupted from numerous nearby vents. Orientation of andesite dikes suggest that the Mina-Hawthorne region was undergoing extension in a northeasterly direction concurrent with andesitic volcanism. East-west faults and some north-northwest trending faults were active as
predominately dip-slip faults during the time of andesite deposition
and, as a consequence, controlled its deposition. Both fault sets are
compatible with a northeasterly direction of extension. The angle
formed by the two sets is about 60° suggestive of a conjugate
relationship. The predicted northeasterly extension approximately
bisects the acute angle formed by the conjugate faults as expected.
Short periods of erosion occurred during the andesite deposition
followed by a longer period (about 6 to 8 my) before the extrusion of
the basalt. The orientation of the extension direction rotated from
northeast to west-northwest sometime after 17 myBP, possibly between
17 and 6 myBP. Older north-northwest faults formed as well.
Susequent offset of east-west faults may be explained by the cessation
of movement along those faults along with continued motion along the
north-northwest faults all resulting from the change in extension.

PLIOGENE TO PRESENT

Basalt, which may be as old as lower Pliocene (Ross, 1961) or as
young as 2.8 myBP (Marvin, et al., 1977), was extruded onto a faulted
terrain as indicated by draping of fault scarps by the flows.
Lacustrine, fanglomeratic, and fluvial sediments were deposited in
valleys and basins before, during, and after basalt extrusion. Either
regional uplift began or the rate of uplift increased causing
dissection of the sedimentary sheets sometime after about 13 myBP.

Deposition of fanglomerates and fluvial material is occurring at present. Although there are only a few fault scarps found displacing recent sediments, continued seismicity indicates that the area is still undergoing extension (Gianella and Callaghan, 1932; Speed and Cogbill, 1979a).


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