GEOLOGY OF THE EASTERN PART
BEATY BUTTE FOUR QUADRANGLE, OREGON

by

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INTRODUCTION

Location and Accessibility

The Beaty Butte Four Quadrangle is located in the southernmost part of Harney County, Oregon. The thesis area includes about 130 square miles which lie between 42° 00' and 42° 15' north latitude and 119° 00' and 119° 08' west longitude. (Plate 1) Burns is 95 miles north, Lakeview 100 miles west and Denio 40 miles east.

Access to the area during dry weather may be gained by traveling north on dirt roads which join Nevada State Highway 8A at Thousand Creek Ranch and Big Springs, and by traveling south on a dirt road that joins the Frenchglen-Fields road at the base of Catlow Rim.

Previous Work

This thesis is the first recorded geologic investigation of the eastern part of the Beaty Butte Four Quadrangle. However, considerable geologic work has been done in nearby areas.

Blake (5), I. C. Russell (24), and Waring (30, 31)

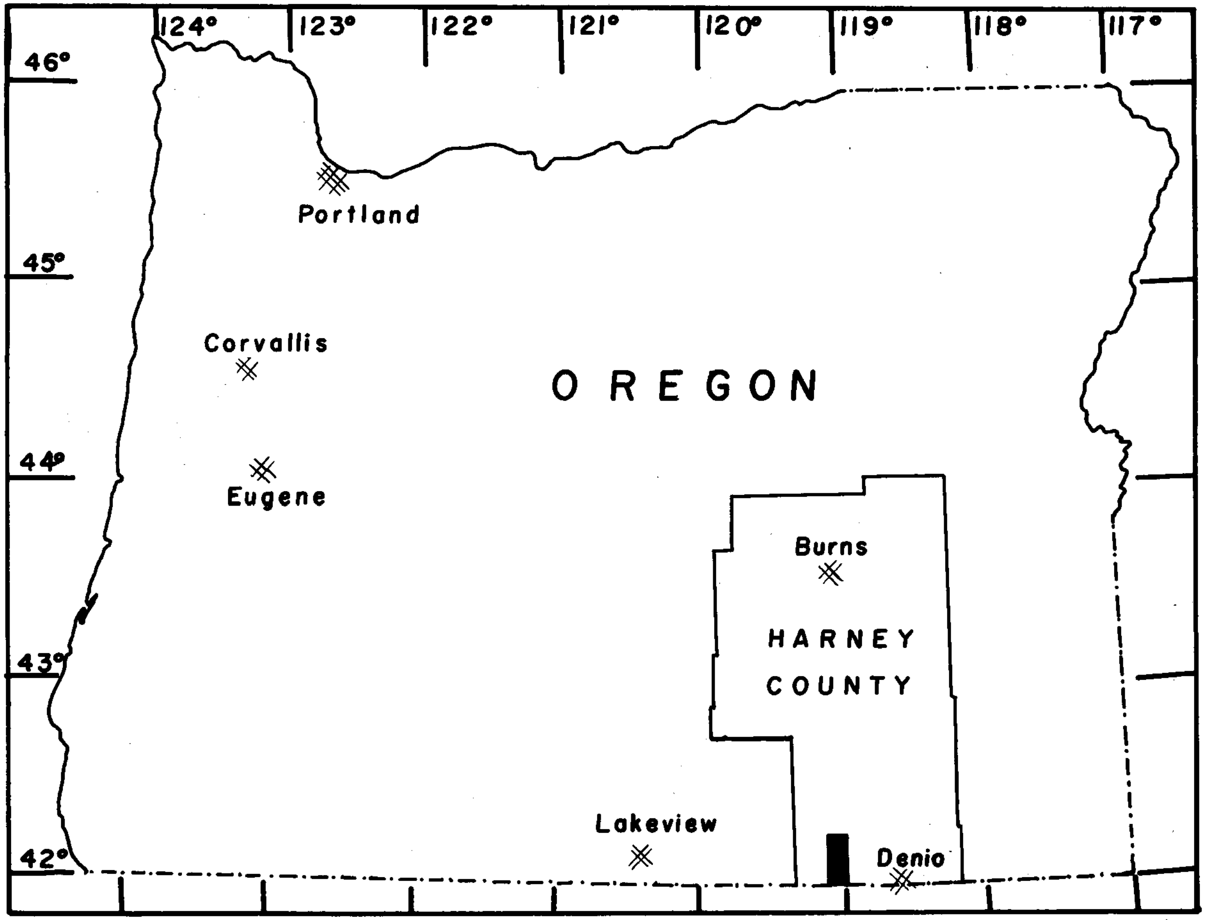


Plate I. Index map showing location of the eastern part, Beaty Butte Four Quadrangle, Oregon.

have made reconnaissance studies in southeastern Oregon.

Merriam (17) described the mammalian fossils and stratigraphy at Thousand Creek and Virgin Valley, Nevada. Fuller (11) described the stratigraphic sequence at Steens Mountain, and Piper, Robinson and Park (21) mapped and recorded the stratigraphic sequence in the Harney Basin.

Cochran (7) is currently working on the structure and stratigraphy of the Pueblo Mountains. Johnson (13) and Blair (4) mapped areas adjacent to the east side of the thesis area. Other workers in the region are listed in the bibliography.

Present Work

This report is based upon field work done during 11 weeks between June 15 and September 17, 1958, and laboratory work done during the spring and summer of 1959. Geology was plotted on areal photographs at a scale of 1:30,000, and then transposed to the Beaty Butte Four planimetric quadrangle map enlarged to a scale of 1:31,680.

Fault-strike frequencies were determined by using the bearings of the fault traces as plotted on the base map. Inaccuracies are introduced by the lack of topographic control. However, the steepness of the faults and a general low relief along the fault traces minimize the inaccuracies.

The faults have been numbered for convenience of reference. The numbering system is illustrated in Plates 10, 11, and 12, pages 69, 70 and 74.

Geography

Locations of the major physiographic areas are shown in Plate 4. (Page 38) Hawks Mountain, 7,200 feet in elevation, is the highest peak in the thesis area. The lowest point is at the intersection of Funnel Canyon and the eastern boundary of the area where the elevation is about 5,000 feet. This gives a maximum relief of about 2,200 feet.

No climatological data is available. However, the climate is characterized by little precipitation and large seasonal and daily temperature ranges. Summers are hot with occasional thundershowers; winters are cold and windy with some snow.

Vegetation consists mainly of short grass, sagebrush and widely scattered juniper trees. The grass is used for cattle and sheep grazing.

STRATIGRAPHY

Regional Stratigraphy

The ages and stratigraphic positions of the mapped units are known mainly from stratigraphic relations and fossils described in adjacent areas. The following paragraphs present a summary of this evidence.

A small flora has been found in the Alvord Creek formation, which includes the earliest Tertiary rocks exposed on the east face of the Steens Mountains. Chaney (11, p. 114) dated the flora as Middle or Upper Miocene. Later, Axelrod (2, p. 247) dated the same flora as Lower Pliocene, and Wolf (10) dated another collection from the same locality as Middle Pliocene.

The Steens basalt is stratigraphically above and therefore younger than the Alvord Creek formation on Steens Mountain. No fossils have been described from the Steens basalt.

Fossil vertebrates were found in tuffs immediately overlying the Steens basalt at Beaty Butte. Wallace (30, p. 117) dated the fauna as Middle Miocene.

Merriam (16, p. 199-304) described Middle or Upper Miocene vertebrate fossils from the Virgin Valley formation. The Virgin Valley formation overlies the Lone Mountain formation (an equivalent of the Canyon rhyolite) which overlies the Steens basalt.

Thus, the Steens basalt and the overlying Lone Mountain formation are younger than rocks dated Lower or Middle Pliocene by fossil flora and older than rocks dated as Middle or Upper Miocene by fossil vertebrates. This indicates a basic discrepancy in the dating techniques. The writer considers the vertebrate datings to be the most reliable and, therefore, considers the Steens basalt and the Lone Mountain formation to be Middle Miocene in age.

The Danforth (?) ignimbrite unconformably overlies the Lone Mountain formation east of the thesis area. (13, p. 44) It disconformably underlies the Thousand Creek tuffs on the western flank of the Pueblo Mountains. (7) Merriam (18) has dated the Thousand Creek, using fossil vertebrates, as Middle Pliocene. Campbell (6) correlates the Danforth with the Rattlesnake formation of Central Oregon, dated by Thayer (28) as Middle Pliocene. This correlation is tentatively accepted in this thesis.

Mesa basalt overlies the Thousand Creek tuffs with no angular discordance. An unconformity is indicated by the canyon filling of Mesa basalt in the Thousand Creek at Railroad Point southeast of the mapped area. The occurrence of gravel between the tuffs and the overlying basalt in some areas also suggests a hiatus. For this reason the Mesa basalt is considered post-Middle Pliocene in age.

The stratigraphy is tabulated in a generalized correlation chart (Plate 2), representing five general periods of deposition: Middle and Upper Miocene basalts, rhyolitic lavas and ignimbrites; Upper Miocene tuffaceous sediments; Lower-Middle Pliocene ignimbrites; Middle Pliocene tuffaceous sediments; and post-Middle Pliocene basalts.

Local Stratigraphy

Steens Basalt

Fuller (11, p. 101) used the name Steens Mountain basalt for the 3000 feet of olivine basalt flows that overlie the Steens Volcanic series on the east face of the Steens Mountains. He traced the formation as far south as the western flanks of the Pueblo Mountains. From this latter point it may be traced almost continuously to the northeastern part of the mapped area. Piper, Robinson and Park (22, p. 50) shortened the name to Steens basalt.

The Steens basalt is exposed over 11 square miles in the northeastern part of the area and in two small areas on the F-50 fault scarp that passes through the central part of the mapped area. (Plates 12 and 15, pages 74, 88) The exposures are good, especially along the numerous fault scarps. Individual flows range from 5 to 50 feet in thickness, but the total thickness could not be measured

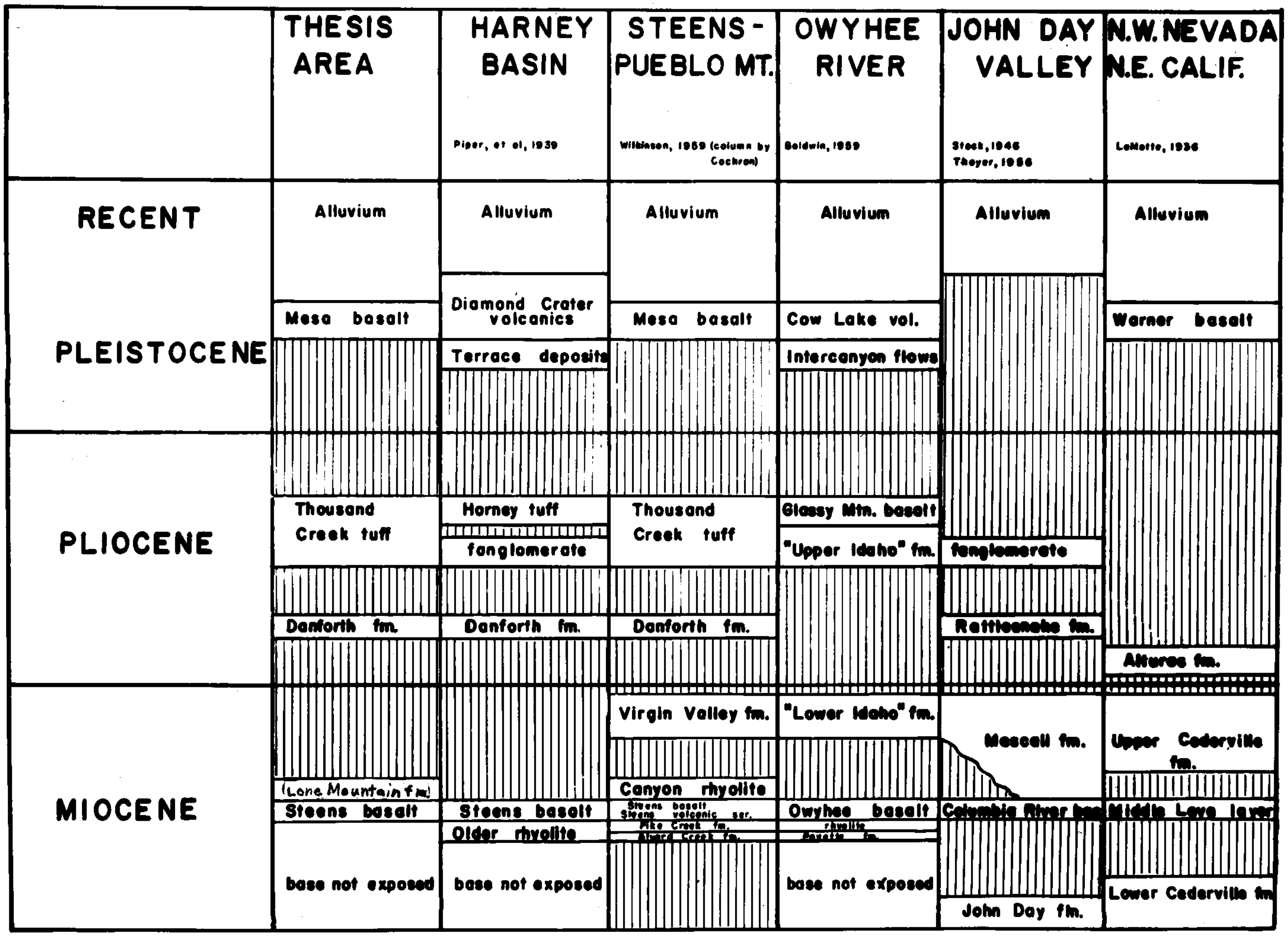


Plate 2. Correlation Chart.

Table I

SUMMARY OF EXPOSED FORMATIONS

Age	Formation	Description	Thickness In Feet
Recent	Alluvium	Gravel, sand, clay and alkaline lake deposits.	(?)
Post-Middle Pliocene	Mesa basalt	Olivine basalt	0-100
Post-Middle Pliocene	Older alluvium	Chiefly gravel derived from the Lone Mountain formation.	0-200 (?)
Middle Pliocene	Thousand Creek (?)	Red and white reworked tuff with pumice lenses.	0-100
	Disconformity[1]		
Lower-Middle Pliocene	Danforth (?)	Poorly-welded pumiceous tuff-breccia ignimbrite.	0-50
	Angular Unconformity		
Middle Miocene	Lone Mountain formation	Ignimbrite and rhyolitic flows with related vitrophyres	300 +
	Disconformity[2]		
Middle Miocene	Steens basalt	Hypersthene-bearing, platy and massive basalt.	1,000 +

1. Contact not observed in thesis area. Disconformity described by Cochran (7) from the Pueblo Mountains.

2. The disconformity is not apparent locally, but is described by Johnson (13), east of the thesis area.

inasmuch as the base of the unit is not exposed. Johnson (13, p. 16) measured a minimum thickness of 840 feet at Catlow Rim, two miles east of the area.

Lithology. Massive gray basalt, massive black basalt, and platy basalt were noted in the field but not mapped separately. These rock types recur at several levels in the unit and are horizontally variable. The problem of tracing individual flows is complicated by the many faults and the discontinuous nature of the outcrops between the scarps.

The massive basalts are jointed in two or more directions normal to the surface of flow. (Figure 1) Some of the massive flows are vesicular near the top of the flows; others are dense throughout. The platy flows lack the vertical jointing and vesicles of the massive flows. The platy parting formed nearly parallel to the surface of flow but has since been contorted into many small folds.

Though gray to black on fresh surfaces, the basalt weathers red. Fresh samples are porphyritic to the unaided eye. Clear, lath-shaped plagioclase phenocrysts are set in a fine-grained groundmass.

Microscopically, the hypersthene-bearing Steens basalts are generally glomeroporphyritic. Phenocrysts comprise 10 to 30 per cent of the rock. Labradorite, hypersthene, clinopyroxene, and rare crystals of olivine commonly form the phenocrysts.

Figure 1. Vesicular upper part of a massive, black basalt flow in the Steens basalt. Note the two directions of jointing which intersect at right angles and are normal to the surface of flow marked by the hammer.

Labradorite comprises 50 to 80 per cent of the phenocrysts. It varies from calcic to sodic labradorite, many of the crystals showing either normal or oscillation zoning. A few crystals exhibit reverse zoning. Most plagioclase crystals are extensively fractured and partly resorpted. Unzoned crystals are resorpted in irregular patches or along cleavage traces. However, zoned crystals are resorpted in their most calcic parts. Some of the embayments are filled with hypersthene, indicating that the hypersthene formed after the plagioclase.

Pyroxenes form 10 to 30 per cent of the phenocrysts. Hypersthene phenocrysts are clear, show good cleavage, and are pleochroic green to pink. Many hypersthene crystals have reaction rims. The alteration products are a green micaceous mineral, magnetite, hematite, and clay minerals. Zircons, apatite, and magnetite inclusions are present. Rarely olivine crystals were found as cores in the hypersthene phenocrysts. They are extensively altered to a reddish-brown iddingsite-like material, possibly saponite. Clinopyroxene occurs as both pigeonite and augite phenocrysts. Reaction rims on the clinopyroxene are similar to those of the hypersthene.

The groundmass is pilotaxitic and composed of small labradorite laths, iron oxides, nontronite (?), and minor amounts of pigeonite and apatite. Magnetite is abundant in the groundmass. Some of the magnetite has been altered to hematite and limonite.

Origin. Williams and Compton (35, p. 29) suggested that the Steens basalt was emplaced by large-scale fissure eruptions. There is no recognizable source for the basalt in the mapped area. If any feeder dikes are present, they are covered by later volcanics or alluvium.

The many flows that form the Steens basalt were probably extruded during a relatively short period of time, as indicated by the absence of baked soil horizons and the uniformity of basalt composition throughout the section.

The basalt on Steens Mountain is an olivine basalt in contrast to the hypersthene-bearing basalt of the thesis area. Either the lavas were extruded from different parts of the magma chamber or at a different time from the same source.

Lone Mountain Formation

Gray felsites and vitrophyres disconformably overlie the Steens basalt. The felsites are traceable by almost continuous exposure south to Beat Canyon, Nevada, where Merriam (17, p. 32) named them the Canyon rhyolite formation. This unit is herein renamed the Lone Mountain formation for its exposures on the crest and flanks of Lone

Mountain. The necessity for renaming the formation is brought about by the fact that the unit is in part a welded tuff and because mineralogically it is for the most part not a rhyolite.

Porphyritic rocks having glassy groundmasses, here termed vitrophyres, are distinguished from those with non-glassy groundmasses, here termed felsites. These two rock types are mapped separately. All vitrophyric rocks are associated with felsites. In some outcrops the flow structures of the vitrophyre are discordant to the flow structures of the felsite, and the vitrophyre appears to be intrusive into the felsite. However, the two rock types are concordant in other outcrops. Johnson (13, p. 36) found concordant vitrophyric rocks at the base of the formation. Most concordant-vitrophyre exposures in the thesis area are within the Lone Mountain formation rather than at its base. (Figures 2 and 3) It was not determined whether these bodies are sills, flows, or chilled facies. Vitrophyre-felsite contacts are sharp. Alternating bands, 1 to 20 feet in thickness, of vitrophyres and felsites were found in the east half of sec. 19, T. 40 S., R. 32 E. This banding may be the result of injection of vitrophyre into the felsite.

Both rock types are jointed in two to four directions normal to surface of flow. Some felsites have platy

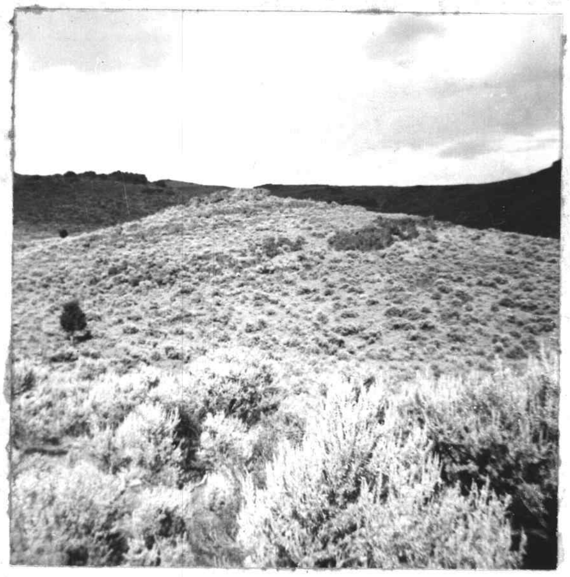


Figure 2. A corcordant vitrophyre in the Lone Mountain formation at Juniper Spring. Light-colored felsites outcrop above and below the vitrophyre.

Figure 3. A concordant vitrophyre in the Lone Mountain formation on the Basco Horst in sec. 16, T. 39 S., R. 31 E.

parting, which is interpreted as a cooling feature. The author was unable to distinguish initial contractional jointing from tectonic joints. Weathering along joints on Lone Mountain has formed hoodoo structures. (Figure 4)

The Lone Mountain formation has been extensively eroded. However, recent faulting has provided numerous exposures.

Some of the structures in the Lone Mountain formation have been determined, but the great variations in attitude and the presence of numerous slickensided boulders indicate that many faults were not mapped. These structural problems have made it impossible to determine the thickness of the formation.

The base of the formation is exposed at Basco Horst, Funnel Graben, Catlow Rim, Hawks Mountain, and Actey Rim. Steens basalt is the underlying unit in all areas. The contact shows little relief at most localities. Catlow Rim (S. ½, sec. 18, T. 39 S., R. 32 E.) is an exception; there the contact is found along a high-angle fault. Johnson (13) describes considerable relief along the contact to the east. Variations in attitude within both units made it impossible to determine whether an angular unconformity exists.

Lithology-Vitrophyre. Vitrophyres are gray, black and red. They are commonly banded parallel to the

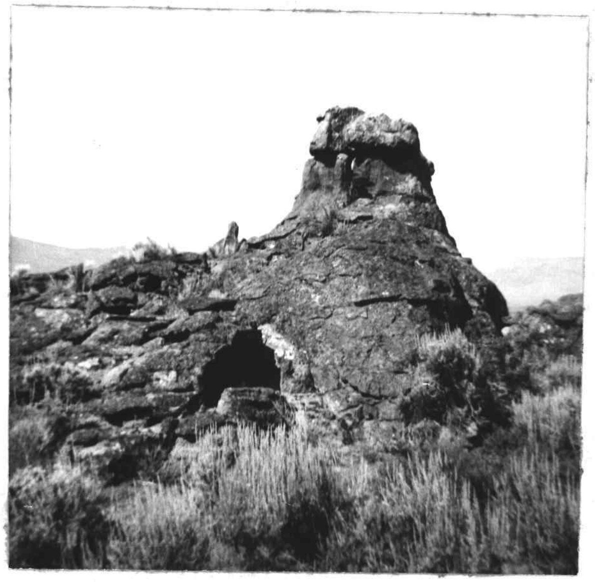


Figure 4. A hoodoo formed in the felsite on Lone Mountain in sec., 12, T. 40 S., R. 31 E.

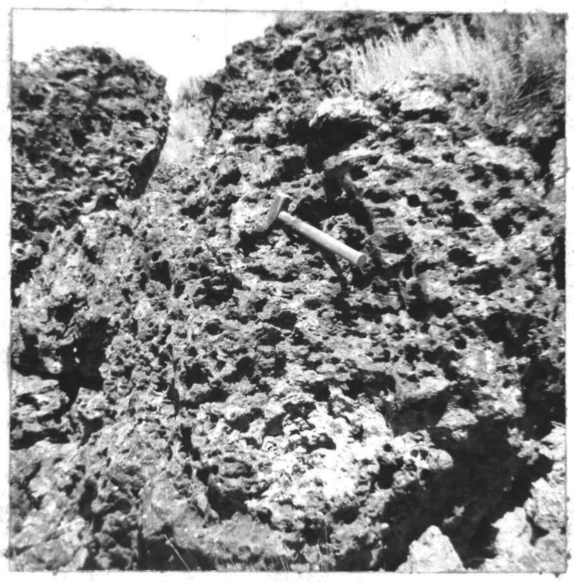


Figure 5. A vesicular, spherulitic, sanidine-bearing felsite exposed northwest of Hawksiewalksie Playa in N.E. ¼, sec. 36, T. 40 S., R. 30 E.

direction of flow - strikingly so where black and red bands alternate.

Feldspar and biotite phenocrysts are visible to the unaided eye. The groundmass is dense and glassy; some glass is perlitic.

In thin section the groundmass is composed of iron ores and crystallites in addition to the glass. In some rocks the ores are concentrated in flow bands which are crenulated suggesting viscous lava.

Feldspar phenocrysts comprise 10 to 50 per cent of the rocks. Oligoclase and anorthoclase are the principal feldspars; sanidine is common but occurs in minor amounts. The discordant rocks contain oligoclase in contrast to the concordant rocks which contain anorthoclase and oligoclase in almost equal quantities. Johnson's concordant vitrophyres have a preponderance of anorthoclase. Some oligoclase crystals are rimmed by anorthoclase, indicating that the anorthoclase crystals formed by reaction of the oligoclase with the residual magma.

Anorthoclase is recognized by its thinly laminated two directional polysynthetic twinning and its distinctive intermediate axial angle of 46 degrees. Twinning laminae intersect at 90 degrees. The spotty extinction in some crystals resembles irregular microperthitic intergrowths. However, it is more likely that the patches are remnants of plagioclase that have not been converted to anorthoclase.

Sanidine occurs as clear crystals which are easily recognized by their axial angle of less than 30 degrees. Some crystals show Carlsbad twinning.

Biotite, which averages about 5 per cent of the vitrophyres, is the most abundant mafic mineral. It is strongly pleochroic brown or dark brown to nearly black. Biotite in the discordant vitrophyres is little altered, but the biotite in the concordant vitrophyres is extensively altered to iron ores, mostly magnetite. Reddish brown biotite occurs in a few rocks, with abundant zircons as inclusions.

Clinopyroxene and hypersthene occur in minor amounts. Apatite and zircon are found as small euhedral to subhedral crystals.

Lithology-Felsites. Megascopically there are three distinct types of felsites. One is a gray porphyritic rock that is dense to finely vesicular and forms massive to platy outcrops. The second type is eutaxitic with red, yellow, and gray bands. Sanidine phenocrysts are visible in most specimens. The third rock type is gray to buff-colored and contains ellipsoidal holes 1/2 to 2 inches long. (Figure 5) Aligned lenticels are common; sanidine phenocrysts can be seen in most specimens.

Petrographically the felsites vary between two end members. One end member will be referred to as the microcrystalline felsite and the other as the spherulitic felsite. The microcrystalline rocks are for the most part rocks that are gray and dense in hand specimens. Some eutaxitic rocks are microcrystalline and others spherulitic. The vesicular rocks are spherulitic.

The microcrystalline rocks are greatly similar to the concordant vitrophyres. They differ in that they have microlitic groundmasses rather than glassy ones. The microlites are clear with a low birefringence and an index of refraction less than that of balsam. Magnetite is abundant; hematite occurs in varying quantities. Vesicles are lined with hematite, tridymite, and quartz.

Phenocrysts comprise 5 to 50 per cent of the microcrystalline felsites; feldspars comprise over 90 per cent of the phenocrysts. Oligoclase and anorthoclase are the dominant feldspars; the percentage of anorthoclase is higher than in the vitrophyres. Some oligoclase crystals are rimmed by anorthoclase. Sanidine phenocrysts occur in minor amounts. Biotite is the most abundant mafic mineral and is extensively altered to magnetite and hematite. Augite and hypersthene occur in minor amounts.

The spherulitic rocks have larger groundmass microlites than the microcrystalline felsites. These microlites, lath-shaped, of low birefringence and an index of refraction between 1.520 and 1.543, are probably sanidine. Quartz was detected between the feldspar microlites in a few rocks. Some of the spherulites are independent and spherical in shape. Others are crowded together and have irregular outlines. Some eutaxitic rocks contain alternate bands of spherulites and iron ores. Many of the bands of iron ores continue uninterruptedly through spherulites and indicate that the spherulites formed after the flow stopped. The spherulitic bands contain most of the phenocrysts and vesicles. Plumose arrangements of microlites are found in many rocks. The wedged discontinuous nature of these microlite aggregates indicates that they may be devitrified pumice fragments.

Vesicles not filled with spherulites contain tridymite, hematite and sometimes quartz. Many of the tridymite crystals are larger than the microlites in the groundmass.

Phenocrysts are less abundant in the spherulitic rocks. Highly fractured, partly resorpted sanidine phenocrysts form 5 to 20 per cent of the rocks. A few of the sanidine phenocrysts contain plagioclase cores. Oligoclase and anorthoclase occur in minor amounts or are absent.

The biotite is completely or almost completely altered to magnetite. Pyroxenes are almost entirely absent; those present are extensively altered to a green micaceous mineral.

Many rocks are intermediate between the end members. In fact there seems to be a complete gradation from the discordant vitrophyres to the spherulitic felsites. Some seemingly significant mineral and rock variations are:

1. The groundmass varies from glassy with crystallites through a groundmass of small microlites to a groundmass of larger microlites that have spherulitic structures.

2. Groundmass iron ores increase in abundance from the vitrophyres to the spherulitic felsites.

3. The vitrophyres are not vesicular, the microlitic felsites are finely vesicular, and the spherulitic felsites are the most vesicular. The abundance of tridymite is directly proportional to the vesicularity.

4. Feldspar variations seem to be significant. Those in the discordant vitrophyres are predominantly oligoclase. The concordant vitrophyres and microlitic felsites contain oligoclase and anorthoclase in varying quantities. Anorthoclase rims many oligoclase crystals. The spherulitic felsites are dominantly sanidine. A few sanidine phenocrysts have plagioclase cores.

5. Biotite is fresh and unaltered in the discordant vitrophyres. It is partly resorpted in the concordant vitrophyres and microlitic felsites, and is entirely resorpted in the spherulitic felsites.

The general terms vitrophyre and felsite are used in place of more exact rock names because of the great variations previously described. Rocks vary from latites through quartz latites and trachytes to rhyolites in mineral composition. In addition there is evidence that at least some of these are ignimbrites. However, all these rocks are related to the same magma and, therefore, are discussed together in the more general rock terms.

Origin. It has been demonstrated that the alkali feldspars form a solid solution series at temperatures above 660°C. (16)(3, p. 483) The coexistence of sanidine and plagioclase in rhyolitic rocks is explained as a disequilibrium feature, that is, plagioclase crystallizes first but then reacts with the melt to form sanidine. (29, p. 130-137) Magmas that are rapidly cooled after the beginning of this reaction but before its completion will contain two feldspars.

The Lone Mountain volcanics record a great many stages of reaction between unaltered oligoclase and sanidine, anorthoclase forming an intermediate product. The cross-hatch twinning on the anorthoclase crystals formed during a monoclinic phase but the crystals inverted to a triclinic form during cooling. (15) In contrast, the sanidine remained monoclinic and the plagioclase probably never had monoclinic symmetry. The monoclinic-triclinic inversion temperature is related to the feldspar composition, the higher the potassium concentration the lower the inversion temperature. Inasmuch as both sanidine and anorthoclase are high temperature forms the amount of potassium in the lattice was the critical factor determining the symmetry. Therefore, the reaction of oligoclase to anorthoclase to sanidine represents increased potassium substitution into the lattice. It is probable that the plagioclase crystallized first but that sanidine was the stable high temperature form.

Vesicularity proves the presence of volatile substances. Biotite resorption is related to the loss of volatiles at high temperatures, and most of the devitrification of the glassy groundmass probably occurred while the rocks were hot and permeated with gases. (34, p. 157) The sanidine-bearing rocks show the greatest modification due to the presence of volatile constituents and the oligoclase-bearing rocks the least modification. Perhaps, then, the volcanic sequence contains rocks that extruded from different levels in the magma chamber and therefore had slightly different compositions and were at slightly different stages of crystallization.

Merriam (17, p. 32) described the felsites surrounding Virgin Valley as rhyolites. Johnson (13, p. 39-44) redescribed them as ignimbrites, his principal evidence being the occurrence of welded shard textures at the base of the unit. He thinks the vitrophyres represent chilled facies and the spherulitic rocks the silicified central parts of the ignimbrites. He attributes the viscous flow and eutaxitic structures in the upper portions of the unit to silicification and compaction. (13, p. 40)

The author had the opportunity of looking at

Johnson's thin sections and is in full agreement that the textures described as vitroclastic are the products of an ignimbrite. Sanidine is the feldspar found in these glassy rocks. It should be noted, however, that the shard texture was found at only a few localities and only at the base of the unit.

Many features in the middle and upper parts of the unit indicate the viscous flow of a rhyolite. Microfolds caused by viscous flow are common. Some parts of the unit are highly vesicular as in a lava. The sharp felsite-vitrophyre contacts and the discordant nature of some of the vitrophyres indicate that they are discrete units and not chilled facies.

It is therefore apparent that both ignimbrites and lavas are present in the Lone Mountain volcanics. Perhaps the initial extrusion was as an ignimbrite but most of the gas pressure was released during this extrusion and subsequent extrusions were in the form of viscous lavas.

Danforth (?) Formation

Four outcrops of vitric tuff-breccia are exposed on the Actey Piedmont in sec. 24 and 25, T. 39 S., R. 30 E. and sec. 31 T. 39 S., R. 31 E. These outcrops are tentatively correlated with the Danforth formation, which was named by Piper, Robinson and Park (22, p. 43) for outcrops near Danforth Ranch in Harney County. The correlation is based upon the lithologic similarity between the tuff-breccia and the upper member of the Danforth in the type area. These rocks are similar to the Rattlesnake ignimbrite of central Oregon and like the Rattlesnake are considered to be Middle Pliocene in age.

White pumiceous material is exposed at several small outcrops in the northeastern part of the area, the most notable being in sec. 6, T. 39 S., R. 32 E. Johnson found similar material in the Danforth (?) farther east.

The tuff-breccia underlies piedmont alluvium which in turn underlies the Mesa basalt. Its base is not exposed. The white pumice overlies the Steens basalt and is not covered. It is less than 5 feet thick and forms patchy outcrops. The tuff-breccia has a thickness of at least 20 feet on the Actey Piedmont. (Plate 4, page 38)

The tuff-breccia is friable and easily weathered. Soil and/or alluvial gravels cover most of the area in which the Danforth (?) could be exposed, but outcrops are found along gullies.

Vertical jointing is present but is highly imperfect. Weathering along the joints has produced many oddly shaped caverns.

Lithology. The Danforth (?) tuff-breccia is buff to light gray in color. About thirty per cent of the rock is composed of partially collapsed pumice fragments as much as 2 inches long. A few rounded felsite pebbles were found. The matrix is composed of unwelded glass shards, many of which contain bubbles. Microscopically the Danforth (?) is over 95 per cent glass and devitrification products. Small amounts of potassium feldspar, plagioclase, quartz, and clinopyroxene are present.

Origin. The tuff-breccia appears to be an unwelded ignimbrite. No source area was found. It may be related to the Danforth ignimbrite which spread over much of south-eastern Oregon.

Thousand Creek (?) Formation

Merriam (16) described two similar reworked tuffs, at Thousand Creek and Virgin Valley, Nevada. In this region the tuffs are separated by a Northwest-trending ridge of Lone Mountain volcanics. Though similar in appearance, the two tuffs contain different fossil vertebrates. These fossils date the Virgin Valley as Middle or Upper Miocene and the Thousand Creek as Middle Pliocene.

Tuffs can be traced by discontinuous outcrops from the type area of the Thousand Creek formation to the south-eastern part of the thesis area. However, the outcrops in the thesis area are on the Virgin Valley side of the north-west-trending ridge. Lithologically the tuffs in the thesis area more closely resemble the Thousand Creek than they do the Virgin Valley, but a positive correlation can be made only by vertebrate fossils.

The tuffs form a low rolling topography. Only three outcrops are present in the area; gravel and soil generally cover the tuff. However, much of the area mapped as older alluvium in the southeastern part of the area is probably underlain by tuff.

The tuffs are nearly horizontal. They form an angular unconformity with the underlying Lone Mountain formation and a paraconformity with the overlying Mesa basalt. The paraconformity is indicated by the alluvial gravels that occur between the tuffs and the basalt in some areas.

Lithology. Outcrops consist of alternating beds of red and white reworked tuffaceous clays, silts and local lenses of felsite and pumice gravels. (Figure 6)

The sediments are poorly compacted and bedding is not readily apparent. Gravel beds and primary color bands were used to determine the attitudes.

The reworked ash is composed of partially devitrified glass grains in a clay matrix. Magnetite grains are scattered throughout the clay. A few zircon crystals are present as inclusions in the glass.

Pumice occurs in lenses of well-rounded, small pebbles which are frothy and not collapsed. The pebbles are

Figure 6. Thousand Creek (?) tuff exposed in sec. 18, T. 41 S., R. 32 E. This section has red tuff underlying and tuffaceous gravel overlying white tuff.

cemented by a brown undetermined clay mineral. Some of the gravels near the top of the formation contain subrounded to rounded felsite pebbles, cobbles and boulders loosely packed in a tuffaceous matrix.

Origin. These water-laid tuffs and gravels are basin deposits. They may have resulted from an ash fall that was subsequently eroded from the topographic highs and deposited in the basins. Erosion continued into the Lone Mountain felsites and gravels were deposited in the basins on top of the tuff.

Older Alluvium

Unconsolidated gravels composed of subangular to subrounded felsite boulders, cobbles and pebbles set in varying quantities of tuffaceous material were found in areas that are currently being eroded. (Figure 7) The principal outcrops are on Actey Piedmont, Winnemucca Canyon, the southern slope of Hawks Mountain, and the Basco Hills. (Plate 4)

The Lone Mountain felsites are the source of almost all the boulders, cobbles, and pebbles. Vitrophyre pebbles are found in a few small areas. Obsidian pebbles are scattered throughout the gravels.

The alluvium was deposited in low areas caused by faulting along the northwest-striking system. It was

Figure 7. A poorly sorted subangular gravel composed of felsite pebbles, cobbles and boulders. This older alluvium is exposed in sec. 18, T. 41 S., R. 32 E.

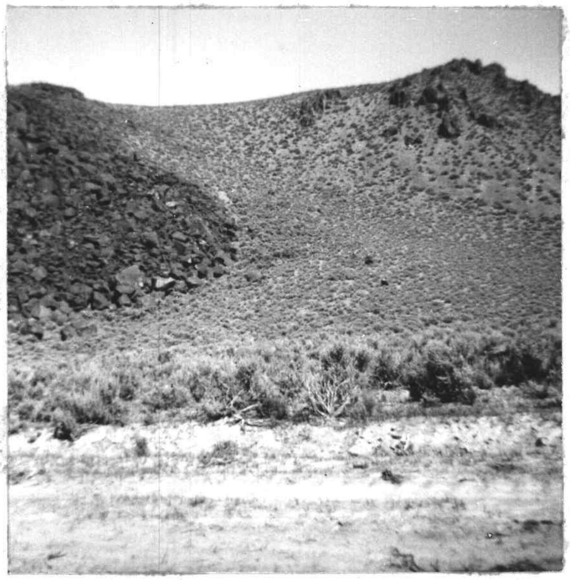


Figure 8. Lone Mountain Mesa basalt contact on the F-34 fault scarp at Remnant Hill in sec. 5, T. 40 S., R. 31 E.

deposited on the Thousand Creek (?) tuffs in the southeastern part of the thesis area, on the Danforth (?) at the Actey Piedmont, on the Lone Mountain felsites in Winnemucca Canyon, and on the Steens basalt in the Basco Hills. Mesa basalt flowed onto the alluvium in the southeastern part of the area and on Actey Piedmont.

The faulting which followed the Mesa basalt flow left some areas of alluvium topographically high. The alluvium is now being eroded from these high areas.

Mesa Basalt

Merriam (17, p. 36) used the name Mesa basalt for the thin sheet-like olivine basalt that forms the "rim-rock" around Virgin Valley, Nevada.

Outcrops in the southern part of the thesis area are traceable by continuous exposure to the type area. Correlation of this basalt with the basalt exposed in the central and northwestern parts of the thesis area is based upon lithologic similarity, uniformity of thickness, and an almost horizontal attitude.

Mesa basalt flowed over a major part of the thesis area. (Plate 3, page 33) In the northwest the basalt forms a high plain that is broken locally by fault scarps. The high plain terminates at F-34 and to the southeast, in Hawks Valley, the basalt is exposed in small irregular patches. The southeastern edge of the thesis area marks the northern edge of another basalt high plain which

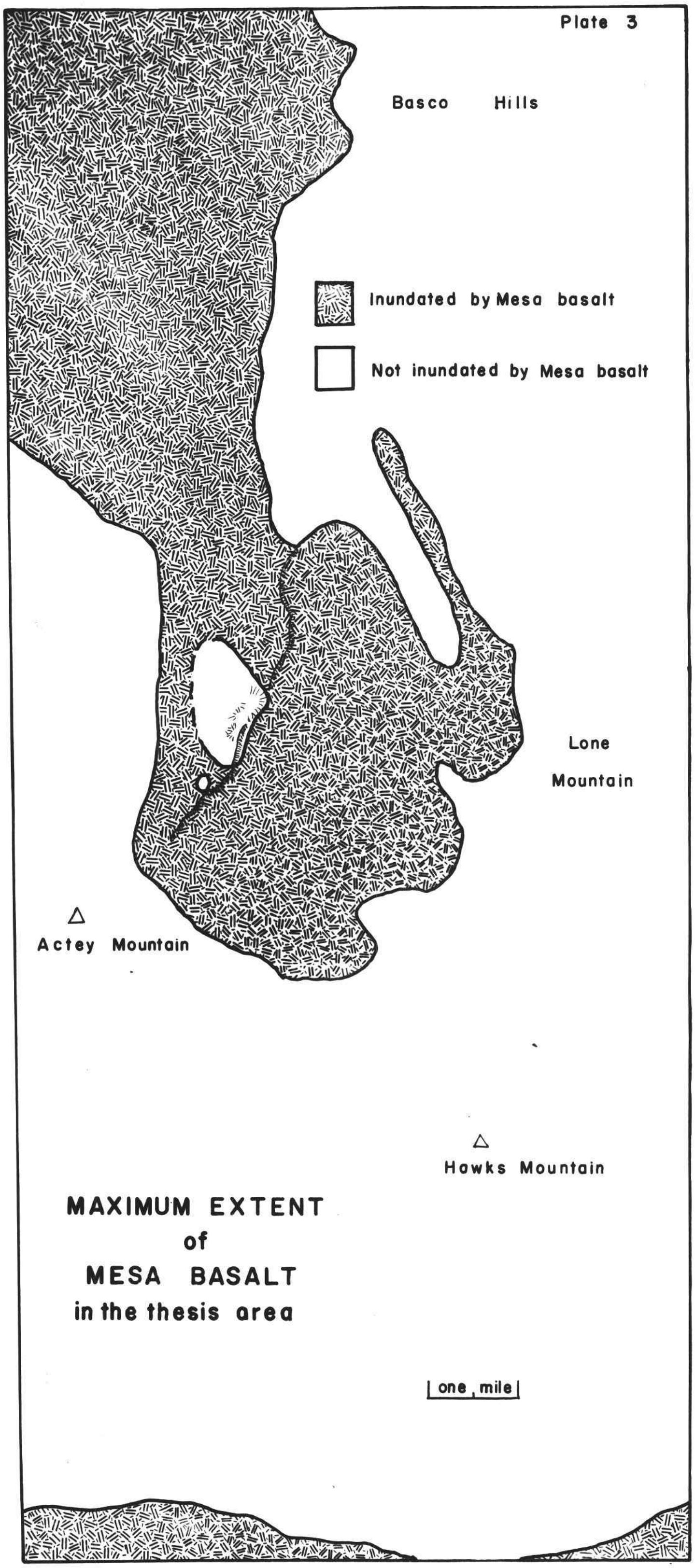


Plate 3
Basco Hills
Inundated by Mesa basalt
Not inundated by Mesa basalt
Lone Mountain
Actey Mountain
Hawks Mountain
MAXIMUM EXTENT
of
MESA BASALT
in the thesis area
one mile

extends south to Virgin Valley.

The Mesa basalt is about 30 feet thick at the southern boundary of the thesis area. It is at least 60 feet thick at the F-34 scarp in Hawks Valley and about 50 feet thick at the entrance to Funnel Canyon. Merriam (17, p. 36) estimates a thickness of 25 feet at Virgin Valley.

The surfaces of the high plains contain few outcrops. Basaltic rubble covers most of the surfaces. Large continuous outcrops are found along fault scarps; basalt talus accumulations are common at the bases of the scarps.

Little weathering has occurred and so the basalt has a fresh gray-black appearance. It is jointed in two or more directions normal to the surface of flow. Columnar jointing occurs in the SE ¼, sec. 7, T. 40 S., R. 31 E.

Lithology. The Mesa basalt is a black, amygdaloidal, finely porphyritic olivine basalt. Bottle-green olivine can be seen with the aid of a hand lens. Vesicles are numerous and are as much as an inch long. Many of the vesicles are filled with secondary calcite.

Microscopically the basalt is a fine-grained, nearly equigranular, holocrystalline olivine basalt. The few phenocrysts present have a glomeroporphyritic texture which is superposed upon a felty groundmass. Olivine and labradorite form most of the phenocrysts; hypersthene phenocrysts are few. The groundmass is composed of clinopyroxene, second generation olivine and labradorite, magnetite, and alteration products.

Labradorite forms about 55 per cent of the basalt. Labradorite phenocrysts are highly fractured; a few show oscillation zoning. Its average composition is Ab_{45}.

Olivine comprises about 20 per cent of the basalt. Its axial angle is estimated to be 90°, so it is probably chrysolite. Both generations have reaction rims of magnetite, iddingsite, chlorite, and serpentine (?). The phenocrysts are subhedral to anhedral, and the groundmass grains are anhedral.

Both augite and pigeonite are present as phenocrysts; the groundmass pyroxenes are primarily pigeonite. Augite was distinguished from pigeonite by axial angle measurements. (14, p. 309-311) The clinopyroxene grains are light brown to colorless anhedral crystals. They have a diabasic texture though in local areas the texture is subophitic.

Hypersthene occurs as rare phenocrysts which are clear, non-pleochroic, and extensively fractured but lack reaction rims. Pyroxenes comprise about 20 per cent of the basalt.

Magnetite occurs as primary grains in the groundmass and as an alteration product of the olivine.

Origin. The large areal extent and the thinness of the flow indicate a highly mobile lava. No source for the

Mesa basalt was found within the thesis area, though Beaty Butte may have been the source for the lava in the northeastern part.

<u>Quaternary Alluvium</u>

Large areas of alluvium occur at Hawksiewalksie playa and Hawks Valley. Most areas of deposition are structural lows formed during the post-Mesa basalt faulting. The alluvium ranges from gravels to montmorillonoid clays.

Many local areas of deposition are found along the bases of fault scarps. Many small scarps on the back slope of Hawks Mountain face up-slope. The scarps dammed the drainage, thus forming areas of sedimentation. These sediments are poorly sorted tuffaceous gravels.

Alluvium occurs at several small sink holes in the Mesa basalt in the northwestern part of the thesis area. Here the alluvium forms a thin veneer of less than 10 feet over the basalt and is composed of a mixture of silt, clay and basalt rubble.

Small patches of white tuff are exposed at several localities. The age of the tuff is unknown. Obsidian pebbles of unknown origin are scattered throughout the alluvium.

PHYSIOGRAPHIC MAP of the THESIS AREA

I Hollyhock Area

- A. Hollyhock High Plain
- B. Actey Piedmont
- C. Remnant Hill

II Lone Mountain Area

- A. Basco Hills
- B. Funnel Canyon
- C. Lone Mountain

III Hawks Valley Area

- A. Hawks Valley
- B. Winnemucca Canyon

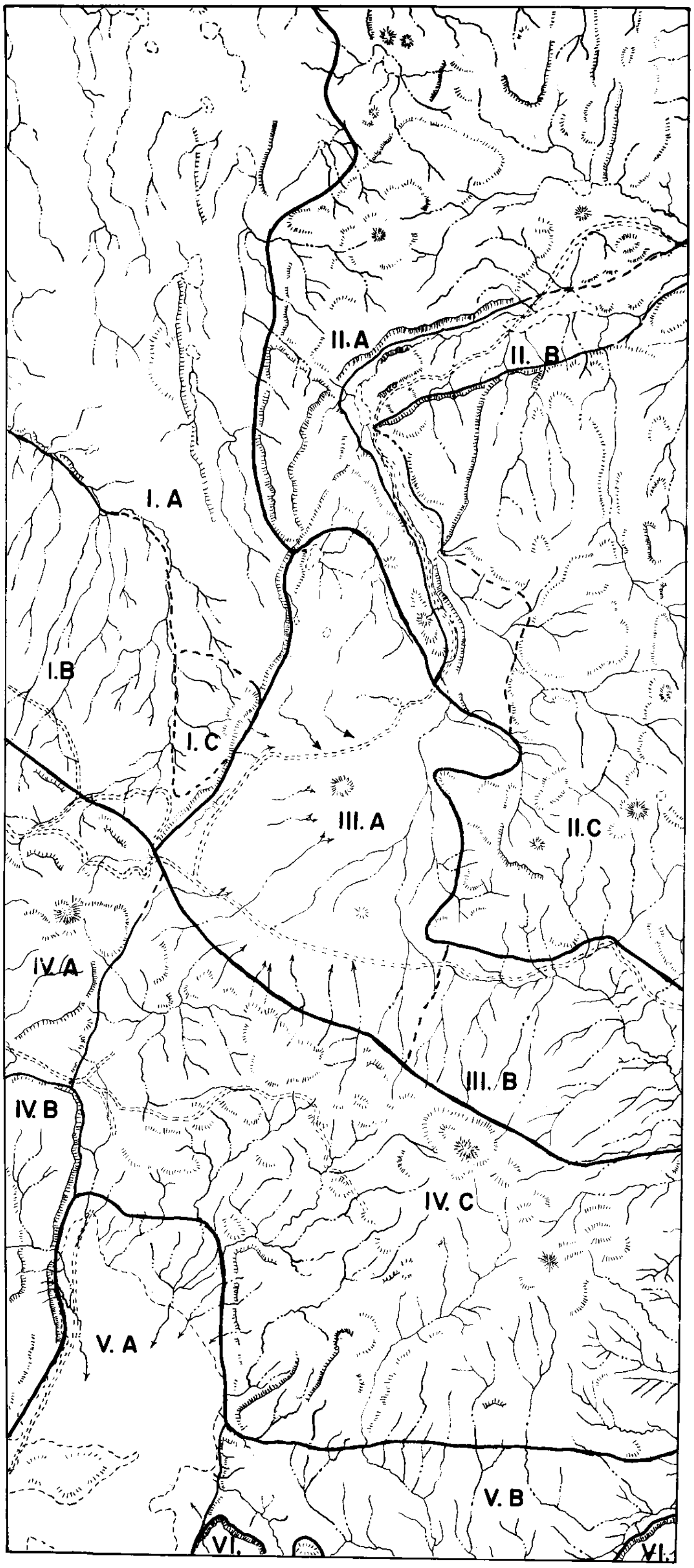
IV Actey-Hawks Mountain Area

- A. Actey Mountain
- B. West Hawksiewalksie Fault Blocks
- C. Hawks Mountain

V Hawksiewalksie Area

- A. Hawksiewalksie Playa
- B. Southern Lowlands

VI Mesa Basalt High Plain Area


II. A
II. B
I. A
I. B
I. C
III. A
II. C
IV. A
III. B
IV. B
IV. C
V. A
V. B
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VI.

PHYSIOGRAPHY

The Beaty Butte Four quadrangle is located in the northern Basin and Range physiographic province. Topography is structurally controlled, with long, steep fault scarps as the most distinctive feature. Faulting increased the relief and caused subsequent incisement of the valleys throughout most of the area.

Fault block topography typical of the Great Basin is found in the thesis area. Horsts, grabens, and tilted fault blocks form major physiographic features. The high plain formed by the Mesa basalt in the northwestern part of the thesis area is another major feature.

The thesis area is subdivided into six physiographic areas, each of which has been subdivided making a total of 13 areas. (Plate 4, page 38)

The physiography is discussed in terms of these areas.

Hollyhock Area

The Hollyhock area is a high plain that lies above Hawks Valley to the southeast and Catlow Valley to the north, but lies below the Basco Hills to the east, Actey Rim to the south, and Beaty Butte to the northwest. The plain slopes gently to the north, some gullies draining into Catlow Valley north of the thesis area, others draining into playas in the northern part of the thesis area.

Early youthful topography persists over most of the area. Remnant Hill contains an older erosion surface that has been rejuvenated.

Hollyhock High Plain

Topography is controlled by the almost horizontal, resistant Mesa basalt. Basaltic rubble covers the flow rock in much of the area, and alluvium covers it in low areas.

Eleven small playas are distributed over the area. Each is less than ½ mile in length and most are less than ¼ mile in width. These lake beds are internally drained and form sink areas on the plain. Four of the playas are located in sag areas along the hanging walls of high-angle normal faults. Five other playas are located in low areas in the basalt. The playa in sec. 33, T. 38 S., R. 31 E. is located on the backslope of the tilted fault block formed by F-33. (Plate 10, page 69) Alluvium eroded off the Basco Hills has accumulated against the backslope.

The northward slope of the plain may indicate that the Mesa basalt has a gentle northerly dip.

Actey Piedmont

The Actey piedmont is a partly dissected piedmont alluvial plain which has formed upon the downthrown block of F-50. (Plate 12, page 74) Faulting along F-50 caused an increase in the gradient. Subsequently Actey Rim started to erode and is still in the process of being eroded. Alluvium, consisting primarily of gravel, was deposited upon the piedmont. Post-Mesa basalt faulting caused further increase in the gradient with the result that the piedmont has become rejuvenated. V-shaped gullies 10 to 50 feet wide with broad flat interfluves, have been eroded into the piedmont.

Consequent streams run north down the slope to the Mesa basalt contact. At the contact the streams have eroded into the alluvium and flow to the northwest along the basalt contact.

Four outcrops of Danforth (?) and two of Lone Mountain felsites protrude through the alluvium. Danforth (?) outcrops capped by gravel indicate that they were exhumed after the rejuvenation. Felsite outcrops are at a higher elevation than the alluvium and may never have been covered.

Remnant Hill

Remnant Hill is a steptoe about which the Mesa basalt flowed. (Figure 8, page 31) Basalt divides the hill, composed of Lone Mountain felsites, into two parts; a small knob is exposed about $\frac{1}{4}$ mile south of the main part of the hill. Faulting along F-34 truncated the east side of the hill which forms a part of the scarp.

Drainage flows west and northwest in shallow, incised gullies that have formed on the rolling hill.

Lone Mountain Area

Funnel Canyon separates two mountainous areas, the Basco Hills and Lone Mountain. These three areas are collectively referred to here as the Lone Mountain area.

The north and central parts of the area have flat to rolling upland surfaces that are broken by numerous fault scarps. Topography in the southern part of the region is highly irregular.

Basco Hills

North-trending fault blocks and two northwest-striking grabens are the dominant topographic features. The southern part of the area is a horst here named the Basco Horst. It is bounded by steep fault scarps, but the upper surface is a smooth to undulating plain. This surface, which is a remnant of the pre-faulting topography, is being dissected by gullies. The graben formed by faults

F-17 and F-18 (Plate 10, page 69) is a distinctive U-shaped valley extending across the horst so as to form hanging valleys on both sides of the horst.

Northward the horst terminates against a number of fault blocks. These blocks are formed in the Steens basalt; however, they display the same erosional surface as the Basco Horst. The intermittent lake in sec. 1, T. 39 S., R. 31 E. is located at the intersection of a north-trending graben with a northwest-trending graben. The basin drains eastward in an incised gully that flows along F-8 to Funnel Canyon.

Drainage on the Basco Horst runs to the northwest. Most of the gullies are short and steep. To the north, drainage is controlled by the fault blocks. Major gullies run north, south, northwest and southeast, in the grabens and on the step blocks. Shorter gullies have formed on the scarps.

Funnel Canyon

Funnel Canyon begins at the northern end of Hawks Valley and empties into the southern end of Catlow Valley. It is composed of two parts, a southern part that trends N. 20°W. and a northern part that drains N. 70°E. The northern part occupies the bottom of Funnel Graben.

Funnel Canyon drained into Hawks Valley at the time of the Mesa basalt flow. This is indicated by the fact that the basalt thins from Hawks Valley to the north in Funnel Canyon. The most northerly outcrop of Mesa basalt in Funnel Canyon is just south of fault F-34. The basalt leveled the southern part of Funnel Canyon. The subsequent formation of Funnel Graben caused a reversal of the drainage and the canyon now empties into Catlow Valley to the north.

The gully that formed after the Mesa basalt flow intrenched itself in the Lone Mountain felsite at the basalt contact on the west side of the canyon. As the gully was cut down it migrated eastward. So now the west side of the canyon is barren of basalt while the east side contains an almost complete section of Mesa basalt.

The F-35 fault scarp, which forms the west side of Funnel Graben acts as a barrier that turns the canyon to the northeast. Three intermittent lakes are found in the canyon bottom. The southernmost dry lake formed on the tilted fault block between faults F-34 and F-15. A gully has since cut through the F-34 scarp, and the lake now drains into Funnel Graben. The other two dry lakes formed in areas that were topographically low at the time of the formation of Funnel Graben. The barriers have been eroded through and the lakes now drain to Catlow Valley.

Lone Mountain

The northern part of Lone Mountain has smooth, rolling interfluves and deeply entrenched gullies. A few well-defined fault scarps are present. The erosional surface found in the Basco Hills is found here as well.

The southern part of Lone Mountain has irregular topography and is the highest part. Many of the outcrops are highly weathered and hoodoos are common. (Figure 4, page 17) A small playa in sec. 6, T. 40 S., R. 31 E., is peculiarly situated near the top of Lone Mountain. (Figure 9) A fault was traced from the southwest to the southern edge of the playa where it was lost under the alluvium. Perhaps the playa formed in a sag area along this fault (F-25).

North-striking faults in sec. 1 and 2, R. 40 S., R. 31 E, intersect the principal drainage lines at right angles. The scarps have been breeched in a few places, and the result is an angular drainage pattern.

Hawks Valley Area

Hawks Valley proper and Winnemucca Canyon together form the Hawks Valley area. Hawks Valley is broad and flat. Many intermittent streams flow into the valley but drainage lines are poorly defined. All drainage lines in the valley empty into Funnel Canyon.

Winnemucca Canyon is separated from Hawks Valley by a

Figure 9. A small playa located near the top of Lone Mountain along F-25 in sec. 6, T. 40 S., R. 31 E.

Figure 10. View from the backslope of Hawks Mountain to the south showing Hawksiewalksie Playa. F-43 is visible in the middle of the picture. Note the incisement of the gully south of the fault scarp.

low divide of Lone Mountain felsites that extends from the north base of Hawks Mountain to Scotts Cache. Drainage lines entering Winnemucca Canyon are incised into the piedmont alluvium and the felsites. The canyon drains into Thousand Creek Valley.

Actey-Hawks Mountain Area

The Actey-Hawks Mountain Range is a tilted fault block trending N. 55°W. The major block contains several smaller fault blocks. A north-trending graben formed by faults F-34 and F-69 separates Hawks Mountain from the other two areas. (Plate 12, page 74) An east-trending graben formed by faults F-59 and F-63 separates Actey Mountain and the West Hawksiewalksie fault blocks.

Actey Mountain

The center of Actey Mountain has a rolling erosional surface. Two step blocks are located northeast of the summit. The first step is about 150 feet below the central block and, like the central block, is undissected. The second step block is partly dissected. It terminates at the F-50 fault scarp. A conspicuous bowl-shaped depression is located in sec. 12, T. 40 S., R. 30 E. The basin is on the back slope of a fault block formed by fault F-50 and terminated at the F-59 fault scarp. A gully has been cut by headward erosion through the F-50 scarp and the basin is now drained north to Catlow Valley.

Actey Mountain is tilted down to the southwest, but its tilted nature is slight compared to that of Hawks Mountain.

West Hawksiewalksie Fault Blocks

Two step-fault blocks are located south of Actey Mountain and west of Hawksiewalksie Playa. Fault F-46 separates the two north-trending blocks. The northern part of the blocks are tilted down to the south, but the southern parts are not tilted. Drainage flows south down the back slopes of the tilted blocks to the hinge line where it joins an east-draining gully. South of the hinge line, gullies drain east, and are deeply intrenched at the fault scarps.

Both blocks have broad, flat interfluves. The area is in an early stage of dissection.

The southern part of the western block is cut by a northeast-striking graben which terminates at F-46. The graben originally drained to the southwest, but headward erosion has cut a gully through the small horst to the southeast and the graben now drains to the southeast.

Hawks Mountain

Hawks Mountain is a fault block that is tilted to the southwest. Many small discontinuous fault scarps are found on the backslope. These scarps are subparallel to F-50 and define blocks that are tilted in the same direction as the major block.

Drainage is structurally controlled as the major gullies run southwest down the backslope. The smaller scarps on the backslope formed barriers that ponded the drainage in several areas. Subsequently the barriers were eroded through and an angular drainage pattern resulted, as in sec. 32 and 33, T. 40 S., R. 31 E. (Figure 10, page 46)

Gully profiles are variable, being steep and V-shaped where they cut through scarps, but almost flat in the areas that were ponded.

Erosion proceeded at a greater rate on the F-50 scarp than on the backslope in sec. 19 and 20, T. 40 S., R. 31 E. with the result that the drainage runs north into Hawks Valley.

Hawks Mountain is presently in a youthful stage of dissection.

Hawksiewalksie Area

Hawksiewalksie Playa

Hawksiewalksie Playa is a structural depression formed by a north-striking graben. It is terminated on the north by the back slope of Hawks Mountain and on the south by the erosional termination of the Mesa basalt. The playa is flat and featureless with the exception of a small hill in sec. 13, T. 41 S., R. 30 E. The hill was topographically high prior to the recent faulting, but was downfaulted. Accumulation of sediments in the playa has further diminished the relief.

Southern Lowlands

The southern lowlands include the area that is east of Hawksiewalksie Playa, south of Hawks Mountain, and north of the Mesa basalt High Plains area. It is an area of rolling topography that has formed on the Thousand Creek tuffs. Drainage runs south off Hawks Mountain, but as it approaches the high plains it turns to the east and west. The major drainage runs eastward out of the thesis area, and a small drainage system runs west into Hawksiewalksie Playa.

Mesa Basalt High Plains

Only the northern edge of the high plains is included in the thesis area. The small butte in sec. 22, T. 41 S., R. 31 E. is a remnant of the plain, isolated by rotational slumping of the basalt on the Thousand Creek tuff and subsequent erosion.

GEOLOGIC STRUCTURE

Regional Structure

The Great Basin records a long history of diastrophism. Folding and thrust faulting occurred at various intervals during the Paleozoic and Mesozoic, with the last stage of thrusting terminating in the late Mesozoic throughout much of the Great Basin. Block faulting started in the middle Tertiary and possibly is still in progress.

Miocene and younger volcanics cover most of south-central and southeastern Oregon. Thus, in this region pre-Miocene thrusting and folding are concealed, but the post-Miocene block faulting is well exposed. Controversy exists concerning the nature of the block faulting. Most observers consider the north-striking grabens, horsts, and tilted fault blocks to be a result of high-angle, normal faulting. Gilbert (19, p. 184) suggested that the release in horizontal pressure is the result of deep-seated folding. Some geologists feel that the blocks formed along high-angle reverse faults. Smith (27) postulates that Steens Mountain formed by high-angle reverse faulting along its eastern face. Fuller and Waters (12) disagree, stating that the mountain formed by high-angle, normal faulting.

A wrench fault origin for the fault blocks has been suggested. Moody and Hill (18) state that structures throughout the world are related to a basic wrench-fault system. According to this concept the north-trending Basin and Range structures are the result of second order wrench faults. Donath (9) studied the area north of Summer Lake, Oregon, and concluded that the fracture system was formed by a wrench-fault stress orientation, but that little lateral movement occurred. He believes that subsequent normal faulting along the older fractures formed the fault-block topography. Rommey (22) measured a recent fault at Dixie Creek, Nevada, and found that it had twice as much lateral as vertical movement. Pakiser (21) describes left-lateral faulting in the vicinity of Owens Valley, California. He relates Cenozoic volcanic activity to areas of relative tension formed in the regions where the faults terminate. In contrast, Page (20) studied the recent faulting at Pleasant Valley, Nevada, and concluded that it was normal faulting. Cochran (7) has found evidence of late Tertiary thrusting in the Pueblo Mountains of south-eastern Oregon.

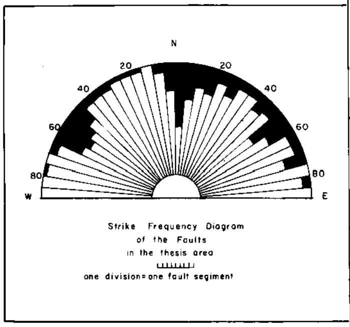
The thesis area is situated within this structural problem area. Fault trends in the thesis area are similar to trends elsewhere in the northern Great Basin. Therefore, it is hoped that the following discussion will contribute to the knowledge of the regional structure.

Summary

All rocks older than Quaternary alluvium have been subjected to deformation. The Steens basalt and Lone Mountain formation are more deformed than the younger rocks. The platy Steens basalt and parts of the Lone Mountain felsites have been deformed into small tight folds. Both units are extensively faulted. Younger units, of which the Mesa basalt is the most extensive, are faulted but not folded.

Faults

Faults have three principal trends, N. 0-15°E., N. 40-60°E., and N. 40-60°W. All are high-angle faults and show vertical displacement. Evidence for faulting includes fault scarps, stratigraphic displacement, springs, truncation of structures, derangement of drainage, abrupt changes in canyon profiles, and local accumulations of sediments. Fault scarps are abundant with the most impressive being formed by faults F-50, F-34, F-22 (Figure 11), F-32, and F-35. (Plates 10, 11 and 12, pages 69, 70 and 74) Stratigraphic displacement is apparent on fault F-50 where Steens basalt is exposed below Lone Mountain felsites on the fault scarp but only the felsites and alluvium are exposed on the down-thrown block. Fault-controlled angular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Strike Frequency Diagram
of the Faults
in the thesis area
one division = one fault segiment

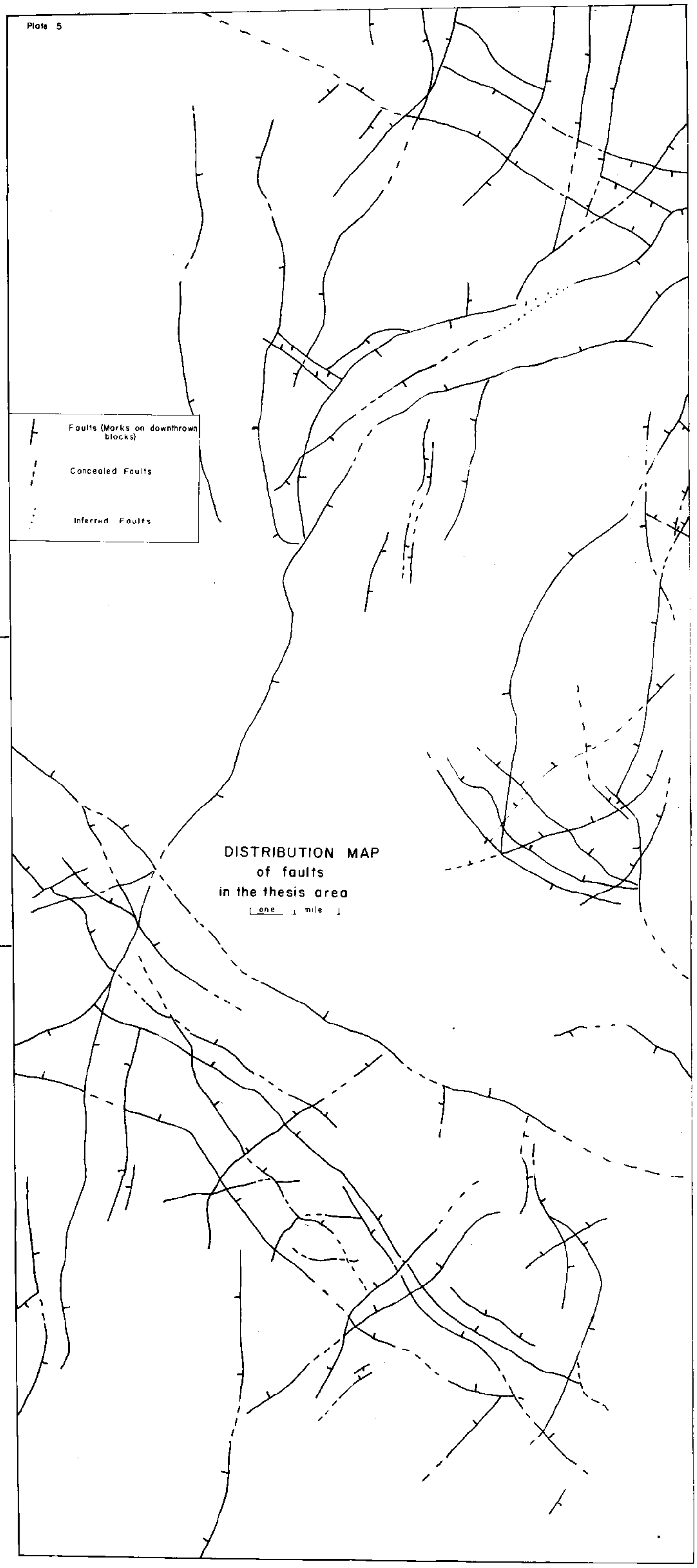
Plate 5
Faults (Marks on downthrown blocks)
Concealed Faults
Inferred Faults
DISTRIBUTION MAP
of faults
in the thesis area
one mile

Plate 6

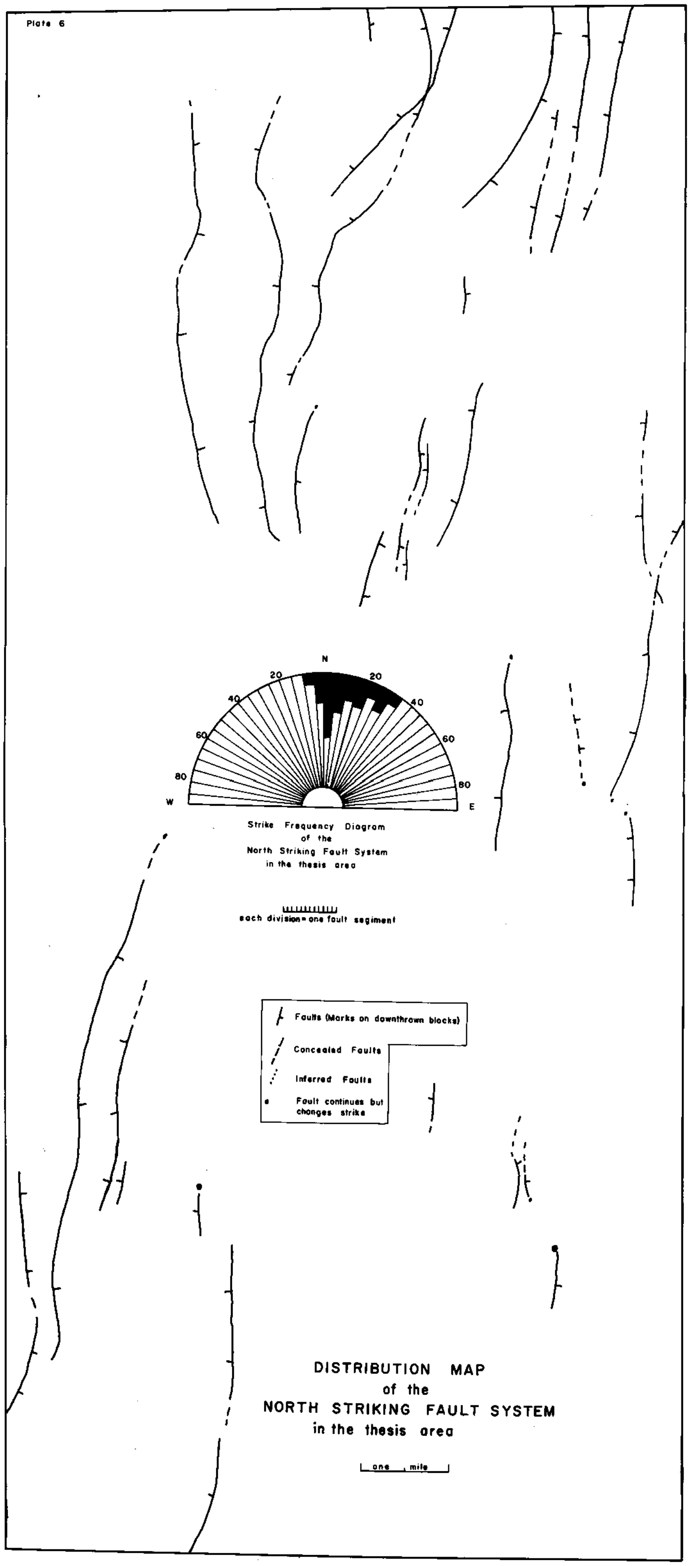
Plate 6
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Strike Frequency Diagram
of the
North Striking Fault System
in the thesis area
each division = one fault segment
Faults (Marks on downthrown blocks)
Concealed Faults
Inferred Faults
Fault continues but changes strike
DISTRIBUTION MAP
of the
NORTH STRIKING FAULT SYSTEM
in the thesis area
one mile

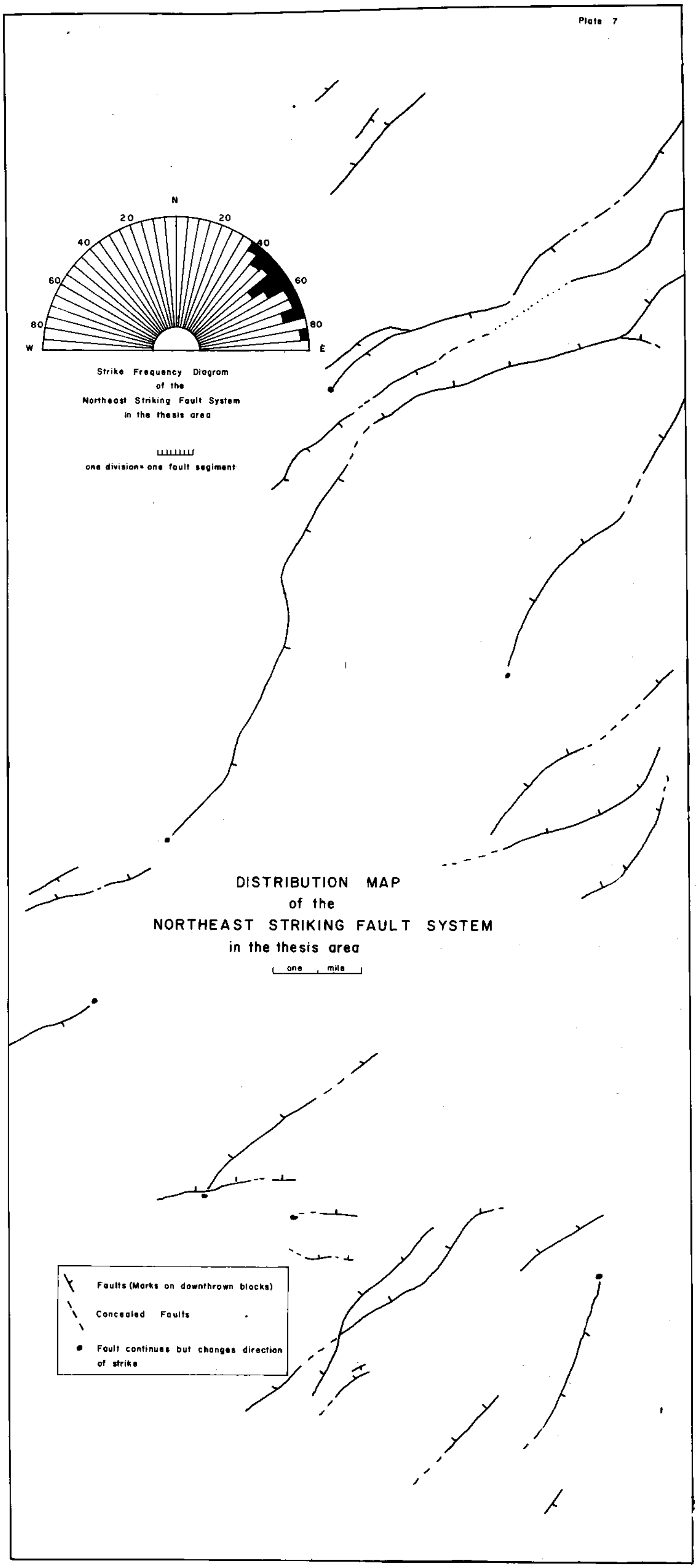
Plate 7
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Strike Frequency Diagram
of the
Northeast Striking Fault System
in the thesis area
one division= one fault segment
DISTRIBUTION MAP
of the
NORTHEAST STRIKING FAULT SYSTEM
in the thesis area
one mile
Faults (Marks on downthrown blocks)
Concealed Faults
Fault continues but changes direction of strike

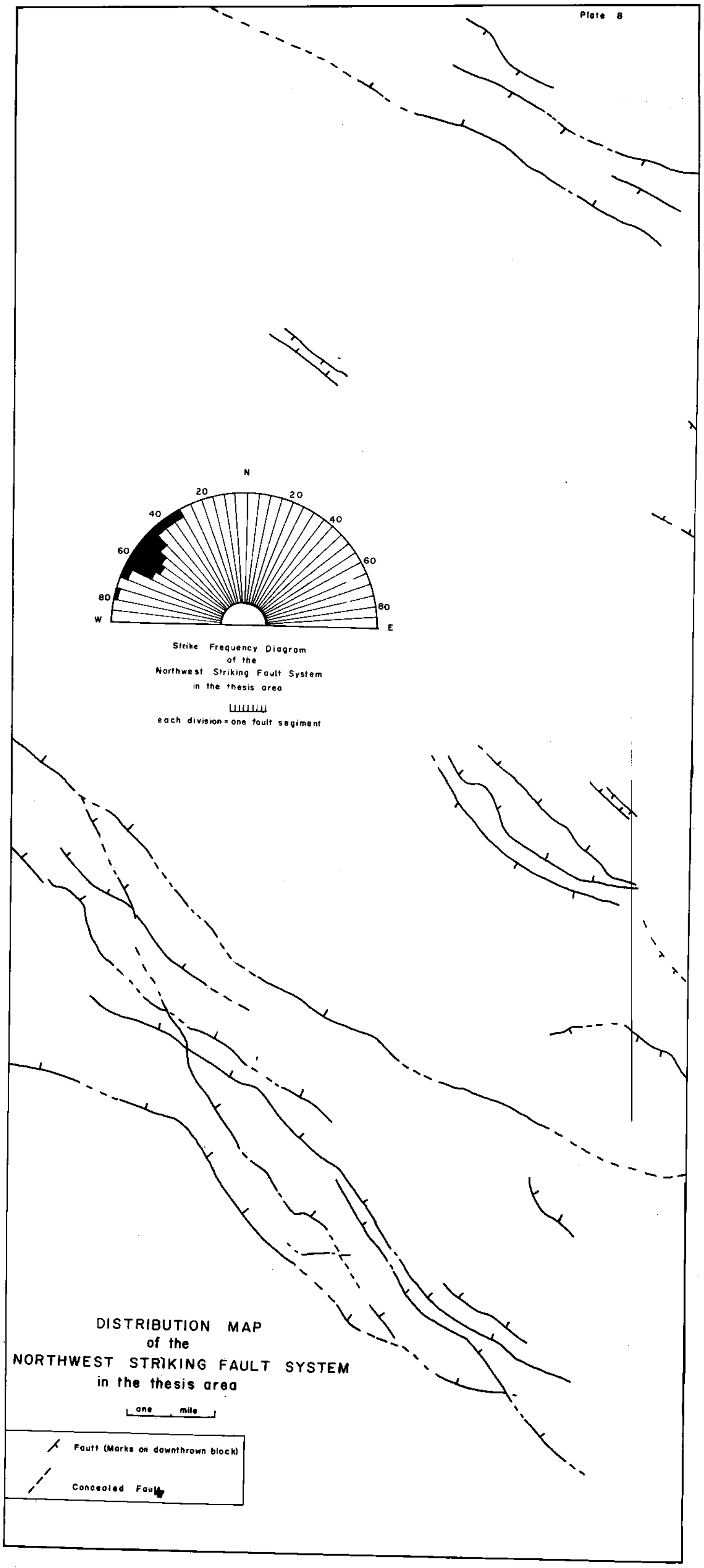
Plate 8
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Strike Frequency Diagram
of the
Northwest Striking Fault System
in the thesis area
each division = one fault segiment
DISTRIBUTION MAP
of the
NORTHWEST STRIKING FAULT SYSTEM
in the thesis area
one mile
Fautt (Marks on downthrown block)
Concealed Fault

Figure 11. The F-22 fault scarp as viewed from the southwest E½, sec. 12, T. 40 S., R. 31 E.

Figure 12. A small graben formed by F-34 and F-69 as viewed from the north. This graben separates Hawks and Actey Mountains.

drainage is present on Lone Mountain and the back slope of Hawks Mountain. Drainage lines run parallel to fault traces in many areas. Known folds (Plate 9, page 65) and faults terminate at scarps and indicate that these scarps are true fault scarps. Incisement of drainage lines as they cross fault scarps is well displayed on the back slope of Hawks Mountain and on the West Hawksiewalksie fault blocks. Accumulations of thick alluvial deposits at Actey Piedmont and Winnemucca Canyon are evidence of displacement along fault F-50. Extreme variations in attitude within the Lone Mountain formation and the Steens basalt indicate that the faulting is even more extensive than that mapped.

North-Striking Faults

Faults striking between N. 5°W. and N. 20°E. are considered members of the north-striking fault system. The abundance of faults and their variations in strike are shown in Plate 6, page 55.

Most north-striking faults are marked by well-defined fault scarps which collectively form several horsts, step blocks, and grabens. Hawksiewalksie Playa is located in one of the grabens. Fault F-44, which has a vertical displacement of about 100 feet, forms the eastern boundary of the graben. (Plate 12, page 74) The step blocks formed by faults F-34 and F-46 form the western side of the graben.

The F-34 and F-46 scarps are approximately 100 and 50 feet respectively.

The Hollyhock Graben is formed by faults F-31 and F-32 in the southern part and F-31 and F-33 in the northern part. Faults F-31 and F-33 have 50-foot scarps in contrast to fault F-32, which has a 400-foot scarp. (Figure 13) North-striking grabens, horsts and step blocks in the northern Basco Hills have 100- to 250-foot scarps.

F-22 is marked by a distinct, 200-foot fault scarp that extends from the southern base, over the top, and down the northern side of Lone Mountain. (Figure 11, page 58) Juniper Spring marks the fault trace on the southern slope.

The north-striking fault scarps are steep and sharply defined. Most displacement appears to be dip slip.

Northeast-Striking Faults

Faults that strike between N. 40°E. and N. 60°E. are considered in the northeast-striking fault system. The northeast-striking faults are not, on the whole, as well defined as the north-striking ones. Exceptions are faults F-34 and F-35, which form Funnel Graben. F-34 is a pivot fault. Southwest of the latter's intersection with Funnel Canyon, its northwest side is upthrown relative to the southeast side, forming a near vertical 100-foot scarp, and northeast of the intersection the southeast is upthrown

Figure 13. The Basco Horst as viewed from the Actey Piedmont. Note the low relief on the piedmont and on top of the horst. The F-32 fault scarp is seen on the horizon.

Figure 14. Hawks Mountain as viewed from Juniper Springs. Fault F-50 is at the base of the mountain.

relative to the northwestern side, forming a near-vertical 300-foot scarp. Both scarps diminish in height to the northeast. Fault F-10 forms an intermittent scarp along the bottom of Funnel Graben. The northeastern part of fault F-10 was correlated with the central part of fault F-10 in the field. Subsequent study indicates that this fault segment could equally well be the northeasterly extension of fault F-34.

F-23, F-24, and F-25 are northeast-striking faults on Lone Mountain. (Plate 11, page 70) Their traces are marked by deeply eroded fault scarps, slickensided boulders, and abrupt changes in the attitude of the felsites. The eroded nature of the scarps along with a lack of stratigraphic control make displacement difficult to estimate. The F-24 and F-23 scarps are left hanging on the northwest-trending F-26 scarp.

A few northeast-striking faults are found on Hawks Mountain. Scarps vary from 20 to more than 150 feet in height. These faults tend to be more pronounced toward their southern reaches as the scarps decrease in height to the northeast.

Northwest-Striking Faults

Faults striking between N. 40°W. and N. 60°W. are considered in the northwest-striking fault system.

Northwest-striking faults form the Actey-Hawks Mountain Range, the graben at Winnemucca Canyon, and two grabens in the Basco Hills. F-50 is a high-angle normal fault with a displacement of about 1000 feet that extends completely across the area. (Figure 14, page 61) The scarp is partially dissected but forms a straight, steep, and imposing cliff. Steens basalt is exposed on the fault scarp at Hawks Mountain and Actey Rim. Two springs mark the fault trace, one on the north side of Hawks Mountain and the other two miles west of the area.

The numerous small faults on the back slope of Hawks Mountain are subparallel to F-50. Most of them are several miles in length but have less than 75 feet of displacement. These small faults form a series of small discontinuous scarps.

F-26 forms the southern boundary of Lone Mountain. Its scarp is highly dissected but has a maximum relief of 300 to 350 feet. F-27 and F-29 have highly eroded intermittent fault scarps. Numerous slickensided boulders were found along the fault traces.

Faults F-17 and F-18 form a small graben that traverses the Basco Horst. Hanging valleys are formed on the F-32 and F-35 fault scarps where the graben intersects them.

Faults F-7, F-8, and F-9 form a graben that cuts across the Basco Hills. They have high-angle fault scarps that vary in height from less than 20 to about 100 feet. Fault F-8 terminates at F-5 on the west and F-10 on the east.

Fault Types

All are high-angle faults with primarily vertical displacement. The physiography is dominated by the fault-block topography that is thought to have formed by normal faulting.

Folds

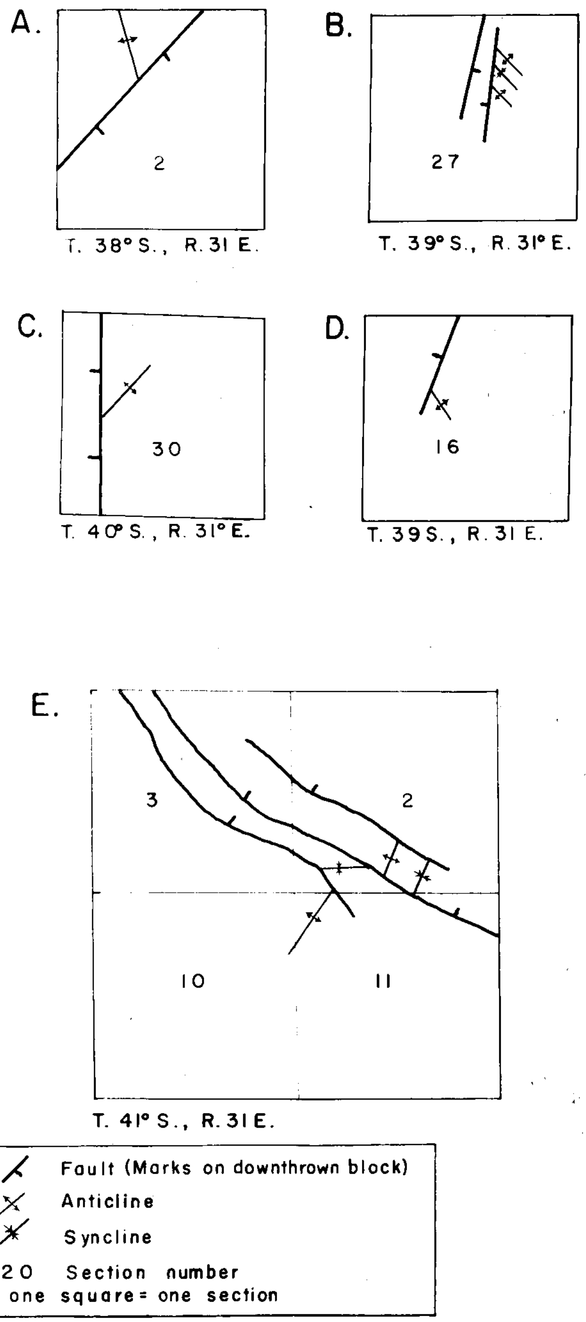
The Lone Mountain felsites and the platy Steens basalt have been folded into a number of small folds.

Only one fold in the Steens basalt was large enough to map. (Plate 9, A, page 65) This fold affects the massive as well as the platy basalt but is quite small. In most areas the platy basalt is deformed into small, tight folds but the overlying and underlying massive basalt is undeformed. This may indicate that the platy basalt is the less competent unit, and that these are drag folds. However, it is also possible that the massive basalt, which is well jointed, absorbed the stress by forming numerous small faults along the jointing surfaces.

Six areas of folding were mapped in the Lone Mountain

Plate 9

Sketch Maps showing Fold-Fault Relations



felsites. (Plate 9, B, C, D, E, page 65) The folds illustrated in B are adjacent to a north-striking graben. The folds are extremely small and tight with very steep dips. They may be drag folds. However, over and underlying competent layers were not found. The fold axes intersect the fault at an angle of about 62°. Theoretically this is about the angle that primary folds intersect wrench faults. The folds illustrated in A and D have the same general trends and relationships to the adjacent faults as those in B.

The fold shown in C strikes to the northeast and terminates at the north-striking fault F-69 and the northwest-striking F-43. The fold is small but distinct.

The small folds illustrated in E are interesting because of their differences in attitude. Perhaps the differences in attitude are due to differences in the stress orientations on the individual small fault blocks.

Little folding has occurred in rocks younger than the Lone Mountain formation. Some of the numerous variations in attitude in the Lone Mountain formation and the Steens basalt are due to initial flow structures, but much is due to folds and faults too small to map.

Sequence of Deformation

Summary

Three stages of deformation are recognized. The first two stages occurred before the Mesa basalt flow but the third stage came after the flow. In the area to the east, Johnson demonstrated that the first stage of deformation came after the deposition of the Lone Mountain formation but before the deposition of the Danforth (?). The second stage of faulting is post-Danforth (?) and pre-Thousand Creek (?), and the third stage of faulting is post-Mesa basalt but pre-Quaternary alluvium.

Faults formed during the first stage strike to the north and to the northeast. Folding occurred at this time. The second stage formed northwest-striking faults. The third stage refaulted the fractures formed during the first stage and may have formed some new fractures.

Evidence supporting these conclusions is given in the following paragraphs.

Lone Mountain Area

The Lone Mountain volcanics covered most, if not all of the thesis area. These flows covered the area burying the topography and leaving a region of low relief.
Plate 3, page 33, is a sketch map showing the maximum extent of the Mesa basalt. The Mesa basalt did not flow into

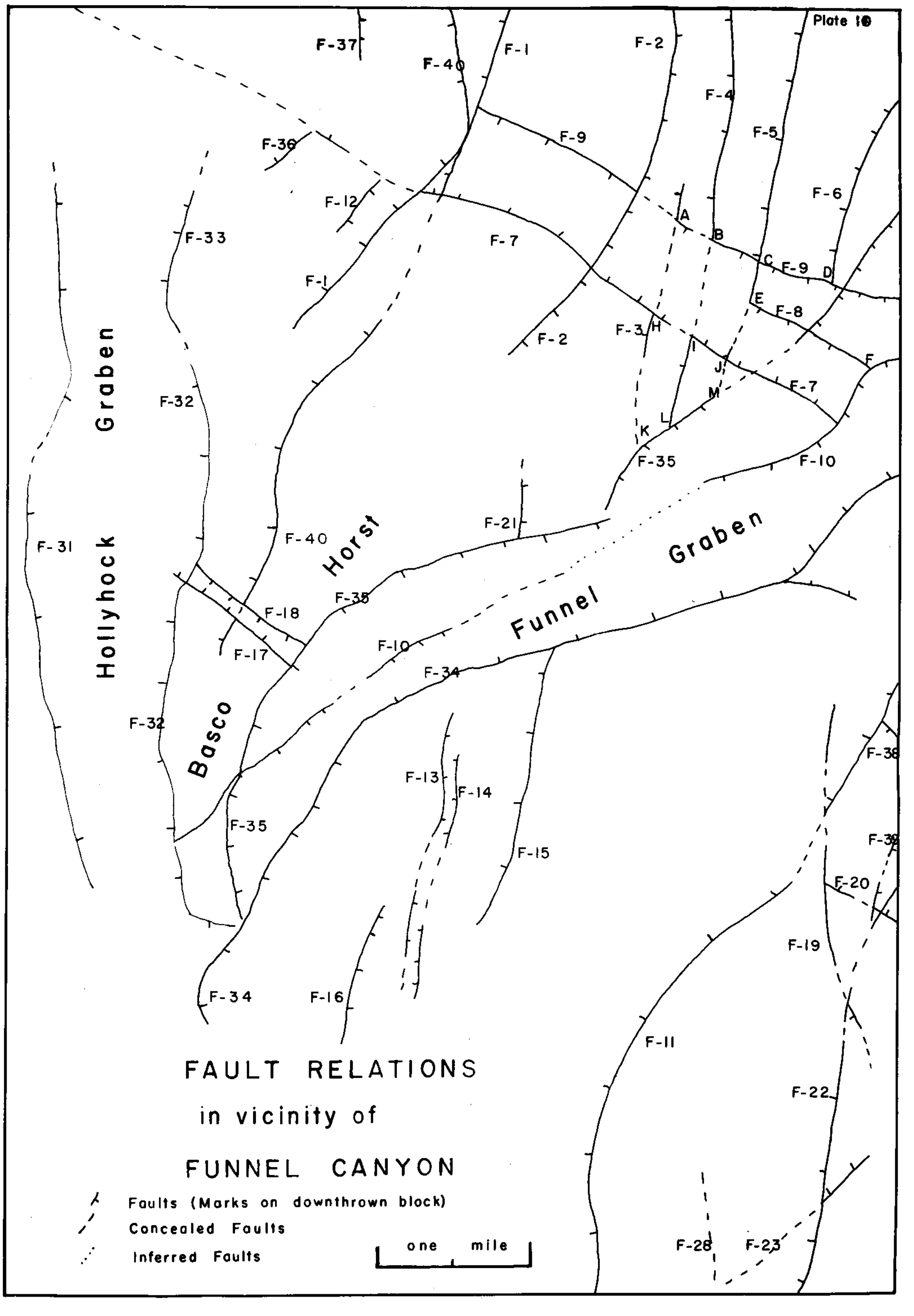
the Lone Mountain area. This indicates that a positive area had formed between the times of the Lone Mountain and Mesa basalt flows. This positive area could have been formed by differential erosion or by tectonic forces.

Mesa basalt flowed over the Hollyhock High Plateau to the F-32 fault scarp where it terminated. Therefore, the faulting along F-32 occurred before the Mesa basalt flow. Fault F-33 is a northern extension of F-32 that displaces the Mesa basalt. It is evident, then, that two stages of faulting have occurred along this fault, one coming before the Mesa basalt flow and the other after the flow.

To the east faults F-13, F-14, and F-15 do not displace the Mesa basalt, but fault F-16, which is parallel to the above, displaces the basalt. Small-scale folds are associated with F-13, F-14, and F-15, but not with F-16.

None of the northwest-striking faults displace the Mesa basalt. F-7 has a well defined fault trace in the Basco Hills, but the trace is lost to the northwest under the Mesa basalt. The trace is exposed again at the northern edge of the area in the Steens basalt. This dates fault F-7 as occurring after the Steens basalt flows but before the Mesa basalt flow.

The fact that Mesa basalt did not flow into Funnel Graben is evidence that the graben formed after the flow. This is born out by fault F-34 which continues southwest



FAULT RELATIONS
in vicinity of
FUNNEL CANYON

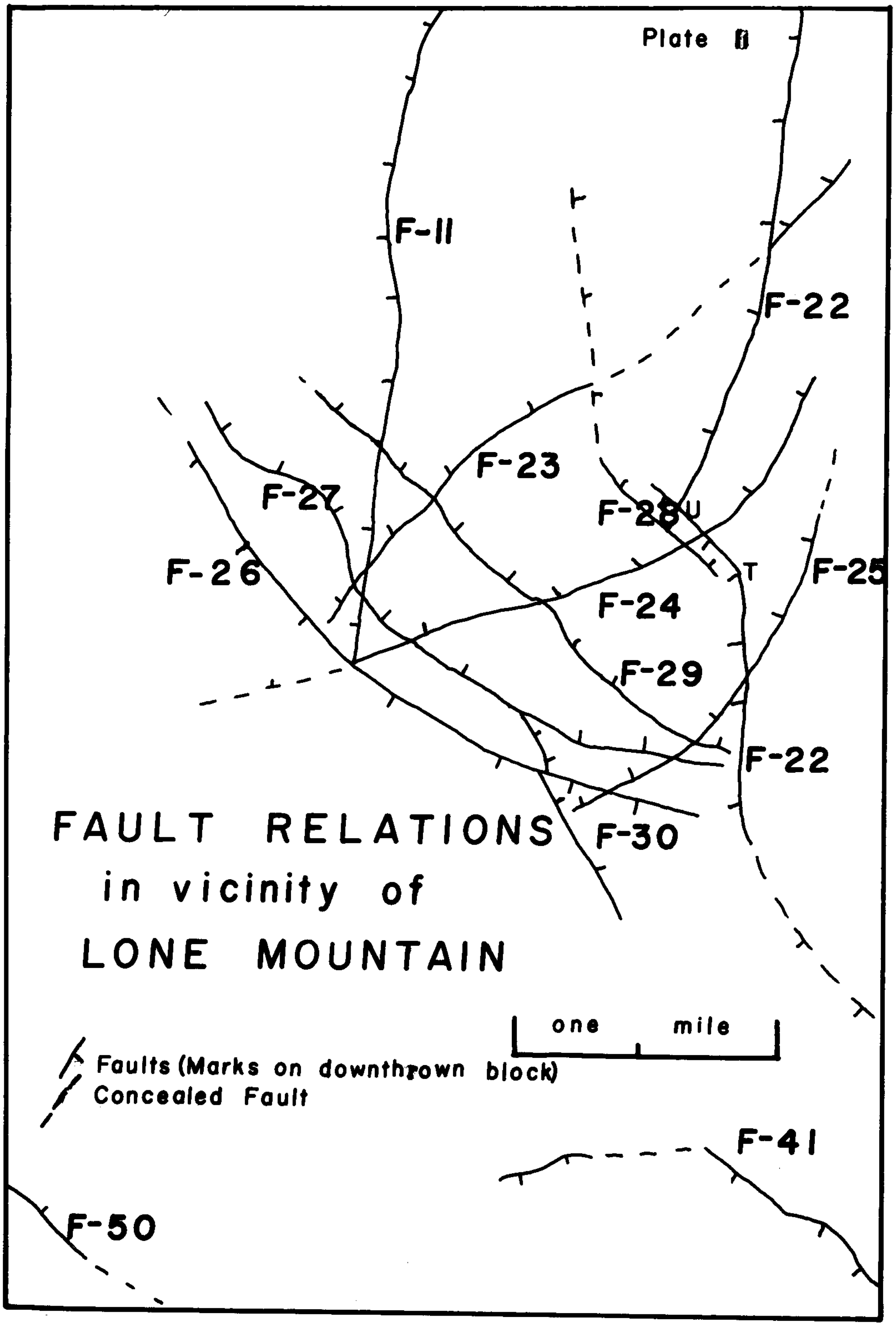


Plate II
F-11
F-22
F-23
F-27
F-28
U
T
F-25
F-26
F-24
F-29
F-22
F-30
FAULT RELATIONS
in vicinity of
LONE MOUNTAIN
one mile
Faults (Marks on downthrown block)
Concealed Fault
F-41
F-50

to Hawks Valley where it displaces Mesa basalt. Fault F-10 has discontinuous scarps along its trace. It appears to be an old fracture that has been refaulted in parts.

The northeast-striking faults on Lone Mountain appear to be too highly dissected to have been faulted during the most recent stage. They do not displace the Mesa basalt though F-24 was traced to the basalt contact.

Northwest-trending faults on Lone Mountain do not displace the Mesa basalt despite the fact that they were traced to the Mesa basalt-Lone Mountain contact. North-striking F-22 is thought to have formed during the last stage of faulting because of its bold, undissected fault scarp. Its strike is deflected to the northwest between points U and T. (Plate 11, page 70) In this area it reoccupies an older northwest-trending fracture.

In the preceding paragraphs it has been shown that north-, northeast-, and northwest-striking faults formed after the deposition of the Lone Mountain volcanics but before the Mesa basalt flow. Johnson (13, p. 24) demonstrated a pronounced angular unconformity between the Lone Mountain formation and the Danforth (?) formation. Northwest-trending faults have formed many fault-block structures usually associated with normal faulting. Extensive tilting and folding is not commonly associated with normal faulting. The north- and northeast-striking faults were formed prior to the Mesa basalt flow and were then refaulted after the flow. The Basin-and-Range structures formed by these faults formed during the last stage of faulting. Therefore, it is probable that the tilting and folding occurred during the first stage of faulting along the north- and northeast-striking fractures.

F-40 laterally displaces a nearly vertical vitrophyre sill (?) about 50 feet but does not displace either faults F-17 or F-18. This evidence helps substantiate the idea that the first stage of faulting along the north- and northeast-striking fractures occurred before the northwest-striking faults.

The structural sequence is well displayed in the northern Basco Hills where a northwest-striking graben formed by faults F-7, F-8, and F-9 intersects a north-striking graben and step blocks formed by faults F-2, F-3, F-4, F-5, and F-6. (See Plate 10, page 69) Faults F-7 and F-9 can be traced completely across the structure but F-8 terminates abruptly at E and F. Faults F-3, F-4, F-5, and F-6 have undissected fault scarps that extend southward to A, B, E, and D. Their fault traces are covered by alluvium in the intervals AH, BI, and EJ. Highly eroded fault traces are found in the intervals HK, IL, and JM.

The explanation is that the north-trending fractures were first formed and the northwest-trending graben was formed later with F-8 faulting only the block previously formed by F-5 and F-10. The third stage of faulting occurred as block movements. One fault block was formed by faulting along F-1 and F-2, a second by faulting along F-4 and F-9, a third by faulting along F-5 and F-8, and a fourth by faulting along F-6, F-9 and F-35. The result is that northeast of the northwest-striking graben there are distinct, well-formed fault blocks while within the graben the faults are concealed by alluvium, and southwest of the graben the eroded fractures, remnants of the first stage of faulting, are apparent.

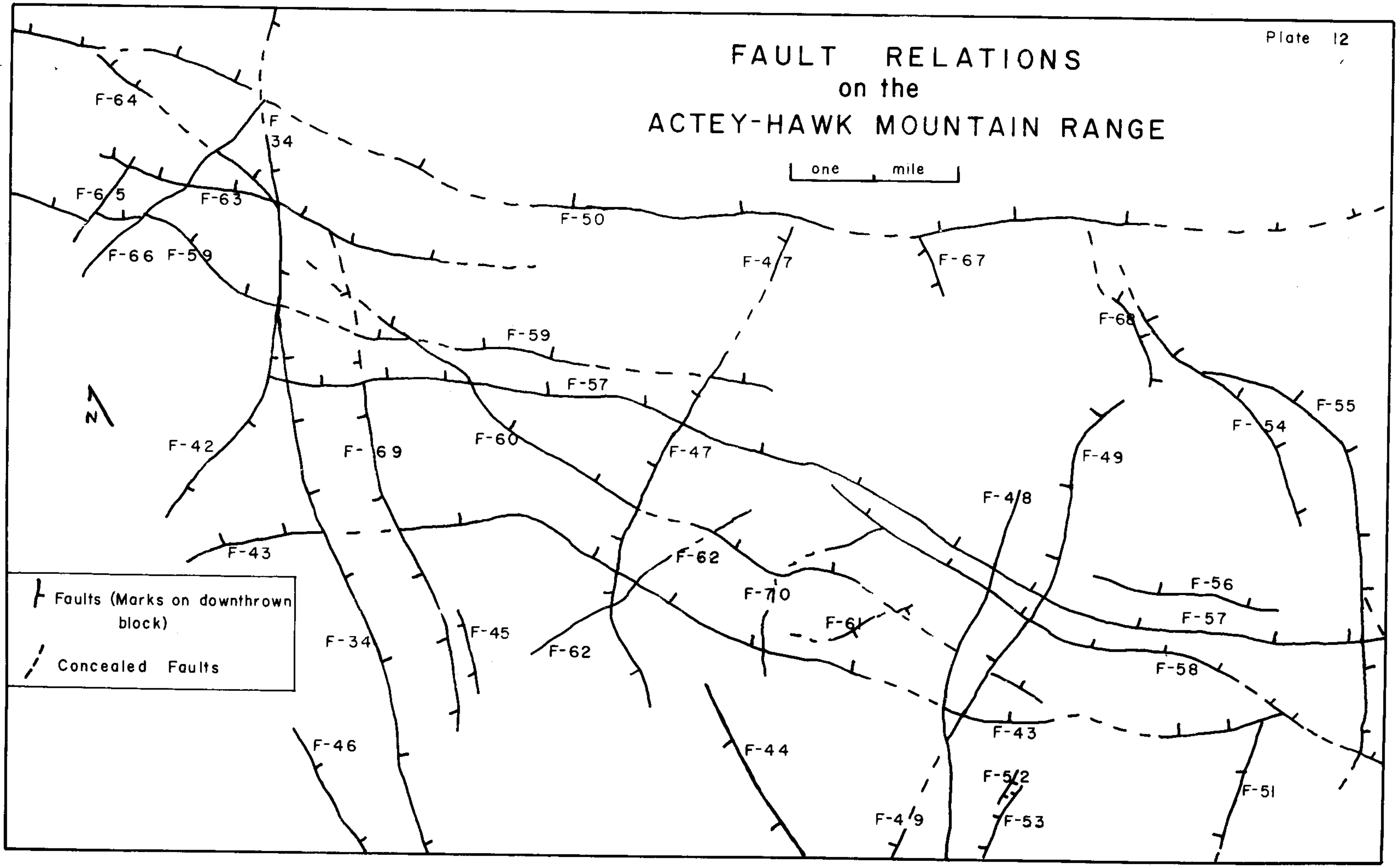
Actey-Hawks Mountain Area

The Actey-Hawks Mountain range is dominated by northwest-striking fault F-50. Mesa basalt flowed to the foot of the F-50 fault scarp but not beyond, indicating that F-50 formed before the basalt flow. The great thickness of tectonically controlled piedmont alluvium covering the Danforth (?) on the Actey Piedmont indicates that the Danforth (?) is older than or nearly contemporaneous with F-50 faulting.

The Hawksiewalksie Graben is post-Mesa basalt because fault F-46 displaces the Mesa basalt at the southern edge of the thesis area, and fault F-34 displaces it at Hawks Valley.

Plate 12

FAULT RELATIONS on the ACTEY-HAWK MOUNTAIN RANGE



Most of the north- and northeast-trending faults have undissected fault scarps at the base of the Hawks Mountain back slope. The scarps decrease in height and sharpness towards the top of the range. It appears that older fractures have been refaulted but primarily towards the base of the back slope.

Faults F-67 and F-68 are older than F-50. This is indicated by their lack of pronounced fault scarps despite fairly large amounts of displacement, and their truncation by F-50.

Mechanics of Deformation

Discussion

Anderson (1) demonstrated that the three fundamental types of faults, normal faults, thrust faults, and wrench faults, differ only in the relationship between the principal stress axes and the earth's surface. Faulting occurs along shearing planes. Ideally the planes of maximum shearing intersect at 90°, with the maximum and minimum stress axes bisecting the angles thus formed and the intermediate axes forming along the line of intersection.

In actuality the shearing planes do not normally intersect at right angles. The maximum principal stress axis bisects the acute angle which is usually about 60°.

Plate 13

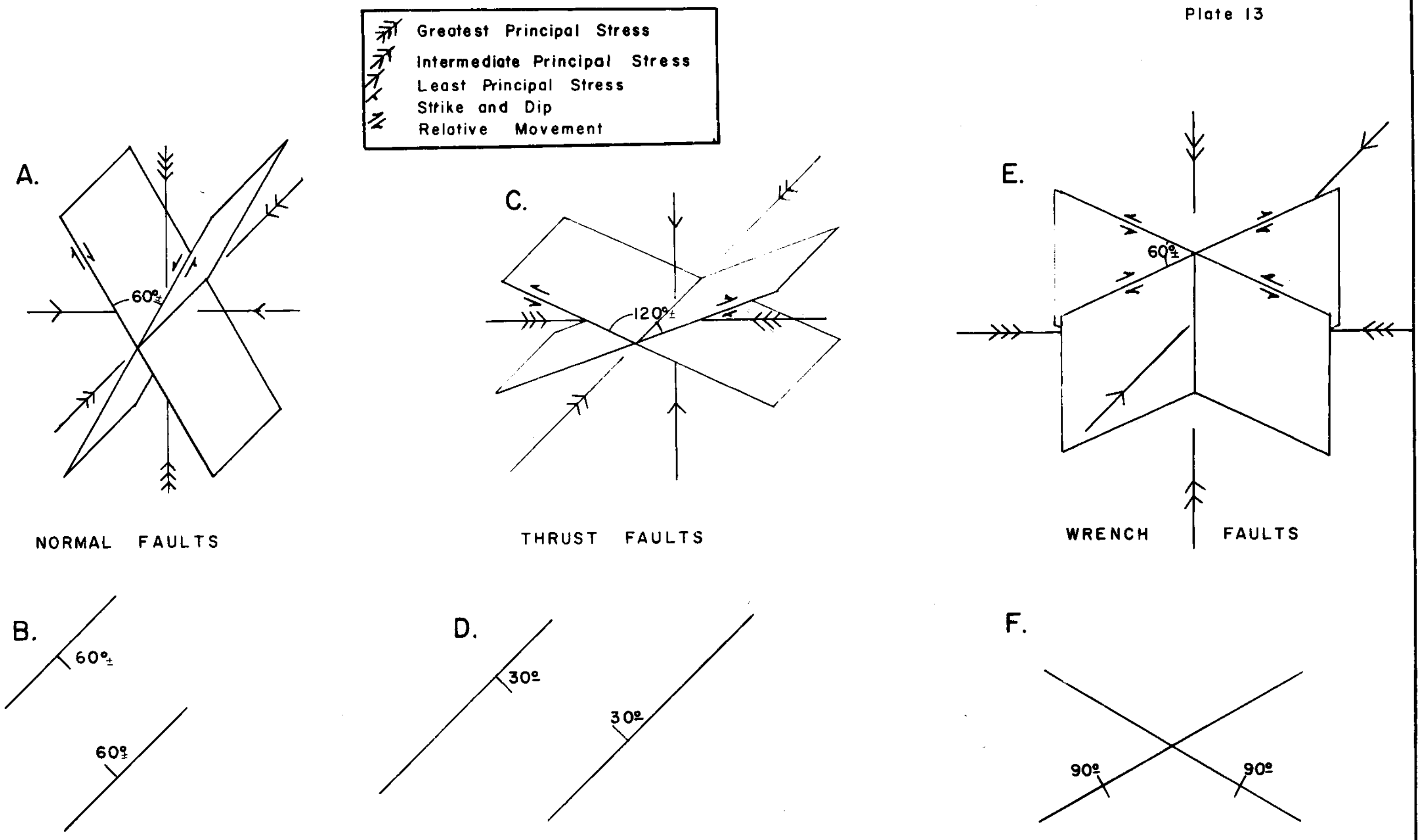


Plate 13. A., C., and E. show stress and fault plane relations in the three main types of faults. B., D., and F. show map relations of the same fault types.

Gravity is a source of stress in faults occurring near the surface of the crust. Except in areas where intrusives are being injected or extrusives are being ejected, the vertical component is constant. The thesis area records an extensive history of volcanism and so changes in vertical stress must be considered along with changes in the horizontal components.

Normal faults form when the vertical stress axis is the axis of greatest principal stress. The faults strike parallel to the intermediate principal stress axis and have dips ranging from 45 to 70 degrees. (Plate 13, page 76)

The vertical axis is the least principal stress axis in thrust faulting. Thrust faults tend to strike parallel to the intermediate axis and dip 30 degrees or less, but there is a great deal of variation in strikes and dips.

Wrench faults commonly have two directions of strike which intersect at an angle that is less than 90 but more than 45 degrees. The maximum principal stress axis bisects the acute angle and the least principal stress axis bisects the obtuse angle. Wrench faults have near-vertical dips and horizontal displacements.

Folding is not normally associated with normal faulting. Drag folds may be formed along normal faults but they are small and their axes closely parallel the strike of the faults. Thrust faults are intimately related to folding. The primary fold axes and drag fold axes are parallel or subparallel to the strike of the thrusts. Since wrench faults strike about 30 degrees from the greatest principal stress axes and the axes of primary folds are normal to the same stress axis, then the fold axes intersect the faults at about 60 degrees.

Assumptions made in fault mechanics are that the stress field is acting upon an isotropic homogeneous solid and that different solids will react in a similar manner. Therefore, variations from the results indicated above are to be expected in nature.

First Stage of Deformation

Two sets of fractures were formed, one striking north and the other northeast. Several grabens and horsts occur along these fractures, but these structures are related to a later stage of deformation.

The fracture system formed during the first stage of deformation is interpreted to have formed under a wrench-fault stress system. This is indicated by the two sets of fractures that intersect at 45 to 55 degrees. A second indication is that many of the fault scarps have nearly vertical dips, and a third indication is that small tight folds intersect the fault traces at about 60 degrees.

Wrench faults have a predominantly lateral displacement. Faults in this area show little or no lateral displacement, but it should be remembered that the physiographic evidence is obscured by two later stages of normal faulting and that stratigraphic displacement is difficult to measure. The stratigraphic evidence is confined to Steens basalt-Lone Mountain formation contacts and felsite-vitrophyre contacts within the Lone Mountain formation. The only known occurrences of lateral displacement are where fault F-40 dextrally displaces a concordant vitrophyre about 50 feet and where fault F-47 sinistrally displaces a vesicular felsite about 100 feet.

Perhaps the explanation to the problem is that the stress difference was not great, and that the minor folding, along with fracturing and minor displacements along shearing planes and joints, relieved the stress difference.

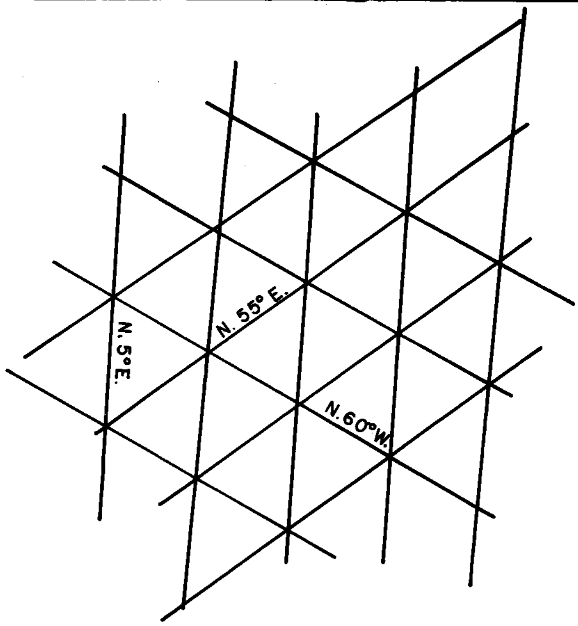
Plate 14 B, page 80, shows the approximate stress orientation. The principal stress directions were interpreted from the fracture directions.

Second Stage of Deformation

The second stage of deformation produced a system of subparallel northwest-striking, high-angle, normal faults. (Plate 8, page, 57) The fault orientations indicate that the principal stress axes have nearly the same orientation

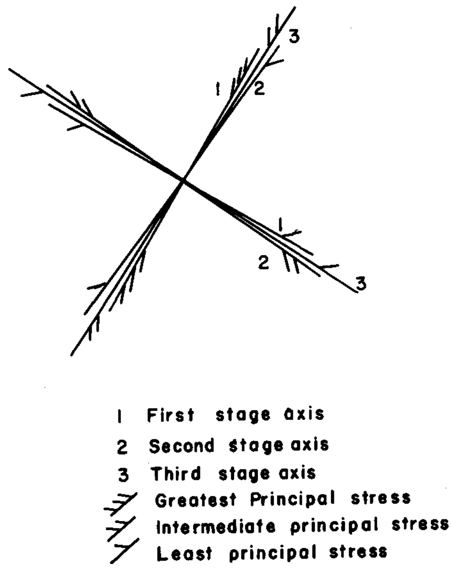
Plate 14

A.



Equidistant lines are drawn parallel to the average strikes of the North and Northeast Fault Systems. The short diagonal of the parallelograms thus formed is the strike of the Northwest Fault System.

B. Approximate orientation of the horizontal principal stress axes for the three stages of deformation.



as those of the first stage. However, the relative magnitudes changed so that the northeast axis was the least principal stress instead of the maximum principal stress axis, and the vertical axis was the maximum principal stress axis rather than the intermediate principal stress axis.

<u>Third Stage of Deformation</u>

North- and northeast-striking grabens and horsts formed during the third stage. The divergence in strikes formed by these normal faults is due to the fact that the faulting occurred in the fractures formed during the first stage. This explains the exceptionally steep dips found on some of these normal faults.

Since much of the faulting occurred along older fractures the stress orientation is difficult to determine. The fact that the northwest-striking faults were refaulted only in a few small areas helps define the stress orientations. That the north- and northeast-striking fractures were refaulted but the northwest ones weren't is evidence that the least principal stress axis had a northwest-southeast orientation and the maximum principal stress was vertical.

There is a noticeable variation in fault scarp heights. The scarps on the back slope of Hawks Mountain diminish to the north and northeast as do the ones in the Basco Horst and Funnel Graben areas. If the vertical stress component was essentially constant, then these differences might be due to differences in the horizontal stress components.

Two stages of normal faulting follow a stage of probable wrench faulting. The fault pattern has such a configuration that the faults formed during the second stage form the short diagonals of the parallelograms created by faults of the first stage. (Plate 14, A, page 80) All three stages of faulting could have formed with the same principal stress axes orientation by varying the magnitudes of the axes. These features indicate that the three stages of deformation are in some way related. Unfortunately this relationship is not understood.

GEOLOGIC HISTORY

Several thousand feet of Middle Miocene Steens basalt flowed over the area and concealed all of the underlying geology. These fissure eruptions were periodic, resulting in numerous thin flows.

Extrusion of Middle or Upper Miocene Lone Mountain felsites and vitrophyres in the form of ignimbrites and lavas terminated a period of erosion. Occurrence of shard textures at the base of the unit and of viscous-flow structures higher in the section indicates that the first extrusions were ignimbrites followed by lavas.

Northeast-southwest compressional forces caused tilting and formation of north- and northeast-striking conjugate shear fractures.

The area was then eroded to low relief upon which the Middle Miocene Danforth (?) ignimbrite was extruded. The Danforth (?) probably formed a wide-spread, thin, sheet-like unit. Extensive normal faulting along a northwest-striking system disrupted the strata forming such topographically prominent areas as the Actey-Hawks Mountain Range and Winnemucca Graben.

Uplifted areas were eroded with extensive alluvial deposits being formed in structural lows, especially at the base of the F-50 fault scarp.

A Middle Pliocene ash fall covered the southern part of the area. The ash was then eroded from the hills and redeposited in the basin forming the Thousand Creek (?) tuff. Erosion continued into the underlying rocks resulting in the deposition of gravel on the tuff. Mesa basalt flowed as a highly fluid lava into canyons and basins forming a thin, sheet-like deposit that covered the gravel.

Normal faulting followed the basalt flow occurring along the previously formed north- and northeast-striking fractures, with Hawksiewalksie Graben, Basco Horst and Funnel Graben being formed.

Faulting caused an increased gradient causing the area to be rejuvenated. Youthful topography persists over the area at the present time. Upland areas have low relief except for widely-spaced, deeply-intrenched, V-shaped valleys. Alluvium has accumulated in grabens. A recent ash fall is indicated by the occurrence of white ash in the alluvium at a few scattered localities.

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