PETROLOGY OF EARLY TERTIARY VOLCANIC ROCKS IN THE IRON SPRINGS DISTRICT UTAH

by

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PETROLOGY OF EARLY TERTIARY VOLCANIC ROCKS IN THE IRON SPRINGS DISTRICT UTAH

INTRODUCTION

Study of the Iron Springs district, by the United States Geological Survey, has been in progress since 1943. Economic interest in the district centers around magnetite-hematite ores that occur as replacement bodies in limestone at the margins of three early Tertiary laccolithic intrusions. The Survey study is intended to provide a comprehensive account of the areal geology, with emphasis on the mechanism of emplacement of the intrusions and the origin of the mineralizing emanations that formed the associated iron ore bodies.

One of the major rock units in the district is a group of volcanics that form the outermost rings of target patterns formed by rocks uparched by the intrusions. The volcanics were evidently spread out on the surface just previous to the emplacement of the intrusions. Because of this time relationship and because the volcanic rocks are closely similar in chemical composition to the intrusive rocks, they have an important bearing on the major problems mentioned above. In addition, the volcanics are of special interest, on their own merit, because they consist mainly of tuffs which exhibit distinctly different types of lithifaction. Some of the tuffs are merely crystal ash which was compacted after deposition while others exhibit various degrees of welding by their own heat at the time of deposition. One such tuff is so completely welded that it is readily mistakable for a flow.

The writer's attention was directed to the problem of the origin of the volcanic rocks by J. H. Mackin during the summer of 1949 when he assisted Mackin in the field. This report is based on study of the field relations, and examination of about one hundred thin sections during the winter of 1949-1950. During the petrologic study particular attention was directed to microtextures and microstructures in an effort to understand the manner of origin of the volcanic rocks.

The writer wishes to thank Mackin for his guidance and assistance throughout the study, and J. D. Barkdale and Howard Coombs for their interest and help in the petrologic study.

GENERAL GEOLOGY

The Iron Springs district is located in the Great Basin just west of the Hurrican Fault zone in southwestern Utah (see Figure 1).

Elevations range from 5400 to 7900 feet. The slopes and tops of the hills and mountains are covered with open growths of Juniper and Desert Pinion; locally thick tangles of Scrub Oak and Mountain Mahogany occur above about 6100 feet. The lower desert areas are sparsely covered by Sage Brush, Greasewood, and other desert plants. Except for the alluvium covered desert basins and talus accumulations at the base of cliffs, exposures are excellent.

The geologic map (Figure 2) and the columnar section (Figure 3) illustrate the relation of the volcanic rocks to the general geology of the district. On the map details of the structure of the sedimentary rocks have been greatly simplified, as have some of the details of post volcanic faulting near the southern border of the area.

Seven 7½' quadrangles, and a report on the Iron Springs district are being prepared by Mackin for the U.S.G.S.

The first geologic event recorded in the district was the deposition of the Jurassic Homestake formation, which grades upward into the "Entrada" formation also of Jurassic age. The

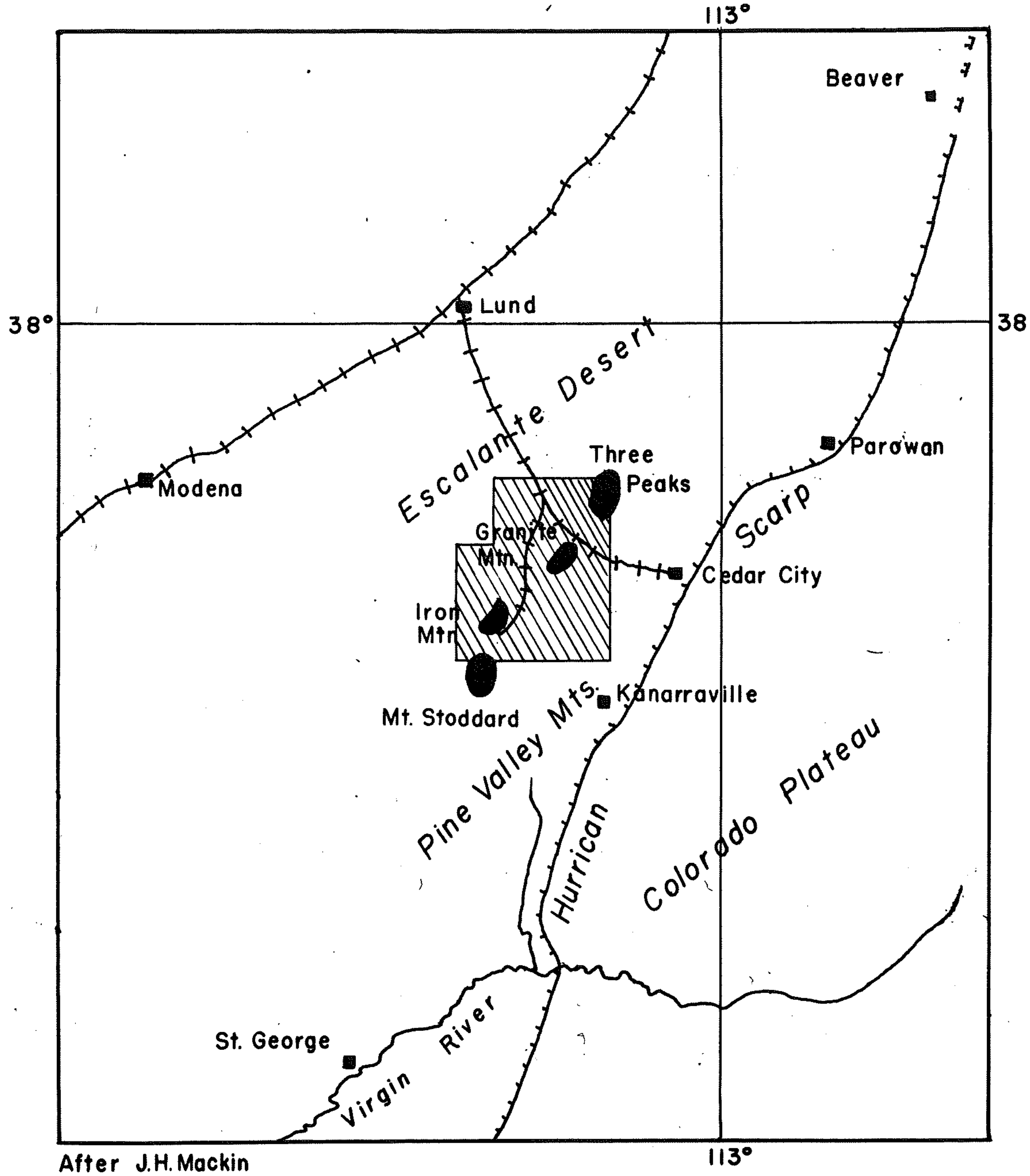

FIGURE 1 INDEX MAP. THE RULED BLOCK SHOWS THE LOCATION OF FIGURE 2

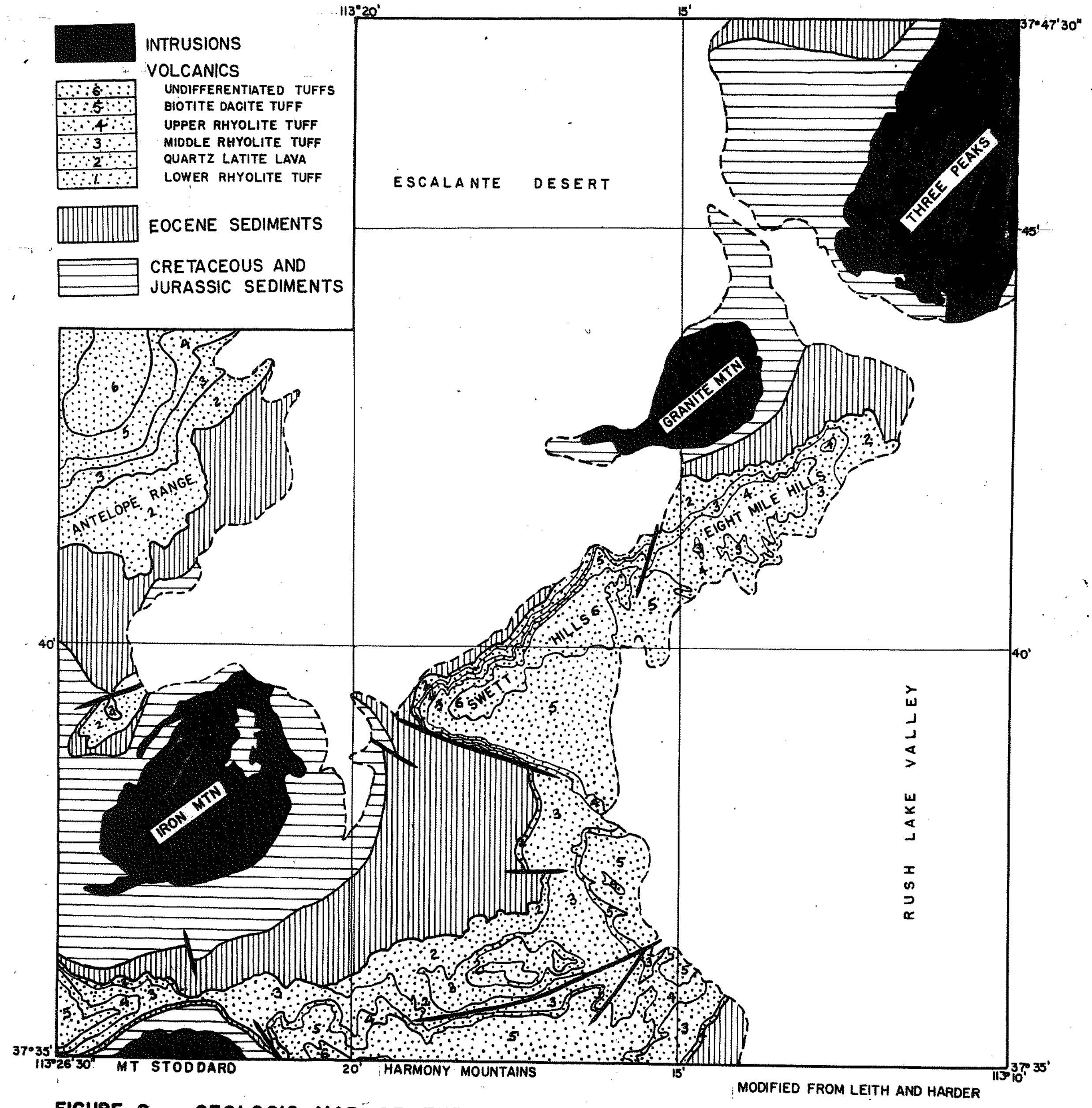

FIGURE 2 GEOLOGIC MAP OF THE IRON SPRINGS DISTRICT

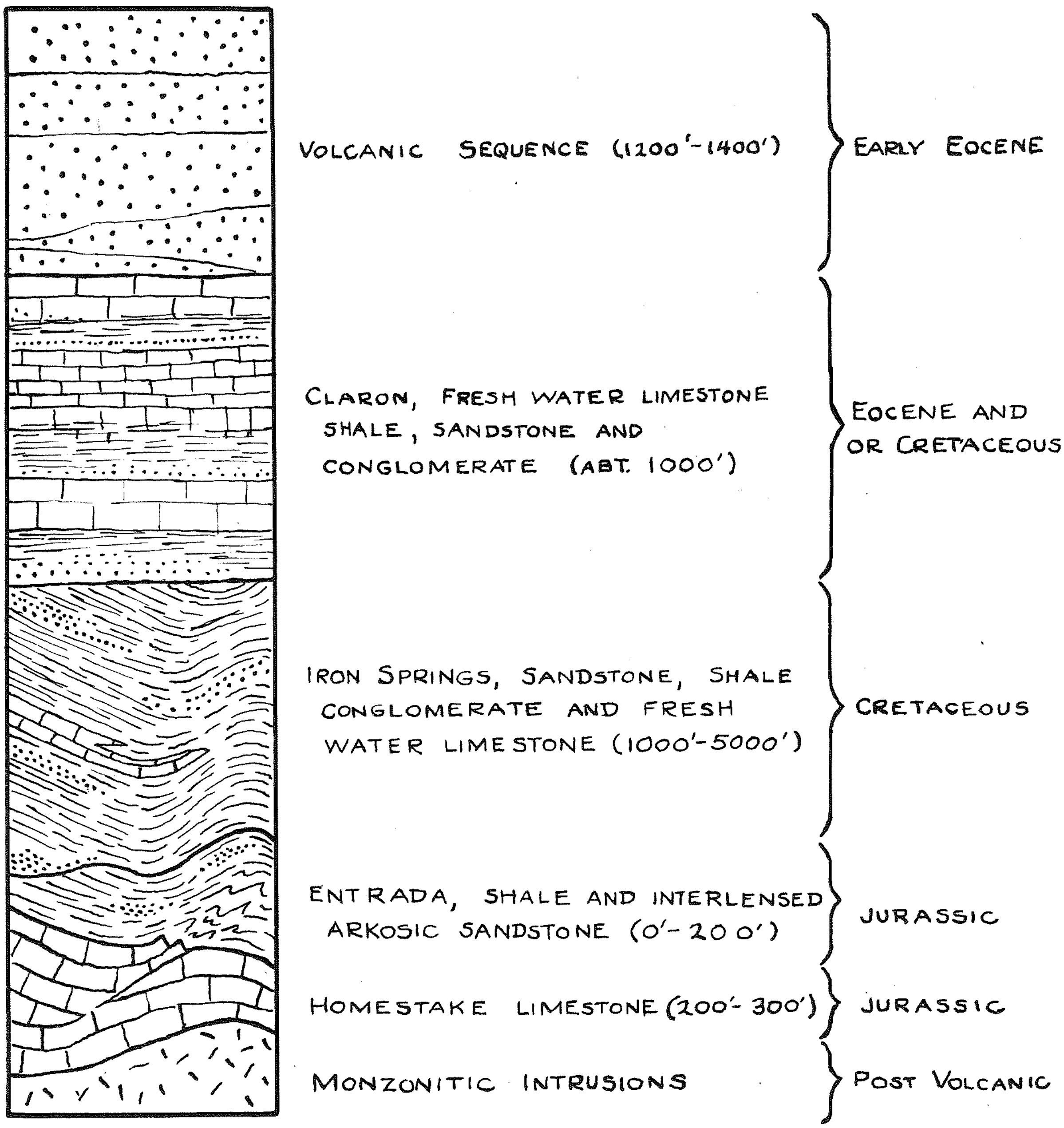

FIGURE 3 GEOLOGIC COLUMN OF THE IRON SPRINGS DISTRICT

Iron Springs formation, of probable Cretaceous age, lies disconformably on an erosion surface cut into the earlier formations.

Following the deposition of the Iron Springs formation there occurred a period of strong deformation confined largely to a narrow belt trending N 30 E thru the district.

The Claron formation overlies the folded and eroded Iron Springs formation unconformably. The Claron is equivalent to the Pink Cliffs Wasatch of the Colorado Plateau and is, therefore, late Cretaceous or early Eocene in age.

Near the end of Claron deposition there occurred a period of intense volcanism during which the sequence which forms the subject of this paper was formed. These volcanic rocks are everywhere conformable on a Claron depositional surface.

Following the volcanic episode laccolithic intrusions were emplaced within the narrow northeasterly trending zone of strong pre-Claron deformation. The intrusions are concordant at the base of the Jurassic Homestake limestone. Locally intrusive faulting has brought the Cretaceous into contact with the intrusions.

At many places around the Three Peaks, Granite Mountain, and Iron Mountain intrusions the Homestake limestone is replaced to form magnetite-hemitite ore bodies. Mackin (1947) has shown that this iron was derived directly from the intrusive rock.

Since the intrusions were emplaced erosion has been active. In general the more easily eroded sedimentary rocks form valleys and lowlands while the intrusive and volcanic rocks form mountainous uplands. All of the rocks of the district are displaced by basin and range faults.

VOLCANIC SEQUENCE

General Statement

Figure 2 illustrates the distribution of the volcanic sequence after deformation and erosion; the volcanics undoubtedly once covered the whole district, and extended for some distance to the south, west, and north.

Table 1 shows the units that make up the volcanic sequence. Numbers at the right correspond with the numerical designation of the volcanics in a reconnaissance report by Leith and Harder (1908, p. 50).

TABLE 1

SUCCESSION OF VOLCANIC UNITS IN THE

IRON SPRINGS DISTRICT

6.	Undifferentiated tuffs	
5.	Biotite Dacite tuff	7
4.	Upper Rhyolite tuff	3&5
3.	Middle Rhyolite tuff	2
2.	Quartz Latite lava	1
1.	Lower Rhyolite tuff	not described by Leith and Harder

Lower Rhyolite Tuff

Distribution

The Lower Rhyolite tuff is best exposed just off the map northwest of the Three Peaks intrusion, where it is 20 to 40 feet thick; reconnaissance indicates that it thickens and becomes coarser northward. The unit is also exposed locally on the northwest end of the Swett Hills and along the east side of the Antelope Range, where the thickness is probably less than 15 feet. Everywhere the Lower Rhyolite tuff is conformable on the Claron. No remnants of this unit or detritus from it are found at this horizon in the southern part of the district. Thus it is probable that the present southward thinning and termination represent its original extent.

Megascopic Description

A typical specimen of the Lower Rhyolite tuff is a light reddish brown color. The groundmass is fine-grained, lusterless, and has the appearance of an unglazed porcelain. Phenocrysts of feldspar and biotite make up thirty to forty percent of the rock volume.

Microscopic Description

Figure 4 is a photomicrograph of a typical specimen. The groundmass is composed entirely of ash sized glass fragments. The glass is speckled with minute magnetite crystals and tiny birefringent microlites probably formed by devitrification. Thus it is believed that it was originally a loose mass of ash which was compressed by overlying volcanic units and lithified by devitrification.

The feldspar phenocrysts are sanidine and andesine-labradorite in about equal quantities. Biotite, although usually fresh, is occasionally altered to magnetite and chlorite along cleavage cracks. Hornblende is completely altered to magnetite and chlorite, its original presence being attested to by euhedral crystal outlines. Quartz occurs only as rare, widely scattered crystals.

FIGURE 4
LOWER RHYOLITE TUFF

Showing vitroclastic structure largely obscured by devitrification. North of Three Peaks. P - plagioclase; S - sanidine; H - magnetite and chlorite from altered hornblende. x 60.

Quartz Latite Lava

Distribution

The Quartz Latite lava unit occurs thruout the district. It varies in thickness from a maximum of about 500 feet to absent in a few small areas. Although the mineralogy is apparently constant thruout, and the appearance is locally uniform, there are marked changes in structure and color from place to place. The variation in appearance, and local thinning and termination suggest that the unit may consist of different flows at different places, but no proof such as the overlapping of one flow upon another has been observed. The unit is conformable upon either the Lower Rhyolite tuff or the Claron sediments. The contact with the lower tuff is perfectly sharp, with less than an inch of contact effect at the top of the underlying tuff. The contact with the uppermost Claron sediments is usually concealed, but is characterized by abundant chert float.

Megascopic Description

The groundmass of the Quartz Latite is hard, dense, and has the appearance of an unglazed porcelain. Thruout the groundmass are scattered phenocrysts, principally feldspar with minor amounts of biotite. Vesicles commonly occur within the unit and are always strongly drawn out by flowage. Variations in the rock are: color, size and abundance of vesicles, amount and kind of vesicle filling, and the local presence of an aa breccia on the top.

A strongly foliated purple phase is found at or near the top of the unit at several places. This phase is strikingly similar to the middle foliated layer of the Upper Rhyolite tuff. (see below). The foliation is due to strongly flattened, light purple lenses, which differ from the lenticules in the Upper Rhyolite in that they are drawn out in addition to being flattened.

Microscopic Description

The photomicrograph, Figure 5 shows the somewhat devitrified groundmass typical of the unit. The nonfragmental character of the groundmass, along with the strongly drawn out vesicles distinguish this flow rock from the chemically similar pyroclastics. Phenocrysts thruout the unit are mainly orthoclase with minor amounts of andesine-labradorite and biotite.

The groundmass (Figure 6) of the strongly foliated top phase is composed of flattened and bent glass particles, similar to those which make up the groundmass of the Upper Rhyolite tuff. The flattened and drawn out lighter bands are composed of a felty mass of feldspar laths and fine grained quartz similar to, but more even in texture than, the lenticular

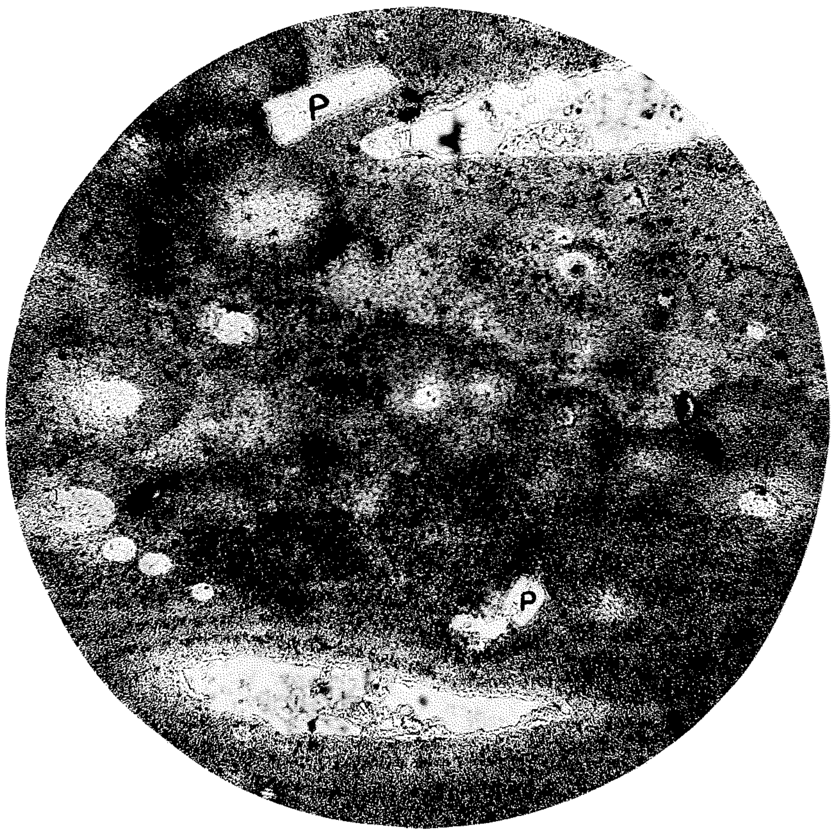

FIGURE 5
VESICLAR GLASS OF THE QUARTZ LATITE LAVA

The glass is partly devitrified and the vesicles are strongly drawn out by flowage. North of Three Peaks. P - plagioclase. x 60.

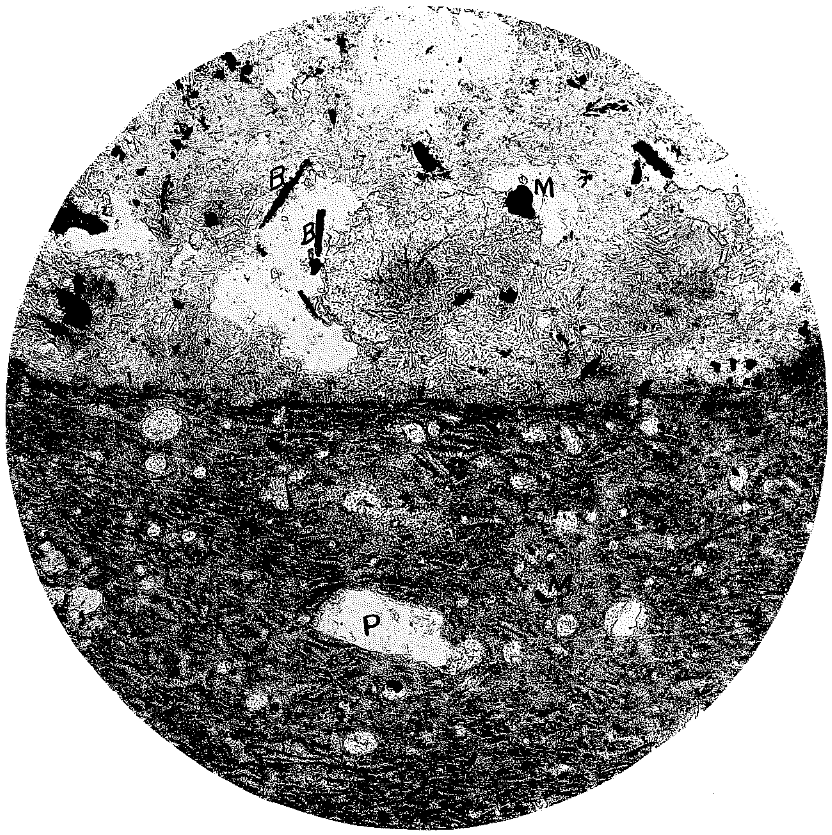

FIGURE 6
STRONGLY FOLIATED TOP OF THE QUARTZ LATITE LAVA

The lower half of the photomicrograph is the groundmass of strongly flattened pyroclastic glass. The upper half is the fine grained quartz and feldspar filling of a flattened lenticule. North end of the Eight Mile Hills. P - plagioclase; B - biotite; M - magnetite. x 60.

fillings of the middle layer of the Upper Rhyolite tuff. This top foliated phase probably represents a deposit of welded pyroclastic material which was laid down on top of the still hot and flowing lava.

Sufficient work has not been done with the unit to be sure of the details of variation within it from place to place in the district.

Middle Rhyolite Tuff

Distribution

The Middle Rhyolite tuff is remarkably uniform in thickness (300 to 400 feet) and mineralogy thruout the district. It is conformable upon the preceding flow unit and locally upon Claron sediments.

Megascopic Description

The Middle Rhyolite tuff is light gray, light pink, or light lavender in color. The groundmass is fine-grained, usually lusterless, and has a chalky appearance. Phenocrysts, mainly quartz and feldspar, with minor amounts of biotite and hornblende, make up ten to twenty percent of the volume of the rock. Thruout the unit are small angular fragments of other volcanic rocks, which are commonly less than one-half inch in maximum dimension.

Locally at the northeast end of the Eight Mile Hills the typical rock described above grades downward into a medium to dark brown basal phase, with a glassy appearing groundmass, which includes occasional thin stringers of pure black glass, up to one-sixteenth inch thick.

Microscopic Description

The photomicrograph, Figure 7 is typical of the Middle Rhyolite tuff. The groundmass has a vitroclastic texture made up entirely of glass fragments or shards. The shards have rudely triangular outlines with concave edges, and are thought to represent broken fragments of glassy froth and bubbles. The fragmental nature of the groundmass is partially obscured by devitrification which causes the glass to have finely speckled birefringence. The writer believes that devitrification, possibly due to its own gaseous emanations, was largely responsible for the lithifaction of the unit.

Figure 8 is a photomicrograph of a specimen from the glassy basal phase. Devitrification is not strong and the shards which make up the groundmass are clearly seen. Here the shards are flattened and bent without fracturing indicating the presence of considerable heat which probably welded the basal phase to give it its present glassy appearance.

Thruout the unit the phenocrysts are mainly quartz,

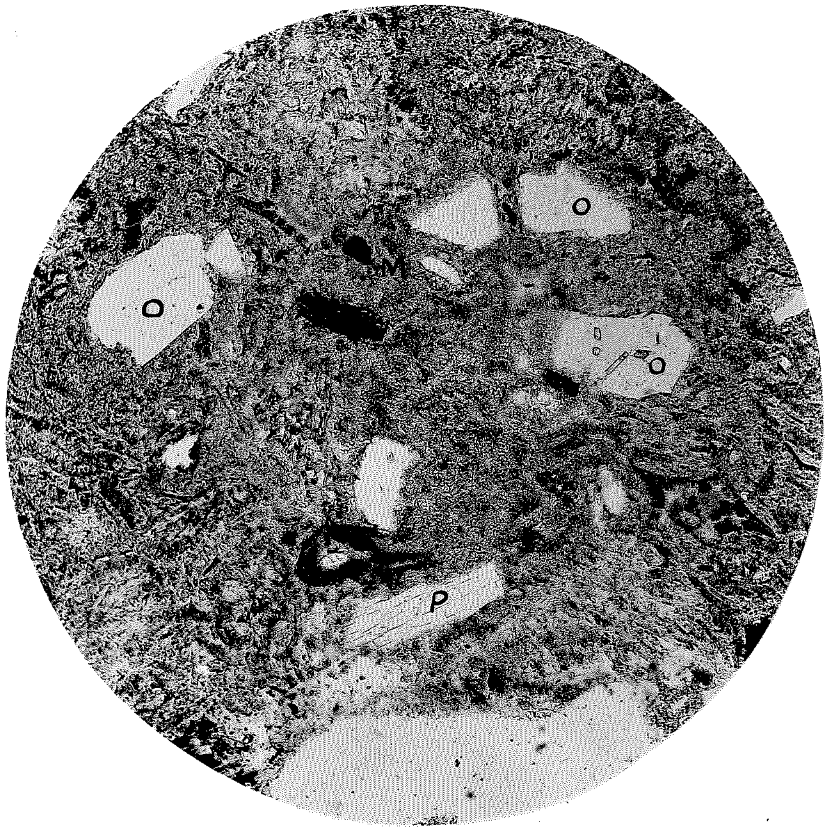

FIGURE 7
MIDDLE RHYOLITE TUFF

Showing devitrified vitroclastic structure.
North end of Eight Mile hills.
P - plagioclase; O - orthoclase;
M - magnetite. x 60.

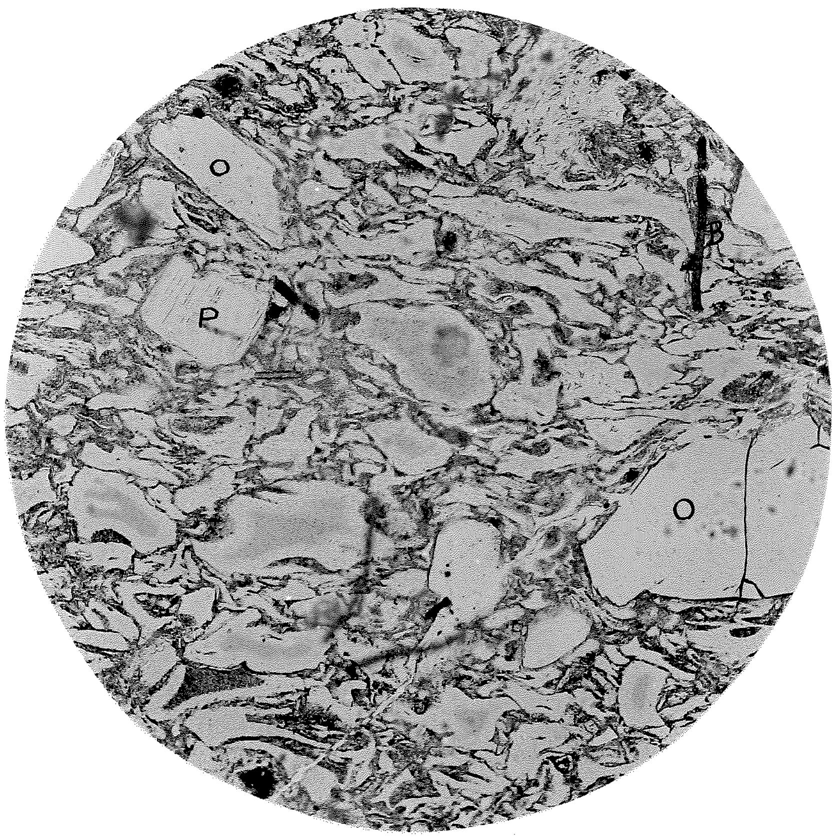

FIGURE 8
BASAL GLASSY PHASE OF THE MIDDLE RHYOLITE TUFF

Showing flattened and welded glass shards.
Northeast of the Eight Mile Hills.
O - orthoclase; P - plagioclase;
B - biotite. x 60.

orthoclase and plagioclase with less abundant biotite and magnetite. Hematite and limonite are scattered thru the groundmass of the darker brown glassy phase at the northeast end of the Eight Mile Hills.

Upper Rhyolite Tuff

Distribution

The Upper Rhyolite tuff is composed of three distinct phases or layers which persist thruout the district, namely a basal layer of black and red glasses a few tens of feet thick, a middle strongly foliated layer 50 to 100 some feet thick, and a top hard dense phase 20 to 50 feet thick. The overall thickness is 150 to 300 feet. The Upper Rhyolite tuff is everywhere conformable upon the Middle Rhyolite tuff.

Megascopic Description

The basal 5 to 15 feet of the lower glass layer is always a lustrous fresh black obsidian. At the top of the obsidian are scattered red glass spots about one-eighth inch in diameter; the spots become more abundant upward and within a foot or two the rock is entirely red glass. Another black obsidian layer, similarly related to the red glass commonly occurs 10 to 20 feet above the basal obsidian. The red glass is less lustrous than the black glass, and has a porcelainous appearance. Near the top of the red glass there is often a zone ten to thirty feet thick with numerous flattened lenticular shaped openings two to five inches in diameter and one-half to one and one-half inches thick.

The red glass grades upward within a few feet into the middle strongly foliated phases (see Figure 9). The groundmass is reddish brown and has the same semi-lustrous appearance as the red glass. The strong foliation is due to extremely flattened white to light gray lenticules, which are generally about one-eighth inch thick and four to six inches across. They range from about one-sixteenth inch thick and one-fourth inch long, to several inches thick and a foot or two across. They are spaced from about one-eighth to one-half inch apart. The lenticules superficially resemble flow lines in a vertical outcrop, but they are simply flattened and are not drawn out as would be the case if they were due to flowage. The filling of the lenticules is fine grained quartz and feldspar; often the filling is incomplete and drusy, and occasionally includes some minute magnetite crystals. The lenticules are interpreted as gas formed openings which were flattened by the load of the overlying tuffs, and later filled by emanations from the unit itself. Gilbert Wilson (1950) has shown that quartz and albite can be transported in and crystallized from the vapor phase at between 400 to 500 degrees centigrade.

The middle phase grades at its top into the upper dense

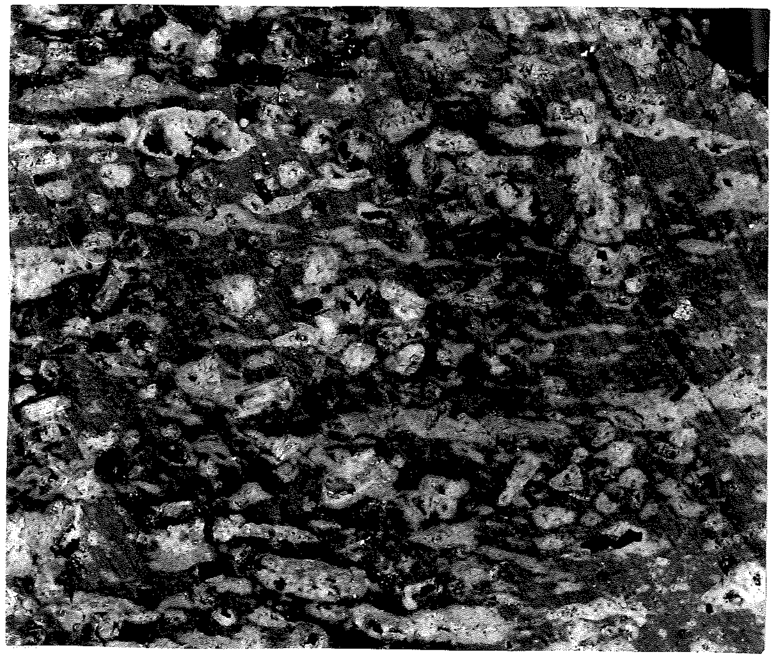

FIGURE 9

FLATTENED LENTICULES IN THE STRONGLY FOLIATED PHASE OF THE UPPER RHYOLITE TUFF

Hand specimen showing the lighter colored flattened lenticules. In the upper left hand corner is seen a partly filled or drusy lenticule. Northwest Eight Mile Hills. x 16.

phase. This phase is a light lavender gray to reddish gray color. The groundmass is semi-lustrous and uniformly dense thruout.

In all the phases of the unit are found phenocrysts predominately of feldspar, with minor amounts of biotite and magnetite. The lath like prisms of feldspar show strong horizontal alignment, but no preferred lineation. This suggests, as do the flattened gas-formed openings, that there was strong vertical compression and flattening of the unit by the weight of the next overlying tuff, which probably covered it almost at once.

Microscopic Description

The photomicrograph, Figure 10 shows the characteristic structures and textures of the lower glass phase. The groundmass is composed of flattened glass particles or blebs. The blebs differ from the shards of the other pyroclastic units in that they do not have angular boundries. This suggests that they were molten droplets of glass rather than hot angular fragments. These blebs were viscous enough to be extremely flattened, bent, and molded to each other without being fractured. Where two phenocrysts are adjacent the glass particles are squeezed between and bent around the crystals. Such lack of rigidity implies the presence of considerable heat, which the writer believes was sufficient to rather thoroughly weld the previously separate

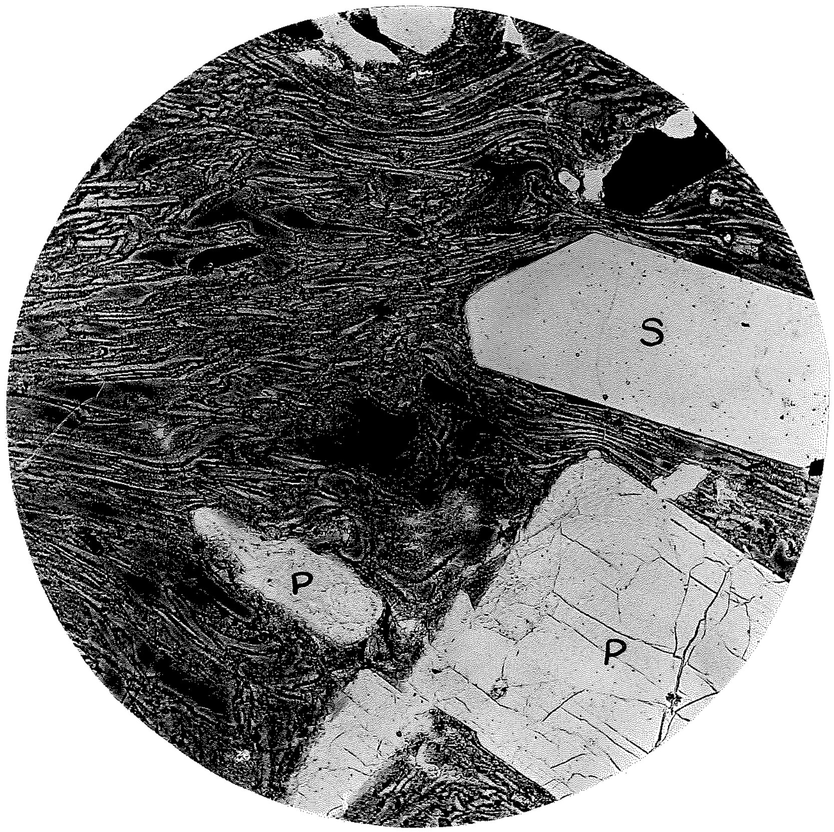

FIGURE 10
BLACK GLASS OF THE UPPER RHYOLITE TUFF

Showing flattened glass blebs squeezed between two phenocrysts. Northwest Eight Mile Hills. P - plagioclase; S - sanidine; M - magnetite. x 60.

glass particles.

Figure 11 shows the transition between black and red glass. The small spots of red glass are seen to be areas of radially arranged microlites formed by devitrification of the black glass. The boundries of these spots of microlites cross the flattened glass blebs without regard to their presence. From this it seems evident that the red glass is merely devitrified black glass.

Figure 12 is a photomicrograph of the strongly foliated phase of the unit. Devitrification is strong and partly masks a flattened bleb texture similar to that of the lower glass phase.

Microscopically (see Figure 13) the lenticules are seen to be filled with a heterogeneous mass of cryptocrystalline quartz and tiny laths of feldspar; included in this mass are larger crystals which are the same as the phenocrysts in the rest of the unit.

The photomicrograph (Figure 14) shows the groundmass of the dense upper phase. It shows some evidence of having been fragmental, but diagnostic features are generally absent and were it not for the gradation from the obviously pyroclastic lower phases, it could well be a dense lava. Devitrification is strong and as previously noted the phenocrysts are oriented in a manner suggesting strong flattening.

Thruout all the phases of the unit the phenocrysts are

FIGURE 11

TRANSITION BETWEEN BLACK AND RED GLASS OF THE UPPER RHYOLITE TUFF

Dark patches are devitrification spherulites which grew without regard to the flattened blebs of the black glass. North Eight Mile Hills. S - sanidine. x 60.

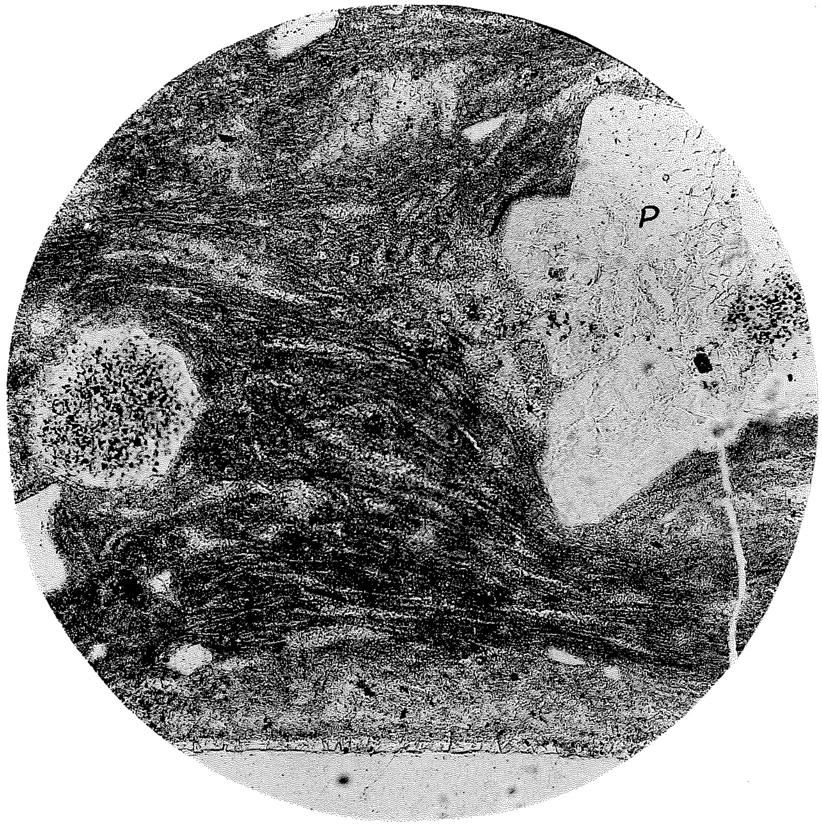

FIGURE 12
STRONGLY FOLIATED PHASE OF THE UPPER RHYOLITE TUFF

Showing flattened bleb texture similar to Figures 10 and 11 partly obscured by devitrification. North Eight Mile Hills. P - plagioclase. x 60.

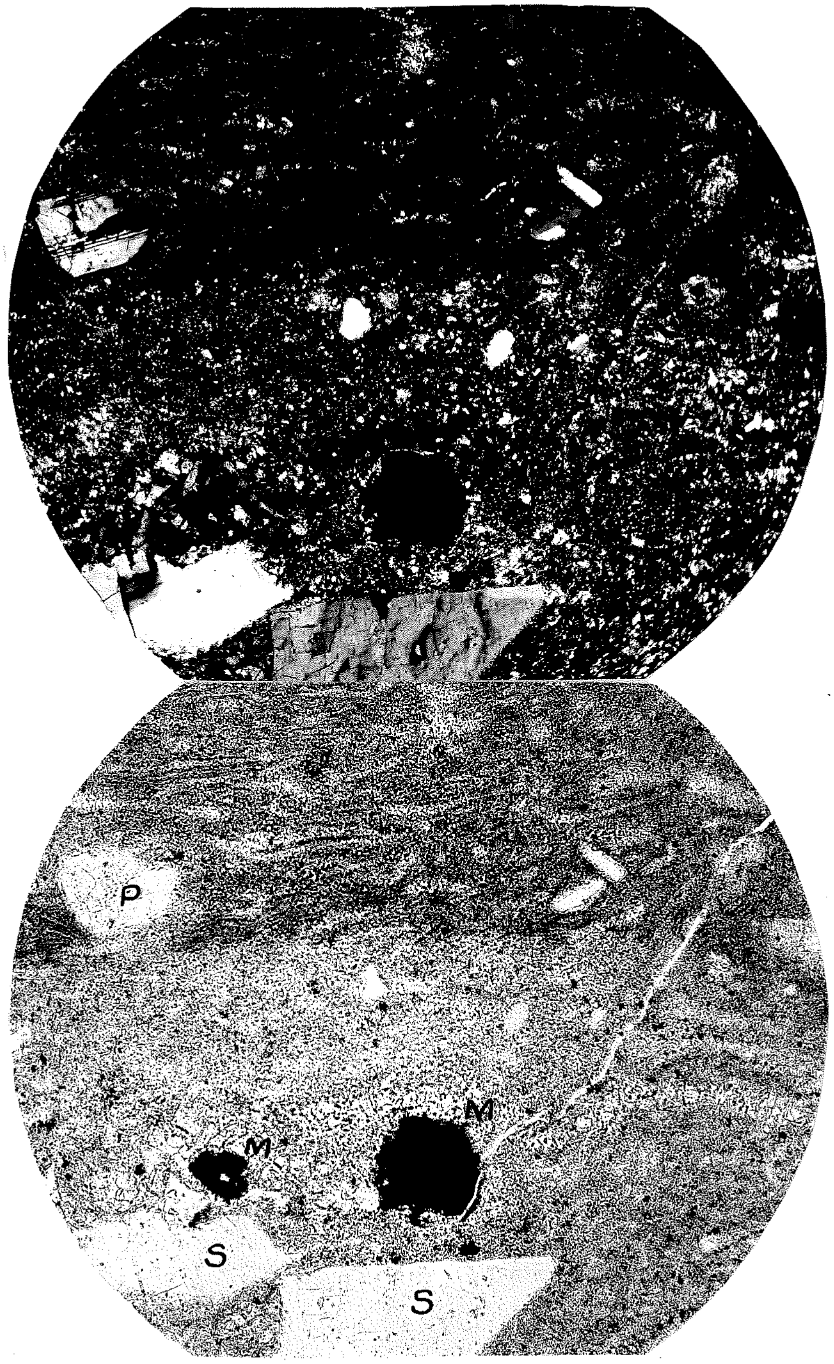

FIGURE 13
LENTICULAR FILLING OF THE STRONGLY FOLIATED PHASE OF THE UPPER RHYOLITE TUFF

The lower part of each picture shows the cryptocrystalline and fine grained feldspar filling of a lenticule. The upper part of each picture is the same devitrified flattened bleb texture as Figure 12. Upper picture crossed nicols, lower plane light. North Eight Mile Hills. S - sanidine; P - plagioclase; M - magnetite. x 60.

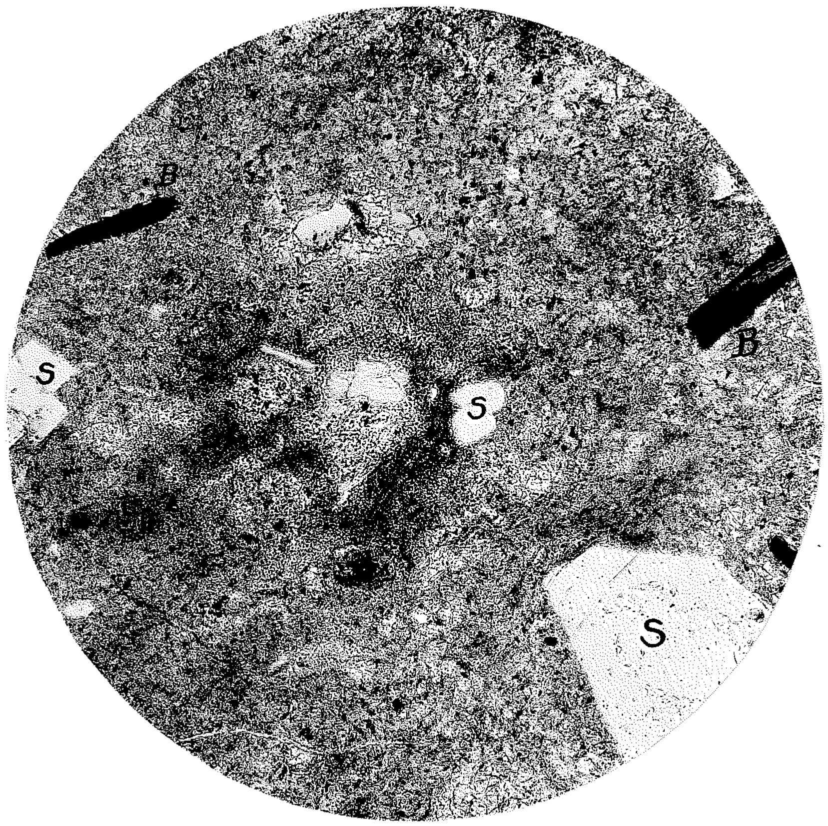

FIGURE 14
UPPER DENSE PHASE OF THE UPPER RHYOLITE TUFF

Vitroclastic texture largely obscured by devitrification. North Eight Mile Hills. S - sanidine; B - biotite. x 60.

sanidine, plagioclase, biotite and magnetite. Biotite, though often fresh, is commonly altered to magnetite and chlorite.

Biotite Dacite Tuff

Distribution

The Biotite Dacite tuff occurs thruout the district with a uniform thickness of about 300 feet. Everywhere the contact with the underlying unit is sharp and conformable.

Megascopic Description

The Biotite Dacite tuff is a light orangish brown or salmon color. The groundmass is fine-grained, lusterless, and chalky appearing. Phenocrysts, mainly feldspar and biotite with subordinate amounts of brown hornblende, quartz and diopside, make up about fifty percent of the rock volume. Angular fragment of other igneous rocks, less than an inch or two across are scattered thruout the unit.

Microscopic Description

Microscopically the groundmass (Figure 15) is a finely divided mass of angular ash sized glass fragments or shards. Devitrification is seen as salt and pepper appearing birefringence in the glass. No flattening or bending of glass shards is apparent and the rock was probably lithified by compaction and

FIGURE 15
BIOTITE DACITE TUFF

Showing the fragmental glassy groundmass and the numerous phenocrysts. Eight Mile Hills. B - biotite; P - plagioclase; S - sanidine; H - hornblende; D - diopside; M - magnetite. x 60.

devitrification rather than welding.

The phenocrysts are mainly biotite and plagioclase, with subordinate amounts of orthoclase, magnetite, diopside, quartz and hornblende. The plagioclase ranges from basic andesine thru labrodorite. The biotite, hornblende and diopside are generally fresh and unaltered.

Undifferentiated Tuffs

Overlying the Biotite Dacite tuff is a sequence of several tuff units which, unlike the lower units, thicken and thin from place to place. They have not been studied in sufficient detail to be separated and correlated with confidence. For the most part they appear to be merely consolidated tuffs; however, welding is locally evident near the base of some of the units.

A whitish, chalky appearing tuff overlies the Dacite tuff in the southern and western part of the district. This whitish tuff is often separated from the Dacite tuff by sands and gravels which resemble Claron sediments in appearance and rock types. The sediments occur as a thin veneer lying upon the flat top of the Biotite Dacite tuff; apparently this surface was not exposed long enough for appreciable weathe ring or erosion.

The next higher unit is very similar in appearance to the Dacite tuff except that the matrix has a pinker cast and contains twenty to thirty percent accidental fragments of other volcanic rocks. In the northwest and southern part of the district it is separated from the whitish tuff by another thin veneer of Claron type sediments. In the Swett Hills and the eastern half of the Eight Mile Hills the whitish tuff is absent and this unit rests upon the Biotite Dacite tuff and is separated from it only by occasional thin lenses of sand and gravel.

Other tuff units probably occur still higher in the sequence, especially in the Harmony Mountains.

Chemical Composition of the Volcanic Rocks

Chemical analyses of some of the volcanic rocks, as given by Leith and Harder (1908, p. 58), are tabulated in Table 2, as well as being graphically illustrated in Figure 16.

Analysis 2 is an average Quartz Latite. It was selected to give a name to the lava unit as it is probably typical of a larger part of the unit than analysis 2'. The difference between analyses 2 and 2' strengthens the possibility that this unit represents more than one flow.

Analysis 3 is apparently contaminated with $CaCO_3$. This has been subtracted and the analysis recalculated to 100 percent;

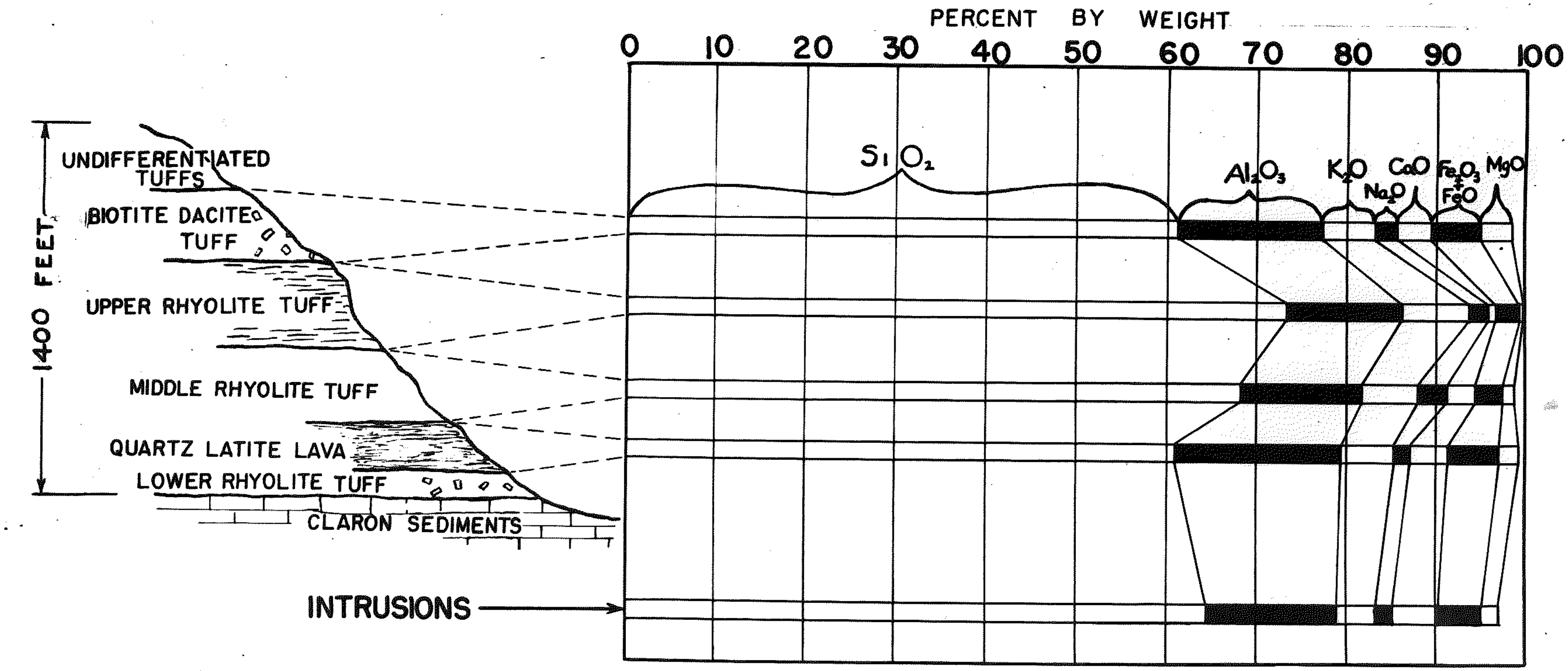

FIGURE 16 COMPARISON OF VOLCANIC AND INTRUSIVE ROCKS

TABLE 2

CHEMICAL COMPOSITION

	2	2'	3	3'	4	5	Int.
SiO_2	64.83	58.04	66.38	70.03	73.71	61.05	65.29
Al_2O_3	16.68	18.96	13.72	14.47	13.34	16.03	11.57
Fe_2O_3	3.74	5.88	2.23	2.35	1.35	5.42	2.10
FeO	1.22	1.33	.80	.84	.76	.98	2.67
MgO	.79	1.11	.54	.57	.81	3.03	2.87
CaO	2.85	6.12	5.49	2.42	1.32	5.40	4.85
Na_2O	.86	2.26	2.50	2.64	1.80	1.43	2.10
K_2O	7.56	4.08	5.20	5.48	7.10	5.58	5.18
H_2O	.92	2.05	.92	.97	.54	.81	2.32
P_2O_5	.35	.34	.08	.08	.07	.30	.22
CO_2	-	-	-	-	-	-	-
BaO	.11	.04	.11	.11	.10	.08	.17
	99.91	100.21	100.49	99.96	100.36	100.11	99.34

2* Quartz Latite lava from Antelope Range.
2' Andesite from same unit as above from north of Mount Staddard.
3 Middle Rhyolite tuff from Eight Mile Hills.
3' Middle Rhyolite tuff. Recalculated on the basis of 100 percent after removing CaO and CO_2.
4 Upper Rhyolite tuff from Antelope Hills.
5 Biotite Dacite tuff from Swett Hills.
Int. Fresh intrusive monzonite from east Granite Mountain.

[*note the above numbers of the units are the same as those in Table 1 on page 9] the result is shown in column 3'.

Analysis 4 is a typical rhyolite. Leith and Harder believed that this unit was abnormally high in silica because of secondary infiltration. The writer sees no reason to believe that any silica was added from any outside source.

The analysis of the Biotite Dacite tuff (5) is too low in silica for a typical dacite, but the presence of quartz phenocrysts determines the name.

The analysis of the intrusive quartz monzonite is included in the tabulation to show the chemical similarity between the volcanic and intrusive rocks.

As no analysis of the Lower Rhyolite tuff was available, the index of refraction of the groundmass glass was determined. It was found to vary between 1.495 and 1.500, these being typical values for a Rhyolitic glass.

Iron in the Volcanic Rocks

In view of the chemical similarity between the intrusive rocks and volcanic rocks, it is noteworthy that veinlets of magnetite are occasionally found in the upper phase of the Upper Rhyolite tuff, and that magnetite concentrations sometimes occur in the flattened lenticules of the middle foliated phase of same unit.

Mackin has demonstrated that the emanations which formed the ore bodies associated with the intrusions were derived directly from the intrusive rock. He (1947, p. 45) describes the process as follows:

> Where open tensional joints penetrated into the partly consolidated crystal mesh, iron rich emanations, deuteric in origin, escaped into the fissures from the immediately adjacent wallrock; deuteric alteration was halted and the selvage rock, bleached or with light green femics, is fresh at the outcrop. Between the joints and in parts of the intrusion not reached by them prior to complete consolidation, deuteric iron was largely entrapped, and continued alteration produced a rock that crumbles under weathering influences.

The selvage rocks occur as narrow zones of hard fresh rock along either side of the joint cracks. This rock is poor in femic minerals, having been the source of the iron rich emanations. The crumbly rock which retained its deuteric fluids shows euhedral outlines of biotite, hornblende and augite crystals, which are now largely chlorite speckled with magnetite.

It has been impossible to demonstrate similar clear-cut evidence to account for the iron concentrations in the Upper Rhyolite tuff. However it is interesting to note that mafic minerals thruout the tuff sequence are often altered to chlorite and magnetite (see Figure 4). The alteration products are largely confined to euhedral outlines of the altered mafic minerals, showing that alteration, probably deuteric, took place after the tuffs were laid down. The presence of openings attributed to escaping gas and the later filling of these openings also indicates the presences of an abundance of volatiles and late deuteric emanations probably similar to those which escaped from the laccolithic rocks and formed the ore bodies.

Origin of the Volcanic Rocks

Leith and Harder (1908) mapped all the volcanic units as flows. That the Quartz Latite with its drawn out vesicules and nonfragmental groundmass is a flow or flows seems certain. However the other units differ from it in their rather uniform thicknesses over wide areas. This fact alone, in view of the reputed viscosity of such acidic lavas, raises a question concerning the origin of these units. That they are pyroclastic is clearly shown by the clastic nature of their glassy groundmasses.

It is equally apparent that some of the glassy material was intensely hot at the time of deposition. The glass fragments, making up the basal phase of the Middle Rhyolite tuff and most, if not all of the Upper Rhyolite tuff, have been distorted without fracture and welded together.

C. M. Gilbert (1938) has concluded, in his very convincing analysis of the origin of the Bishop tuff, that such extensive welded pyroclastic deposits were probably deposited from <u>nuée ardente</u> [burning or fiery cloud] type of eruptions.

Recent use of the term welded has occasionally been synonymous with compaction and consolidation. The writer believes it would be well to restrict its use to those pyroclastic deposits in which the particles were fused together by their own heat at the time of deposition. P. Marshall (1935) coined the term "ignimbrite" [deposit of burning clouds] to apply to such welded pyroclastics. In view of the recent widespread recognition of such deposits, such a term would seem to deserve a place among igneous genetic names.

Problem of the Source of the Volcanic Rocks

The source of the Iron Springs Volcanic rocks has not been determined; however that the different units thicken in different directions is enough to show that the material could not have been erupted from a single vent. It has been suggested, in view of the chemical similarity between volcanics and intrusives, that the volcanics may have been erupted from the conduits which later fed the intrusions, but even if such were the case the evidence must necessarily have been destroyed by the later rising intrusive magmas. Some of the volcanic units thicken away from the known intrusions, and they at least could not be derived from the site of these intrusions.

Age of the Volcanic Sequence

The complete conformity between the Claron sediments below and the base of the volcanic sequence above; along with the occurrence of Claron-like gravels between some of the higher units, indicates a Claron age for the volcanics. The lithology and succession of the Claron formation is essentially identical with the Pink Cliffs Wasatch. Spieker (1946), working in the nearby Colorado Plateau, has shown that the Wasatch is late Cretaceous and/or Eocene in age. Since the volcanics are late Claron in age they are probably early Eocene.

The sharpness and regularity of the contact between the volcanic units indicates very short intervals of time between the deposition of the individual units.

SUMMARY OF CONCLUSIONS

The writer concludes that all the volcanic units of the sequence, except the Quartz Latite lava unit, are tuffs deposited from *nués ardente* type volcanic eruptions. The tuffs were erupted from several different vents, and the individual eruptions must have followed one another in rapid succession.

Some of the tuffaceous material was lithified by compaction and devitrification some time after it was laid down, while some of it was welded by its own heat at the time of deposition. These welded deposits could properly be called welded tuffs or "ignimbrites."

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