Geology of the Wildcat Hills, Utah

Ronald C. Howes
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GEOLOGY OF THE WILDCAT HILLS, UTAH

by

Ronald C. Howes

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

MASTER OF SCIENCE

in

GEOLOGY

Approved:

Major Professor

Committee Member

Committee Member

Dean of Graduate Studies

UTAH STATE UNIVERSITY
Logan, Utah

1972
ACKNOWLEDGMENTS

The writer is especially grateful to Dr. Donald R. Olsen for his helpful suggestions during the field work and petrographic work, and for his advice in the preparation of this thesis. Gratitude is also extended to Dr. Clyde T. Hardy, Dr. Raymond L. Kerns, Jr., Dr. Robert Q. Oaks, Jr., and Dr. J. Stewart Williams for their advice and instruction.

The writer is especially appreciative of his wife, Patricia, for typing the first drafts, for her helpful suggestions, and her encouragement.

Ronald C. Howes
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>Location and General Geology</td>
<td>1</td>
</tr>
<tr>
<td>Purpose and Scope</td>
<td>1</td>
</tr>
<tr>
<td>Previous Work</td>
<td>3</td>
</tr>
<tr>
<td>IGNEOUS ROCKS</td>
<td>4</td>
</tr>
<tr>
<td>Basalt</td>
<td>4</td>
</tr>
<tr>
<td>Occurrence</td>
<td>4</td>
</tr>
<tr>
<td>Field description</td>
<td>4</td>
</tr>
<tr>
<td>Petrography</td>
<td>5</td>
</tr>
<tr>
<td>Welded Tuff</td>
<td>8</td>
</tr>
<tr>
<td>Occurrence</td>
<td>8</td>
</tr>
<tr>
<td>Field description</td>
<td>8</td>
</tr>
<tr>
<td>Petrography</td>
<td>9</td>
</tr>
<tr>
<td>Rhyolite</td>
<td>11</td>
</tr>
<tr>
<td>Occurrence</td>
<td>11</td>
</tr>
<tr>
<td>Field description</td>
<td>11</td>
</tr>
<tr>
<td>Petrography</td>
<td>13</td>
</tr>
<tr>
<td>Perlite</td>
<td>16</td>
</tr>
<tr>
<td>Occurrence</td>
<td>16</td>
</tr>
<tr>
<td>Field description</td>
<td>16</td>
</tr>
<tr>
<td>Petrography</td>
<td>17</td>
</tr>
<tr>
<td>Andesite</td>
<td>19</td>
</tr>
<tr>
<td>Occurrence</td>
<td>19</td>
</tr>
<tr>
<td>Field description</td>
<td>19</td>
</tr>
<tr>
<td>Petrography</td>
<td>20</td>
</tr>
<tr>
<td>SEDIMENTARY ROCKS</td>
<td>22</td>
</tr>
<tr>
<td>Oquirrh Formation</td>
<td>22</td>
</tr>
<tr>
<td>Occurrence</td>
<td>22</td>
</tr>
<tr>
<td>Field description</td>
<td>22</td>
</tr>
<tr>
<td>Petrography</td>
<td>23</td>
</tr>
<tr>
<td>Section</td>
<td>Page</td>
</tr>
<tr>
<td>----------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>Lake Bonneville Group</td>
<td>25</td>
</tr>
<tr>
<td>Occurrence</td>
<td>25</td>
</tr>
<tr>
<td>Description</td>
<td>25</td>
</tr>
<tr>
<td>Lake Bonneville shorelines</td>
<td>26</td>
</tr>
<tr>
<td>GEOLOGIC STRUCTURES</td>
<td>28</td>
</tr>
<tr>
<td>Faults</td>
<td>28</td>
</tr>
<tr>
<td>Range and Basin faults</td>
<td>28</td>
</tr>
<tr>
<td>Caldera faults</td>
<td>29</td>
</tr>
<tr>
<td>Volcanic Structures</td>
<td>30</td>
</tr>
<tr>
<td>Rhyolite and perlite vents</td>
<td>32</td>
</tr>
<tr>
<td>Perlite dikes</td>
<td>33</td>
</tr>
<tr>
<td>Andesite vents and diatremes</td>
<td>33</td>
</tr>
<tr>
<td>Flow structures</td>
<td>37</td>
</tr>
<tr>
<td>GEOLOGIC HISTORY</td>
<td>38</td>
</tr>
<tr>
<td>Regional Setting</td>
<td>38</td>
</tr>
<tr>
<td>Structural and Igneous Events</td>
<td>38</td>
</tr>
<tr>
<td>Lake Bonneville</td>
<td>41</td>
</tr>
<tr>
<td>LITERATURE CITED</td>
<td>42</td>
</tr>
</tbody>
</table>
LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Index map</td>
<td>2</td>
</tr>
<tr>
<td>2. Basalt inclusion in rhyolite. The inclusion is located in the rhyolite outcrop in the southern portion of Sec. 24, T. 13 N., R. 11 W.</td>
<td>6</td>
</tr>
<tr>
<td>3. Differential weathering of rhyolite. View is to the north on the southern portion of the rhyolite outcrop in the southern part of Sec. 24, T. 13 N., R. 11 W.</td>
<td>12</td>
</tr>
<tr>
<td>4. Large lithophysae in rhyolite. The outcrop is located in the northwest corner of Sec. 30, T. 13 N., R. 10 W.</td>
<td>14</td>
</tr>
<tr>
<td>5. Flow banding and lithophysae in rhyolite. The outcrop is located in the northwest corner of Sec. 30, T. 13 N., R. 10 W.</td>
<td>14</td>
</tr>
<tr>
<td>6. Alignment of obsidian pellets parallel to flow banding in an interbedded rhyolite-perlite unit. The outcrop is located in the northwestern portion of Sec. 30, T. 13 N., R. 10 W.</td>
<td>18</td>
</tr>
<tr>
<td>7. Silicified breccia of Oquirrh Formation. View is to the northeast in the southwestern portion of Sec. 22, T. 13 N., R. 10 W.</td>
<td>24</td>
</tr>
<tr>
<td>8. Columnar jointing in a compound basalt neck. View is to the southwest. The neck is located in the northwest portion of Sec. 31, T. 13 N., R. 10 W.</td>
<td>31</td>
</tr>
<tr>
<td>9. Diatreme in andesite. The diatreme is located in the southwestern portion of Sec. 17, T. 13 N., R. 10 W.</td>
<td>35</td>
</tr>
<tr>
<td>10. Rotated blocks and fragments of andesite in diatreme</td>
<td>35</td>
</tr>
</tbody>
</table>

LIST OF PLATES

<table>
<thead>
<tr>
<th>Plate</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Geologic map of the Wildcat Hills</td>
<td>pocket</td>
</tr>
<tr>
<td>2. Flow banding around rhyolite and perlite vents</td>
<td>pocket</td>
</tr>
</tbody>
</table>
ABSTRACT

Geology of the Wildcat Hills, Utah

by

Ronald C. Howes, Master of Science

Utah State University, 1972

Major Professor: Dr. Donald R. Olsen
Department: Geology

The Wildcat Hills, located in Curlew Valley of northwestern Utah, are composed of a series of late Tertiary extrusive and dike rocks. Five volcanic rock types have been identified: an andesite, a rhyolite, a perlite, a basalt, and a welded tuff. Hydration of obsidian pellets contained in the flows has produced some of the perlite. Diatremes in the andesite attest to the high-volatile content and the explosive extrusion of some of the lavas. A compound basalt neck indicates that basalt was extruded at the Wildcat Hills and is not an erosional remnant of the basalt flow from the base of the Raft River Mountains which lie west of the study area.

The basalt was extruded during the late Tertiary. Initial extrusion was probably along early Basin and Range faults. The welded tuff was extruded next and was followed by the extrusion of the rhyolite after which caldera subsidence was initiated and the remaining acidic magma was injected into the fractures to form a complex of short ring dikes of perlite. After the formation of the perlite dikes and perhaps concurrently with continued caldera subsidence, a magma of andesitic composition was extruded along caldera faults and possibly Basin and Range faults. Following extrusion of the magmas, the erosive processes
began lowering the Wildcat Hills. More recently, Pleistocene Lake Bonneville was the principal agent of erosion and deposition, forming prominent terraces along the hills.
INTRODUCTION

Location and General Geology

The area of study was limited to the Wildcat Hills, which cover an area of 48 square miles (Figure 1), in Curlew Valley in northwestern Utah. Curlew Valley is situated between the Raft River Mountains to the west and the Summer Ranch Mountains to the east. The northern boundary of the mapped area is about 7 miles south of U.S. Highway 30 S, and 22 miles southwest of Snowville, Utah. All parts of the Wildcat Hills are accessible by dirt roads and trails which criss-cross the area.

The hills consist of late Tertiary basalt, andesite, rhyolite, perlite, and welded tuff. The area is presumably underlain by thick Paleozoic rocks such as the Pennsylvanian Oquirrh Formation which crops out at the south end of the hills. All of the lowland areas are covered with Quaternary lake sediments and alluvium. Toward the east, Tertiary basalt crops out in the Cedar Hills, and to the west and southwest are numerous basalt outcrops of similar age located between the Raft River and Hogup Mountains.

Purpose and Scope

The purposes of this study were to map and explain the geology of the Wildcat Hills, to locate centers of extrusion of the lavas, where possible, and to describe the various rock types, the structures, and the geologic history of the area. It is hoped that a better knowledge
Figure 1. Index map.
of the geology of the hills will contribute to a better understanding of the regional geology.

Field work was done during the summer and fall of 1970. The petrographic and x-ray examinations were completed in the winter of 1970-71. All field mapping was plotted on vertical aerial photographs at a scale of approximately 1:20,000 and with a vertical exaggeration of 2.67. The geologic map was produced from a mosaic of these photographs by tracing mapped contacts and structural details on a transparent acetate overlay. The scale was subsequently reduced to 1:12,000 by the use of an opaque enlarger. All flow thicknesses were measured with a steel tape and Brunton compass. Textures and microflow features were measured with a 6-inch rule divided into tenths of an inch.

Samples were collected from outcrops, numbered, and the location plotted on the aerial photographs. Thin sections were mounted in epoxy and then ground to a thickness of 0.03 mm. X-ray diffraction was used in identifying those minerals which could not positively be identified by using the petrographic microscope.

**Previous Work**

Essentially no previous work has been done in the area covered in this thesis. Small-scale mapping of the Wildcat Hills, 1:250,000, is shown on the Geological Map of Northwestern Utah (Stokes, 1963). Geologic mapping was done east of the hills in the North Promontory Mountains and Hansel Valley by Adams (1962). West of the study area, Felix (1956) mapped the eastern part of the Raft River Mountains.
IGNEOUS ROCKS

Basalt

Occurrence

The basalt crops out on the south edge of the Wildcat Hills south of the rhyolite and perlite and north of the Oquirrh Formation. The basalt occurs in the southern part of the mapped area with the major outcrop being located in Secs. 30 and 31, T. 13 N., R. 10 W. The basalt covers an area 1 mile long north to south and 0.7 mile wide. A smaller outcrop of basalt is located just south of the larger outcrop. The basalt is as thick as 277 feet.

Field description

The basalt ranges in color from reddish brown in the upper scoriaceous part of the flows to a dark gray to black in the lower parts of the flows. Both fresh and weathered surfaces have about the same color although at times a grayish-white film of calcium carbonate from weathering gives the appearance of a slightly lighter color. Flow banding is not apparent megascopically in the basalt. Commonly the basalt is vesicular. The vesicles are, in part, filled by calcite. Inclusions of calcarenite, in appearance similar to the Oquirrh Formation, which crops out to the south, are not uncommon. The only phenocrysts noted in hand specimen are plagioclase. Columnar jointing is noted in the main outcrop and is present in the entirety of a compound basalt neck of a smaller outcrop to the south. The columns have an average thickness of about 18 inches, but are smaller in the central part of the neck.
Petrography

The basalts have an intersertal texture. They are composed of plagioclase, glass, augite, olivine, and magnetite. The plagioclase is in the labradorite range (An₅₅⁻₇₀). Crystals range from less than 0.01 to 0.09 inch in length. Labradorite makes up about 55 percent of the basalt, glass 15 percent, augite 5 percent, magnetite 10 percent, olivine less than 1 percent, and vesicles about 15 percent. Calcite commonly fills the vesicles. Growth rings in the calcite make the amygdales appear much like large oolites or pisolites. The calcite was derived from either the weathering of the labradorite, or from Lake Bonneville, or from deuteric solutions. Some magnetite is partially altered to hematite. The magnetite ranges from euhedral to subhedral. Occurrences were noted where the plagioclase penetrated the augite, evidencing that the augite crystalized after the plagioclase.

Thin sections were made from a basalt outcrop 6 miles west of the study area and from a flow exposed in a road cut on Highway 30, north of the study area. The major difference between these basalts and those of the study area is the quantity of olivine phenocrysts, which makes up less than 1 percent of the basalt of the Wildcat Hills, 2 percent in the basalt along Highway 30, and 5 percent in the basalt from the western flow.

The mineralogical composition of basalt inclusions in the rhyolite (Figure 2) is similar to that of the basalt outcrops in the study area. However, there is a larger percentage of glass in the inclusions; 45 percent, as compared to 15 percent in the basalt outcrops. One inclusion of quartz in a basalt xenolith was surrounded by glass. If this
Figure 2. Basalt inclusion in rhyolite. The inclusion is located in the rhyolite outcrop in the southern portion of Sec. 24, T. 13 N., R. 11 W.
basalt is of the same origin as the basalt outcrops, the quartz inclusion is not difficult to explain since the basalt was ejected through the Oquirrh Formation in this area. An interesting glomeroporphyritic texture occurs in one basalt inclusion. The groundmass is composed of plagioclase and glass but throughout the rock larger plagioclase crystals occur in isolated groups with from four to nine plagioclase crystals up to 1 mm in length radiating from a common center. Possibly this texture developed in response to two different viscosities in the magma during crystallization. The clustered plagioclase phenocrysts grew at localized centers of crystallization in the magma during the initial period of cooling under conditions of high mobility due to high-volatile content and high temperature. The smaller plagioclase crystals possibly crystallized at a later time under conditions of lower mobility caused by both lower temperatures and volatile content. The absence of any intermediate-sized crystal suggests a sudden change in the viscosity, perhaps due to a sudden loss of the volatiles.

Magnetite is highly concentrated in comparison to pyroxene. Bowen has stated that magnetite is one of the first minerals to crystallize from a melt (Bowen, 1928, p. 59). Either the iron has been selectively enriched over magnesium by reaction series crystallization early in the history of the magma and occurs as magnetite in the remaining lava, or the original magma was rich in iron, as appears to be the case with the Tertiary dikes near Preston, Idaho, according to Parry D. Willard.
Welded Tuff

Occurrence

Welded tuff crops out only in one location in the Wildcat Hills. It occurs in the west-central part of the mapped area in Secs. 18 and 19, T. 13 N., R. 9 W., and covers an area 0.8 mile long east to west and 0.7 mile wide. It is in contact with rhyolite on the east and with lake sediments elsewhere. The welded tuff appears in Lake Bonneville-cut terraces and because of this the total thickness is not known, but it must be at least 45 feet thick.

The center of the eruption of the ash flow is assumed to have been up slope from the exposure of the welded tuff at or near vent number 2 in the northeast corner of Sec. 19, T. 14 N., R. 10 W. Probably the conditions of ejection were much like those described by Williams (1957) in which flowing avalanches were initiated by low-pressure upwelling of effervescent magma. As Fisher (1966, p. 128) points out, such glowing avalanches commonly develop the textures and structures of welded tuff deposits. The issuance of an ash-flow tuff followed by rhyolitic lava from the same vent is perhaps explained by a decrease in volatile content. Similar cases have been recorded in which the ejection of tuff has been followed by ejection of rhyolitic lava (Robinson, 1913, pp. 43-49).

Field description

The welded tuff in the study area is the only unit to have apparently been formed by a nuee ardente or ash-flow type of phenomenon. In this paper the following definition of welded tuff will be used:
Welded tuff: a rock or rock body in which the vitric particles have some degree of cohesion because they were hot and viscous at the time of their emplacement. (Peterson, 1970, p. 67)

Peterson notes that such eruptions consist of an overriding cloud of gas and dust and a "basal avalanche." It is in the basal flow that the bulk of the pyroclastic material is transported and from which deposition takes place.

Through tracing of a preferred orientation of microscopic and megascopic components due to flow lineation, it has been shown that the flow direction of an ash-flow tuff can be determined (Elston and Smith, 1970, pp. 3398-3406). However, the welded tuff is poorly exposed in the Wildcat Hills, being exposed predominantly along an old shore line where few of the blocks are in place. Thus, it is not possible to determine a flow direction.

The welded tuff is light gray in color on both weathered and fresh surfaces. The degree of welding is variable throughout the rock unit. In some cases, glass shards are visible in hand specimen, while in others welding has taken place to the extent that no shards are visible either megascopically or microscopically. When visible, these shards are small, usually with a length less than 0.1 inch, which is three to six times the diameter. The shards have essentially the same gray color of the rock unit. Little zoning, gradation, or flow lineation were noted in the outcrops, and the bulk of the information regarding the welded-tuff characteristics has come from petrographic study.

**Petrography**

The welded tuffs are composed of more than 99 percent glass and less than 1 percent of quartz and potassium feldspar. In some samples,
there is virtually no retention of the tuff structure; nevertheless, perlitic fractures and embryonic spherulites are common. In other samples, glass shards are visible and perlitic fracturing and spherulites are uncommon. Also in the latter cases it is common to find short, discontinuous, darker-colored bands of slightly more glassy material oriented parallel to the bedding. Evidently these darker bands are due to higher degrees of welding than in the surrounding tuff. It has been observed that during the process of welding pumice darkens, and in strongly welded zones can be completely black (Ross and Smith, 1961, p. 24). Such zones of maximum welding have been observed in the ash-flow tuffs at Valles Mountain, New Mexico, where the position of maximum welding is believed to be related to the position of maximum load (Ross and Smith, 1961, p. 47). Such a condition was not noted in the Wildcat Hills.

Short, discontinuous flow lines, which are locally parallel, are the only vague remnant of tuff-flow structure left. Ross and Smith (1961, p. 60) show a photomicrograph of a welded tuff with similar discontinuous lines, and although they do not state what these lines represent, they appear to be flow lines. In some layers little welding has taken place and glass shards are visible megascopically while in others the tuff is almost glassy. In none of the sections is any devitrification observed, and the glass shards, where visible, are nearly parallel.
Rhyolite

Occurrence

Isolated rhyolite outcrops occur in the central part of the Wildcat Hills principally in Secs. 19 and 20, T. 13 N., R. 9 W., and Sec. 24, T. 13 N., R. 10 W., over an area 2.5 miles long in an east to west direction and 1.5 miles wide. The rhyolite is commonly in contact with perlite, but in one outcrop it is in contact with welded tuff. Rhyolite is the predominant rock around all vents with the exception of vent number 5. The thickest rhyolite outcrop, which is due south of vent number 1, is 293 feet thick.

Field description

The rhyolite flows range in color from a grayish pink to a light gray on weathered surfaces. The color varies according to the amount and coloration of the spherulites. Fresh surfaces have approximately the same color range but show a sharper delineation of flow banding. Flow banding is not well displayed on weathered surfaces. The interior of rhyolite blocks weathers more rapidly than the exterior, leaving a sort of shell-type structure (Figure 3). The differential weathering occurs because the outside, having cooled much faster is quite glassy and impervious, while the interior is quite porous and affords easier access for water. Phenocrysts visible in hand specimen are almost invariably quartz. With the exception of the quartz, phenocrysts are lacking and make up far less than 1 percent of the rock. Obsidian pellets are very rare in the rhyolite, in contrast to the perlite, in which they are common. Occasionally basalt inclusions are found in the rhyolite.
Figure 3. Differential weathering of rhyolite. View is to the north on the southern portion of the rhyolite outcrop in the southern part of Sec. 24, T. 13 N., R. 11 W.
Spherulites, amygdales, and lithophysae are common in the rhyolite (Figure 4). Amygdales and lithophysae are both highly variable in size and occurrence. Lithophysae range from less than 1 inch up to 8 inches in diameter and amygdales from less than 1 inch to 4 inches in diameter. Their occurrence and size is a function of the volatile content of the lava from which they cooled (Johannsen, 1932, p. 20). Some of the rhyolite flows contain no lithophysae or amygdales, while in others they constitute as much as 60 percent of the rock. The rather random occurrence of the spherulites is probably related to differences in volatile content and viscosity of the lava from point to point in a flow, and with differences in volatiles, the viscosity, and rates of cooling of individual flows. They occur as often near the bottom of flows as they do near the top. Very commonly the lithophysae and amygdales are flattened parallel to the flow direction with the diameter parallel to the plane of flow two to five times the diameter perpendicular to the flow plane.

The occurrence of flow banding is fairly common in the rhyolite (Figure 5), with individual interband thickness ranging from less than 0.1 inch up to greater than 2 feet. The color of the individual bands ranges from pink to brown through gray. In some instances the flow banding trends uncontorted for tens of feet in distance while in other cases it is extremely contorted, turning back upon itself 180 degrees several times within a distance of less than 1 foot.

**Petrography**

In thin section the rhyolite is seen to consist of tridymite, potassium feldspar, mostly sanidine, and oligoclase phenocrysts in a
Figure 4. Large lithophysae in rhyolite. The outcrop is located in the northwest corner of Sec. 30, T. 13 N., R. 10 W.

Figure 5. Flow banding and lithophysae in rhyolite. The outcrop is located in the northwest corner of Sec. 30, T. 13 N., R. 10 W.
glassy to aphanitic matrix with minor hematite from the alteration of magnetite. The phenocrysts range in size from 0.01 to 0.07 inch. Spherulites are present with diameters to 8 inches. Amygdales of tridymite are also present. Boyd (1961, p. 392) noted in the rhyolite plateau of Yellowstone Park that the dominant silica mineral in the groundmass of the unaltered rhyolite is tridymite.

None of the devitrification characteristics of ash-flow tuffs described by Ross and Smith (1961, p. 26) have been seen in any of the thin sections of the rhyolite. Many of the amygdales are elongate in approximately the same direction, undoubtedly due to continued flowage while semimolten. The same mechanism has been described for the Columbia River basalt in which vesicles higher up in the flow are flattened parallel with the base of the flow (Waters, 1960, p. 360).

The presence of numerous spherulites, which are composed predominantly of tridymite and range in size from less than 0.01 inch to 8.0 inches, does not necessarily rule out an ash-flow mechanism for deposition because, according to Ross and Smith (1961, p. 27), spherulites, although less common than might be expected, may form in welded tuffs. However, they do point out that if flow banding or any linear element other than horizontal jointing is continuous for more than a couple of feet, this lessens the probability of the ash-flow type of deposition. In the Wildcat Hills rhyolite flow banding is common and continuous for tens of feet. Glass shards are not present in the rhyolite and no post-deposited devitrification, characteristic of ash-flow tuffs, has been noted. It is thus apparent that the rhyolite was deposited as a lava flow and not by an ash-flow mechanism as was the welded tuff.
Grooves and ridges in the rhyolite and perlite are occasionally seen on shear surfaces. These are composed of, or coated with, a thin veneer which was identified by x-ray defraction as being predominantly plagioclase. A similar occurrence has been described by Christiansen and Lipman (1966, p. 678) at Forty Mile Canyon, Nevada. They explain these markings as rows of spherulites or phenocrysts aligned parallel to foliation. In this case, the markings may be aligned rows of embryonic spherulites coating shear surfaces in the flows.

**Perlite**

**Occurrence**

The perlite is the most widely distributed of all the igneous rocks in the Wildcat Hills. It covers an area of about 2.5 miles long in an east to west direction and 1.5 miles wide. It crops out as dikes in Secs. 11, 12, 13, and 14, T. 13 N., R. 10 W., in the northwest corner of the Wildcat Hills. It also crops out as flows and dikes in Secs. 23 and 24, T. 13 N., R. 10 W., and in Secs. 17, 18, 19, 20, and 30, T. 13 N., R. 9 W., in the central part of the Wildcat Hills.

**Field description**

The perlite is variable in color, ranging from grayish olive through grayish-blue-green to a dark gray. The grayish blue-green color is by far the most prominent. Weathered and fresh surfaces have about the same hues.

Flow banding occurs quite commonly, but is more prominent in the perlite occurring in the dike structures than in the perlite occurring in flows. Flow banding is accentuated by parallel layers of semiround
obsidian pellets (Figure 6). The pellets have diameters ranging from less than 0.1 inch to 0.4 inch.

Spherulites, amygdales, and lithophysae are also found in the perlite, and the occurrences are quite similar to those in the rhyolite. They are commonly flattened parallel to the flow direction. Amygdales range in diameter from 0.1 inch to 4.0 inches while lithophysae vary from 0.1 inch up to as much as 11.5 inches in diameter. Generally, the more amygdales, lithophysae, spherulites, or obsidian pellets within perfect examples, are found throughout the perlite. Most commonly, the obsidian pellets are found surrounded by a rim of glass with this perlitic fracture, suggesting that the pellet is the unfractured core of a perlite "kernel."

Perlite and rhyolite, in general, have the same chemical composition, except that perlite contains more water than rhyolite. The essential differences between the two rocks are the more glassy texture and the distinctive perlitic fracture in the perlite. Also, in this instance, the perlite contains obsidian pellets which the rhyolite usually lacks.

**Petrography**

The perlite is composed of about 98 percent glass and about 2 percent potash feldspar phenocrysts. The perlitic fracture is extensive throughout the glass. Usually obsidian pellets in the perlite are surrounded by a concentrically patterned perlitic fracture. Ross and Smith (1955, p. 1077), in a study of water and other volatiles in volcanic glasses, found that obsidian contains only a few tenths of 1 percent of water while perlite contains from 2 to 5 percent. It was also noted that a sharp contact exists between the perlite and obsidian. Because of the
Figure 6. Alignment of obsidian pellets parallel to flow banding in an interbedded rhyolite-perlite unit. The outcrop is located in the northwestern portion of Sec. 30, T. 13 N., R. 10 W.
differences in water content, and the sharp contact between the perlite and obsidian, Ross and Smith (1955, p. 1080) concluded that perlite has formed through the hydration of obsidian after emplacement. This explanation fits the perlite at Wildcat Hills studied in thin section quite well, since a sharp boundary does exist between the obsidian and perlite. The perlite which lacks the obsidian pellets has probably been completely hydrated. The sequences of interbanded rhyolite and perlite can be explained by the occurrence of bands of hydrated obsidian in the flows.

Andesite

Occurrence

The andesite crops out only in the northern portion of the Wildcat Hills, principally in Secs. 5, 8, 9, 16, 17, and 22, T. 14 N., R. 9 W., and covers an area 3 miles long, northwest to southeast, and 2 miles wide. The thickest section of andesite, 189 feet thick, is located in Sec. 16, T. 14 N., R. 9 W. It thins to zero toward the north and south.

Field description

The andesite flows make up the largest single rock unit in the Wildcat Hills. On a fresh surface the color ranges from a medium gray to a medium dark gray. Weathered surfaces often have a chalky-white film coating of CaCO₃ which may have resulted from the weathering of the plagioclases. Weathered surfaces are medium gray. In four isolated occurrences the andesite displays a prominent red-brown band on both fresh and weathered surfaces due to the presence of a dark red-brown glass.
Flow banding is readily apparent only in the medium-gray andesite containing medium- to dark-gray bands. Possibly flow banding in the medium-dark gray andesite is masked because the rock is the same color as the banding. At times a reddish-brown flow banding is noted in the medium-gray andesite. Flow banding, where it is visible, is fairly uncontorted and quite evenly spaced. The interband spacing ranges from less than 0.1 inch in some outcrops to more than 3 inches in others. All phenocrysts noted are plagioclase (An$_{30-50}$). Some are as much as 0.3 inch long measured along the c-axis. No quartz phenocrysts are noted. No obsidian pellets are found in the andesite.

**Petrography**

Two distinct types of andesite are noted in thin section, one with about 60 percent glass, and one with about 90 percent glass. The principal andesite, or the more abundant rock, has a hyaloophitic texture with glass comprising about 60 percent of the rock. The balance of the rock is largely plagioclase, augite, and magnetite. The plagioclase, determined from the extinction angle on the albite twins by the Michel-Levy method (Heinrich, 1965, p. 364) is andesine (An$_{48-50}$). In some of the thin sections, augite phenocrysts comprise as much as 8 percent of the rock and magnetite about 2 percent while others are devoid of augite and contain as much as 15 percent magnetite. In some samples the magnetite is altered to hematite. Calcium carbonate is sometimes found as a fracture filling. The calcium carbonate may have resulted from weathering of the plagioclase with subsequent deposition of the carbonate in fractures or from Lake Bonneville water infiltrating the rock. Flow banding is expressed as zones of medium dark-gray glass parallel to zones of
medium dark-gray glass parallel to zones of medium-gray glass. The plagioclase crystals in the flow banding are orientated with the long axis parallel to the flow direction.

A particular texture is noted in some of the plagioclase phenocrysts. The plagioclase contains irregular elongate to rounded inclusions of light-brown glass throughout the crystal but apparently more common on cleavage planes. These glass inclusions seem to be the result of partial melting of early formed crystals or of an older rock of which the plagioclase was a constituent. In some cases crystallites are abundant in the glass.

The second type of andesite is noticeably different in appearance, having reddish-brown color zones within light- to dark-gray zones. In some instances the zones with the reddish-brown color make up the bulk of the hand specimen. The second type of andesite is distinguished from the first by a glass content as high as 90 percent, and by containing both colorless and reddish-brown to yellow glass. Microflow lineation is very distinctive in both glasses but the flow patterns in the two glasses do not match. The red glass locally protrudes into the white glass and into the plagioclase. Apparently the red glass was injected into an earlier rock causing the rock to melt. The plagioclase appears to have been melted, presumably by contact with the dark glass, while the pyroxene was not. Inclusions of a lighter glass are also present in the plagioclase as a result of melting of the plagioclase as it was invaded by the darker glass.

The index of refraction of the dark glass is 1.514 and the colorless glass, 1.519. Both glasses are therefore intermediate in composition (Wahlstrom, 1947, p. 251). Possibly the darker glass contains some trace impurity which causes the darker color.
SEDIMENTARY ROCKS

Oquirrh Formation

Occurrence

One exposure of Oquirrh Formation crops out in the extreme south end of the mapped area in Secs. 5, 6, 7, and 8, T. 13 N., R. 9 W. Other outcrops are located due east of the large basalt outcrop and are located in Secs. 28, 29, 32, and 33, T. 13 N., R. 9 W.

Field description

The maximum exposed thickness of the Pennsylvania-Permian Oquirrh Formation in the Wildcat Hills is 86 feet. It is extremely uniform with no megascopic indication of bedding; however joints parallel the bedding plane. A quartz arenite is the only unit of Oquirrh that is exposed in the Wildcat Hills. Fresh surfaces are medium gray. It weathers light brown to light gray.

Bissell (1959, pp. 93-127) described five members of the Oquirrh Formation based predominantly on fusulinids. Possibly, the Wildcat Hills outcrop is the Cedar Fort Member of the Oquirrh Formation, since this is the only member that is not predominantly limestone. It can only be positively stated that the Wildcat Hills outcrop is not the Hall Canyon Member which is exclusively limestone. Since no fusulinids were found, the only fossils observed being foraminifera found in thin sections, it remains uncertain which member is exposed on the study area.
A silicified breccia (Figure 7) occurs in a lone outcrop in the southwestern corner of Sec. 22, T. 13 N., R. 10 W., in the eastern part of the study area. The breccia was developed along a north-south fault zone.

Individual breccia fragments range in size from 0.1 inch to as much as 3 inches measured along the longest diameter. The fragments, as nearly as can be identified, are limestone, quartz arenite, and possibly siltstone, probably from the Oquirrh Formation. Some of the fragments have been substantially rounded by the silicification process. The silica matrix appears light gray in color both on fresh and weathered surfaces.

In thin section the matrix appears to be finely aphanitic light gray silica containing many small partially assimilated fragments of Oquirrh less than 0.1 inch in diameter. The boundary between the larger fragments and the matrix, although sharper than the boundaries between the matrix and the partially assimilated smaller fragments, is still somewhat vague. All of the fragments have been altered by the silica to the extent that positive identification is impossible. A vague indication of a parallel lineation is present in the matrix. It may represent a zonal or progressive advance of the silification.

Petrography

The Oquirrh exposed in the study area would be classified as a quartz arenite using Folk's classification (Folk, 1968, p. 124). Grains of quartz are semirounded and only moderately well sorted. The rock is composed of 95 percent quartz grains and about 5 percent calcium carbonate cement.
Figure 7. Silicified breccia of Oquirrh Formation. View is to the northeast in the southwestern portion of Sec. 22, T. 13 N., R. 10 W.
Lake Bonneville Group

Occurrence

Lake sediments are found in terrace deposits, but are not limited to terraces and can be found throughout the Wildcat Hills. Alluvium occurs in numerous washes throughout the Wildcat Hills in close association with lacustrine sediments. The Lake Bonneville Group and recent alluvium have not been differentiated in mapping the area.

Description

The Lake Bonneville Group and associated sediments consist predominantly of soil and sands with a few local accumulations of gravel in some washes. Locally, in the hills themselves near perlite outcrops, concentrations of obsidian grains weathered out of the perlite appear in the sediments. Periodic rains are responsible for the transport of the alluvium. No perennial streams exist in this area since the rainfall is only about 10 inches per year (Felix, 1956). Farther away from the hills less and less of the sedimentary material is recognizable as having been derived from the Wildcat Hills. The deposits are predominantly lake-bottom sand, silt, and clay of Lake Bonneville. Locally, wind-blown sand is abundant. It commonly covers the alluvium and lake sediments.

Tufa occurs commonly in the area of study and is found as envelopes around isolated boulders, fault and fracture fillings, deposits on the bottom of ledges or steep outcrops, and cement in slump breccias along Lake Bonneville terraces. The calcium carbonate could have been derived from the weathering of the calcium-rich plagioclases in the lavas and
the calcite cement of the Oquirrh. Another possibility is that the tufa is a normal shoreline deposit from Lake Bonneville; similar cases have been noted around Utah Lake at the south end of the Lake Mountains (Bissell, 1959, p. 127). Most probably both Lake Bonneville and weathering of the plagioclase contributed to the formation of the tufa. The color of fresh and weathered surfaces is a light gray. The tufa is tan, homogeneous calcium carbonate, with no other characteristics than growth banding and an occasional void. Coatings as thick as 11 inches have been observed on some boulders and fracture fillings of tufa as thick as 5 inches have been noted.

**Lake Bonneville shorelines**

Lake Bonneville formed prominent shoreline features in the Wildcat Hills especially in the andesite in Secs. 16, 17, and 21, T. 13 N., R. 10 W., and the southern portions of the rhyolite-perlite outcrops in Secs. 24 and 30, T. 13 N., R. 10 W. The most prominent shoreline can be traced on preliminary United States Geological Survey topographic map of Snowville No. 25-W, Utah, Scale 1:24,000, 1967. The shoreline is between 4,800 and 4,810 feet elevation. Terraces are up to 110 feet wide. Gilbert (1890, p. 128) noted that the Provo-level terraces are far broader than the Bonneville-level terraces. Eardley, Gvodetsky, and Marshall (1957, p. 1167) stated that the Provo terrace is generally prominent and strong and greatly overshadows any minor beaches immediately above or below it. Gilbert (1890, p. 406, 417) calculated the elevation of the Provo shoreline to be 4,871.2 feet at Kelton, which would place the Provo shoreline 61.2 feet above the major shoreline in the Wildcat Hills. The tops of the Wildcat Hills rise up to 5,077 feet.
and any shoreline at 4,871.2 feet would intersect the hills. However, in this area no other shoreline occurs above the 4,810 foot level which is shown on the topographic map. Eardley, Gvodetsky, and Marshall (1957, p. 1167) find that on the average, deposits associated with Provo I standstill occur at an elevation of about 4,800 feet, which would fit nicely with the occurrence in the Wildcat Hills.

The author believes that the main terrace at the Wildcat Hills is probably a Provo-level terrace because it is the major shoreline in this area. Sediments are noted above the Provo level that attest to higher lake elevations, but no major terraces are associated with them.

In one of the gullies on the west side of the rhyolite outcrop area, a cross section is exposed where a unit 15 inches thick of obsidian sand cemented with calcium carbonate overlies a one-foot section of rounded rhyolite cobbles and boulders. This, in turn, overlies more obsidian sand which contains some glass shards. This sediment was evidently deposited by Lake Bonneville and is overlain by 3 to 4 inches of Holocene sediments. The rounded rhyolite boulders attest to the erosive action of the lake during high energy conditions. It is apparent that the ancient lake undercut rhyolite and andesite cliffs, and has rotated many of the larger boulders and blocks from the cliffs.

On the south end of the rhyolite outcrop, a conglomerate of perlite or rhyolite is cemented with calcium carbonate and trends for tens of feet at the same elevation. This apparently formed in a shore environment when the lake was at one of its intermediate levels above the Provo shoreline.
GEOLOGIC STRUCTURES

Faults

Basin and Range faults

Two distinct fault types are noted in the Wildcat Hills. They are a north-to-northeast-trending system of normal faults and an arcuate set of ring-like faults. The former group seems to be related to Basin and Range faulting which began according to different authors, in the Oligocene (Nolan, 1943, p. 183) or the late Pliocene (Gilluly, 1928, p. 1118-1120). Where Basin and Range faults can be traced in outcrop, they are expressed as relatively fresh, clean, and sharp fractures, giving the impression that the latest movement is relatively recent. The most recent movement on the faults caused little measurable displacement, so the most recent fracturing of the volcanic rocks is not the principal movement on the faults, but represents minor movement on older faults. The fault which trends a few degrees east of north in Sec. 24, T. 13 N., R. 10 W., and then turns a few degrees west of north can be traced for over 30 feet as a sharp fracture in the southern rhyolite cliff before being covered. In several places, this sharp fracture is open to a width of as much as 18 inches and is open vertically to a depth of greater than 5 feet before being filled with breccia and gravel. It is the best exposed fault in this area, both on the ground and in aerial photographs.

The easternmost fault on the map is the one along which the silicified breccia formed. Unhealed fractures in the silicified breccia are due to post-silicification movement on the fault. This fault is
aligned with faults north of the area, which Cook (1964) located by gravity surveys. Lineations in the Lake Bonneville Group are seen on the aerial photographs of the area, suggesting recent movements on the fault.

Caldera faults

The pattern of the perlite dike swarm in the northwest corner of the mapped area is indicative of the pattern of faults produced by the subsidence of overlying rock into a partially depleted magma chamber. A small set of perlite dikes in Secs. 18 and 19, T. 14 N., R. 10 W., has evidently followed a fault pattern also related to subsidence. Two of the dikes, the southernmost two, have acted as feeder dikes, and the quantity of material extruded by a single dike exceeds that of any single dike in the northwestern swarm.

An occurrence of perlite along the southern slope of the rhyolite-perlite outcrop area along the southern border of Sec. 24, T. 13 N., R. 10 W., is also related to caldera-subsidence faults. The perlite has pushed up through the fractures, shouldering aside the earlier rhyolite. These structures have also acted as feeder dikes. Extruded perlite dips away from the crest of the fault at steep angles on both sides.

The arcuate shape of the dikes in the northwest suggest caldera subsistence. The curved faults on the southeast and the southwest also suggest the subsidence of the roof rocks into the caldera. The amount of subsidence is nowhere measurable because of similarity of rocks on both sides of dikes or lack of rock exposures near the dikes. The dikes were probably formed by the filling of caldera faults by a silicic magma.
Possibly gravity surveys would reveal dikes that are presently covered and give a more complete ring-dike pattern. The faults that occur in the basalt in Sec. 30, T. 13 N., R. 9 W., as well as the curved faults connecting the three andesite hills in Secs. 20 and 30, T. 13 N., R. 10 W., are also undoubtedly caldera faults.

The two faults cutting the basalt outcrop trend in a more easterly direction than the other faults and lack the sharp features of the faults in the rhyolite. Fault breccia in the basalt and aerial photograph lineations outside the basalt were used in tracing the faults. These faults are here considered to be related to subsidence of the caldera because they trend at such a large angle to the Basin and Range structures.

Volcanic Structures

The small outcrop of basalt located in the northwestern part of Sec. 31, T. 13 N., R. 10 W., due south of the major basalt outcrop of the study area is a unique case in which a compound basaltic neck is exposed. Well-developed columnar jointing radiates away from the center of these necks (Figure 8). As explained by Waters (1960, p. 353), columnar joints develop perpendicular to isothermal surfaces. In this case the isothermal surface was the outer surface of the neck in contact with the enclosing rocks, so a radiating pattern was developed in the columnar jointing. The smaller neck, located in the western half of the larger neck, has pushed up through the larger neck disorienting the earlier columns causing them to point upward toward the center of the neck. Other columnar jointing occurs in a small area in the southern part of the major basalt outcrop, but the jointing in the necks is the best developed in the study area.
Figure 8. Columnar jointing in a compound basalt neck. View is to the southwest. The neck is located in the northwest portion of Sec. 31, T. 13 N., R. 10 W.
Rhyolite and perlite vents

Five rhyolite and perlite vents have been mapped in detail (Plate 2). These five are not necessarily the only vents in the rhyolite-perlite outcrop but no others have been located to date. Other vents may exist also for other rock types of the area. It has been pointed out, for example, that in nuee ardente-type deposits the source vents from which they issued generally have not been identified (Cook, 1957, p.51). Any other evidences for vents located in the study area have been masked by sediments or destroyed by erosion.

The vents are in the northern part of Sec. 19, T. 13 N., R. 10 W., the southern part of Sec. 19, T. 13 N., R. W., the southern part of Sec. 24, T. 13 N., R. 10 W., and the central part of Sec. 19, T. 13 N., R. 10 W. The rock types are predominantly rhyolite with interbedded perlite. The fifth vent, located just northeast of the vent in the southern part of Sec. 24 is in perlite. However, some rhyolite appears on the outer margin of the latter vent area, overlapping the perlite. It would almost appear that the rhyolite had been eroded out of the center of the vent area, leaving only that on the fringes, and the underlying perlite zone. The vent near the southern part of Sec. 19, T. 13 N., R. 10 W., contains considerable perlite as well as rhyolite. However, in the other three cases, rhyolite was clearly the last material that emanated from the vents. The eruptive center in the southern half of Sec. 24, T. 13 N., R. 10 W., differs from the others in that it appears to have originated as a fissure eruption. The trend of the fissure is N. 85° W. Rhyolite dips away steeply on all sides. In all cases vents were located by tracing flow banding up dip. All vents are found in topographically high positions.
Perlite dikes

Perlite dikes are located in the northwestern corner of the mapped area in Secs. 11, 12, 13, and 14, T. 13 N., R. 11 W., and in the north-central portions of the mapped area in Secs. 17, 18, and 19, T. 13 N., R. 10 W. The dikes consist of light-gray perlite with flow banding lineation often accentuated by bands of obsidian pellets oriented parallel to the flow banding. A few small spherulites occur in the perlite. The dip may be either toward or away from the hills.

The longest dike occurs in Sec. 17 and 18, T. 13 N., R. 10 W. This dike is exposed for over 1,400 feet and is as wide as 150 feet in places. The dikes in the northwestern swarm are all considerably smaller than this, the largest being over 600 feet long and 200 feet wide. Some are as small as 50 feet long and less than 20 feet across. Probably the lengths and widths of the exposures are not significant because the exposed dikes are probably erosional remnants of longer, more continuous dikes that are not completely exposed. The only recognizable difference in the dikes is the presence of more obsidian pellets, lithophysae, and amygdales in the dikes in the northwest compared to the other dikes.

Andesite vents and diatremes

Several vents, exclusive of the diatremes, were located in the andesite by tracing the flow banding in those areas where it was visible. The andesite vents have not been noted on the map. The vents are highly brecciated zones from which the flow banding diverges in all directions. In the southeastern part of the andesite outcrops, flow banding is commonly visible. In the northern, western, and southwestern portions flow banding is difficult, if not impossible, to see megascopically in outcrop.
As mentioned previously, some of the andesite is composed predominantly of two colors of glass. The glass-rich samples were taken from isolated occurrences in the west-central part of the andesite outcrop. They were distinctive because of their reddish coloration. Outcrops of three other such glassy andesites occur as three small isolated hills surrounded by rhyolite and perlite in Secs. 17 and 20, T. 13 N., R. 10 W. These small hills may be andesite vents.

Two diatremes in the andesite (Figure 9) attest to the volatile content of the magma and the explosive release of volatiles that at times took place during extrusion. The diatremes are composed of angular to rounded fragments of andesite (Figure 10), some as large as several feet across and others as small as a few tenths of an inch across. Large angular blocks as much as 10 feet across have not been rotated appreciably from their original orientation, as indicated by the flow banding in the blocks compared with that in the andesite surrounding the diatremes. The small fragments, on the other hand, are quite jumbled and rotated. The larger rounded blocks have been noted to occur near the lower exposed levels of the diatremes. Perry (1961, p. 370) explains the rounding effect and the disorientation of the fragments in a volcanic breccia as an effect of the explosive release of volatiles. He says:

... catastrophic break-through of gas to the surface could explain the evidence of comminution, rounding, chaotic mixing, and churning of breccia fragments observed as a late or end stage effect in many pipes. (Perry, 1961, p. 370)

In the larger pipes in the Wildcat Hills there is slumping of the larger blocks from the sides of the pipe toward the center.
Figure 9. Diatreme in andesite. The diatreme is located in the southwestern portion of Sec. 17, T. 13 N., R. 10 W.

Figure 10. Rotated blocks and fragments of andesite in diatreme.
Locke (1926) noted a similar subsidence effect in breccia pipes and concluded that this is a result of a net removal of rock from inside the breccia pipe. He believed this is due to a corrosive effect of early solutions followed by a later period of mineral deposition.

Hack (1942, p. 353) noted in the diatremes of the Hopi Buttes in Arizona that the walls flare outward and dip at an angle of 5 to 40 degrees towards the center indicating that the diatremes are funnel-shaped and narrow downward. He feels that this was the result of an inward collapse of debris from the walls of the pipe followed by upwelling of lava, the deposition of tuff and partial subsidence.

Neither of the two major diatremes extend completely to the surface, coming only as close as about 4 feet from it in present exposures. Evidently the more rapid cooling of the upper part of the flow resulted in a rock that was competent enough to maintain mechanical equilibrium and support or else the upper flows formed after the diatreme. A similar condition called the "topping out" of pipes close to the surface has been reported in the Capote Mine of Cananea (Perry, 1961, p. 370).

Another possibility for the origin of the Wildcat Hills diatremes might be phreatic explosions occurring in or under the andesite flows. Such explosions, which are caused by ground water being converted to steam from the heat of the flows, and which do not expel any essential ejecta, would fit these diatremes. No tuff such as Hack (1942, p. 361) noted in the Hopi Buttes in Arizona was found associated with the Wildcat Hills diatremes.
Flow structures

Flow features in rhyolite have been utilized at Wildcat Hills to locate vents from which flow bands dip radially outward, establish the position of dikes from which the flows dip outward, and to establish the rhyolite as a magmatic flow rather than a welded tuff.

Disorientation of flow bands in closely associated blocks of andesite aid in locating diatremes in the andesite. On a microscopic scale the flow banding is very complex within the andesite unit. Cross-cutting flow directions suggest the mingling of two different andesite magmas, or the melting of one unit by another.

Banding within the perlite units suggests differing degrees of hydration of the perlite. The banding is accentuated by obsidian pellets in less-hydrated bands. Banding in the welded tuff is produced where welding is more complete.

As a general rule, banding is chaotic on a broad scale, as might be expected of flow units in a collapsing caldera with numerous arcuate dikes. Flow bands thus become more useful in the study area to define local features.
GEOLOGIC HISTORY

Regional Setting

In the Paleozoic Era, the Cordilleran miogeosyncline, ranging over Nevada and central Utah, subsided and was filled with the great thickness of sediments that now make up the thick Paleozoic formations such as the Oquirrh Formation, that underlie the Curlew Valley region (Eardley, 1962, p. 37). Following a period of relative quiescence during the Mesozoic, the Laramide orogeny occurred in the Cretaceous and early Tertiary during which time the Paleozoic rocks were folded and faulted. Beginning in the Oligocene, Basin and Range faulting started (Nolan, 1943, p. 185) and has continued to the present. During this period of deformation basalt, perlite, rhyolite, welded tuff, and andesite were ejected through and onto the old Paleozoic rocks, forming the Wildcat Hills. The hills were later eroded below their original heights. Finally, in the Pleistocene, Lake Bonneville covered the area and further eroded the Wildcat Hills.

Structural and Igneous Events

Initial basalt-rhyolite extrusion probably occurred along Basin and Range faults. The history of volcanism in the Wildcat Hills started with the ejection of basalt. This is suggested by basalt layers far under the valley floor and by the fact that several basalt inclusions of composition similar to the basalt outcrops have been found in rhyolite of the area, so the rhyolite was extruded through a basalt zone.
However, since the textures of the inclusions and the flows differ, they are not of necessity the same rock.

At one time the basalt flow from the Raft River Mountains to the west and the Cedar Hills to the east, covered a much larger area and probably extended far out into Curlew Valley. Most of the basalt was eroded prior to the development of Lake Bonneville (Felix, 1956, pp. 91-92). The composition and texture of the basalts in the Raft River Mountains are very similar to that of the Wildcat Hills. Both have intersertal textures, both have about 50 percent labradorite, and augite phenocrysts and magnetite are contained in both. The major difference is in the presence of more magnetite in the Wildcat Hills samples, showing that the magma was more iron-rich, and the presence of more olivine in the Raft River samples. Although it can be seen that the two basalts are generally similar in composition and age, it cannot necessarily be said that the Wildcat Hills basalt originated as flows from the Raft River Mountains or even from the same magma chamber. The presence of the basaltic necks strongly indicate a local source for Wildcat Hills basalt.

Two test wells, Federal No. 1 and Federal No. 2 (Peace, 1956) drilled by the Utah Southern Oil Company in 1954 hit lava flows at 160-205 and 200-215 feet, and at 390-575 feet, which are probably related to, but older than the basalt flows in the area of the Cedar Hills and Wildcat Hills. Anderson (1931, pp. 65-66) gives a Pliocene age for the basalt flows in the Raft River Mountains. Since the basalt flows throughout this area are apparently related to the same general period of igneous activity, the age of the Wildcat Hills basalt is probably Pliocene.
Apparently the welded tuff, and the rhyolite-perlite and andesite flows followed the emplacement of the basalt. During and after the extrusion of the rhyolite lavas, the caldera faults formed. These concentric subsidence faults acted as relief area through which the remainder of the siliceous part of the melt was ejected, forming perlite dikes. The evidence for the siliceous dikes being older than the andesite is not clear-cut, but seemingly it does make sense for the subsidence faulting to have occurred shortly after, if not concurrently with, the ejection of the later portion of the rhyolitic lava and for the last quantities of the siliceous magma and some andesite to be ejected through these faults. The ages of the rhyolite and andesite units relative to one another is somewhat uncertain. The best field evidence is the presence of three small hills of andesite apparently poking through the perlite-rhyolite units. Since these three hills are aligned, the andesite emplacement may have been fault controlled. This fault has the general curvature of a caldera fault, and most probably developed during or after the rhyolite-perlite extrusion. Ejection of the andesite followed the faulting, so the andesite is younger than the rhyolite. Unfortunately, these outcrops have been weathered extensively, and the surrounding rhyolite is eroded and covered by lake sediments to the extent that it is impossible to see any flowage of the rhyolite around these hills as would be expected if they are remnant knobs of andesite surrounded by rhyolite flows. It is equally impossible to see any flowage pattern in the andesite showing it was ejected through the rhyolite. No inclusions of one unit within the other have been found. It appears on the basis of fault control that the andesite ejection followed that of the rhyolite.
Since the larger fault bordering the southern and eastern portion of the hills can be traced through a portion of the andesite outcrop, a late stage of this faulting continued after the andesite was ejected. Weak fracturing, principally joints in the rhyolite, suggests later activity along the Basin and Range faults. Late fault movement is also suggested by lineations shown by aerial photographs to extend into Lake Bonneville Group from known faults in rhyolite and andesite.

Lake Bonneville

Following the late Tertiary expulsion of lavas, the Wildcat Hills were lowered by erosion. In the Quaternary Period, Lake Bonneville then inundated the area (Gilbert, 1890, p. 438). At its highest stage the lake rose 400 to 500 feet over Curlew Valley (Crittenden, 1963, p. E 10). A great amount of erosion in the Wildcat Hills occurred during Lake Bonneville times. Substantial terraces and shorelines were cut in the rhyolite and andesite. Much of the sediment in Curlew Valley in the vicinity of the Wildcat Hills was derived from the hills and distributed by lake currents.

Erosion of the hills since Lake Bonneville receded to the present Great Salt Lake has been principally through the agents of rain wash and flash floods. Wind has been effective, as is seen in the local sand dune areas, but has been of less importance than rain wash.
LITERATURE CITED


