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Structure and Petrography of the Tertiary Volcanic Rocks Between Death Creek and Dairy Valley Creek (Box Elder Co.), Utah

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STRUCTURE AND PETROGRAPHY OF THE TERTIARY VOLCANIC ROCKS BETWEEN DEATH CREEK AND DAIRY VALLEY CREEK (BOX ELDER CO.), UTAH

by

E. Matthew Hare

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of

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E. Matthew Hare

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ABSTRACT

Structure and Petrography of the Tertiary Volcanic

Rocks Between Death Creek and Dairy Valley

Creek (Box Elder Co.), Utah

by

E. Matthew Hare, Master of Science

Utah State University, 1982

Major Professor: Dr. Donald W. Fiesinger
Department: Geology

Several volcanic flows lie between Death Creek and Dairy Valley Creek, near Etna, Utah. The major, central portion of the volcanic flows is composed of dacite and dacite vitrophyre. An elongate ridge in the southeastern corner of the study area and several small outcrops in Death Creek Valley are composed of rhyolite and rhyolite vitrophyre. Additional rock types include conglomerate, volcanic ash, and tuffaceous sedimentary rock of the Tertiary Salt Lake Formation, Paleozoic limestone, and Tertiary basalt.

Dacite and dacite vitrophyre samples are porphyritic, containing phenocrysts of plagioclase, quartz, biotite, amphibole, orthopyroxene, and iron-titanium oxides. Rhyolite and rhyolite vitrophyre samples are porphyritic, containing phenocrysts of plagioclase, alkali feldspar, quartz, and iron-titanium oxides, with minor amounts of biotite and amphibole. Plagioclase phenocrysts are complexly twinned, zoned, and corroded in dacitic samples; whereas, they are simply twinned, unzoned, and uncorroded in rhyolitic samples. Quartz and alkali feldspar pheno-

crysts contain glass-filled inclusions and are subrounded in rhyolitic samples.

Average chemical analyses of five dacitic samples yield weight percent: SiO_2, 69.11; TiO_2, 0.31; Al_2O_3, 14.18; Fe_2O_3, 1.26; FeO, 1.23; MnO, 0.04; MgO, 0.54; CaO, 2.72; Na_2O, 3.30; K_2O, 4.07; P_2O_5, 0.13; H_2O^+, 1.89; H_2O^-, 0.46; total, 99.27. Average chemical analyses of three rhyolitic samples yield weight percent: SiO_2, 76.66; TiO_2, 0.12; Al_2O_3, 11.80; Fe_2O_3, 0.58; FeO, 0.43; MnO, 0.01; MgO, 0.09; CaO, 0.78; Na_2O, 2.69; K_2O, 5.26; P_2O_5, 0.02; H_2O^+, 1.17; H_2O^-, 0.22; total, 99.85.

The volcanic flows of the study area are believed to be derived from fusion of sialic material within the crust which differentiated to form dacite and rhyolite. The dacite is believed to be the first magma extruded in the study area; whereas, the rhyolite represents the later extruded magma. Evidence supporting this relative emplacement is the restriction of rhyolite to the southeastern corner of the study area and the intrusion of rhyolite into dacite in the narrows of Death Creek Valley.

The volcanic flows of the study area are believed to have been derived during the second stage of Basin and Range volcanism beginning approximately 14 million years ago. The study area rhyolite has chemical compositions similar to those rhyolites of bimodal basalt-rhyolite fields formed during the second stage of Basin and Range volcanism which includes high silica contents, higher alkali to calcium ratios, and greater sodium contents compared with rhyolite of calc-alkalic fields.

(64 pages)

INTRODUCTION

Purpose

A large, massive, north-south-trending body of extrusive igneous rock straddles the border of northwestern Utah and northeastern Nevada. This mass of Late Tertiary volcanic rock, occupying an area of approximately 90 square miles, has been termed the Rhyolite Mountains by Doelling (1980).

The study area is located at the northeastern tip of this main volcanic mass, in the vicinity of Etna, Utah. Specifically, the section of volcanic rocks that lies between Death Creek and Dairy Valley Creek has been selected for this study.

The purpose of this investigation is to identify the significant volcanic rock units in the area and to produce a geologic map illustrating the distribution and structural relationships of these volcanic rocks. In addition, the determination of petrographic characteristics and chemical compositions of selected samples representing the various volcanic rock units is presented.

Location and Accessibility

The study area is located eight miles southwest of the town of Grouse Creek, near the small town of Etna, Utah. The towns of Etna and Grouse Creek, with a combined population of approximately 125 people (M. Tanner, personal communication), are situated in the northern portion of Grouse Creek Valley (Figure 1).

Grouse Creek Valley is a shallow, trough-shaped depression that extends from the Goose Creek Mountains to the Great Salt Lake Desert, thirty miles to the south. In general, Grouse Creek Valley is an agricultural and ranching district with the majority of the populace residing in either the town of Etna or of Grouse Creek. The remainder of the population resides on ranches and farms in the central and northern parts of the valley.

The main access route to Grouse Creek Valley is by proceeding approximately seventy-five miles southwest of Snowville, Utah, on State Highway 30, and then twenty miles northward, on improved graveled roads, to the town of Grouse Creek. Access to the field area proper is attained by traveling on unimproved dirt roads, south of the town of Etna.

Geologic Setting

Grouse Creek Valley is situated in the northeastern section of the Great Basin, a subprovince of the Basin and Range physiographic province (Fenneman and Johnson, 1946). Highly faulted, Upper Permian sedimentary rocks and Tertiary volcanic rocks of the Goose Creek Mountains bound the northern and western portions of Grouse Creek Valley. The eastern boundary of Grouse Creek Valley is delineated by the Paleozoic sedimentary rocks and Precambrian intrusive rocks of the Grouse Creek Mountains (Stokes, 1963; Doelling, 1980). The southern end of Grouse Creek Valley widens considerably and gradually grades into the northwestern corner

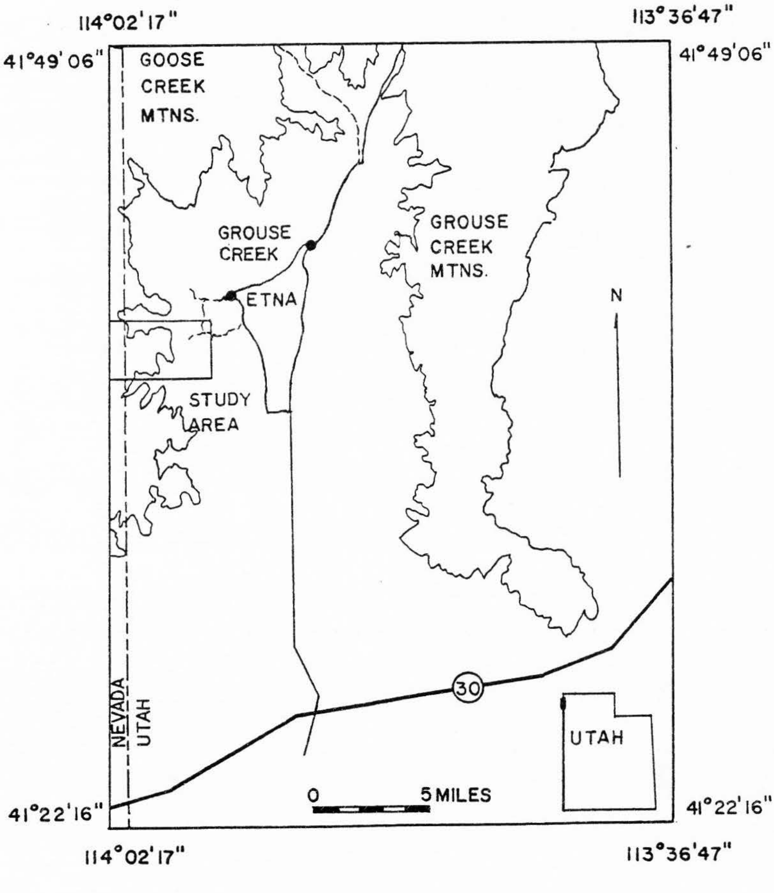


Figure 1. Index map of study area.

of the Great Salt Lake Desert.

The valley floor, lying nearly four thousand feet below the surrounding mountains, is dominated by volcanic ash and tuff of the Salt Lake Formation overlain by recent alluvial and colluvial sediments (Hood and Price, 1970). Modification of pre-existing landforms within Grouse Creek Valley was induced by wave and current action, at or below the 5180 foot level, by Pleistocene Lake Bonneville (Hood and Price, 1970). Wave cut benches and ancient shoreline features are especially evident and dominate the physiography of southern Grouse Creek Valley.

Previous Work

The majority of geologic mapping that has been carried out in the vicinity of the study area is represented by the geologic map in the Utah Geologic and Mineral Survey report for Box Elder County (Doelling, 1980) and the geologic map for the state of Utah (Stokes, 1963). The volcanic rocks of the study area have been described as undifferentiated "Late Tertiary rhyolite-dacite-quartz latite flows" with "bimodal assemblages of rhyolite and basalt" (Stokes, 1963).

Smith (1980) made a detailed investigation of three rhyolitic domes, adjacent to the study area, near the town of Etna, Utah. Smith and others (1980) presented a report on this material. Age dates on several samples from Smith's area, presented in a later section, were determined by S. H. Evans (Univ. of Utah, personal communication). Armstrong and others (1976) presented age determinations on basalt and vitrophyre units in the region. A study on the influence of igneous rock parent material on clay mineral formation was made by Kolesar and others (1979) on volcanic rocks adjacent to the study area.

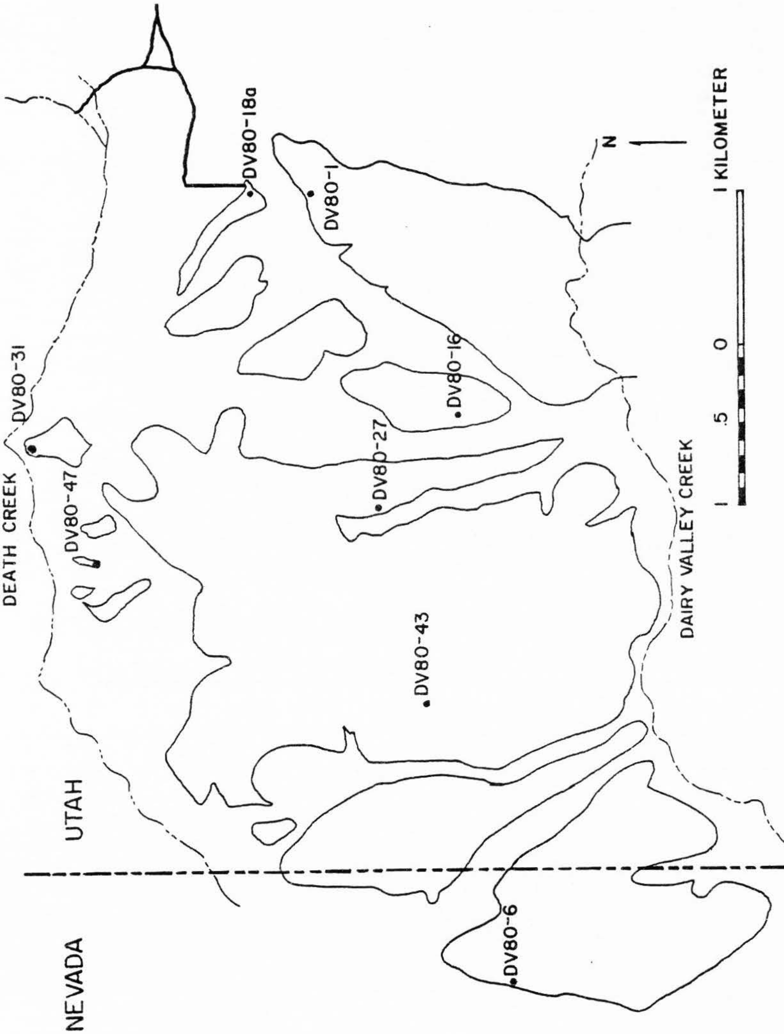
The Tertiary stratigraphy of Goose Creek Valley, which includes the voluminous Salt Lake Fromation, was described by Heylmun (1965), and Mapel and Hail (1956). Hood and Price (1970) presented a report on the hydrology of Grouse Creek Valley.

Sampling Procedures and Analytical Methods

Field work consisted of producing a geologic map of the volcanic rocks within the study area and collecting fresh, representative samples for further study. Fifty-two samples were collected; of this total, eight samples were selected as representing the two main rock types, rhyolite and dacite, and their vitrophyric counterparts. The locations of these samples are shown on the sample location map (Figure 2) and the co-ordinates are presented in Table 1.

Modal analyses were determined, based upon 1,000 points per thin section. Whole-rock chemical analyses were performed following the procedures of Maxwell (1968). Microprobe analyses were carried out on feldspar and pyroxene phenocrysts, using polished sections of the eight samples, in order to determine the average end-member compositions. Analyses consisted of 50 spots per mineral, per sample. This portion of the research was carried out using the ARL EMX SM electron microprobe at the Department of Geology and Geophysics, University of Utah. Procedures for the correction of microprobe data followed those of Bence

Figure 2. Sample location map. Thick solid lines represent dirt roads leading to study area. Thin solid lines represent approximate margins of volcanic rocks. Lightly dashed lines represent intermittant streams. Heavier dashed lines represent state boundaries.



DEATH CREEK
DV80-31
DV80-18a
DV80-1
DV80-47
DV80-27
DV80-16
DV80-43
DV80-6
UTAH
NEVADA
DAIRY VALLEY CREEK
N
1
.5
0
1 KILOMETER

Table 1. Sample locations

Sample No.	Sample Location	Rock Type
DV80-1	Lat $41^{\circ}38'31''$ N., Long $113^{\circ}59'26''$ W.	Rhyolite
DV80-6	Lat $41^{\circ}38'08''$ N., Long $114^{\circ}02'48''$ W.	Dacite vitrophyre
DV80-16	Lat $41^{\circ}38'16''$ N., Long $114^{\circ}00'11''$ W.	Dacite vitrophyre
DV80-18a	Lat $41^{\circ}38'16''$ N., Long $113^{\circ}59'08''$ W.	Dacite vitrophyre
DV80-27	Lat $41^{\circ}38'36''$ N., Long $114^{\circ}00'34''$ W.	Dacite vitrophyre
DV80-31	Lat $41^{\circ}09'47''$ N., Long $114^{\circ}00'20''$ W.	Rhyolite
DV80-43	Lat $41^{\circ}38'27''$ N., Long $114^{\circ}01'40''$ W.	Dacite vitrophyre
DV80-47	Lat $41^{\circ}39'33''$ N., Long $114^{\circ}01'04''$ W.	Rhyolite vitrophyre

and Albee (1968) and Albee and Ray (1970), and they were carried out using the computer programs of Nicholls and others (1977). These programs were run on the Burroughs 6800 computer, Utah State University.

ROCK UNITS

General Statement

Rhyolite, dacite, and their vitrophyric equivalents comprise the bulk of the mappable rock units in the study area. These rocks represent the fine-grained components of the acid igneous rock suite based on the field classification scheme of Compton (1967) and the IUGS classification scheme (Streckeisen, 1979). Additional rock outcrops include Paleozoic limestone of the Permian Phosphoria Formation, conglomerate, volcanic ash, tuffaceous sedimentary rock of the Tertiary Salt Lake Formation, and basalt of Tertiary age.

Foliation patterns, flowage features, and characteristic cooling zones coupled with overall structural characteristics indicate that the volcanic mass of the study area is comprised of several flow units. These rhyolite and dacite flow units possess rapidly chilled exterior margins of vitrophyre. The quantity of rhyolite vitrophyre and dacite vitrophyre in the study area is great enough so that they have been mapped separately from their crystalline counterparts. In cases where exposures of complete flows occur, there is a gradual transition from the glassy outer margin of the flow to the more slowly cooled, crystalline interior. Several textural zones often exist in this transition from glass to crystalline rock, and they seem to be a result of flow emplacement and cooling history.

Igneous Rocks

Dacite

Dacite is the dominant rock type found in the study area and it covers approximately five square miles. The central portion of the volcanic mass is dacitic, with the remaining rock types found along the northern, western, and eastern margins of the study area. The absence of large (1-4mm) quartz phenocrysts coupled with distinct color and weathering characteristics are the criteria used to distinquish dacite from rhyolite in the field.

Fresh samples of dacite range in color from greyish red to pale yellowish brown. Weathered samples show a greater color variation due to bleaching and staining, and range from very light grey to light brown. Dacite samples are porphyritic with phenocrysts of plagioclase accompanied by smaller phenocrysts of biotite and hornblende.

Dacite vitrophyre

Dacite vitrophyre denotes the glassy counterpart of dacite. The phenocryst assemblage is essentially the same as dacite, suggesting intratelluric crystal growth. However, in the vitrophyre the groundmass is entirely composed of glass as opposed to the crystalline groundmass in dacite. Vitrophyre forms by rapid cooling, prohibiting the liquid phase from crystallizing, leaving a glassy groundmass (Jackson, 1970; Stewart, 1979). The cooling rate at which glass forms is determined in part by the composition of the magma, especially the silica and water contents, and cooling may take place over a period of months or years (Stewart, 1979).

Examples of dacite vitrophyre having undergone devitrification are numerous and appear most pronounced in areas directly exposed to meteoric conditions. Devitrification of the glassy groundmass may take place in hydrated glasses over a period of a few million years (Lipman, 1965). Dacite vitrophyre is commonly located immediately adjacent to a larger dacite unit, occurring along the bottom, margin, or more rarely the top.

Dacite vitrophyre exhibits a range in color from dark grey to black in fresh samples, while weathered samples display a color range of light grey to brownish grey. Devitrification imparts a greyish hue to the normally blackish vitrophyre.

Vitrophyre weathers quite easily beginning with a dull black resinous rind and ending with a friable, flaky texture. This feature is not dependent on time but rather on the degree of hydration (Lipman, 1965).

Dacite and dacite vitrophyre textures

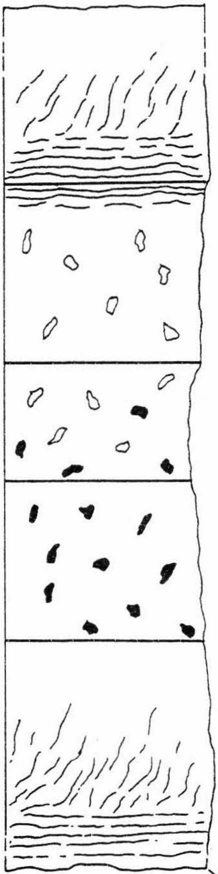
Five textures are common within the complete dacite units, and they appear to be genetically related. These textures are: 1) massive dacite; 2) brecciated dacite; 3) mixed; 4) brecciated dacite vitrophyre; and 5) massive dacite vitrophyre. A schematic columnar section is presented in Figure 3 illustrating the occurrence and relationship of these five textures to each other. It should be noted, however, that these textural types are most conspicuous in the larger, more complete volcanic sections; they by no means include all of the minor textural variations found.

The massive dacite texture is homogeneous with respect to color except in the more central portion of the unit where contorted flow banding dominates. Tabular foliation is a common structure found in the lower portion of this textural type and is a feature attributed to emplacement of the flow rather than cooling history. Similar tabular foliations, in a rhyolite flow, are described by Christiansen and Lipman (1966). Tabular layers range from six centimeters to one-half meter thick. This textural type is the most resistant to physical and chemical weathering, and represents the bulk of dacite extruded from any single source.

The brecciated dacite texture is most often found immediately underlying or bordering the massive texture, although in some cases it has been found in an overlying position. Broken, angular fragments of dacite, measuring up to thirty centimeters in diameter, lie in a matrix of dacite. This textural type is moderately affected by physical and chemical weathering. Zones of brecciated dacite measure from thirty centimeters to seven meters thick.

A third common texture, the mixed variety, is intimately related

Figure 3. Columnar section of dacite flow unit. Represents the transition from a basal vitrophyre unit upwards and into the more crystalline dacite interior.



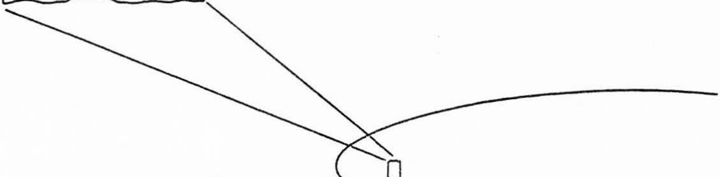
MASSIVE DACITE - Homogeneous color, flow banded interior, and basal tabular foliations. Ranges from 5m to 75m in thickness.

BRECCIATED DACITE - Angular fragments of dacite in a matrix of dacite. Ranges from 30cm to 7m in thickness.

MIXED - Angular fragments of dacite and dacite vitrophyre in an intermingled matrix of dacite and dacite vitrophyre. Ranges from 30cm to 2 1/2m in thickness.

BRECCIATED DACITE VITROPHYRE - Angular fragments of dacite vitrophyre in a matrix of dacite vitrophyre. Ranges from 30cm to 2 1/2m in thickness.

MASSIVE DACITE VITROPHYRE - Homogeneous color, flow banded interior, and basal tabular foliations containing lithophysae. Ranges from a minimum of 1m to an undetermined maximum thickness.



(representative flow unit)

to dacite and dacite vitrophyre and is found underlying the brecciated dacite textural unit. This mixed texture is characterized by broken, angular fragments of dacite and dacite vitrophyre lying in a matrix of intermingled dacite and dacite vitrophyre. Zones of the mixed textural type range from thirty centimeters to two and one-half meters thick. This textural type is most affected by physical and chemical weathering.

The brecciated dacite vitrophyre texture is very similar in habit and form to that found in dacite. The main difference is that broken fragments of dacite vitrophyre lie in a matrix of dacite vitrophyre. This textural unit represents the transition from the mixed texture to the massive dacite vitrophyre texture. Zones of brecciated dacite vitrophyre range from thirty centimeters to two and one-half meters thick.

Massive dacite vitrophyre is similar in texture to massive dacite in that it is homogeneous with respect to color and tends to form tabular foliations nearest its exterior margins. Complete units of massive dacite vitrophyre are somewhat rare in the study area making approximate determinations of maximum thickness difficult. Spherulites and lithophysae tend to occur in the tabular foliated sections of this textural type; whereas, flow banding characteristics are more conspicuous in the innermost portions of this unit.

Regarding the brecciated and mixed textures, it appears that lithified dacite and/or dacite vitrophyre was broken apart by continued movement of the main lava body allowing magma to fill the interstices, which consequently solidified, forming these three textural types. Volcanic breccias formed by disruption of semi-solid lava due to its own movement are termed autobreccia and are monolithologic (Parsons, 1967).

These five textural types may crop out singularly, depending on the degree of preservation, but more commonly occur as a set with the massive dacite texture representing the central, crystalline portion of the flow unit and grading outward through the mixed texture and eventually out through the vitrophyre textures.

Rhyolite

Rhyolite is the second most abundant rock type found in the study area. A large ridge in the southeastern corner of the study area, plus numerous small outcrops in Death Creek Valley, combine to form an area of approximately one square mile. The presence of large (1-4mm) quartz phenocrysts, in addition to distinctive weathering characteristics and color, help to distinquish rhyolite from dacite in the field.

Fresh samples of rhyolite range in color from greyish red to pale brown. Weathered samples are light brownish grey to greyish brown. Iron staining, which imparts a reddish color to the rhyolite, often masks the true color of the outcrop.

The rhyolite is porphyritic with phenocrysts of quartz, plagioclase and alkali feldspar measuring up to five millimeters in length, set in an aphanitic groundmass. Smaller grains of hornblende are visible in hand specimen.

Rhyolite vitrophyre

Rhyolite vitrophyre is most abundant along the western edge of the mass of rhyolite in the southeastern corner of the study area. As is typical of vitrophyre, it forms as a quickly chilled skin relative to the main rhyolite body. The phenocryst assemblage in both rhyolite and rhyolite vitrophyre is similar, indicating that the origin of the phenocyrsts is unrelated to surface cooling rates. The presence of quartz phenocrysts and close association with rhyolite distinguish rhyolite vitrophyre from dacite vitrophyre.

Rhyolite vitrophyre, in fresh samples, ranges in color from dark grey to black. Weathered samples range from brownish grey to pale yellowish brown with lighter shades of grey becoming dominant with increasing devitrification.

Plagioclase, quartz, and alkali feldspar dominate the phenocryst assemblage, with a size range of one to five millimeters. Hornblende, and more rarely biotite, are visible in hand specimen, generally measuring less than one millimeter in length.

Rhyolite and rhyolite vitrophyre textures

Textures in rhyolite do not show the same degree of variability as those found in dacite. This might be partly explained by the highly siliceous, and therefore, highly viscous nature of the magma, preventing large scale internal movement once completely extruded.

The massive texture is the most common form of rhyolite in the study area. Tabular foliations accompanied by lithophysae and crystal-lined cavities occur in the outermost portions of the flow. Source areas, resembling fissure extrusions, display vertical foliation and brecciation. The main example of this feature is found in the canyon of Dairy Valley Creek located in the S 1/2, Sec. 35, T. 11 N., R. 19 W.

Rhyolite vitrophyre has textural characteristics similar to dacite vitrophyre. The massive texture is the most common type found. Spherulites, lithophysae, and flow banding are common features of this textural type.

Basalt

Basalt crops out in the northwestern corner of the study area. The approximate boundaries of this basalt unit are based on the extent of the dark-brown colluvium that is derived from the unit.

The color of fresh samples is greyish black; whereas, weathered samples display a range in color from greyish brown to black.

Phenocrysts of plagioclase with clinopyroxene, averaging 0.4mm in length, display the typical subophitic texture common to basalt. Olivine, iron-titanium oxides, and iddingsite constitute the remaining dominant minerals visible in thin section.

Due to its limited occurrence, little information could be gathered regarding the macroscopic properties of this basalt unit.

Sedimentary Rocks

Limestone

A large outcrop of fossiliferous limestone interlayered with mudstone is found in the southwestern part of the study area. The carbonate rocks on the northeastern border of Nevada, where the outcrop is located, have been described as cherty limestone with sparse dolomite, shale, and sandstone of Lower to Upper Permian age (Stewart and Carlson, 1978). More specifically, this limestone correlates closely with the description of the Meade Peak member of the Permian Phosphoria Formation (Stokes, 1963). Alizaren Red stain was used to test for the presence of dolomite in the limestone, but results were negative.

The bedding in the outcrop dips 25^{o}-30^{o} S., with local variations in dip direction produced by faulting. This limestone is light grey to grey and is interbedded with dark-grey mudstone that is laden with chert nodules.

The limestone, in thin section, is grain supported with sparry calcite acting as the cementing agent. Minor amounts of detrital quartz are present. Faecal pellets dominate the non-skeletal grain assemblage and skeletal components include bryozoan, brachiopod, ostracod, crinoid, and mollusk fragments.

Salt Lake Formation

The age of the Salt Lake Formation, based on K-Ar dates, lies in the range of Late Eocene to Late Pliocene (Smith and Nash, 1976). Of the numerous rock types categorized under the Salt Lake Formation, only conglomerate, volcanic ash, and tuffaceous sedimentary rock are found in the study area. These rock types are found at the margins of the main volcanic mass along the lower elevations.

The volcanic ash and tuffaceous sedimentary rock range in color from very light grey to medium light grey. Outcrops exhibit well-defined bedding planes. Beds range from a few centimeters to nearly one meter thick, with outcrops measuring several meters in thickness.

The groundmass of the volcanic ash and tuff is composed of non-welded, non-compacted, and partially iron-stained glass shard fragments. Quartz is the only phenocryst phase in the ash samples; it forms distinctive embayed crystals. An outcrop of tuff breccia occurs in the northwestern corner of the study area and is marked by large (1-5cm) fragments of consolidated ash with quartz and hornblende set in a moderately pumiceous-appearing matrix. The presence of this tuff breccia may indicate a close proximity to its source, perhaps being derived from the same location as the flows, though at an earlier time. Many ash and tuff samples from the Tertiary Salt Lake Formation have been analysed as being rhyolitic in composition (Smith and Nash, 1976).

The conglomerate of the Salt Lake Formation in the study area is medium light grey and contains pebbles of quartzite and chert set in a fine-silt to medium-sand-sized matrix. Carbonate grains, iron-titanium oxides, and zircon crystals are common constituents of the conglomerate.

Secondary silicification forms conspicuous bands within the pre-existing voids. Carbonate and silica are the main cementing agents of this rock type.

STRUCTURE

Flows

Dacite

The central portion of the study area, covering an area of approximately five square miles, is comprised of several dacite flows. Erosion of the flows and extensive colluvium make the distinction of separate flow units difficult. However, the larger flow units and several eruptive centers have been recognized.

Foliation patterns, when taken as a whole, tend to be quite variable throughout the entire region. On a smaller scale, certain consistencies begin to emerge. Sections of dacite near probable centers of eruption exhibit foliation patterns that are vertical with a general north-south trend. As the distance increases away from these eruptive centers, the foliation patterns become increasingly horizontal and planar with the dacite becoming more massive.

Dacite vitrophyre, where preserved, is found underneath and along the outer margins of individual flow units. One exception is a large section of dacite vitrophyre that overlies dacite in the NE 1/4, Sec. 33, T. 11 N., R. 19 W. This section of vitrophyre lies immediately west of an eruptive center and is believed to be a remnant cap.

Brecciated sections of dacite and dacite vitrophyre are common throughout these flows. Brecciation generally appears at the eruption centers and at the contacts between dacite and dacite vitrophyre.

Sharp, non-brecciated contacts between these two rock types are also present in a few areas.

Rhyolite

A large ridge of rhyolite is located in the southeastern portion of the field area, occupying an area of approximately one square mile. This rhyolite ridge is but the tip of a larger rhyolitic mass that extends directly southward from the study area. The portion of the rhyolite mass that lies within the study area is elongate in a northeast-southwest direction and is marked by a flat, featureless cap of colluvium.

Foliation patterns in the rhyolite mass, across the canyon of Dairy Valley Creek, are vertical and maintain a north-south trend. The foliation patterns remain vertical throughout most of this ridge while strike directions tend to parallel the ridge margins.

Massive, vertical walls of rhyolite vitrophyre crop out along the western edge of this ridge while the eastern margin is noticeably void of vitrophyre. The absence of rhyolite vitrophyre along the eastern margin suggests the possibility of normal faulting, with the valley side down, along the length of this flow.

Eruptive Centers

Three fissure-eruption centers, and possibly a fourth, have been located in the study area. One of the most obvious eruptive centers for rhyolite is clearly seen in the narrows of Dairy Valley Creek. Flaggy and brecciated rhyolite maintains a vertical attitude with a minor degree of flaring towards the top of this cross-cut view. Flow banding is quite contorted in this area but overall it shows a vertical trend.

The remaining eruptive centers are found in the dacite flows. Another cross-cut view of a fissure eruption is found on a small ridge to the west of the rhyolite ridge. This fissure is shown in cross section A-A'. This eruptive center displays an intermixing of dacite and dacite vitrophyre accompanied by distinct flaring of foliations. This is a relatively small fissure eruption believed to contribute to minor flow units within the immediate area.

The third and largest eruptive center is not as clearly defined as the previous two. This eruptive center along the ridge crest (SE 1/4, Sec. 28, T. 11 N., R. 19 W.) trends north-south and is characterized by vertical and near vertical foliations of dacite. Evidence in support of this location as an eruptive center consists of the following. Directly south of the ridge crest, massive cliffs mark the erosional remnant of a voluminous dacite flow. The same feature is encountered to the north and north-east of the ridge crest. In these directions, however, a set of three flow units totalling nearly fifty meters in thickness is found dipping gently towards the ridge crest. A large section of dacite vitrophyre overlying dacite is present to the west of the ridge crest. Vitrophyre overlying dacite or rhyolite is extremely rare in the study area due to its susceptibility to weathering. The presence of such a large mass of vitrophyre overlying dacite suggests that the vitrophyre is either the top of the underlying flow unit or it is the base of an eroded, overlying flow unit. However, evidence elsewhere for an eroded, overlying flow unit is lacking; and the partially brecciated contact between the vitrophyre and underlying dacite suggests a single unit.

A fourth eruptive center may lie in the extreme southwest corner of the study area. The ridge in this area is characterized by vertical and flaggy foliations trending N 40° W. The vertical nature of the dacite of this area is similar to that found in other areas of eruption, but further supporting evidence is lacking.

Faults

Normal faulting is thought to be significant along the eastern portion of the study area specifically along the eastern margin of the rhyolite ridge in the southeast corner of the study area. Several lines of evidence support normal faulting along this ridge, the first of which is the lack of rhyolite vitrophyre, which would normally be expected. One exception to this lack of vitrophyre is a highly broken and brecciated outcrop of rhyolite vitrophyre in the bottom of Dairy Valley Creek at the mouth of the canyon (SE 1/4, Sec. 35, T. 11 N., R. 19 W.). This outcrop appears to be fractured by fault movement post-dating solidification. Several outcrops of rhyolite and rhyolite vitrophyre occur at low elevations (SE 1/4, Sec. 35, T. 11 N., R. 19 W.) a few hundred feet east of the main rhyolitic body. These outcrops show no signs of consistency or uniformity of attitude with the main rhyolite mass, thus suggesting that they may be on the downthrown side of a normal fault that partially truncated the eastern margin of the rhyolite ridge.

Two other faults, possibly interrelated, are found on the north side of the mouths of Death Creek and Dairy Valley Creek. In both instances, slickensides trend approximately N 20° E. Directly above both sets of slickensides are zones of brecciated rhyolite with textures different from those attributed to flow emplacement and cooling history. Large, angular fragments of rhyolite appear compacted and show no signs of a magmatic matrix binding them together. This evidence suggests lateral strike-slip movement in these localities and possibly along the whole eastern margin of the study area occurring concurrently with or post-dating normal faulting.

The cliffs on the northern face of Burnt Mountain consist of three flow units dipping gently to the southwest. These flow units are vertically offset in three separate localities suggesting a north-south fault plane with vertical movement.

A section of dacite vitrophyre on the ridge in the southwest corner of the study area displays a conspicuous offset relative to adjacent units (N 1/2, Sec. 16, T. 43 N., R 70 E.). No other evidence of faulting is found, and the possibility of a pre-consolidation offset or gravity sliding exists.

PETROGRAPHY

Rocks

Dacite

Classification of samples DV80-6, DV80-16, DV80-18a, DV80-27, and DV80-43 is not reliable based solely on modal compositions. These samples contain a glassy groundmass with minor quantities of microcrystalline components. Using the IUGS classification of volcanic rocks (Streckeisen, 1979), these five samples are classified as dacite based on the absence of alkali feldspar in the mode and the degree of oversaturation with respect to silica. Modification of the classification scheme was needed to accurately portray the quartz content represented in the glassy groundmass. Normative quartz in excess of 25 weight percent for these samples clearly indicates oversaturation with respect to silica, and is consistent with classification of these rocks as dacites.

These samples contain phenocrysts of plagioclase, biotite, amphibile, orthopyroxene, and iron-titanium oxides. Quartz is present as phenocrysts in samples DV80-16, DV80-18a, and DV80-27. Alkali feldspar is absent from all five dacitic samples. Average modal analyses of dacite vitrophyre yield 0.9 percent quartz, 15.1 percent plagioclase, and 75.5 percent glass (Table 2).

All samples contain abundant perlitic cracks and microlites. Samples DV80-18a and DV80-43 contain abundant microlites and have a clear to light-grey groundmass. Samples DV80-6, DV80-16, and DV80-27 have a brownish groundmass due to the greater abundance of microlites. Sample DV80-16 has a turbid groundmass and is red due to iron staining.

Rhyolite

The glassy or microcrystalline groundmass of the remaining samples, DV80-1, DV80-31, and DV80-47, also necessitates the use of modal and normative contents in classification. Following the IUGS classification for volcanic rocks (Streckeisen, 1979) these samples are classified as rhyolite based on an average modal content of plagioclase to total feldspar of 13 percent and normative quartz contents in excess of 36 weight percent.

These rhyolite samples contain phenocrysts of quartz, sanidine, plagioclase, and less commonly amphibole and biotite. Samples DV80-1 and DV80-31 contain subrounded phenocrysts set in a fine-grained felsic groundmass. Part of the groundmass of sample DV80-1 is birefringent and consists of radial aggregates of microlites. The rhyolite vitrophyre sample, DV80-47, displays well-formed perlitic cracks and incipient crystal growth due to devitrification. Phenocrysts in this sample also tend to be subrounded. Average modal analyses of rhyolite and rhyolite vitrophyre show 9.1 percent quartz, 8.6 percent sanidine, and 3.4 percent plagioclase.

Table 2. Modal analyses of study area samples (volume percent)

	Dacite					Rhyolite		
Mineral	DV80-6	DV80-16	DV80-18a	DV80-27	DV80-43	DV80-1	DV80-31	DV80-47
Quartz	---	2.5	1.6	0.3	---	8.1	17.0	2.2
Sanidine	---	---	---	---	---	8.4	9.7	7.9
Plagioclase	15.4	16.9	14.3	13.5	15.5	2.3	0.8	0.3
Biotite	1.2	1.3	1.3	---	0.6	---	---	tr.
Amphibole	1.7	0.3	2.8	1.5	1.9	0.1	0.1	tr.
OPX	1.8	0.2	1.1	1.6	2.0	---	---	---
Fe-Ti Oxides	0.9	1.5	0.6	1.0	1.2	---	---	tr.
Glass	78.6	71.3	69.2	82.0	76.0	---	---	41.0
Undifferentiated Groundmass	---	---	9.0	---	2.8	80.6	71.7	48.3
Accessory Minerals*	0.4	6.0	0.1	0.2	---	0.5	0.7	---

*Accessory minerals consist of allanite, zircon, apatite, CPX, and secondary carbonate.

Minerals

Plagioclase

Plagioclase is ubiquitous in all samples studied. Abundance of plagioclase in dacite ranges from 13.5 to 16.9 volume percent with an average of 15.1 volume percent. Abundance of plagioclase in rhyolitic samples ranges from 0.3 to 2.3 volume percent with an average of 1.1 volume percent. Modal analyses are based solely on phenocryst population. Plagioclase appears to be a minor groundmass constituent in samples DV80-6 and DV80-16 and is also present in samples showing extensive devitrification.

The length of plagioclase phenocrysts ranges from 0.1 to 4.0mm with an average length of 1.0mm. Plagioclase laths in the glassy groundmass of samples DV80-6 and DV80-16 are less than 0.1mm in length.

Twinning of plagioclase phenocrysts is common in all samples studied. Twinning varieties include albite, carlsbad-albite, and more rarely pericline. Oscillatory zoning is another feature of plagioclase phenocrysts in most dacitic samples.

Rhyolitic samples generally display uncorroded plagioclase phenocrysts; whereas, the dacitic samples display large, extensively corroded plagioclase phenocrysts that are often surrounded by euhedral plagioclase overgrowths. The presence of fresh, clean plagioclase overgrowths on corroded and resorbed plagioclase cores indicates thermal/compositional disequilibrium or profound changes in pressure

(Cox and others, 1979; Stewart and Roseboom, 1962). A second generation of smaller, more abundant plagioclase phenocrysts in the dacitic samples tend to be uncorroded with a noticeable absence of overgrowths. Phenocryst shapes range from subhedral to euhedral.

Sanidine

Sanidine phenocrysts are present only in the rhyolitic samples. The abundance of sanidine ranges from 7.9 to 9.7 percent with an average of 8.6 volume percent (Table 2). Sanidine is suspected of being present as a groundmass phase in rhyolitic samples although this is difficult to determine due to its small size and resemblance to quartz. The glassy groundmass of dacitic samples appears rich in potassium, as determined by staining methods for alkali feldspar, although no sanidine crystals are visible.

Sanidine phenocrysts range from 0.3 to 2.0mm in diameter. Average maximum dimension for these phenocrysts is approximately 1.0mm. They are anhedral to subhedral, and display numerous fractures, embayed margins and glass inclusions.

Twinning is a common feature of sanidine phenocrysts; when it occurs, it is of the simple type which follows the carlsbad law. Zoning features are not readily discernable due to the small change in refractive index as compared with zoned plagioclase phenocrysts. Microprobe analyses of sanidine phenocrysts indicate that zoning features are not present.

Quartz

Phenocrysts of quartz are present in all samples studied with the exception of DV80-6 and DV80-43. The abundance of quartz in rhyolitic samples ranges from 2.2 to 17.0 with an average of 9.1 volume percent (Table 2). Dacitic samples display an abundance ranging from 0.0 to 2.5 with an average of 0.9 volume percent (Table 2). Quartz is present as an additional groundmass constituent in sample DV80-16. Devitrification, noted in several vitrophyre samples, causes the growth of minute crystals of quartz and feldspar that are often too small for accurate measurement. Tridymite, with its characteristic wedge shape and biaxial character, is accompanied by secondary opal and chalcedony in sample DV80-31 which accounts for the higher SiO_2 value of this sample. Tridymite, opal, and chalcedony are included in the accessory column of Table 2.

Rhyolitic samples display the largest range in size of quartz phenocrysts. These phenocrysts range from 0.2 to 4.0mm in diameter with an average of 1.0mm. Quartz phenocrysts in the dacitic samples, with a notably smaller phenocryst size, range from 0.2 to 1.75mm and have an average diameter of 0.5mm.

The majority of quartz crystals studied possess subrounded, anhedral to subhedral outlines. Rarely are euhedral quartz crystals noted. Embayed margins are a common feature; where these margins are deeply incised, glass-filled cavities have been formed. Numerous grains are fractured and appear to be strained, exhibiting undulose extinction.

Biotite

Biotite is common in four dacitic samples and is sparse in the rhyolitic samples. The abundance of biotite ranges from 0.6 to 1.3 volume percent with an average of 1.1 volume percent (Table 2). Minor amounts of biotite occur in sample DV80-47.

Twinning is rare, but examples are found in sample DV80-16 and occur according to the mica law, twin plane = (110). Biotite is often found closely associated with plagioclase and iron-titanium oxides. Color varies widely between and within samples ranging from olive green to yellowish brown to brownish red. These color variations may be the result of differences in composition and/or pleochroism. The degree of oxidation, where present, ranges from slight to excessive with opacity occurring in the most extensively oxidized crystals.

Most of the biotite phenocrysts found in the dacitic samples are euhedral displaying hexagonal and prismatic forms. Bent phenocrysts are present but rare.

Amphibole and allanite

Amphibole is present in all samples but is rare in the rhyolitic samples. Abundance of amphibole ranges from 0.3 to 2.8 volume percent in dacitic samples with an average of 1.6 volume percent. Amphibole does not occur as a groundmass phase but primarily as phenocrysts.

Amphibole phenocrysts range in length from 0.1 to 2.0mm with an average length of 0.4mm. These phenocrysts have a pleochroic color range from yellowish grey to moderate olive brown.

Twinning is common, and occurs along the (110) and (100) twin planes. There is a cumulophyric relationship between amphibole, plagioclase, and iron-titanium oxides in samples of dacite. This relationship is especially evident in sample DV80-16. Corroded grains with embayed margins are common.

Allanite is rare except in DV80-16 in which it comprises 2.8 percent of the total volume. Allanite ranges from 0.5 to 2.0mm in length with an average of 1.0mm. In sample DV80-16, allanite is dark reddish brown and becomes blackish red with increasing oxidation. Most allanite is subhedral and is closely associated with iron-titanium oxides.

Pyroxene

Pyroxene phenocrysts are absent in the rhyolitic samples but are found in all dacitic samples. Abundance ranges from 0.2 to 2.0 volume percent with an average of 1.35 volume percent. Pyroxene occurs only as a phenocryst phase.

Phenocrysts of pyroxene range in size from 0.05 to 1.0mm with an average of 0.2mm. Pleochroism is generally absent, but when present, ranges from light yellowish green to clear. This feature, coupled with parallel extinction and a biaxial character, indicates that these grains are enstatite.

In general, orthopyroxene grains are subhedral to euhedral with some grains having corroded margins. In many samples enstatite crystals display a cumulophyric texture with plagioclase. Sample DV80-43 contains orthopyroxene phenocrysts that are partially oxidized. Less commonly, these phenocrysts are noticeably hydrated and altered. The magnesium-rich orthopyroxenes are sometimes altered to serpentine, and where alteration is complete, the pseudomorphs show a characteristic bronze-like metallic luster or schiller and are known as bastite (Deer and others, 1963).

Iron-titanium oxides

Iron-titanium oxides are ubiquitous in all samples studied; however, they are rare in the rhyolitic samples, especially DV80-1 and DV80-31. The iron-titanium oxides in the dacitic samples average 1.0 volume percent with a range of 0.6 to 1.5 percent.

The average maximum dimension of iron-titanium oxides in rhyolitic samples is 0.5mm. In dacitic samples they range in maximum dimension from 0.1 to 0.5mm with an average of 0.2mm.

The iron-titanium oxides in the rhyolitic samples are generally less well-formed than those of dacitic samples ranging from anhedral to subhedral. In the dacitic samples the iron-titanium oxides are subhedral to euhedral. Numerous grains appear to be oxidized, which is a contributing factor in the staining of surrounding phenocrysts and groundmass. This feature is especially evident in sample DV80-16 where the entire groundmass is covered with red streaks.

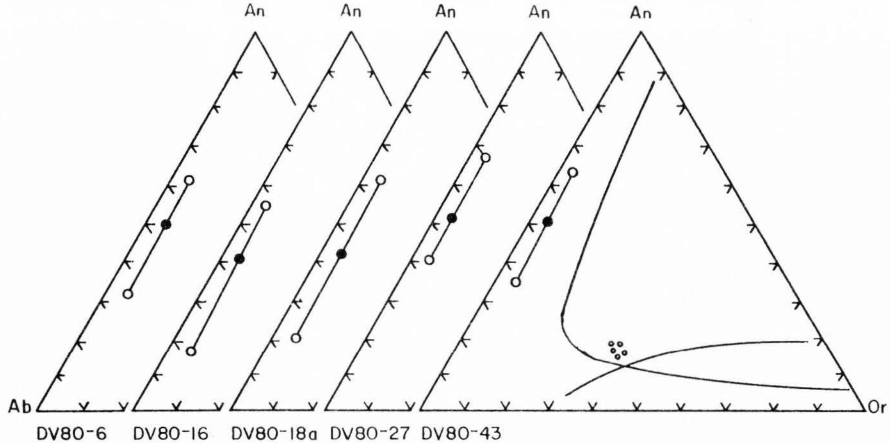
MINERALOGY

General Statement

Microprobe analyses were carried out on polished probe mounts of the eight selected samples to determine their respective weight percent oxides and approximate end members for alkali feldspar, plagioclase, and pyroxene phenocrysts. Groundmass crystals and glass were not analysed. Alkali feldspar phenocrysts were found and analysed in the rhyolitic samples, DV80-1, DV80-31, and DV80-47. Dacitic samples are noticeably void of alkali feldspar phenocrysts. Plagioclase was found and analysed in all samples with the exception of sample DV80-31. Orthopryoxenes were found and analysed in four of the dacitic samples, DV80-6, DV80-18a, DV80-27, and DV80-43.

Plagioclase

Compositional diagrams for feldspars in dacite and rhyolite are presented in Figures 4 and 5, respectively. Analytical data for plagioclase and alkali feldspar phenocrysts are presented in Tables 3 and 4, respectively. Due to a lack of zoning, the range in An content for plagioclase in rhyolitic samples is less than that found in dacite samples. The An content of plagioclase in rhyolitic samples lies in the oligoclase field ranging from An_{29} to An_{19}. The dacitic samples tend to possess plagioclase phenocrysts that are extensively zoned and overgrown, extending their compositional range. Samples DV80-16 and DV80-18a



.**Figure 4.** Electron microprobe analyses of feldspar phenocrysts in dacitic samples. Figures plotted in terms of molecular percent An-Ab-Or. Large, open circles represent ranges in composition for sample, solid circles represent average compositions for sample. Small, open circles in right-hand figure represent normative compositions for dacitic samples. Solidus and liquidus curves from Cox and others (1979).

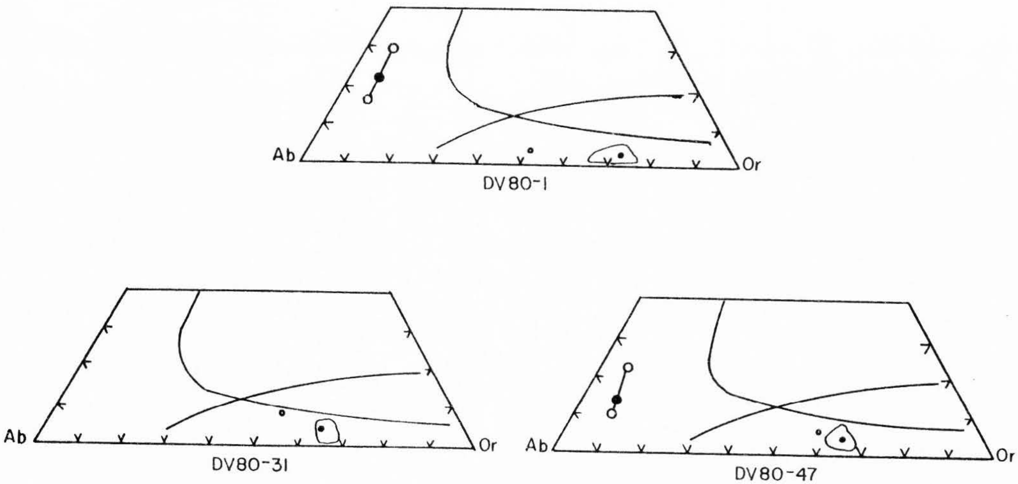


Figure 5. Electron microprobe analyses of feldspar phenocrysts in rhyolitic samples. Figures plotted in terms of molecular percent An-Ab-Or (An not shown). Large, open circles represent ranges in composition for sample. Solid circles represent average composition for sample. Small, open circles represent normative composition for sample. Solidus and liquidus curves from Cox and others (1979).

Table 3. Average microprobe analyses of plagioclase

Weight percent oxides

	DV80-6	DV80-16	DV80-18a	DV80-27	DV80-43	DV80-1	DV80-47
CaO	10.83	8.69	9.60	11.61	11.45	5.37	4.56
Na_2O	5.48	6.61	6.25	5.28	5.30	8.07	8.10
K_2O	0.59	0.82	0.70	0.55	0.63	1.57	1.98
Sum	16.90	16.12	16.55	17.44	17.38	15.01	14.64

Molecular percent end members

An	50.50	40.21	44.19	53.26	52.53	24.58	21.11
Ab	46.23	55.29	52.00	43.77	44.03	66.85	67.87
Or	3.27	4.50	3.81	2.97	3.44	8.57	11.02

Table 4. Average microprobe analyses of alkali feldspar

	DV80-1	DV80-31	DV80-47
Weight percent oxides			
CaO	0.38	0.39	0.36
Na_2O	3.96	4.06	3.96
K_2O	11.79	11.62	10.95
Sum	16.13	16.07	15.27
Molecular percent end members			
An	1.75	1.79	1.77
Ab	33.18	34.05	34.82
Or	65.07	64.16	63.41

Table 5. Average microprobe analyses of pyroxene

	DV80-6	DV80-18a	DV80-27	DV80-43
Weight percent oxides				
CaO	1.43	1.25	1.64	1.61
MgO	19.60	18.45	19.39	18.98
FeO	24.27	27.46	26.78	27.50
Sum	45.30	47.16	47.81	48.09
Molecular percent end members				
Wo	3.00	2.58	3.32	3.24
En	57.12	52.98	54.36	53.21
Fs	39.98	44.44	42.32	43.55

have ranges that place their plagioclase phenocrysts in the labradorite through oligoclase fields. Samples DV80-6, DV80-27, and DV80-43 have a smaller compositional range that places their plagioclase phenocrysts in the labradorite through andesine fields.

Normative plagioclase compositions for dacitic samples are presented in Figure 4. Examination of this figure indicates that dacite samples plot above the liquidus curve. Liquids represented by a point lying above the liquidus curve will initially crystallize plagioclase, but may potentially crystallize sanidine as well (Tuttle and Bowen, 1958).

Alkali feldspar

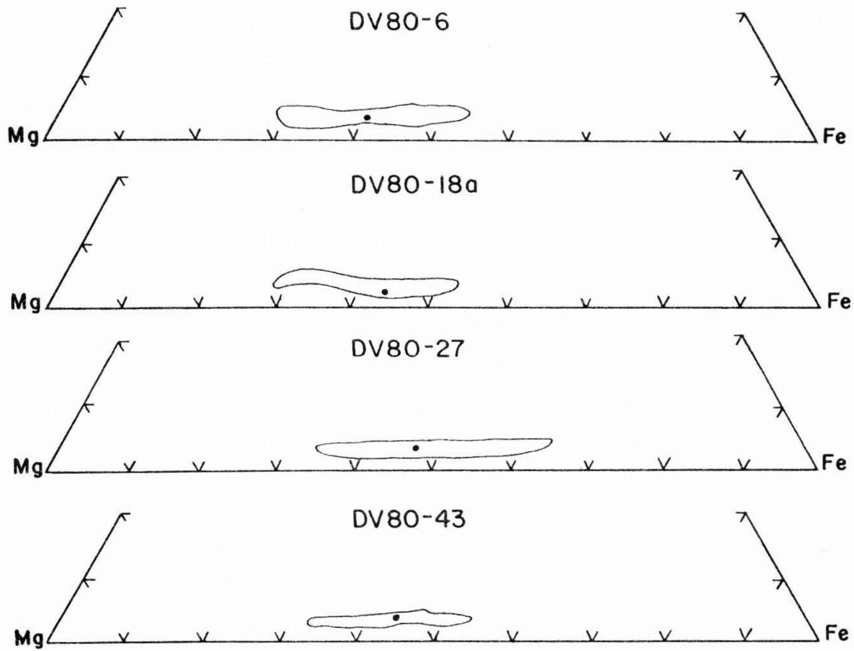
The alkali feldspar phenocrysts analysed in sample DV80-1 possess a small compositional range with respect to Or content ranging from Or_{74} to Or_{64}. The remaining two rhyolitic samples DV80-31 and DV80-47, possess alkali feldspar phenocrysts with Or contents ranging between Or_{69} and Or_{62}. Alkali feldspar phenocrysts in these samples fall into the sanidine field.

Examination of Figure 5 indicates that the normative rhyolite compositions plot below the liquidus field boundary curve and the solid solution curve. Compositions plotting below the solid solution curve should finish crystallization as a single homogeneous feldspar although some will crystallize two feldspars early in the crystallization history of the magma (Tuttle and Bowen, 1958). Modal analyses (Table 2) of rhyolitic samples show two feldspars, suggesting an early crystallization history of feldspar for these rock types. However, the position of the liquidus curve and the solid solution curve is a function of pressure, temperature and composition of the magma and its exact position is not known (Carmichael and others, 1974). This may explain the discrepancy in the rhyolite samples plotting below the solvus and in the single feldspar field (Figure 5).

Orthopyroxene

Analytical data for orthopyroxenes are presented in Table 5 and compositional diagrams are presented in Figure 6. Orthopyroxenes are found in four dacitic samples and are extremely rare in rhyolitic samples. Orthopyroxene phenocrysts lie in the hypersthene to ferrohypersthene field with sample DV80-27 displaying the largest range in Fs content which ranges from Fs_{33} to Fs_{65}. All phenocrysts contain less than eight mole percent Wo at which point the pigeonite boundary occurs.

Figure 6. Electron microprobe analyses of orthopyroxene phenocrysts in four dacitic samples. Plotted in terms of molecular percent end members: wollastonite (not shown), enstatite (Mg), and ferrosilite (Fe). Dots represent the average analysis for each sample.


DV80-6
Mg
Fe
DV80-18a
Mg
Fe
DV80-27
Mg
Fe
DV80-43
Mg
Fe

CHEMISTRY

Dacite

All dacite samples selected for detailed analyses are vitrophyric, and have a minimum of secondary devitrification features. This enables dacitic samples from separate localities to be more readily compared. Chemical analyses and C.I.P.W. norms for these samples are presented in Table 6. In dacitic samples, SiO_2 displays a range in weight percent from 68.74 to 69.65. Variation in weight percent for the oxides FeO, Fe_2O_3, and total H_2O are 1.37, 1.31, and 1.17, respectively. All remaining oxides display variations between samples of less than one weight percent.

Figure 7 is a plot of the major oxides in rhyolitic and dacitic samples versus their corresponding SiO_2 contents. This diagram reveals minor scatter for major oxides in dacitic samples. One exception is the value of total iron in sample DV80-16. This large total iron value may be explained by the highly oxidized nature of biotite and hornblende phenocrysts in this sample. No specific trends in oxide values are discernable over the small SiO_2 range for dacitic samples.

Normative calculations display quartz in the norm exceeding 25 weight percent. Variations in normative anorthite (An), albite (Ab), and orthoclase (Or) are minor pointing out the similarities in CaO, Na_2O, and K_2O values for dacite samples in the chemical analyses. The high value for Fe_2O_3 reported in sample DV80-16 is reflected in the

Table 6. Chemical analyses and C.I.P.W. norms of study area samples

	DACITE DV80-6	DV80-16	DV80-18a	DV80-27	DV80-43	RHYOLITE DV80-1	DV80-31	DV80-47
SiO_2	68.79	69.65	69.16	68.74	69.23	77.88	78.18	72.94
TiO_2	0.32	0.29	0.33	0.30	0.33	0.12	0.14	0.09
Al_2O_3	14.25	14.07	14.26	14.34	14.02	11.74	11.34	12.33
Fe_2O_3	0.72	2.03	1.43	0.77	1.38	0.50	0.50	0.75
FeO	1.64	0.30	1.27	1.67	1.26	0.57	0.21	0.51
MnO	0.03	0.04	0.06	0.05	0.03	0.01	-----	0.02
MgO	0.42	0.53	0.68	0.60	0.49	0.05	-----	0.22
CaO	2.90	2.35	2.77	2.80	2.79	0.77	0.77	0.81
Na_2O	3.29	3.25	3.29	3.45	3.24	3.01	2.78	2.29
K_2-	4.02	4.24	4.10	4.06	3.94	5.06	4.92	5.82
P_2O_5	0.26	0.10	0.10	0.08	0.09	0.02	0.03	0.01
H_2O^+	1.86	1.54	1.54	1.79	2.71	0.24	0.46	2.82
H_2O^-	0.52	0.63	0.38	0.35	0.44	0.05	0.18	0.43
Total	99.02	99.02	99.37	99.00	99.95	100.02	99.51	100.04
Q	27.37	28.97	27.56	25.91	28.79	39.15	41.61	36.21
C	-----	0.10	-----	-----	-----	-----	0.11	0.82
Or	23.76	25.06	24.23	23.99	23.28	29.90	29.07	34.39
Ab	27.84	27.50	27.84	29.19	27.42	25.47	23.52	19.38
An	12.24	11.01	12.03	11.65	12.08	3.58	3.62	3.95
Di-wo	0.19	-----	0.44	0.72	0.49	0.05	-----	-----
Di-en	0.07	-----	0.29	0.30	0.30	0.01	-----	-----
Di-fs	0.12	-----	0.12	0.41	0.17	0.04	-----	-----
Hy-en	0.98	1.32	1.41	1.19	0.92	0.11	-----	0.55
Hy-fs	1.82	-----	0.60	1.61	0.52	0.42	-----	0.21
Mt	1.04	0.26	2.07	1.12	2.00	0.72	0.27	1.09
Il	0.61	0.55	0.63	0.57	0.63	0.23	0.27	0.17
Hm	-----	1.85	-----	-----	-----	-----	0.31	-----
Ap	0.62	0.24	0.24	0.19	0.21	0.05	0.07	0.02
Total	96.66	96.85	97.45	96.85	96.81	99.73	98.87	96.79
Salic	91.22	92.63	91.66	90.75	91.56	98.11	97.95	94.75
Femic	5.44	4.22	5.79	6.10	5.25	1.62	0.92	2.04

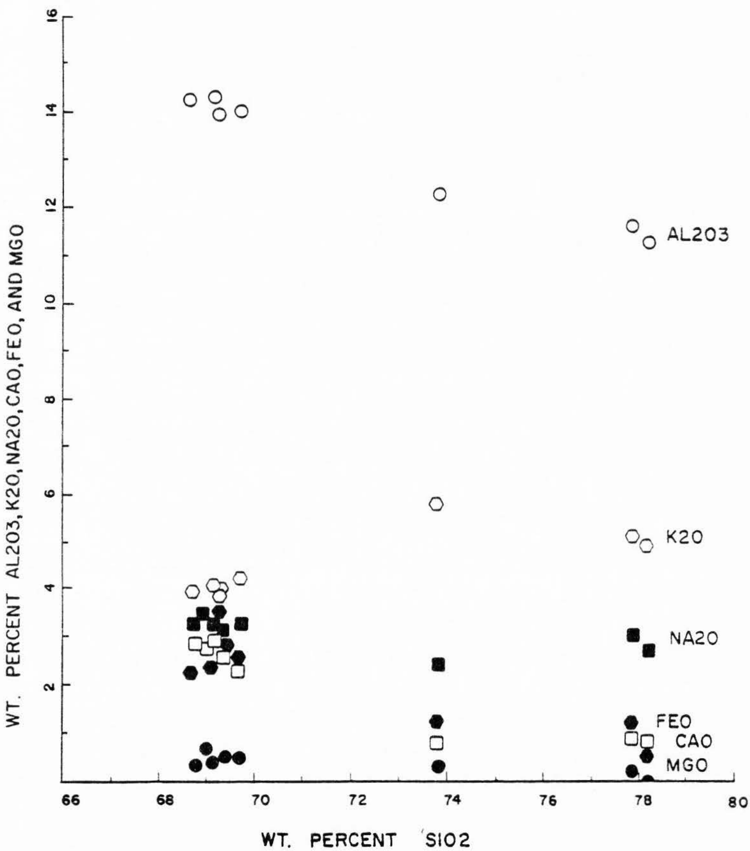


Figure 7. Variation diagram (Harker type) for volcanic rocks of the study area. Total iron is expressed as FeO.

norm by the presence of hematite. Sample DV80-16 also displays corundum in the norm indicating that there is an excess of Al_2O_3 over that taken up by anorthite, albite, and orthoclase.

Rhyolite

The rhyolite samples selected for detailed analyses are crystalline with the exception of sample DV80-47 which is vitrophyric. Analysis of both crystalline and glassy rhyolite allows differences in oxides to be observed which reflect the degree of crystallinity. SiO_2 displays a range in weight percent from 73.94 to 78.18. Total water displays a range of 2.96 percent. All other oxides vary less than one percent.

Examination of Figure 7 reveals the obvious difference in weight percent SiO_2 between glassy and crystalline rhyolite. The low SiO_2 value in sample DV80-47 coupled with a large total H_2O content suggests that this sample has been extensively hydrated. Leaching of glassy volcanic rocks will tend to remove SiO_2 and Na_2O leaving an apparent increase in Al_2O_3 (Lipman, 1965). In sample DV80-47, K_2O shows an increase over the crystalline rhyolites (Figure 7) indicating that leaching has not preferentially removed this oxide. Increase in K_2O in glassy rocks, compared with their crystalline counterparts, may partially be explained by base exchange in which K_2O substitutes for some of the leached Na_2O (Lipman, 1965). When considering the transition from dacite to rhyolite samples, all oxides tend to decrease with the exception of K_2O and Na_2O.

Normative calculations display quartz in the norm exceeding 36 weight percent (Table 6). Sample DV80-47 has a large value for orthoclase which reflects the large K_2O content in the chemical analyses. All rhyolite samples display low anorthite values due to correspondingly low CaO values in the chemical analyses. Samples DV80-31 and DV80-47 display corundum in the norm indicating excess Al_2O_3 over that taken up by anorthite, albite, and orthoclase.

Analyses 5 and 6 in Table 7 are of rhyolitic vitrophyre and rhyolite from Fortymile Canyon, Nevada. SiO_2 and Al_2O_3 are lower and K_2O is higher in the vitrophyric lava than in the crystallized lava. This trend in oxide values is similar to that observed in the rhyolite samples from the study area.

Comparative Analyses

Comparison of Table 6 with Table 7 shows that the dacites and rhyolites of the study area contain greater amounts of SiO_2 and K_2O but lesser amounts of Al_2O_3, Na_2O, CaO, and total FeO relative to samples from other areas. Correspondingly, these trends are reflected in the normative calculations. Quartz (Q) and orthoclase (Or) are higher in the norms of the study area samples; whereas, albite (Ab), anorthite (An), and magnetite (Mt) are lower.

Comparison of the average crystalline rhyolite from the Etna domes (Smith, 1980) in column 8 (Table 7) with the crystalline rhyolites of

Table 7. Chemical analyses and C.I.P.W norms of selected samples

	DACITE		RHYOLITE					
	1	2	3	4	5	6	7	8
SiO_2	65.01	62.68	72.82	74.57	75.40	77.30	75.39	78.43
TiO_2	0.58	0.57	0.28	0.17	0.18	0.14	0.14	0.10
Al_2O_3	15.91	17.07	13.27	12.58	12.20	12.60	11.48	10.65
Fe_2O_3	2.43	2.31	1.48	1.30	0.59	0.73	0.83	0.95
FeO	2.30	3.01	1.11	1.02	0.34	0.14	0.53	0.21
MnO	0.09	0.12	0.06	0.05	0.03	0.02	0.02	0.01
MgO	1.78	2.44	0.39	0.11	0.16	0.27	0.13	0.20
CaO	4.32	6.14	1.14	0.61	0.56	0.46	0.93	0.73
Na_2O	3.79	3.82	3.55	4.13	3.00	3.00	2.71	3.10
K_2O	2.17	1.21	4.30	4.73	5.30	5.00	5.39	4.67
P_2O_5	0.15	0.16	0.07	0.07	0.02	0.02	0.02	0.04
H_2O^+	0.91	0.46	1.10	0.66	2.40	0.37	1.70	0.76
H_2O^-	0.28	-----	0.31	-----	0.18	0.17	0.27	0.18
CO_2	0.06	-----	0.08	-----	0.05	0.05	-----	-----
Total	99.78	99.99	99.96	100.00	100.41	100.27	99.54	100.03
Q	22.70	18.93	32.89	31.05	36.42	39.52	37.09	41.21
C	-----	-----	1.06	-----	0.67	1.58	-----	-----
Or	12.82	7.15	25.41	27.95	31.32	29.55	31.85	27.60
Ab	32.07	32.32	30.04	34.95	25.33	25.38	22.93	26.23
An	19.99	25.86	4.69	1.82	2.65	1.84	3.25	1.35
Wo	-----	-----	-----	-----	-----	-----	0.06	0.27
Di	0.06	2.88	-----	0.64	-----	-----	0.91	1.08
Hy	5.83	7.60	1.44	0.56	0.40	0.67	-----	-----
Mt	3.53	3.35	2.14	1.88	0.67	0.11	1.21	0.42
Il	1.09	1.10	0.54	0.32	0.34	0.27	0.27	0.20
Hm	-----	-----	-----	-----	0.13	0.65	-----	0.63
Ap	0.36	0.38	0.17	0.17	0.05	0.05	0.05	0.10
Cc.	0.14	-----	0.17	-----	0.11	0.11	-----	-----
Total	98.59	99.57	98.55	99.34	97.83	99.73	97.62	99.09

1. Dacite (average), (Cox and others, 1979, Appendix 2).
2. Dacite and dacite obsidian (average), (Nockolds and others, 1978, Table 4-1, no.5).
3. Rhyolite (average), (Cox and others, 1979, Appendix 2).
4. Alkali rhyolite and rhyolite obsidian (average), (Nockolds and others, 1978, Table 4-1, no. 2).
5. Vitrophyre rhyolitic lava, Fortymile Canyon, NV. (Lipman, 1965, Table 1, no. 8a).
6. Crystallized rhyolitic lava, Fortymile Canyon, NV. (Lipman, 1965, Table 1, no. 8b).
7. Vitrophyric rhyolitic lava (average), (Smith, 1980, Table 9).
8. Crystallized rhyolitic lava (average), (Smith, 1980, Table 9).

the study area shows little variation with respect to SiO_2, CaO, and total alkalis, but there is a slight increase in Al_2O_3. The rhyolites of the study area are also petrographically similar to those rhyolites presented in columns 7 and 8 (Table 7), both containing phenocrysts of quartz, plagioclase, sanidine, and minor quantities of biotite and hornblende. Geographically, the rhyolite flows of the study area are located at a minimum distance of approximately one mile from the rhyolite domes of Smith (1980). Similarities between these two rhyolite outcrops suggest that they may have similar origins and possibly represent the same magma.

The dacites and rhyolites of the study area are metaluminous with alkali to aluminum ratios between 0.62 and 0.89 with the exception of samples DV80-31 and DV80-47. Metaluminous rocks are defined as having mole proportions of Al_2O_3 lower than ($CaO+Na_2O+K_2O$), but Al_2O_3 proportions greater than (Na_2O+K_2O) in addition to the presence of anorthite in the norm (Carmichael and others, 1974).

Petrogenesis

The Basin and Range province is an area marked by high heat flow and a relatively thin crust underlain by a low velocity, partially melted zone (Scholz and others, 1971). Fusion of sialic material at the interface of the crust and partially melted zone is a conceivable origin for the flows in the study area. Figure 8 displays plots of normative components of the study area samples with respect to the system Q-Ab-Or of Tuttle and Bowen (1958). Rhyolite samples have normative compositions plotting above the quartz-feldspar field boundary curve indicating that at 0.5kb P_{H_2O}, quartz was the first phase to crystallize. Once crystallization of quartz had begun, the liquid changed composition toward the field boundary curve where feldspar began to crystallize. Dacite samples would crystallize quartz first at pressures greater than 3kb. Samples plotting near the thermal minimum, at low water pressure, owe their origin to magmatic processes (Tuttle and Bowen, 1958). This observation supports, but does not prove, fusion of sialic rocks as an origin for the rocks in the study area.

Similarities in chemistry, petrography, and location of the rhyolitic domes of Smith (1980) with the rhyolite of the study area have been presented previously suggesting the possibility of similar origins and common magmas. Depths of origin for the rhyolite domes based on pressure studies range from 18.2 to 0.4km (Smith, 1980). These depths lie well with the crustal thickness of 30km proposed for the Basin and Range province (Scholz and others, 1971).

In the evolution of an acidic magma, the oxides will follow certain trends with respect to varying silica contents. In general, as the silica content of a magma increases the alkali contents will also tend to increase; whereas, the remaining oxides will tend to decrease (Cox and others, 1979). Figure 7 indicates that with increasing SiO_2 content, from dacite to rhyolite, the alkalis, especially K_2O, tend to increase or remain the same while the remaining oxides decrease.

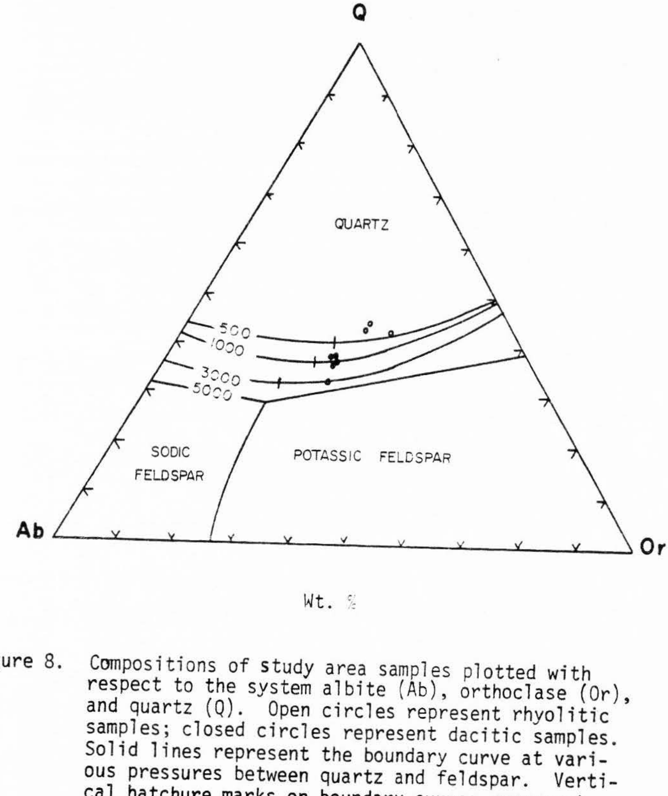


Figure 8. Compositions of study area samples plotted with respect to the system albite (Ab), orthoclase (Or), and quartz (Q). Open circles represent rhyolitic samples; closed circles represent dacitic samples. Solid lines represent the boundary curve at various pressures between quartz and feldspar. Vertical hatchure marks on boundary curves represent isobaric minimums. Ternary diagram from Tuttle and Bowen (1958).

Assuming that the rhyolites and dacites of the study area are related magmatically and that the oxide trends described by Cox and others (1979) are valid, then the dacite may represent the initial magma extruded in the study area while the rhyolite may represent the later extruded magma.

Structural evidence supporting this sequence of events lies in the fact that the rhyolite of the study area is restricted to two main areas. It is found outcropping at the eastern edge of the main dacite flows, and it has intruded upward and into the dacite flows in the narrows of Death Creek Valley.

If it is assumed that the rhyolite and dacite of the study area are products of fusion of sialic material, two possibilities exist regarding their direct relationship to each other. The first is that the fused material represents the parent magma from which differentiation has produced a dacitic magma. Sequential differentiation of the dacitic magma may have occurred to produce the rhyolitic magma. The second possibility is that the parent magma, derived from fusion of sialic material, has undergone differentiation to produce the dacitic magma. Further differentiation of the parent magma occurs to produce the rhyolitic magma. This second possibility suggests that both dacite and rhyolite are differentiation products of the same magma, but that rhyolite is not derived sequentially from dacite.

A small basalt flow crops out in the northwestern portion of the study area. The presence of this basalt outcrop suggests a possible petrogenetic relationship with the nearby dacite and rhyolite. This basalt outcrop may represent the original parent magma from which the dacite and rhyolite flows are derived. However, the specific role that the basalt in the study area may have played in the petrogenesis of the dacite and rhyolite flows is unknown.

Further evaluation of these possibilities would necessitate complete mineral analyses and computer modeling of differentiation processes. Although origins and times of emplacement have been proposed, the direct relation of these two rock types to each other regarding differentiation of parental material remains uncertain.

CONCLUSION

Basin and Range volcanism began approximately 40 to 50 million years ago and was characterized by the extrusion of rhyolite flows, ashflow tuffs, and andesites (Smith, 1977; Christiansen and McKee, 1977). Volcanism ceased at 19 million years and resumed again at 15 million years with a change to bimodal basalt-rhyolite compositions accompanied by crustal extension (Smith, 1977). The basins and ranges in Nevada and northwestern Utah were produced by a complex system of Late Cenozoic faults along which movement has resulted in the relative uplift of linear segments to form the mountains and relative sinking to form the valleys (Stewart, 1980). Evidence in the study area points to this second stage of Basin and Range volcanism as the time of emplacement for dacite and rhyolite flows during the Late Tertiary.

Age date samples were collected at four separate localities within the study area, but analyses have not as yet been completed. Several age dates of nearby rhyolites and basalts may be extrapolated to the study area to assist in approximating the age of the flows. Several rhyolite domes, adjacent to the study area, have been dated by K-Ar methods to yield an age of approximately 12.3 million years (Evans, University of Utah, personal communication). The presence of a basalt unit in the northwestern corner of the study area, in close proximity to the flows, supports the possibility of bimodal volcanism in this area. Another basalt flow three miles west of the study yields an age date of 16.3 million years (Armstrong and others, 1976). The rhyolite of the field area is believed to correlate closely in age with the rhyolite domes of Smith (1980) based upon similarities in chemical and petrographic data. The dacite, based on field relationships, chemical data and oxide trends, is theorized to be slightly older than the rhyolite yet still within the range of the second stage of Basin and Range volcanism.

The flows found in the study area correspond closely to those types extruded during the second stage of Basin and Range volcanism, that is, rhyolite and dacite flows coupled with outpourings of basalt and the lack of ash-flow tuffs (McKee, 1971; Scholz and others, 1971). With respect to rhyolite, there is a distinct difference between those rhyolites of bimodal basalt-rhyolite fields and those of calc-alkalic fields (Christiansen and Lipman, 1972). Rhyolites of bimodal basalt-rhyolite fields generally contain greater than 72 percent silica, have high alkali contents in relation to calcium, and are more sodium-rich than rhyolites of andesitic fields (Christensen and Lipman, 1972). The rhyolites of the study area correlate closely with these criteria.

The dacite and rhyolite flows of the study area are part of a larger body of flows that have a distinct north-south trend. On a smaller scale, sites of extrusion in the study area also maintain this north-south trend. The linear north-south trend of the main volcanic mass and eruptive centers in addition to the linear arrangement of the volcanic domes east of the flows suggests fault control. Extrusion of the flows during the second stage of the Basin and Range volcanism is believed to be through fissures caused by crustal extension concomittant with block and normal faulting (Christiansen and Lipman, 1972; Scholz and others, 1971). Several locations in the study area show evidence of small scale fissure eruptions; however, any large, single or multiple fissures are not discernable. One exception is the fissure patterns of the rhyolite flow in the canyon of Dairy Valley Creek (S 1/2, Sec. 35, T. 11 N., R. 19 W.). The possible presence of normal faulting along the eastern edge of the flows in the study area is a feature that is in concordance with events occurring in the second stage of Basin and Range volcanism.

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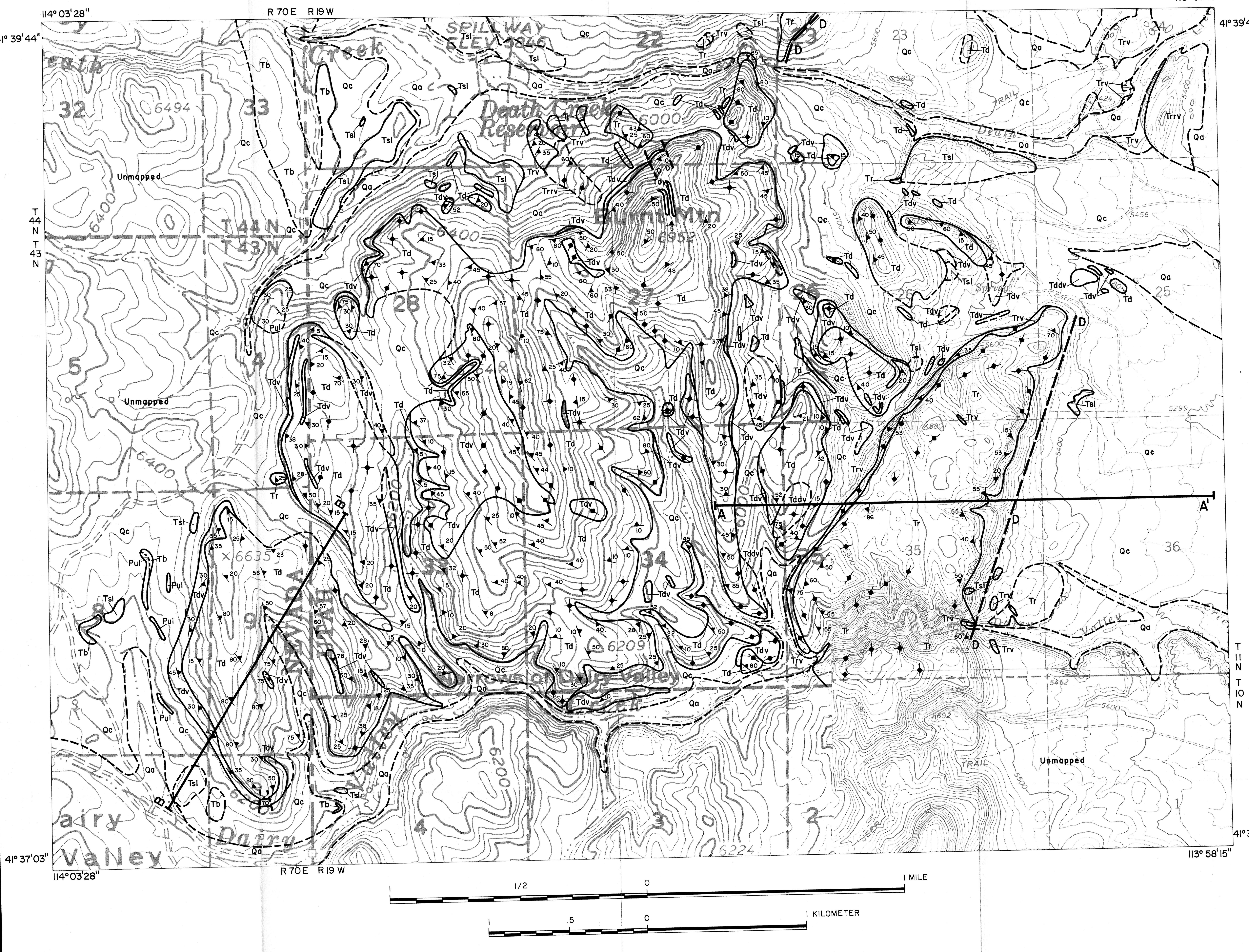
APPENDIX

Table 8. Standards used in microprobe analyses, University of Utah, Department of Geology and Geophysics.

Element	Sanidine	Plagioclase	Pyroxene
Ca	Xl. Bay Lab. 167303	Xl. Bay Lab. 167303	WA-3 WA-9
Na	Tib. Albite	Tib. Albite	
K	Orth. OR-1	Orth. OR-1	
Fe			Ol. R2202
Mg			YS-24



EXPLANATION

QUATERNARY UNITS

Qa	Alluvium
Qc	Colluvium

TERTIARY UNITS

Tr	Rhyolite
Trv	Rhyolite vitrophyre
Trrv	Rhyolite and rhyolite vitrophyre
Td	Dacite
Tdv	Dacite vitrophyre
Tddv	Dacite and dacite vitrophyre
Tb	Basalt
Tsl	Salt Lake Formation

PALEOZOIC UNITS

Pul	Undifferentiated limestone

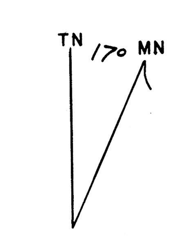
SYMBOLS

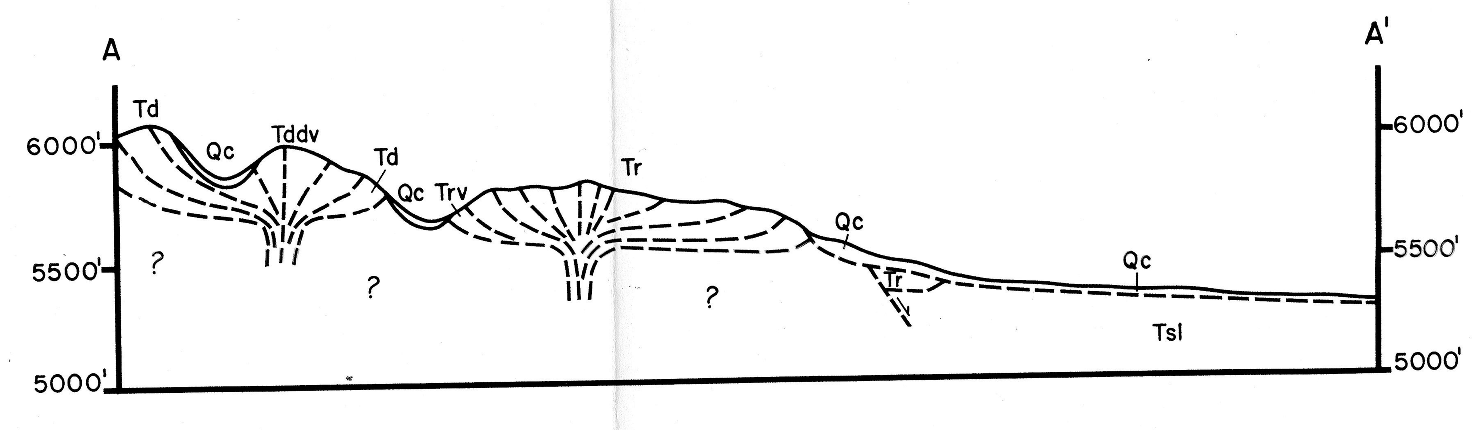
Contacts, dashed where approximately located

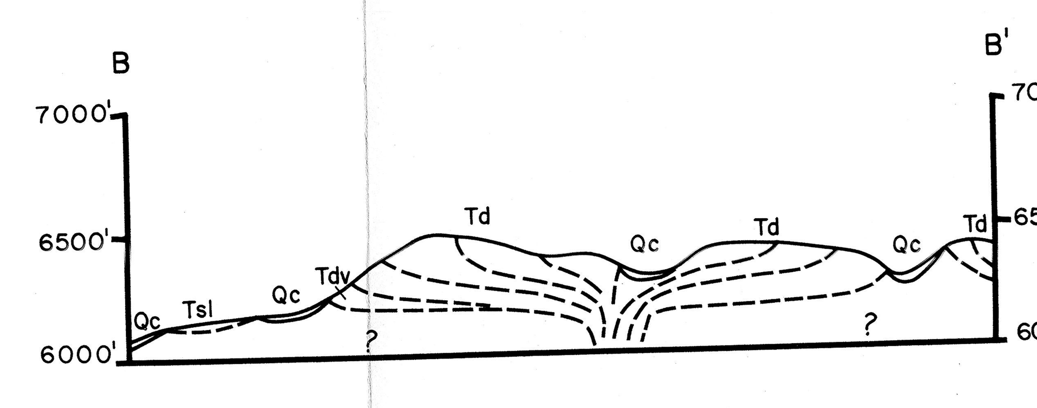
Normal faults, dashed where approximately located
D represents downthrown side

40
Strike and dip of bedding

60
Inclined Vertical Horizontal
Strike and dip of flow foliations







V. E. = 2X

GEOLOGY BY: E. MATTHEW HARE

GEOLOGIC MAP OF AREA BETWEEN DEATH CREEK AND DAIRY VALLEY CREEK (BOX ELDER CO.), UTAH.