GEOLOGY OF THE BULL VALLEY DISTRICT
WASHINGTON COUNTY, UTAH

by

H. Richard Blank, Jr.

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

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Approved by [signature]

Department Geology

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We have carefully read the thesis entitled GEOLOGY OF BULL VALLEY DISTRICT SOUTHWESTERN UTAH submitted by RICHARD HORACE BLANK in partial fulfillment of the requirements of the degree of Doctor of Philosophy and recommend its acceptance. In support of this recommendation we present the following joint statement of evaluation to be filed with the thesis.

Mr. Blank's thesis deals with the geology of an intrusive-extrusive complex in the Great Basin in southwestern Utah. His geologic map shows the distribution of 25 sedimentary and volcanic stratigraphic units ranging in age from Jurassic to Recent, and a number of different types of intrusive bodies. The map covers about 125 square miles in the central part of the eruptive complex. Field work occupied seven months during the summers of 1956, 1957 and 1958.

The principal pre-volcanic structural feature of the area is a northeasterly trending anticlinal fold of Laramide age. Blank's work indicates that the fold was truncated by erosion and covered by a sequence of early Tertiary sedimentary rocks prior to the beginning of volcanism. During a first major period of eruptive activity a total of about 3500 feet of volcanic rock was spread over the surface and quartz monzontie porphyry was emplaced along the axial part of the Laramide structure. During subsequent eruptive periods in the middle and late Tertiary, renewed volcanism on a very large scale was accompanied by intrusion of numerous small rhyolite plugs. The youngest volcanic rocks are basalt flows and cinder cones, some of which are little-eroded. The area is criss-crossed by close-spaced faults into a mosaic of jostled blocks; the intense deformation is clearly an expression of the shifting of bodies of magma in depth and shattering associated with eruptive activity.

Most of the volcanic units are ignimbrites, a special class of eruptive rocks which are neither ordinary lava flows nor ordinary pyroclastic deposits, but show some of the characteristics of both. This class of rocks has been recognized only in the last 25 years, and is as yet poorly understood. Blank is able to demonstrate that one of his intrusive bodies ruptured its roof, that the escaping material behaved as an autoexplosive froth flow in the vicinity of the orifice, and that the resulting deposit grades outward from lava-like material in the vent area into a rock unit with many of the physical characteristics of a typical ignimbrite. This is the first case in which the transition from a hypabyssal intrusive body to an ignimbrite has been reported; Blank's discovery of the relationship is a major contribution.

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INTRODUCTION

Location and Geography

The Bull Valley district is an unorganized mining district located in Washington County, southwestern Utah, about forty miles southwest of Cedar City (see index map accompanying geologic map; also, Figure 1). In the sense employed here, the district embraces several areas of iron ore claims which are closely related geologically. In deference to local usage the term "Bull Valley" is retained for the general vicinity of the junction of Pilot and Moody Creeks near the center of the district. There is no specific valley by that name.

The area mapped comprises about 125 square miles, chiefly in the Bull Valley Mountains, a semi-arid range with a generally sparse cover of pinon, juniper and scrub oak, and a total relief of slightly more than 3000'. There is little rain in the hot summer months but a moderate snowfall during the winter; the average annual precipitation is 14" at Enterprise.

Previous Work

Because of its iron ore potential the Bull Valley district has been the object of many private investigations

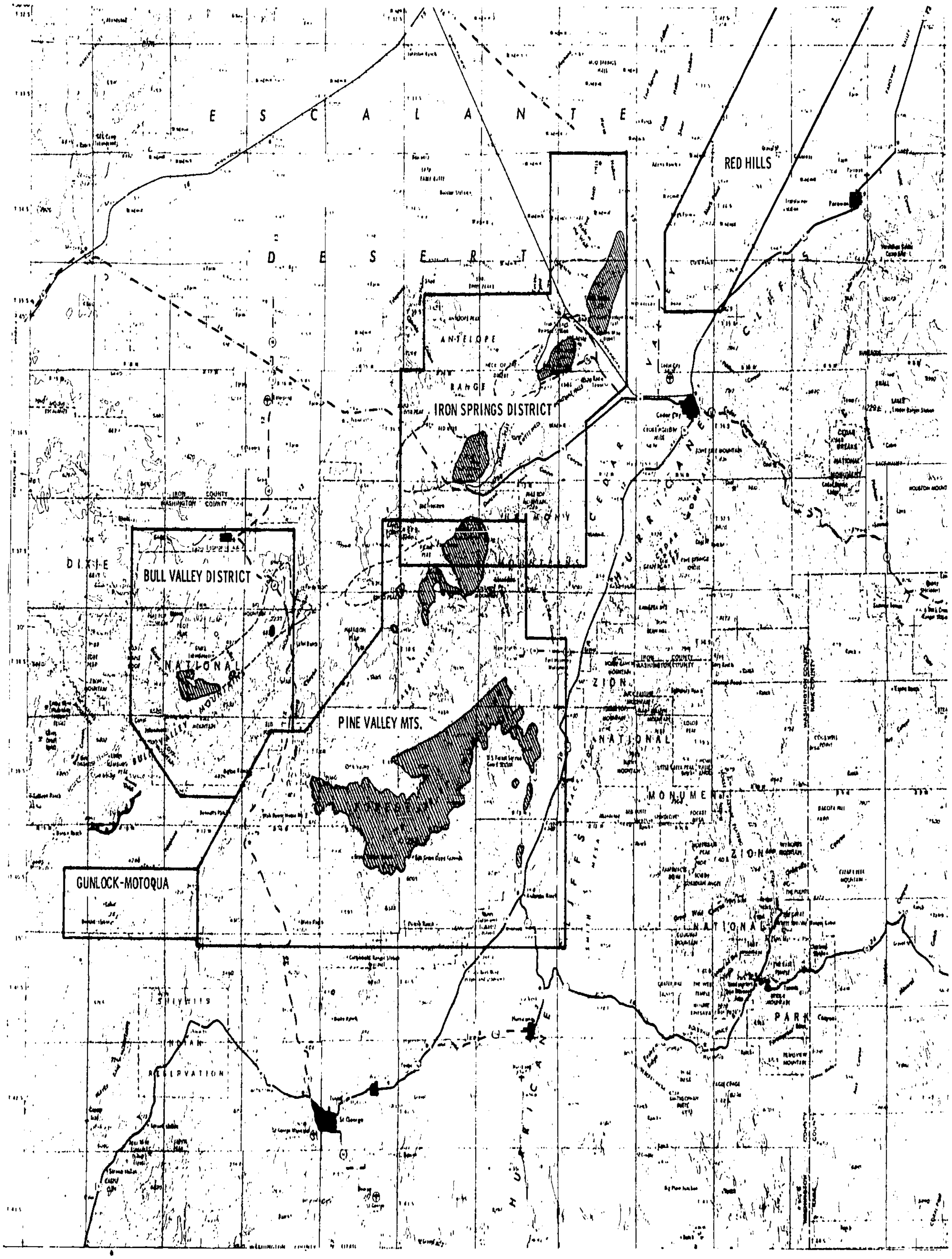


FIGURE 1. Index map of southwestern Utah showing areas mapped by University of Washington group. Exposed monzonite intrusive bodies are shaded; inferred extensions are outlined by dashed lines.

and considerable work by the U. S. Bureau of Mines and Geological Survey. However, there have been few works published on the district. Leith and Harder (1908) compared the iron deposits of Bull Valley with those of the Iron Springs district. Wells (1938) mapped the area of the principal intrusion and made a much more detailed study of the ore deposits; his work established the intrusive-extrusive relationship as well as major elements of stratigraphy. Zoldok and Wilson (1953) published a brief report containing additional data on the Cove Mountain ore and an hypothesis as to its origin.

In recent years several thesis projects in southwestern Utah have been completed by students of the University of Washington. The areas mapped are outlined in Figure 1. They include the Red Hills (Threet, 1952), Pine Valley Mountains (Cook, 1957), and Gunlock-Motoqua area (McCarthy, 1959). Also shown is the Iron Springs district, which has been extensively investigated by Mackin (1947a, 1947b, 1948, 1954); the geologic setting of this area is strikingly similar to that of the Bull Valley district.

Present Investigation

The original objective of the present investigation was to provide an understanding of the general geology of the area, in the light of which an over-all assessment of its economic potential might be made. As the mapping progressed, it became apparent that monzonite and latite associated with a central eruptive complex were the focal point of both academic and practical problems; these rocks became the chief subject of subsequent laboratory investigations. Flattop Mountain, a rhyolite eruptive complex in the northwestern part of the map area, was included because it bears a structural relation to the rest of the district and completes the picture of Cenozoic volcanism.

A study of the iron ore deposits is not within the scope of this thesis. The principal ore bodies encountered in the field are indicated on the geologic map diagrammatically. Diamond drill holes whose logs or cores were available to the writer are also shown.

Field mapping for the project consumed about seven months during the summers of 1956 and 1957 and a brief period during the following season, the mapping being done on aerial photographs at scales of 1:10,000, 1:20,000 and 1:30,000. While photointerpretation was a valuable tool in some parts of the area, more often than not it proved inadequate to resolve the structural and stratigraphic complexities. Inferred faults or fractures in areas of uniform lithology are indicated on the geologic map solely on the basis of photogeology.

A U.S.G.S. topographic sheet on a scale of 1:48,000 (Bull Valley district, 1938) is available for the southern two-thirds of the map area; a smaller scale map (Cedar City sheet, AMS, 1953, 1:250,000) covers the entire district. These maps were used in constructing structure sections. The base map employed consists of enlarged portions of two semi-contolled aerial photomosaics (U.S.D.A., SCS, Utah 329 and 330) coupled with two enlarged high altitude aerial photographs (U.S.G.S., f=6", 1953, nos. 1448 and 1386). Positioning of these elements is illustrated by a diagram accompanying the geologic map (see pocket).

A generalized stratigraphic column for the Bull Valley district is given in Figure 2, page 6.

Laboratory investigations involved the study of some 800 thick rock slices and 375 thin sections. The thick slices were prepared according to the method of Gabriel and Cox (1929) as adapted for acidic volcanic rocks by P. L. Williams (in press). The slices are first polished, then etched with hydrofluoric acid and stained with sodium cobaltinitrite, after which the phenocrysts may be counted using a simple 100-square grid under a binocular microscrope. Histograms depicting phenocryst composition of rock units in the Bull Valley district are presented in Figure 3, page 7. Per cent crystallinity shown by the histograms for acidic rocks, which were constructed from counts made by the above procedure, is always lower than corresponding estimates for basic rocks made in all cases from thin sections. Both methods greatly facilitated the deciphering of the volcanic stratigraphy and correlation with rocks of adjacent areas.

FIGURE 2. Generalized geolo

AGE		UNIT		LITHOLOGY	THICKNESS (FT.)
Quaternary	Recent	Alluvium		Sand, silt, gravel, talus	0-200
Quaternary	Recent	Black Hills basalt		Hypersthene-augite basalt	0-600
Quaternary	Pleistocene	Older alluvium		Coarse gravel	0-300
Quaternary	Pleistocene	Enterprise basalt		Black olivine-augite basalt	0-300
		Reservoir fm.		White to yellowish nonwelded lithic tuffs; white and pink airfall tuffs; volcanic sediments. Age is post-Ox Valley tuff, pre-older alluvium.	0-1400
		Hogs Back fm.	relations unknown	Gray, tan and red biotite-hornblende rhyodacites	0-500
		Cow Creek rhyolite	relations unknown	Gray-purple to brown siliceous rhyolite	0-300
		Shinbone rhyolite	relations unknown	Light tan to gray biotite rhyolite, locally highly vesicular and of low density	0-400
		Ox Valley tuff		Bluish-purple rhyolite vitric-crystal tuff with blue-iridescent sanidine	0-400
		Cove Mt. fm.	Cedar Spring member	White and pink airfall tuffs, volcanic sediments, and green-tan-purple rhyolite vitric tuff (Lower Moody tuff)	0-300
		Cove Mt. fm.	Pilot Creek basalt	Purple to brown and black olivine-augite basalt, locally conspicuously altered	0-400
		Cove Mt. fm.	Racer Canyon tuff	White to gray and yellowish biotite-hornblende rhyolite vitric-crystal tuffs, with abundant lithic fragments, rude stratification and interbedded tuffaceous sediments	0-1500
		Cove Mt. fm.	Willow Spring member	Volcanic sediments; ash; mudflow	0-50
		Maple Ridge porphyry		Purple biotite-augite andesite(?), characterized by coarse plagioclase phenocrysts	0-300
Tertiary		Shoal Creek breccia		Dark, variegated hypersthene-augite-hornblende andesite(?). Locally, amygdaloidal olivine basalt and clastic breccia	0-200

ologic column for the Bull Valley district.

			basalt and clastic breccia	
	Rencher fm.		Rust-colored biotite-hornblende-augite quartz latite crystal tuff locally overlying white to tan tuff breccia of the same composition, and grading into dark red-purple lava of source area	0-1000
	Quichapa fm.	Harmony Hills tuff	Dark pink to red biotite-hornblende-augite quartz latite crystal tuff	0-500
		Little Creek breccia	Variegated augite-hypersthene andesite(?), locally with prominent devitrification structures	0-1200
		Bauers tuff	Red to bluish-purple rhyolite vitric tuff with strong eutaxitic structure	0-200
		Leach Canyon tuff	Pink biotite rhyolite vitric-crystal tuff with conspicuous red lithic fragments	0-350
	Isom fm.	Hole-in-the-Wall tuff	Salmon to purple latite vitric tuff	0-20
		Baldhills tuff	Chocolate-colored latite vitric tuff	0-20
		Vesicular flow	Brown to purple vesicular andesite(?)	0-130
	Claron fm.	Limestone member	Gray massive lacustrine limestone, near the top lighter and finely banded, with interbedded pink to green hornblende-biotite quartz latite crystal tuff (Needles tuff)	0-630
		Siltstone member	Red siltstone, with interbedded pink limestone and black-limestone pebble conglomerate	
		Conglomerate member	Red-gray-buff cobble conglomerate with interlensing sandstone	
Upper Cretaceous	Iron Springs fm.		Mustard brown and variegated sandstone and siltstone, with subordinate gray to maroon shale; conglomerate at the base and near the top	1000-2000
Jurassic	"Entrada" fm.		Olive green and maroon non-calcareous shale	0-130
	Carmel fm.	Moody Wash ls.	Pink-yellow massive limestone	545 plus
		Shale member	Red calcareous shale	
		Homestake ls.	Blue-gray massive limestone, brown thick-to thin-bedded arenaceous limestone, and black ripple-marked calcareous shale	
		Siltstone member	Gray calcareous siltstone	

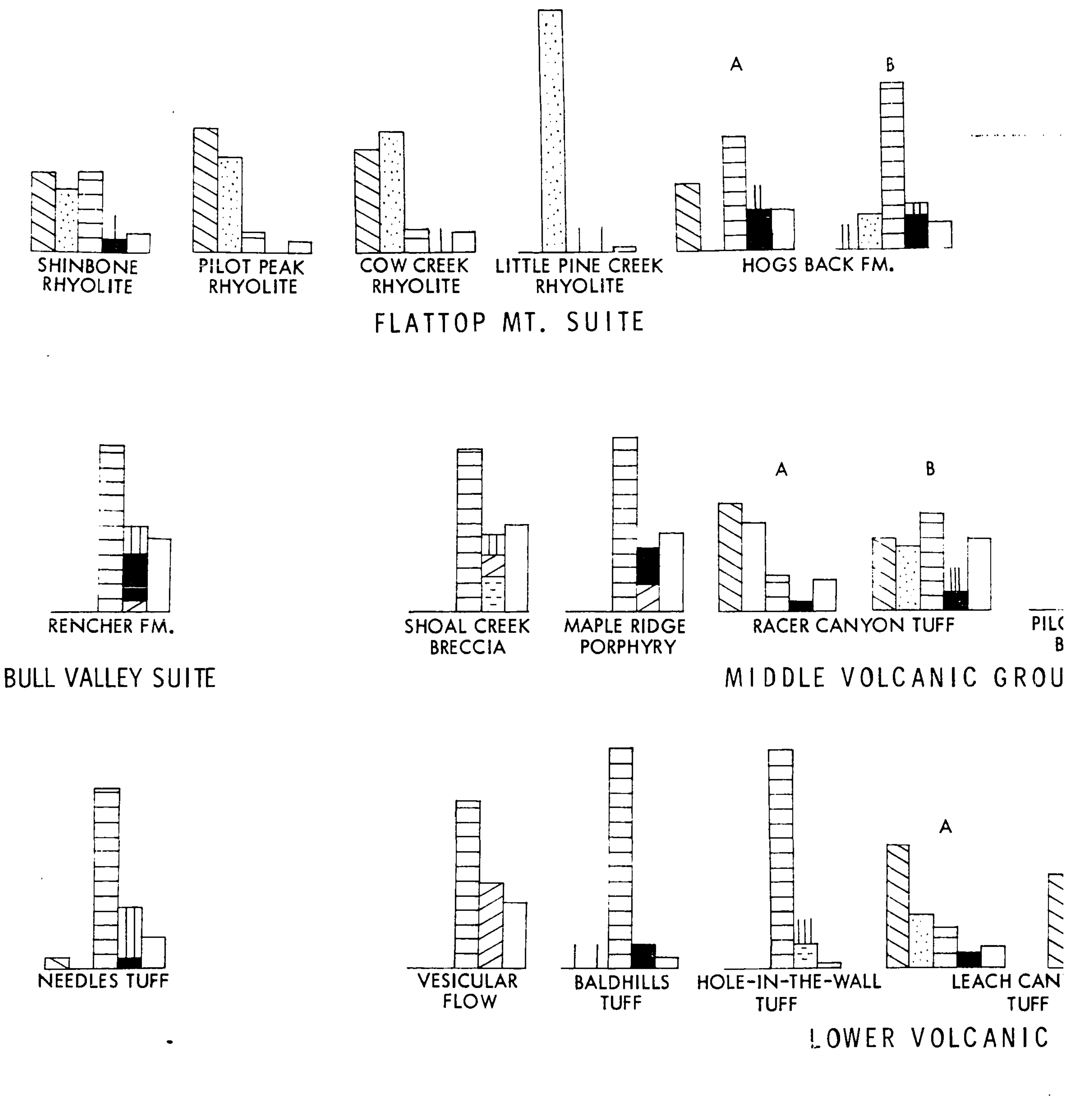
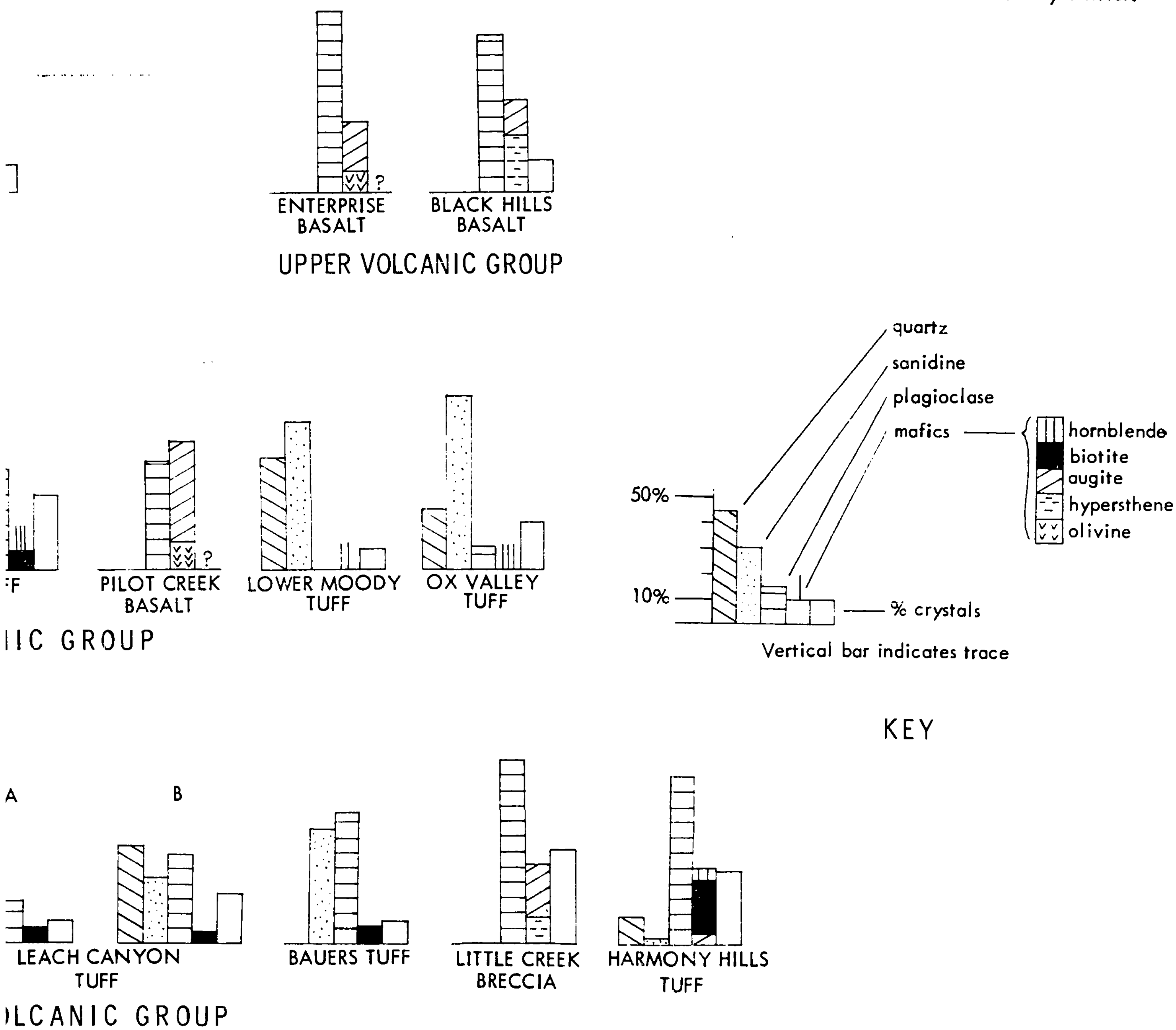

A
B
SHINBONE RHYOLITE
PILOT PEAK RHYOLITE
COW CREEK RHYOLITE
LITTLE PINE CREEK RHYOLITE
HOGS BACK FM.
FLATTOP MT. SUITE
A
B
RENCHER FM.
BULL VALLEY SUITE
SHOAL CREEK BRECCIA
MAPLE RIDGE PORPHYRY
RACER CANYON TUFF
PIL(
B
MIDDLE VOLCANIC GROU
A
NEEDLES TUFF
VESICULAR FLOW
BALDHILLS TUFF
HOLE-IN-THE-WALL TUFF
LEACH CAN
TUFF
LOWER VOLCANIC

FIGURE 3. Histograms showing phenocryst composition of rock units in the Bull Valley district.



Petrographic data were obtained without the use of the universal stage. Except where otherwise noted, plagioclase determinations were made by the a-normal (M-P) method.

Acknowledgments

The writer is greatly indebted to the Columbia Iron Mining Company, Columbia-Geneva Steel Division, United States Steel Corporation, without whose generous support the present investigation would not have been possible. In addition to support in the field, the company provided aerial photographs, thin sections, chemical analyses and magnetic susceptibility data, and the staff of the Raw Materials Exploration Department assisted in many ways. Thanks are especially due S. G. Sargis and J. K. Hayes, who were instrumental in initiating the project; R. C. Campbell, with whom the writer spent his first six weeks in Bull Valley; and P. D. Proctor, whose interest in the project was a source of inspiration. The Gulf Oil Corporation kindly made a loan of additional aerial photographs.

Professor J. H. Mackin of the Department of Geology, University of Washington, guided the work throughout and inevitably stimulated many of the ideas presented. Professors P. Misch and J. D. Barksdale critically reviewed the manuscript. The writer also wishes to express his gratitude to other members of the geology faculty for many valuable discussions, and to his colleagues, D. L. Schmidt, G. M. Miller, P. L. Williams, and W. R. McCarthy, all of whom at various times accompanied the writer in the field.

Thanks are extended to many friends in Enterprise, who helped make the writer's stay there a pleasant one; and to the Lee Rasmussens and Ray and Jay Johnson, for courtesies accorded while mapping on their mineral claims.

Finally, it is a particular pleasure to acknowledge indebtedness to Dr. F. G. Wells of the U. S. Geological Survey. His earlier work not only established many of the conclusions set forth in this thesis but provided a foundation on which to base all subsequent geologic studies of the area.

OUTLINE OF GEOLOGIC RELATIONS

The Bull Valley district, like the Marysvale area 100 miles to the northeast, is essentially an eruptive-tectonic complex. An aggregate total of some 9000' of volcanic material was spread over the district intermittently throughout the Tertiary and Quaternary, and hypabyssal intrusive bodies of monzonite porphyry, rhyolite, and basalt were emplaced, some of them erupting to the surface. The igneous activity was accompanied by intensive deformation characterized by close-spaced high angle faulting.

Pre-volcanic sedimentary rocks are exposed for the most part only where they have been arched up by intrusions, and therefore the early geologic history of the area is relatively obscure. It seems to parallel closely that of the adjacent Pine Valley Mountains, and especially as regards Laramide deformation, that of the Iron Springs district. The following events may be reconstructed from the record in Bull Valley:

(1) Deposition of marine carbonates and fine clastics of the Carmel formation in Jurassic time, with a rather abrupt change in environment to that of the non-calcareous "Entrada" shale and siltstone.

(2) Uplift but no pronounced warping in uppermost Jurassic to Upper Cretaceous time, resulting in erosion of the Carmel and "Entrada" beds.

(3) Beginning in the early Upper Cretaceous, foreland shelf conditions with a vacillating shoreline and deposition of variegated sandstone, shale, and conglomerate of the Iron Springs formation.

(4) Laramide deformation in the late Upper Cretaceous to early Eocene, producing a major anticlinal structure probably continuous with the Iron Springs Gap anticline to the northeast.

(5) Partial planation of the fold by erosion; accumulation of coarse conglomerates of the basal part of the Claron formation. At places in the district, deposition of Claron conglomerates followed those of the Iron Springs formation without interruption.

(6) The onset of an environment of less rapid sedimentation in upper Claron time, and, finally, of fresh water lake conditions whose deposits completely covered the Laramide structure.

The presence of a thin ignimbrite member interbedded with the upper Claron limestones indicates that volcanism, probably centering north of the Bull Valley district, was initiated while the lacustrine environment still prevailed. A succession of sheet-like ignimbrites and intercalated flows were then emplaced on the flattish Claron surface (the Lower Volcanic group). It is not known with certainty which, if any, of these volcanics issued from sources within the district; the ignimbrite sequence can be traced over exceedingly large areas in southwestern Utah.

Toward the end or following the conclusion of this early Tertiary volcanic episode, the axial portion of the Laramide anticline became the site of intrusion of quartz monzonite porphyry. The monzonite arched up its sedimentary and volcanic cover, forming a concordant body trending southwest to northeast across the center of the district from Bull Valley to Big Mountain. At the southwest (Bull Valley) end of the intrusive arch, continued rise of the magma and rapid denudation of the oversteepened structure, probably largely effected by landsliding, resulted in failure of the roof and violent eruption of great quantities of latite magma. The earliest ejecta were tuffs and tuff breccias of probably nuée ardente origin, but these were quickly followed by extravasation of a more liquid phase, the deposits of which suggest an origin transitional from an ignimbrite to the ordinary lava flow. Automorphic alteration of the magma apparently occurred throughout the eruptive episode, and is closely related to the formation of iron deposits in the final stages.

A period of erosion followed the monzonite-latite eruptions. The northwestern portion of the district, on the concave side of the monzonite intrusive arch, was depressed by downwarping or high angle faulting, permitting the accumulation of a considerable thickness of basic intermediate flows and breccias, rhyolite tuffs, and volcanic-derived sediments (the Middle Volcanic group). Most of this material appears to have been spread into the area from the west and northwest, although one unit--an olivine basalt--erupted from a source adjacent to the northern flank of the Bull Valley intrusion. Several unconformities may be present within the succession. The upper units completed the burial of the intrusive arch of the previous episode and hence are also found southeast of that structure.

Renewed or continued collapse of a broad arcuate belt roughly paralleling the monzonite arch in late Tertiary time was accompanied by further accumulation of silicic tuffs and volcanic-derived debris, and uplift of the Flattop Mountain area in the northwest corner of the district by intrusion of rhyolite magma. Silicic stocks and plugs were emplaced both in the Flattop Mountain center and in the trough to the south and east.

The filling of the trough with unconsolidated tuffs and volcanic sediments continued after the close of the rhyolite eruptive episode. Eventually most of the district must have been covered by these deposits. During the period of post-rhyolite fill and subsequent erosion, several generations of basalt were erupted (the Upper Volcanic group), ranging in age from Pleistocene to Recent.

Deep erosion during the Quaternary, probably accompanied by the jostling of high angle fault blocks, has resulted in removal of much of the fill and partial exhumation of the two principal eruptive centers.

SEDIMENTARY ROCKS

General Statement

Sedimentary formations of the Bull Valley district are divisible into two categories: those preceding the initiation of volcanism in the area, and those which post-date the greater part of the volcanic activity. In the first, or pre-volcanic, category, are the Carmel and "Entrada" formations, the Upper Cretaceous Iron Springs formation, and the Upper Cretaceous(?)-Eocene Claron formation. These four units have an aggregate thickness of 2800-3300'. Over much of the district they are buried beneath a cover of volcanic rocks; the chief exposures are on structural highs such as the Bull Valley-Big Mountain intrusive arch and the Manera uplift. Because the same units also occur in the Iron Springs district and Pine Valley Mountains, where they have been described by Mackin (1954) and Cook (1957), respectively, they are not treated at length here.

The largely post-volcanic category consists of a heterogeneous volcanic-sedimentary unit designated the Reservoir formation, which includes material probably ranging in age from late Tertiary to Pleistocene, and two generations of Quaternary gravel and alluvium. The estimated aggregate thickness of these rocks is 1900'.

Pre-Volcanic Units

Carmel Formation (Jc)

The oldest rocks in the Bull Valley district are marine limestone, siltstone, and shale composing the Carmel formation of Jurassic age. As in adjacent areas to the east and south, the Carmel, together with possible Entrada rocks, is the sole representative of the San Rafael group of the Colorado Plateau.

The Carmel is exposed only where uplifted and deformed along the Bull Valley-Big Mountain instrusive arch. Its full thickness is not present in the area mapped, since the lower contact, where seen, is always with quartz monzonite intrusive rock. Elsewhere in southwestern Utah the formation rests without angular discordance upon Jurassic Navajo sandstone.

The lithology of the Carmel exposed on Big Mountain is very similar to that described in the Iron Springs district (Mackin, 1954). A blue-gray, massive to thick-bedded limestone member, the Homestake limestone, composes most of the formation which on Big Mountain is about 200' thick. Locally its upper portion is light gray to buff, fissile, and argillaceous. In some places the Homestake limestone is separated from quartz monzonite by a few feet of brownish siltstone, probably equivalent to the "siltstone member" of the Iron Springs district.

Farther southwest along the intrusive arch, where it is in contact with the Hardscrabble Hollow and Bull Valley intrusions, the Carmel formation is over 500' thick and is composed of siltstone and Homestake limestone members, overlying which are a red calacareous shale member and a massive unit herein called the Moody Wash limestone. The Moody Wash limestone is remarkably like certain massive limestone beds of the Claron formation, being distinguished chiefly by its greater thickness (100-150', compared with a maximum of 15-20' in the Claron). In the upper 90' it consists of faintly bedded, pink-gray-yellow-buff limestone which weathers to a hackly surface and is very resistant. This grades downwards through blue-black argillaceous limestone into red calcareous shale of the underlying member. The red shale and Moody Wash members are probably stratigraphically higher than all of the Carmel in the adjacent Pine Valley Mountains, where Cook (1957) has subdivided the formation into three units, the upper two of which appear to be equivalent to the siltstone member and the Homestake limestone. The remaining unit mapped by Cook is the red, gypsiferous Temple Cap member said by N. C. Williams (1952, p. 65) to be characteristic of the base of the Carmel throughout southwestern Utah. Although present both to south and east this member if not found in the Bull Valley district. It may have served as an horizon of intrusion and been incorporated in the growing laccolithic bodies of magma.

In some places the Homestake limestone is highly fossiliferous. A brown-weathering, thin-bedded black arenaceous limestone 70-80' above the siltstone member in Moody Wash yielded abundant specimens of Pentacrinus columnals. No diagnostic fossils were found in the Moody Wash member nor in the intervening red shale.

A stratigraphic section of the Carmel formation measured at the junction of Pilot and Moody creeks in Bull Valley is as follows:

UNIT	THICKNESS (FT.)
Iron Springs formation	
Disconformity	
Carmel formation	
Moody Wash limestone	
Pink-gray-yellow-buff massive limestone, weathers hackly, forms prominent ridge	90
Blue-black argillaceous limestone, weathers gray-green, grades into massive limestone above and calcareous shale below, fossiliferous in shaly portion	42
Shale members	
Red calcareous shale, arenaceous in places, locally grades into massive argillaceous limestone, weathers in small angular chips	43
Cover	33
Homestake limestone	
Greenish to bluish gray calcareous shale, strongly ripple-marked near base, thin-bedded and friable, usually weathers light colored . .	43

Four distinct pink-buff limestone beds 2-3' thick, interbedded with bluish gray calcareous shale	34
Greenish-yellowish-bluish gray ripply calcareous shale, interbedded with and grading into thin-bedded argillaceous limestone of same color	30
Black to bluish-gray laminated ripply calcareous shale, weathers in fine chips	22
Pinkish brown massive argillaceous limestone, locally with shaly parting, grades into shale above and below, very resistant	15
Shale similar to shale unit above	30
Gray-pink limestone similar to limestone unit above	4
Pinkish gray thin-bedded arenaceous to argillaceous limestone and calcareous shale, weathers light pink to tan, locally cross-bedded and ripply, in places crystalline limestone highly fossiliferous. Near base, black on fresh surface and weathers brown. Basal 16' not exposed	79
Dark blue-gray massive limestone, locally with shaly parting. At top is 6" bed of edgewise black-limestone pebble conglomerate overlain by pink thin-bedded oolitic limestone	57
Siltstone member	
Gray massive to thick-bedded calcareous siltstone, very resistant	29
Intrusive contact	
Bull Valley quartz monzonite porphyry	

"Entrada" Formation (Je)

At several localities on Big Mountain, the Homestake limestone of the Carmel formation is sharply overlain by up to 50' of deep maroon to olive-green shale, which is distinguished on the geologic map as the "Entrada" formation, of Jurassic age. Drill core data indicate a thickness up to 130' of this material. Elsewhere the Carmel beds (Homestake or Moody Wash limestone) are overlain directly by Upper Cretaceous sandstone or conglomerate. These relations, with corresponding approximate thicknesses, are illustrated in Figure 4. The "Entrada" is present only where uppermost

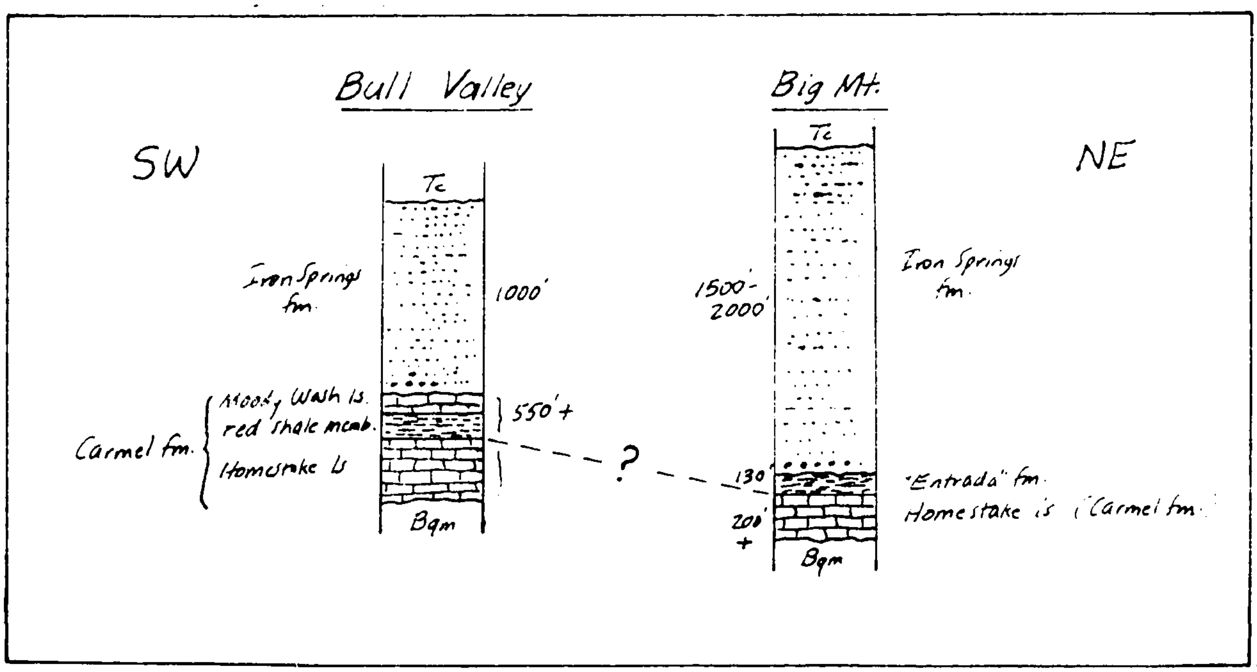


Figure 4. Carmel-Iron Springs relationship on Bull Valley-Big Mountain arch. Tc=Claron fm.; Bqm=quartz monzonite of Bull Valley suite.

Carmel units are missing. It is possible that the "Entrada" is laterally equivalent to the red shale member of Bull Valley and Hardscrabble Hollow Carmel. No evidence was seen of an unconformity separating the "Entrada" from underlying Homestake limestone. Blue gray massive limestone passes gradationally upwards into white to buff laminated limestone, several tens of feet thick. Abruptly but gradationally within a few inches the shaly limestone becomes deep maroon or olive-green, non-calcareous, non-fossiliferous, arenaceous shale which weathers in small angular chips, and has relatively little resistance to erosion. At most places in the Big Mountain area it forms no outcrops. Its presence can sometimes be inferred from float, but in at least one location--a mile southeast of the peak of Big Mountain, where Homestake limestone is exposed in the core of a faulted anticline--it is definitely absent.

The "Entrada" mapped on Big Mountain may, on the other hand, be younger than the entire Carmel section of Bull Valley. In that case it is probably correlative with the plateau Entrada sandstone of Gregory (1950, p. 40) and rests upon an erosion surface on the Carmel formation.

Lithologically it is similar to the Entrada mapped by Cook (1957, p. 34) in the Pine Valley Mountains, and the "basal shale" of the Entrada sandstone in the Iron Springs district (Mackin, 1954), but is much finer-grained than the Entrada of the Plateau.

Iron Springs Formation (Kis)

The Carmel and "Entrada" formations are overlain discomformably in the Bull Valley district by clastic sediments of the Iron Springs formation, of Upper Cretaceous age. Like the Jurassic units, the Iron Springs rocks are exposed chiefly where uplifted along the Bull Valley-Big Mountain arch, but they also occur in the southeast corner of the district.

The Iron Springs formation of the map area can be traced northeastward with few interruptions into the Iron Springs district, where the formation was named by Mackin (1954). There is little change in lithologic aspect between that district and occurrences at Big Mountain: the formation consists predominantly of rust-brown, buff and white massive to thick-bedded sandstone and siltstone, with a few thin interbeds of gray or maroon shale. Farther south and west from Big Mountain, however, the colors appear to become more variegated, with purple, red, and orange predominant. It is not known whether these represent lateral changes or a different part of the section.

There are few if any places in the district where the entire thickness of the Iron Springs formation is present in a continuous unfaulted section. A thickness of 1000' was measured in Moody Wash, adjacent to the Bull Valley intrusion, but the rocks there are deformed by the intrusion and the actual thickness may be somewhat in excess of that figure. It is estimated that the formation is 1500-2000' thick on Big Mountain.

Locally the basal unit of the Iron Springs formation is a conglomerate or conglomeratic sandstone, probably equivalent to the Dakota(?) sandstone mapped by Cook (1957, p. 36) in the Pine Valley Mountains and by McCarthy (oral communication) in the Gunlock-Motoqua area south of Bull Valley. In some places a purple, massive, very resistant quartzite pebble-cobble conglomerate is present near the top of the formation.

Usually the sandstone beds are semi-coherent, loose and friable; locally they may be strongly cemented with silica or carbonate. Jointing is often so prominent and bedding so poorly developed that attitudes are difficult or impossible to determine.

No fossils were found in the Iron Springs formation of the Bull Valley district. The formation is probably equivalent to Cook's "undifferentiated Upper Cretaceous" on the west side of the Pine Valley Mountains, which he considers to be a western facies of the Kaiparowits formation, Straight Cliffs and Wahweap sandstone, and Tropic formation (1957, p. 35), as well as to the Dakota(?) sandstone. These units are generally considered to be of Colorado and Montana age.

Claron Formation (Tc)

On and adjacent to the Bull Valley-Big Mountain intrusive arch, the Iron Springs formation is overlain unconformably by conglomerate, siltstone, and limestone of the Claron formation, of Upper Cretaceous(?)-Eocene age. The angular discordance varies from close to zero degrees on the crest of the arch to about 30° on the flanks (see F, Plate 7, p. 173). In the vicinity of Red Butte, in the southeastern part of the district several miles from the crest of the arch, there is no apparent disconformity separating the two formations. The Iron Springs becomes increasingly conglomeratic in its upper portions and finally gives way to beds of massive conglomerate, which are arbitrarily assigned to the base of the Claron.

The Claron formation is generally subdivisible into three principal members in the Bull Valley district, as it is in the Pine Valley Mountains and the Iron Springs district. These are: basal conglomerate, middle red siltstone and upper gray limestone. A fourth unit, the Needles tuff, occurs interbedded with the upper gray limestones. In Moody Wash, near the Bull Valley intrusion, the formation has a measured thickness of 630'.

The basal conglomerate consists of subrounded to rounded pebbles and cobbles, chiefly of gray limestone and tan quartzite, in a siliceous or calcareous matrix which varies from red to yellowish or gray. Some of this material was probably derived from the Iron Springs and Carmel formations, but much may be from older units, perhaps Paleozoic in age. The thickness is a function of position relative to the intrusive arch--on or near the crest of the arch the conglomerate is very thin or absent, whereas away from the arch it thickens to several hundred feet or more, as illustrated by the sketch of Figure 5. Near Red Butte, for example, it is probably more than 500' thick. Cook (1957, p. 45) reports 959' of Claron conglomerate at Gunlock, a few miles south of the map area.

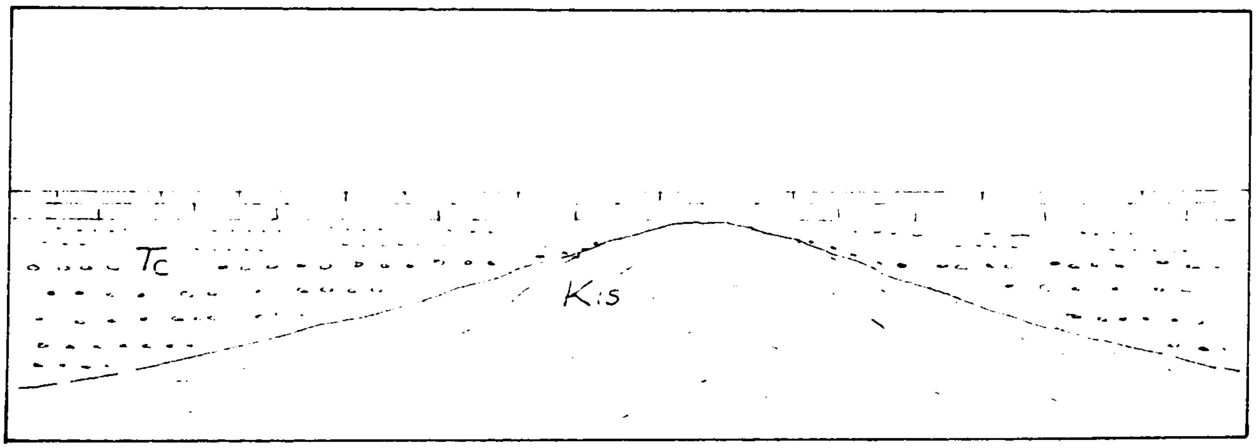


Figure 5. Claron-Iron Springs relations in Bull Valley district. Tc=Claron fm.; Kis=Iron Springs fm.

The middle red siltstone is likewise subordinate or missing on the crest of the arch and best developed remote from that structure. It consists of soft red siltstone, rarely resistant enough to form outcrops, in which are interbedded pink limestone and black-limestone pebble conglomerate beds several to about ten feet thick.

Gray massive or thick-bedded fresh-water limestone of the upper members of the Claron rests directly upon Cretaceous rocks at some places on the arch; elsewhere it overlies the siltstone and conglomerate members. The beds vary from about 6" to 10' in thickness and form strong ledges, generally alternating with weaker siltstone units (E, Plate 7, page 173). They commonly weather to a rough, uneven surface on which attitudes are difficult to ascertain. Algal structures are locally present. Near the top of the formation, the beds tend to become whiter and thinner and locally are characterized by a delicate pink and white banding.

The age of the Claron formation is not known with precision. No fossils were collected from the Claron in the area mapped, and fauna from Claron elsewhere provide poor time markers. It is equivalent to the "Pink Cliffs" Wasatch of the Colorado Plateau, and may encompass a time span from latest Cretaceous to middle Eocene. The Claron-Iron Springs relationship in the Bull Valley district indicates complete burial of a Laramide anticline by the deposits of the Claron formation, as shown in Figure 5.

In areas of structural complexity, difficulties often arise in distinguishing Claron clastic units from similar beds of the Iron Springs formation. Generally the Claron siltstones are more vivid orange and red, and the conglomerates contain a higher proportion of black limestone pebbles. Cement and coloration of the conglomerates are considered poor criteria, since they may show abrupt lateral changes in a given horizon.

Needles tuff. The Needles tuff is a hornblende-biotite quartz latite crystal tuff occurring throughout most of the Bull Valley district interbedded with lacustrine limestone near the top of the Claron formation. It has a measured thickness of 55' on the south side of Moody Wash, where it rests without angular unconformity on gray massive limestone, and is overlain similarly without angular unconformity by 70' of white to gray massive limestone, followed by a succession of younger volcanics. At other places in the district the sub- and suprajacent limestones are thin-bedded and banded, and the Needles tuff may be somewhat thinner or locally absent.

This unit is the oldest volcanic rock in the Bull Valley district. It is known in the northern Pine Valley Mountains and the Iron Springs district, but in these places it is thicker and was apparently not followed by a continuation of the Claron lacustrine type of sedimentation, or else such deposits were removed by erosion. The name has been recently proposed by Mackin (in press) for the much thicker correlative tuff deposit in the Needles Range, 40 miles northwest of Bull Valley.

Megascopically, the tuff is gray-green to pink or purple, moderately welded, shows a strong foliation of phenocrysts, and has rude platy parting. It contains sparse red lithic fragments up to 1/2" in diameter. Often it is characterized by the presence of altered pumice fragments.

The bulk compostion of the rock is shown by the histogram in Figure 3. Plagioclase is identified in thin section as andesine-labradorite (about An50) and usually shows oscillatory zoning with a normal over-all trend. Hornblende and biotite are the ordinary (low temperature) varieties; they are thickly rimmed with hematite. The pryoclastic origin of the unit is clearly attested by the presence of deformed glass shards and fragmental phenocrysts.

Largely Post-Volcanic Units

Reservoir Formation (R)

Although included for descriptive purposes with the "largely post-volcanic sedimentary rocks," deposits mapped as the Reservoir formation consist of an assortment of igneous as well as sedimentary units, with a stratigraphic position between the Middle Volcanic group and Quaternary gravels. They consist of nonwelded tuffs, agglomerates, fine-grained tuffaceous sediments and volcanic-derived conglomerates (see photographs A and B, Plate 7, p.173), which partly fill a great arcuate trough between Flattop Mountain and the Bull Valley-Big Mountain arch, and also occupy a large area in the southern part of the district. The maximum thickness of the formation is estimated to be about 1400'.

The nonwelded tuffs are white or gray to buff-colored, massive deposits highly charged with purple fragments of rhyolite similar to that of the Flattop Mountain suite; they appear to be the products of nuée ardente eruptions, or ignimbrites. This material is present only south of the lower Enterprise reservoir, where it overlies Ox Valley tuff of the Middle Volcanic group. Its emplacement is believed to have been a prologue to the Flattop Mountain eruptive episode. Thick-bedded agglomerate of composition much like that of the ignimbrite deposit, but containing coarser and more numerous purple silicic fragments, occurs on or near Flattop Mountain. It invariably rests directly upon rocks older than Ox Valley tuff in places where the latter unit appears to be missing from the section, and it is overlain by units of the Flattop Mountain suite. In the absence of Ox Valley tuff the first appearance of the agglomerate was mapped as the base of the Reservoir formation.

The major thickness of the Reservoir formation is composed of soft, pink to white and gray tuffaceous sediments, thin-bedded (in some cases, cross-bedded) to massive; and rudely stratified pink or buff-colored volcanic conglomerates. The finer material is probably airfall tuff and ash deposits reworked by streams; it is quite similar to upper units of the Cove Mountain formation in the Middle Volcanic group. Problems arising from difficulty in distinguishing these rocks, as well as the igneous members of the Reservoir formation, from rocks of the Cove Mountain formation are outlined briefly under the heading of "Structural Geology."

Coarser sediments of the formation, largely conglomerates, are interbedded with the finer members but probably become more abundant in the upper portions. In some places they tend to merge with Quaternary gravels, rendering the location of the contact between these two formations very uncertain.

It is evident that the Reservoir deposits were accumulated over a period of time spanning the Flattop Mountain eruptive episode. Probably at least the upper portion of the formation is roughly equivalent in age to the Parunuweap formation of Gregory (1945), which is considered by him to be Pliocene(?). Cook mapped probable Parunuweap northwest of New Harmony in the Pine Valley Mountains, and his description of the lithology in that locality (1957, p. 38) accords well with characteristics of the sedimentary members of the Reservoir formation.

Older Alluvium (Qg)

Quaternary "gravel and older alluvium" shown on the geologic map is for the most part equivalent to the "high-level gravel" of Cook (1957, p. 39) and the "Boulder alluvium" of Proctor, said by the latter writer to have been deposited under conditions of accelerated erosion during the Wisconsin stage of the Pleistocene (1953, p. 41). It consists of sub-angular to rounded boulders and cobbles of all older rock units, in places with a sandy matrix and rude stratification; it is largely unconsolidated but locally is cemented by silica or carbonate. The largest boulders, which reach a diameter of ten feet or more, are usually Ox Valley tuff or basalts of the Upper Volcanic group.

In the southern part of the district the gravels rest upon a pediment cut on the soft deposits of the Reservoir formation. Modern streams have dissected the pediment to a depth of several hundred feet, leaving gravel-veneered remnants at accordant levels. Several pauses in the downcutting are recorded by the presence of lower terrace levels, but the gravel (largely basalt) capping these is not distinguished on the map.

Equivalent gravels are present in the north near the town of Enterprise, but here, where the drainage is interior rather than to the Colorado River as in the southern half of the district, there has been considerably less dissection. The gravels merge insensibly with material mapped as Reservoir formation, so that the indicated contact is in some places rather arbitrary.

Gravel-mantled slopes and remnants of gravel terraces were mapped at many places in the mountainous center of the district. Some of the highest ridges on the Bull Valley-Big Mountain arch are mantled by boulders, for example as indicated on the map north of Hardscrabble Hollow. The high-level gravels may have been deposited during the accumulation of those resting on the pediment; the terraces are probably younger. Older alluvium in the Mountain Meadow area east of Big Mountain consists chiefly of gravel but includes deposits of probable mudflow origin. In some places the gravel is probably as much as 300' thick.

Alluvium (Qal)

Material mapped as Quaternary alluvium consists of modern stream deposits and fine-textured fill material of Recent age. The latter accumulated as a result both of drainage interruption by basalt flows (Ox Valley) and Recent Basin-Range type faulting (Mountain Meadow; Escalante basin). The maximum thickness is estimated to be 200'.

IGNEOUS ROCKS

General Statement

The igneous rocks of the Bull Valley district reveal a long and complex history of eruptive activity. Hypabyssal intrusive rocks and extrusive volcanics comprise the major portion of the map area. Much of the igneous record closely parallels that of the adjacent Pine Valley Mountains and Iron Springs district, but in Bull Valley it is more complete, owing to preservation of certain units from erosion and to the existence of eruptive episodes not affecting the other areas.

Extrusive volcanic rocks include the following genetic types of deposits: lava flows, ignimbrites, airfall tuffs, and intermediate types whose mode of origin is uncertain. Many of the units demonstrably issued from sources within the district. There are two principal eruptive centers: the Bull Valley complex in the center of the map area, of Oligocene-Miocene(?) age, and the Flattop Mountain complex in the northwest corner, of Pliocene(?) age. Each center is a focus of major deformation associated with intrusion and extrusion of large quantities of magma. The rocks produced by the two centers, both intrusive and extrusive varieties, are designated the Bull Valley and Flattop Mountain suites, respectively. For convenience of presentation, volcanic deposits older than the Bull Valley suite are referred to as the "Lower Volcanic group"; those emplaced between the Bull Valley and Flattop Mountain episodes as the "Middle Volcanic group"; and those younger than the Flattop Mountain suite as the "Upper Volcanic group." Major rock units of each division are treated in this section in their chronological order of succession, to the extent that it has been possible to determine. Dike rocks are described briefly at the end of the section.

Inferred intrusive or vent phases of rocks with known stratigraphic position are described along with their extrusive equivalents. An attempt is made to distinguish the phases on the geologic map on the basis of field occurrence, but since intrusive and extrusive varieties are often nearly identical lithologically, the depicted vent boundaries are largely diagrammatic. In some cases the mode of origin of an entire rock unit is unknown.

The term "ignimbrite" is used herein to denote the depositional unit formed by what is inferred to be a nuée ardente-type of eruption. The rock type is referred to as "tuff," or where accidental or cognate fragments are conspicuously coarse and abundant, as "tuff breccia." A rigorous use of the Wentworth-Williams (1932) classification of pyroclastic rocks was considered inconvenient when applied to ignimbrites. In the present work a tuff is loosely described as crystal, vitric, or lithic, or combinations of these, in accordance with the characteristics which serve to distinguish it from other tuffs in the field.

Both regionally widespread, sheet-like ignimbrites and smaller ignimbrites of more limited distribution are present in the district, as well as a type transitional to a lava flow. Cook (1957) has given a comprehensive review of the various volcanic rock types present in the Pine Valley Mountains, all of which are also found in the Bull Valley district, and Mackin (in press) has discussed the nomenclatural problems.

Petrographic data are included with the stratigraphic descriptions, except in the case of the Bull Valley suite, where petrography is treated in a separate section. Chemical analyses for several of the principal formations are presented in Table I, page 36.

No absolute age determinations have been made for any of the igneous rocks of the Bull Valley district. The Oligocene-Miocene(?) age tentatively assigned to the Bull Valley eruptive episode assumes approximate contemporaneity with the zircon-dated monzonite intrusions in the Iron Springs district (Mackin, oral communication); the Flattop Mountain episode is considered Pliocene(?) because it was concurrent with the deposition of material apparently equivalent to the Parunuweap formation, which Gregory (1945) referred to the Pliocene(?) on the basis of fossil fauna.

TABLE I

CHEMICAL ANALYSES

(Courtesy Columbia Iron Mining Co., C. V. Rooney, chief chemist)

	1	2	3	4	5	6	7	8	9
Fe(total)	1.7	.50	1.7	1.1	1.8	3.6	3.9	3.3	4.3
FeO	--	--	--	--	--	.39	.39	.65	.77
SiO2	68.40	80.80	71.20	73.80	69.40	63.4	60.40	63.80	61.80
Al2O3*	18.56	10.38	19.40	16.04	18.98	17.85	18.22	21.42	19.66
CaO	4.20	.60	1.10	.60	2.60	4.20	5.20	1.60	5.00
MgO	.90	.20	.20	.20	1.08	2.45	3.24	2.88	2.55
Na2O	1.24	1.08	1.46	1.57	1.18	1.16	1.12	1.61	1.09
K2O	3.97	3.17	3.57	3.70	3.38	3.38	2.44	1.93	3.61
S	.006	.005	.005	.004	.005	.010	.008	.007	.010
P	.046	.020	.030	.025	.045	.124	.124	.140	.124
Mn	.3	.12	.14	.14	.10	.14	.12	.12	.10
As	.01	.01	.01	.01	.01	.01	.01	.01	.01
Cu	.02	.02	.02	.02	.03	.03	.03	.05	.03
Ni	.01	.01	.01	.01	.01	.05	.04	.03	.03
Pb	.01	.01	.01	.01	.01	.01	.01	.01	.01
Zn	.03	.06	.04	.04	.04	.06	.06	.05	.05
Ti	.60	.80	.97	.61	1.27	1.08	.90	.96	.77

*Al2O3 not corrected for Ti.

1. Hogs Back fm., upper member at eastern extremity of Hogs Back.

2. Cow Creek rhyolite, intrusive phase in Cow Creek canyon.

3. Shinbone rhyolite, Bullrush canyon near mouth of Shinbone Creek.

TABLE I (continued)

4. Ox Valley tuff, hilltop south of entrance to Black Canyon.
5. Racer Canyon tuff, near road west of Dutchmans Ranch, Grassy Flat.
6. Rencher fm., Rusty tuff phase, Rencher section two miles south of Bull Valley intrusion on east side of Moody Wash.
7. Rencher fm., White tuff breccia phase, black basal vitrophyre in Moody Wash two miles south of Bull Valley intrusion.
8. Quartz monzonite of Bull Valley intrusion, pink altered phase.
9. Quartz monzonite of Bull Valley intrusion, gray fresh phase.

Lower Volcanic Group

Isom Formation (I)

General statement. Between the uppermost limestone of the Claron formation and the basal member of the Quichapa formation in most parts of the Bull Valley district are a number of flows, ignimbrites and thin sedimentary interbeds, collectively designated the Isom formation. The name is based on correlation of the ignimbrite members with those of the Isom formation of the Iron Springs district (Mackin, in press). Total thickness of the Isom at any one location in the Bull Valley district does not exceed 150'; in some places it is absent. Isom units apparently overlie the Claron formation without angular unconformity. Because isolated patches of the Isom ignimbrites occur, the upper boundary of the formation is considered to be a surface of erosion.

The three recognized members of the Isom in the Bull Valley district are, from the base upwards, as follows: (1) vesicular flow, (2) Baldhills tuff, and (3) Hole-in-the Wall tuff. This order of succession is based on observations outlined below. The Isom is not subdivided on the geologic map, although the members were usually mapped separately in the field.

Vesicular flow. The vesicular flow is the most extensive member of the Isom formation in the Bull Valley district. It may consist of several flows closely related petrogenetically, with a maximum thickness of about 130', as measured in Moody Wash. The megascopic characteristics vary greatly from place to place within the district. Generally, however, the flows are bluish gray to purple or brown, contain elongate vesicles commonly filled with carbonate or quartz, and tend to weather in smooth, angular, platy chips. Phenocrysts are notably rare (less than 2% of the rock) and consist almost entirely of plagioclase. However, between Gum Hill and Big Mountain, near Utah Highway 18, rocks thought to be the vesicular flow contain about 40% plagioclase phenocrysts. The plagioclase (about An_{60}) generally shows strong fluidal alignment in thin section. Magnetite, apatite, and a pyroxene(?) are also present but are sparse to rare. The groundmass is cryptocrystalline to glassy, with abundant specks and irregular fine grains of an opaque oxide, probably magnetite. As is commonly the case with volcanic rocks, the composition of the vesicular flow is insufficiently known for classification purposes, but the rock is tentatively considered andesite.

An outcrop of purple aphanite in Cove Wash near Wilsons Camp, and a black glassy rock found in contact with upper Claron sediments east of Magotsu Creek, are petrographically similar to the vesicular flow and may be feeder dikes for that unit. Both occurrences are too small to depict on the geologic map.

Southwest of the Bull Valley intrusion, the vesicular flow rests upon several tens of feet of ash and fine-grained volcanic sediments; elsewhere it rests directly on massive gray Claron limestone.

Another variety, which may be a distinct flow, occurs in the area from Big Mountain to Gum Hill and is best exposed at the Highway 18 roadcut where it underlies Hole-in-the-Wall tuff and associated sediments. It is characteristically dark red or black, weathering to platy chips or a hackly surface; some outcrops bear a strong resemblance to those of certain phases of the Little Creek flows in the overlying Quichapa formation. Conspicuously striated plagioclase and augite phenocrysts comprise about 25-30% of the rock in this occurrence, as shown by the histogram of Figure 3. Petrographic examination also discloses phenocrysts of pigeonite, biotite, and serpentinized hypersthene, in an intersertal to intergranular matrix of plagioclase microlites, pyroxene anhedra, secondary chlorite and serpentine, magnetite, and apatite. Numerous spherical vesicles are usually filled with tridymite, quartz, and carbonate.

<u>Baldhills tuff</u>. Near Twin Springs Ranch, west of Big Mountain, the only member of the Isom formation is a rock type not recognized elsewhere in the district. It is a very dense, highly welded, dark chocolate-colored latite vitric tuff containing a few phenocrysts of plagioclase and biotite (see Figure 3), with scattered vesicles and spherical

devitrification structures several millimeters in diameter. Minor sanidine and rare magnetite and sphene were identified in thin section; deformed shards are largely obscured by devitrification. The rock has a distinct microeutaxitic structure but appears massive in outcrop.

On the basis of lithology, the rock is tentatively correlated with the Baldhills member of Isom formation which underlies Hole-in-the-Wall tuff in the Iron Springs district (Mackin, in press; Christman, 1951). In the Bull Valley district the unit (about 20' thick) rests upon Claron limestone and is overlain by Leach Canyon tuff of the Quichapa formation.

Hole-in-the-Wall tuff. The Hole-in-the-Wall tuff is a salmon-colored to purple highly welded latite vitric tuff overlying the vesicular flow at several localities in Bull Valley. The occurrences are erosional remnants of a vast ignimbrite or succession of ignimbrites that must once have covered a large area in southwestern Utah; they are correlated on the basis of lithology and stratigraphic position with the unit of that name in the Iron Springs district, described by Mackin (in press) and Christman (1951).

The best exposures are provided by a road cut (Highway 18) north of Big Mountain, where about 20' of massive dull red-purple aphanitic rock overlie a thin black vitrophyre, which in turn rests upon several tens of feet of bedded white ash. Decomposed glass between the vitrophyre and aphanite gives the erroneous impression that the two are distinct and separate units. Elsewhere the unit is usually seen only as float or in isolated outcrops between the vesicular flow and suprajacent Leach Canyon tuff.

Phenocrysts are very rare except in the basal glass where they constitute as much as several per cent of the rock (see Figure 3). In addition to plagioclase, clinohypersthene, augite, and magnetite were identified in thin section, as well as rare phenocrysts of brown hornblende. Most of the rock consists of strongly flattened and distorted glass shards. Occasional elongate amygdules contain quartz and carbonate.

Quichapa Formation

General statement. The Quichapa formation is a succession of sheet ignimbrites with local intercalated flows, extending throughout much of southwestern Utah and southeastern Nevada. It was named by Mackin (in press) from exposures in Quichapa Canyon in the Iron Springs district; its occurrence in the Pine Valley Mountains has been described by Cook (1957, pp. 53-57).

The formation in the Bull Valley district consists of four members, with an estimated aggregate thickness of 2250'. The succession, from base upwards, is as follows: (1) Leach Canyon tuff, (2) Bauers tuff, (3) Little Creek breccia, and (4) Harmony Hills tuff. Except for the Little Creek unit, which is named for exposures at Little Creek near Pratts Camp in Bull Valley, the names are those of correlative units in the Iron Springs district. Correlation of the ignimbrites is based on the histograms of Figure 3, petrographic characteristics, and stratigraphic position. Since their general description has been given elsewhere, only features of particular interest will be treated here.

Over most of the district, at least, the Quichapa volcanics were probably spread upon an erosion surface of low relief. The "progressive unconformity" of pre-intrusive volcanics noted by Wells (1938, p. 481) was not established in the current study.

Leach Canyon tuff (Ql). The Leach Canyon tuff in the Bull Valley district rests variously upon Isom volcanics, Isom sediments, or Claron limestone, with a maximum thickness of about 350'. Generally it is the basal member of the Quichapa formation, although there are two possible exceptions: in the Big Mountain area and on the Manera uplift, where Little Creek units and Harmony Hills tuff, respectively, may rest depositionally upon older sedimentary rocks. Both of these possible exceptions are tentatively considered to be fault-contacts.

Typically the Leach tuff is a pink, moderately-welded rhyolite vitric-crystal tuff characterized by an abundance of red lithic fragments averaging about 1½" in diameter. Occasional pumice fragments may also be present. Normally the unit is massive, and in some places there is a gray or black glass at the base. The composition of phenocrysts in the majority of slices examined is given by histogram A, Figure 3.

However, in some areas "abnormal" phases are present. In Cove Wash, southwest of the Soft Iron uplift, Leach tuff is dark red, highly welded, and shows strong eutaxitic structure; the modal composition is somewhat different (histogram B). This occurrence is overlain by normal Leach tuff and may therefore merely represent a basal phase. The "abnormal" phases may, on the other hand, indicate the presence of more than one ignimbrite within the member.

Bauers tuff (Qb). Bauers tuff is the upper of two megascopically similar units in the Iron Springs district named by Mackin (in press) the Bauers and Swett Hills tuffs. Both units are widespread to the north and west, but because of either non-deposition or erosion the Swett tuff is not present in the Bull Valley district nor in the Pine Valley Mountains. The Bauers tuff, where present, always rests upon the Leach Canyon member. A single exception occurs north of Red Butte, where these two members are separated by several feet of finely bedded, consolidated ash. Maximum thickness of Bauers tuff in Bull Valley is about 200'.

The Bauers tuff is a red to bluish-purple, highly welded rhyolite vitric tuff, usually containing at its base a strongly developed black vitrophyric phase. The lower portion of the unit is characterized by marked eutaxitic structure, in which flattened white pumice fragments and white streaks, or "schlieren," are prominently contrasted with the red stony matrix. Usually the foliation of the "schlieren" is parallel to the base of the unit and thus may be used to measure attitude, but local contortions may give erroneous values.

Average modal composition of the unit is given in Figure 3. Vitroclastic structure is obvious in thin sections from the basal glass and eutaxitic portions, but completely obscured by devitrification in the massive upper portion.

Little Creek breccia (Qlc). Between the Bauers and Harmony tuffs in most parts of the Bull Valley district there is a thick succession of andesite(?) flows and flow breccias, herein designated the Little Creek breccia. The number of individual flows is not known, but the variety of colors and structures is remarkable, especially in the breccia phases. Maximum thickness of the member is estimated at about 1200', on Copper Mountain, southwest of the Bull Valley quartz monzonite intrusion. This figure may be excessive due to the possibility of repetition by faulting. The unit thins abruptly north of the Manera uplift and again near Red Butte, where Harmony Hills tuff rests directly upon Bauers tuff. The same is true in parts of Little Willow Basin, southeast of Hardscrabble Hollow.

Little Creek breccia always rests upon Bauers tuff except where the latter unit has been tectonically eliminated, or possibly had been removed by erosion prior to the Little Creek episode. Similar dark flow rocks are present at the same horizon in the Iron Springs district and in parts of the Pine Valley Mountains; their westward extent is not known.

Most typically the material is dark red to dark purple, but there are light phases of the same colors, and also gray, green, brown, and black phases. Phenocrysts of green pyroxene and clear or white (where altered) plagioclase are set in a glassy to subvitreous or aphanitic matrix; the rock is usually very dense and hard, and is either massive or shows prominent devitrification structures and brecciation. A red hematite staining in some places produces irregular color bands. Microvesicles are occasionally conspicuous.

The average modal composition of the thin sections studied is shown in Figure 3. Plagioclase (An_{55}-An_{65}) occurs as phenocrysts to about four millimeters long, averaging $1\frac{1}{2}$ millimeters long, and also occurs in all smaller sizes down to fine microlites. Rounding of prism terminae on the larger forms is distinctive. They usually contain abundant vermiform brown pleochroic or bleb-like glass inclusions, and occasionally have a turbid alteration which is more pronounced on the more sodic exterior portions. The pyroxene phenocrysts have about the same size range as the plagioclase and consist of hypersthene and augite. Hypersthene in some cases shows inclined extinction; it comprises 0 to 50% of the pyroxenes. Magnetite occurs abundantly as equant, subhedral phenocrysts and also as small flecks scattered in the groundmass. Very rarely there are rounded, hematite-rimmed crystals of red oxyhornblende and biotite, and prisms of apatite. The groundmass is felty to hyalopilitic, in some cases containing a high proportion of glass. No chemical data are available but the rock is tentatively considered andesite.

In most thin sections the pyroxenes have been partially or wholly altered to pseudomorphic aggregates of pale tan to greenish fibrous serpentine(?) and magnetite. Hypersthene apparently more readily succumbs to this type of alteration than augite, and hence may be entirely altered where augite is fresh. That the alteration is associated with devitrification of the groundmass is demonstrated by photomicrographs G and H of Plate 4, p. 171. The section was cut across a red, stony spherical devitrification structure about one inch in diameter occurring in a black vitrophyric phase. Within the structure the groundmass is turbid and contains much hematite; augite is fresh but hypersthene is largely altered to antigorite(?). On the outside, all constituents are fresh; the groundmass is hyalopilitic, with globulites and fine grains of magnetite, pyroxene, apatite and clear glass in the interspaces between plagioclase microlites.

Devitrification features and associated endomorphic alteration are a common characteristic of Little Creek flows. It may occur in continuous layers an inch or two thick, spaced several inches apart (D, Plate 7, page 173). or as layers of spheroidal structures, or as scattered spheroids with no evident orientation. Layering is commonly parallel to the inferred base of the flow but may also be approximately normal thereto. Rate of cooling and volatile constituents of the melt are probably controlling factors.

The type of brecciation commonly occurring in Little Creek deposits is not tectonic, nor is it likely to be the result of a slowly moving flow engulfing its own congealing upper portion in the way discussed by MacDonald (1953). More probably it is "autobrecciation" of the type described by Curtis (1954) in the Mehrten andesites of California. Round or subround blocks of vitrophyric, vesicular flow material are set in a lighter-colored ashy matrix of the same composition, and on detailed examination, the boundaries of the blocks often cannot be sharply defined (E, Plate 6, page 172). The mechanism of formation of this type of breccia, as set forth by Curtis, is mentioned later in connection with the mode of origin of breccias of the Rencher formation.

Harmony Hills tuff (Qh). The uppermost member of the Quichapa formation, named by Mackin (in press) for exposures in the Harmony Hills, is a biotite hornblende-augite quartz latite crystal tuff strikingly similar in mineralogical and chemical composition to the units of the Bull Valley eruptive suite. It rests variously upon Little Creek breccia, Bauers tuff, and--north of the Manera uplift--directly upon Leach Canyon tuff. The maximum thickness is estimated at 500', south of the Bull Valley intrusion.

Most occurrences of Harmony tuff are lightly to moderately welded, form dark pink to red resistant outcrops, and contain at the base a black to greenish-black vitrophyre. Commonly a eutaxitic foliation of the biotite phenocrysts is strongly developed. Whitish lenticules or discoids are another characteristic feature; these commonly weather into "pocks," from which the depositional attitude may be inferred.

The mineralogical composition is given in Figure 3. No samples from the Bull Valley district were analyzed chemically but the unit is undoubtedly correlative with "Dacite from Swett Hills" in the Iron Springs district, whose analysis is given by Leith and Harder (1908, p. 58). Because of the chemical and mineralogical similarity to the Bull Valley suite (Table I), which is quartz monzonite-quartz latite, the Harmony Hills tuff is perhaps more appropriately designated quartz latite.

Two occurrences of Harmony tuff are of particular significance:

(1) South of Little Spring, Bull Valley. Here phenocrysts constitute over 45% of the rock, at the base of the member near the contact with multi-colored breccia of the Little Creek member. This figure is not approached by any other extrusive unit in the Bull Valley district, and in fact the rock looks much like the intrusive rock to the north across Moody Wash and is similarly jointed. Highly welded vitroclastic structure is evident in thin section.

About $1\frac{1}{2}$ miles to the west, the underlying Little Creek flows and breccia have a measured thickness of 750' and there is no indication that they are appreciably thinner at the locality in question. Yet 300-400' of Harmony tuff overlie the Little Creek unit here. It is suggested that this locality is very near to a vent from which Harmony tuff issued. The possibility is somewhat enhanced by the aforementioned chemical and mineralogical affinities to rocks of the Bull Valley eruptive suite.

(2) East side of Moody Wash, two miles south of the mouth of Bellas Canyon. Exposures demonstrate that Harmony tuff is composed of at least two ignimbrites in this canyon. The lower, redder ignimbrite is overlain by about $1\frac{1}{2}$' of consolidated, finely bedded, ash and tuffaceous sandstone, and then by an upper, pinker ignimbrite which has slightly fewer phenocrysts. The two ignimbrites and the intervening

strata have approximately identical mineralogical composition. No glass or fragment-rich zone is present at the base of the upper member, nor is there any evidence of unconformity. It seems likely that two eruptions followed one another without any significant time lapse.

Bull Valley Suite

Introduction

The term "Bull Valley suite" is used here to denote all rocks produced by the eruptive center referred to earlier as the Bull Valley complex. The suite includes intrusive quartz monzonite, extrusive quartz latite, related latite whose mode of origin is not known, and altered siliceous rocks of unknown origin which are undoubtedly associated with quartz monzonite intrusion. Except for the siliceous rocks all phases of the suite are porphyritic, with conspicuous phenocrysts of plagioclase, biotite, hornblende and augite. Iron deposits and mineralization are also intimately related to this episode of eruptive activity.

The inferred sequence of events in the eruptive history is as follows:

(1) Hypabyssal emplacement of quartz monzonite magma, probably along the axial part of a Laramide structure, to form the Bull Valley-Big Mountain intrusive arch. The intrusion is a concordant body at the Big Mountain end of the arch but semi-concordant or stock-like at the Bull Valley

end. Phenocrysts were formed in the magma under plutonic conditions prior to hypabyssal intrusion.

(2) Solidification of the upper part of the magma, with development of xenomorphic microgranular groundmass textures in the peripheral material and microphenocrysts in material still liquid. This process was accompanied by further rise of the magma at the Bull Valley end of the arch and sloughing off of parts of the roof rock. Magmatic pressure was increased by concentration of volatiles during advancing crystallization.

(3) Sudden rupture of the roof of the Bull Valley end of the arch by explosive volcanism, resulting in the eruption of a nuée ardente of the Pelean type which gave rise to a thick deposit of ignimbrite material, chiefly on the convex (southeast) side of the arch. This event was followed by a very short lapse of time, during which insets were partially resorbed. Automorphic alteration of mafic phenocrysts occurred in parts of the consolidating magma but was not necessarily related to extrusion. Oxidation of iron occurred sporadically in rock close to the surface. Magmatic pressure again increased.

(4) Complete dislocation of the roof at Bull Valley, with eruption of a nuée ardente of the Katmaian type--a less violent explosion than the preceding one. The eruption culminated in the upwelling of a great quantity of magma from which volatiles had been distilled. The resulting

deposits have properties ranging from those of a crystal tuff, through a lava flow with pyroclastic texture, to an ordinary lava flow. During the eruption, blocks of the roof material were carried out over the earlier tuff deposits, and parts of both peripheral monzonite and roof were overturned and eroded by extravasation of the magma. Movement and deposition of iron probably occurred from the time of earliest automorphic alteration but largely postdated this second eruption.

Rocks known by field relations to be intrusive have holocrystalline groundmass textures and are mapped as quartz monzonite, while known extrusive rocks have cryptocrystalline or holohyaline groundmass textures and are mapped as Rencher formation (quartz latites). Since the Rencher material issued from the core of an intrusive body, there is actually complete gradation in mode of origin--hence in texture--between the intrusive and extrusive varieties. Vent material is generally cryptocrystalline and is therefore mapped as Rencher, although deep in the vent the monzonite-latite contact is arbitrary. The Rencher formation also includes certain latites of possible intrusive origin.

Intrusive-extrusive relationships and various "phases" of the Bull Valley suite defined in the succeeding pages are represented diagrammatically in Figure 6, page 54, which depicts a much-generalized restored section through the Bull Valley end of the arch just after eruption of the Rencher magma. The circled numbers refer to critical areas discussed later.

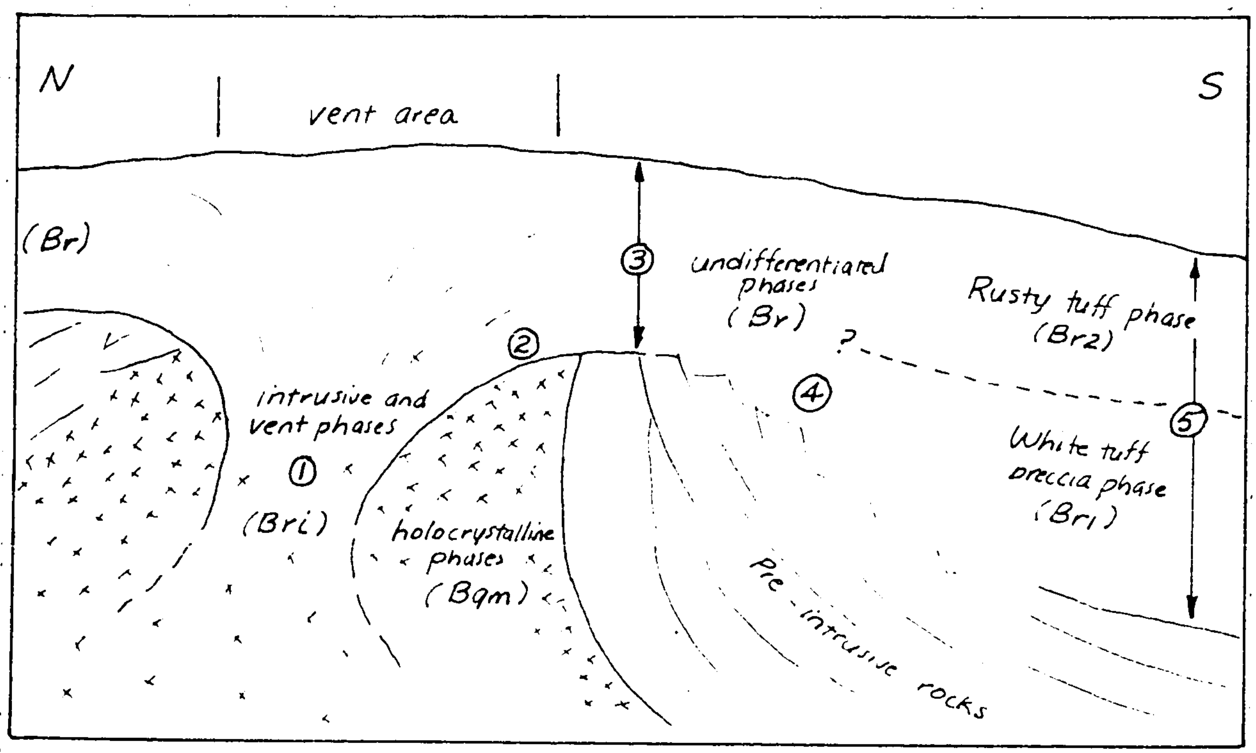


Figure 6. Diagrammatic section through the Bull Valley intrusion: intrusive-extrusive relationship and principal phases of the Bull Valley suite. Circled numbers refer to critical areas discussed below. Bqm=Bull Valley suite, quartz monzonite; Brl, etc.=Bull Valley suite, phases of Rencher formation.

The order of treatment of these rocks is as follows: field occurrences and megascopic properties of monzonite and latite phases are first described without detailed reference to petrography. The petorgraphy of the suite is then presented separately, followed by interpretive remarks regarding the mode of origin of the Rencher effusives and the eruptive history of the complex. Deformation accompanying extrusion as well as later structural modifications involving rocks of the Bull Valley suite are discussed under the section on structural geology.

Quartz Monzonite Phases (Bqm)

General statement. Aeromagnetic data (Columbia Iron Mining Co.) and structural evidence strongly indicate that the Bull Valley-Big Mountain arch has a core of intrusive rock throughout its extent. Quartz monzonite porphyry is exposed at either end of the arch (Bull Valley and Big Mountain), and near the middle (Hardscrabble Hollow). For descriptive purposes these occurrences may be regarded as three separate intrusions--the holocrystalline or quartz monzonite phases of the Bull Valley suite.

The Big Mountain intrusion was evidently the deepest of the three; petrographically it most closely resembles intrusions of the Iron Springs district. The Hardscrabble Hollow intrusion was intermediate, and at Bull Valley the intrusion, although at first relatively deep-seated, eventually eruped to the surface.

Big Mountain intrusion. The Big Mountain intrusion is exposed over a very limited area south of the Majestic fault on the south slopes of Big Mountain (see geologic map). Drill cores, magnetic data, and the general structural pattern indicate that the intrusion is much more extensive than its outcrop area, as demonstrated for example by Section MM' accompanying the geologic map.

Where exposed the intrusion is roofed concordantly by Homestake limestone and siltstone of the Jurassic Carmel formation, except on the west, where it is in contact with Cretaceous Iron Springs sandstone for some distance, possibly due to intrusive or post-intrusive faulting.

The intrusive rock is tan to gray holocrystalline porphyry with a groundmass sufficiently coarse for individual grains to be seen with a hand lens. Mafic constituents are usually altered, but the reddish colors that characterize altered mafics in the other intrusions are notably absent. In some places the rock is strongly jointed and hard; elsewhere, it weathers to roundish slopes of grus.

Hardscrabble Hollow intrusion. An erosional window through the Rencher formation and underlying rocks in the central part of the arch has exposed intrusive quartz monzonite porphyry to about the same extent as on Big Mountain (see geologic map). It is here referred to as the Hardscrabble Hollow intrusion, after the topographic feature by that name. The intrusion is bordered by Homestake limestone of the Carmel formation or Iron Springs sediments; it is believed to be concordantly roofed by the Homestake, but contact relations are not clear. The intrusive structure is asymmetrical to the southeast (Section KK' accompanying map). It is probably a cupola on the Bull Valley-Big Mountain intrusive arch.

Intrusive rock of Hardscrabble Hollow is red, white or gray in different places, the red color being due chiefly to hematite produced by alteration of mafics. It cannot be distinguished from similar phases of the Bull Valley intrusion in hand specimen. Nowhere does the rock form bold ledge outcrops or cliffs--it usually crumbles to coarse sand and forms rounded knolls.

Bull Valley intrusion. The body of holocrystalline porphyry at the southwest end of the Bull Valley-Big Mountain arch is the largest exposed intrusion in the district. Its outcrop pattern is an obtuse wedge whose apex is "The Spine" between Moody and Pilot creeks, as seen in the central part of the geologic map.

It is at this end of the Bull Valley-Big Mountain arch that the magma broke through to the surface and was spread out as the upper phases of the Rencher formation. The form of the intrusion is complicated by deformation accompanying extrusion of the Rencher material, as well as by later faulting, but it is essentially concordant on the south and discordant on the north.

The Bull Valley monzonite is megascopically distinguishable only with difficulty from the Rencher phase with which it is in contact on the northeast side of the wedge. The textural contrast between peripheral monzonite and latite can be seen with the aid of a hand lens, and the former is somewhat lighter in color, but the rocks are so nearly alike that the contact, as shown on the geologic map, may locally be misplaced by as much as several hundred feet. The restored section of Figure 6 illustrates the change from sharp monzonite-latite contact on the periphery of the intrusion to gradational contact in its core.

Peripheral phases of the intrusion are usually light pink or purple. In some places inside the periphery the rock is brown and resistant, as in parts of the gorge of Pilot Creek, but most of the heart of the intrusion--largely subjacent to material of cryptocrystalline texture mapped as Rencher--is white or very light gray, highly altered monzonite breccia. Cook (1957, p. 73) has described four color zones in the Pine Valley laccolith: an upper purple, a middle white, and two lower brown zones, with the middle white zone the most altered of the four and probably the last to solidify. The white interior monzonite of the Bull Valley intrusion is apparently analogous to Cook's middle zone.

Brecciation of the monzonite in peripheral zones probably resulted from forceful extrusion of Rencher material, but in the center of the intrusion it may be due to an autobrecciation process associated with the release of volatiles from a congealing melt (to be discussed later).

A fresh, resistant, "peripheral shell" phase such as described by Mackin (1947a) in the Iron Springs district is not conspicuously present in Bull Valley, nor in exposed monzonite elsewhere along the arch.

Rencher Formation (Quartz Latite Phases)

General statement. A considerable portion of the Bull Valley Mountains, especially higher ridges in the south and central areas, consists of effusive latite porphyry mapped as the Rencher formation. These rocks are in places very similar to the Harmony Hills tuff of the Quichapa formation, both in appearance and in mineralogical composition, but in contrast to the latter they do not have quartz phenocrysts. There is a complete gradation in mega- and microscopic characteristics between the Rencher rocks and the quartz monzonite intrusive rock described above.

The name "Rencher" was first used by Cook (1957) to designate the oldest post-Quichapa volcanic unit in the Pine Valley Mountains. The writer has visited Rencher localities in the Pine Valley Mountains; additional material has been kindly supplied by Cook from that area and by Mackin from the Iron Springs district. Based on petrographic data and the near-continuity of outcrops, the stratigraphic equivalence of the formation in these areas and Bull Valley seems well established.

Along most of the southeast side of the Bull Valley-Big Mountain arch the Rencher formation can be subdivided into two distinct members: a lower unit consisting predominantly of soft white tuff breccia, with associated darker and harder basal material--the "White tuff breccia" phase

(Brl); and an upper, resistant, reddish or rust-colored unit--the "Rusty tuff" phase (Br2). Over much of its extent --especially on or near the crest of the arch--the Rencher cannot be so subdivided and is mapped as "undifferentiated extrusive phases" (Br). This rock is believed to be largely the Rusty tuff phase, but probably includes some material of the White tuff breccia phase as well.

Latite which is inferred on the basis of field relations to be above or in the vent through which Rencher magma erupted to the surface is mapped separately as "intrusive and vent phases" (Bri), although it is often indistinguishable from definite extrusive phases. The same symbol denotes material of latite texture in the interior of the Bull Valley intrusion contiguous to the vent, and other occurrences of latite whose origin (intrusive, vent or extrusive) is not known.

Southwest of the Bull Valley intrusion, undifferentiated latite is overlain in a few places by additional latite deposits which have not as yet been definitely correlated with any other phases. These are mapped as "Upper phases on Cove Mountain" (Br3). They do not appear in the diagrammatic section of Figure 6; their relationship to other Rencher phases is illustrated later in Figure 10, page 74.

The various phases are described in the following pages. For convenience, a brief description of the altered siliceous rock is also included in this section, although it is not considered a part of the Rencher formation.

White tuff breccia phase (Brl). The White tuff breccia phase of the Rencher formation is apparently the deposit of a single paroxysmal eruption from the Bull Valley end of the intrusive arch. Although none of this material can be traced directly into a known conduit, the approximate position of its source may be reasonably inferred on the basis of lithology and pattern of distribution.

The unit is distinctly mappable only on the south and southeast side of the arch. It generally rests with little or no angular discordance upon Harmony tuff of the Quichapa formation, but in many places--particularly southeast of the arch, where deformation effects accompanying Bull Valley eruptive activity may have extended to the periphery of the district--it overlies various faulted and brecciated Quichapa members. Maximum thickness (about 500') probably occurs within one to two miles of the Bull Valley intrusion. Here the foreign and cognate fragments are largest and most numerous, and the basal portions of the phase contrast most strongly with the upper portions; at more distant points the unit becomes a uniform, nonwelded or lightly welded crystal tuff.

Relatively close to the inferred vent--in a location analogous to (5), Figure 6, about two miles south of the Bull Valley intrusion--the White tuff breccia phase comprises the rock types illustrated diagrammatically in Figure 7. The upper part of the unit is soft white or light gray tuff breccia, with a high content of cognate inclusions and foreign fragments. This grades downward into more resistant light tan latite tuff containing fewer fragments and less-distinct cognate inclusions. The light tan material rests upon dense, dark red latite practically devoid of fragments, with a contact that is abrupt but apparently gradational

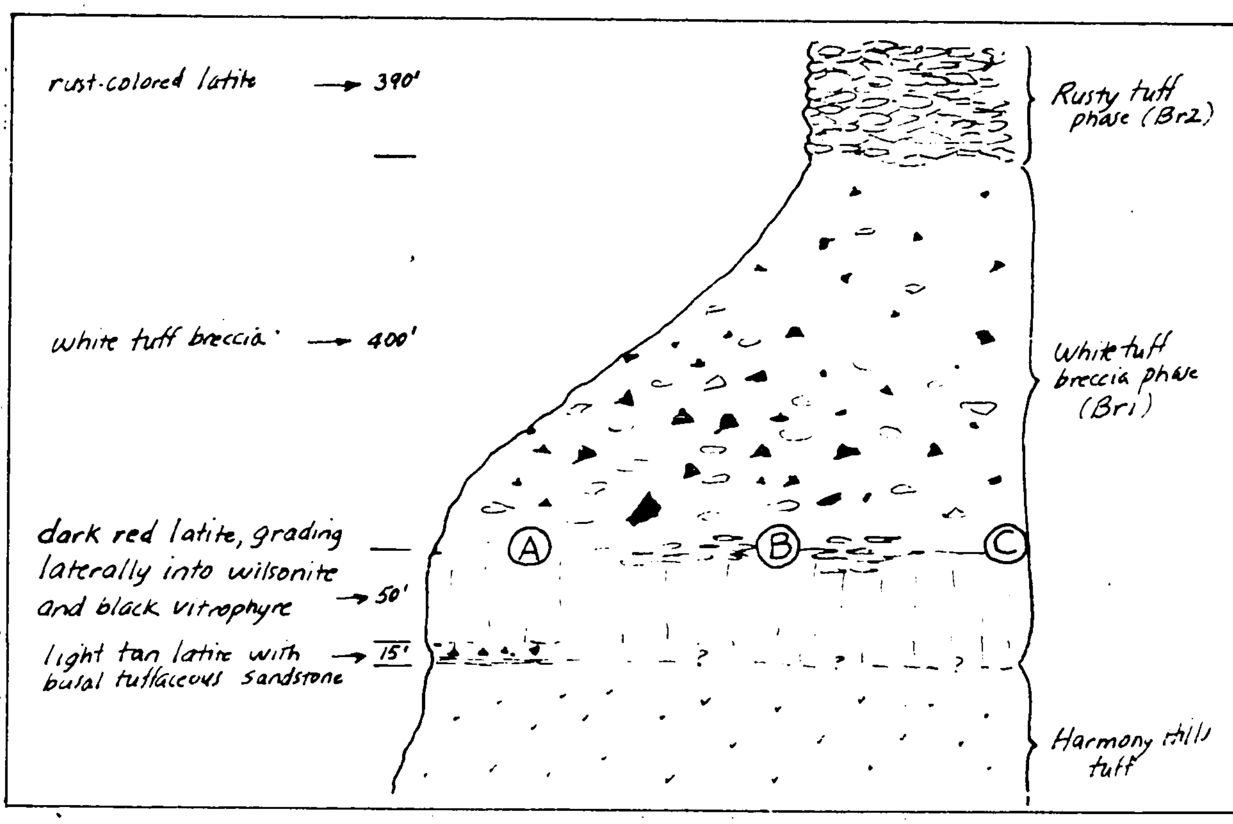


Figure 7. Diagrammatic sketch of Rencher White tuff breccia phase in Moody Wash, two miles south of Bull Valley intrusion, a locality analogous to (5), Figure 6. Numbers give measured thicknesses; circled letters indicate type of contact of basal material with overlying latite. A, gradational; B, wilsonite; C, sharp.

within 2 or 3' (A, Figure 7). Elsewhere in the same vicinity it makes a knife-edged contact with black vitrophyric latite (C of Figure 7; see also C, Plate 5, page 171) or is gradational into black glass through several tens of feet of material (B, Figure 7) in which lenticules of black vitrophyre 1-2" in diameter are set in a red, lithoidal matrix and are foliated parallel to the base of the unit. Marshall (1935, p. 330) terms this type of rock "lenticulite" or "wilsonite." The wilsonite and black vitrophyre are assumed to grade laterally into the dark red latite, as illustrated in the diagram.

At one location the dark red latite gradationally(?) overlies a few feet of light tan latite very similar to the tan rock above. Several inches of tuffaceous sandstone separate the entire phase from Harmony tuff of the subjacent Quichapa formation.

Foreign fragments appear to be abundant at the very base of the White tuff breccia phase, to be rare in basal glass or its equivalent (the dark red latite), and to become more numerous and larger as the dark latite grades upward into light tan latite and white tuff breccia, reaching a maximum in the latter. Such a vertical distribution of foreign fragments indicates that complete mixing of upper and lower portions of this deposit during the eruption could never have occurred. In a general way the lateral distribution of foreign fragments is a function of distance from the vent. A block the size of an automobile was found in tuff breccia south of the Cove Wash fault, two and a half miles from the vent, although most fragments average only about 4-6" at that distance. South of the Garden Spring fault block, about a mile closer to the vent, a block of Quichapa rock several hundred feet in extent is observed to have disintegrated in its upper portions, providing fragments for the white tuff breccia as illustrated in Figure 8, page 65. Large fractures in otherwise coherent Quichapa material are filled with Rencher latite. The base of the block was not actually seen but it appears to rest upon basal material of the White tuff breccia phase. Probably the block was torn from a position on the roof of the arch during the eruption, and was carried to its present position by the combined forces of the eruption and gravity.

All pre-intrusive rock types known in the district are represented by fragments in the White tuff breccia phase of Rencher. There are also numerous fragments of purple or tan quartz monzonite porphyry. The lithologic similarity and proximity of these to the Bull Valley intrusion indicate that they are pieces torn from that body, which must therefore have formed a hard crystalline shell by the time of the first Rencher effusive activity.

In some places cognate inclusions constitute as much as about 30% of the rock in the White tuff-breccia phase, greatly outnumbering foreign fragments. They are generally

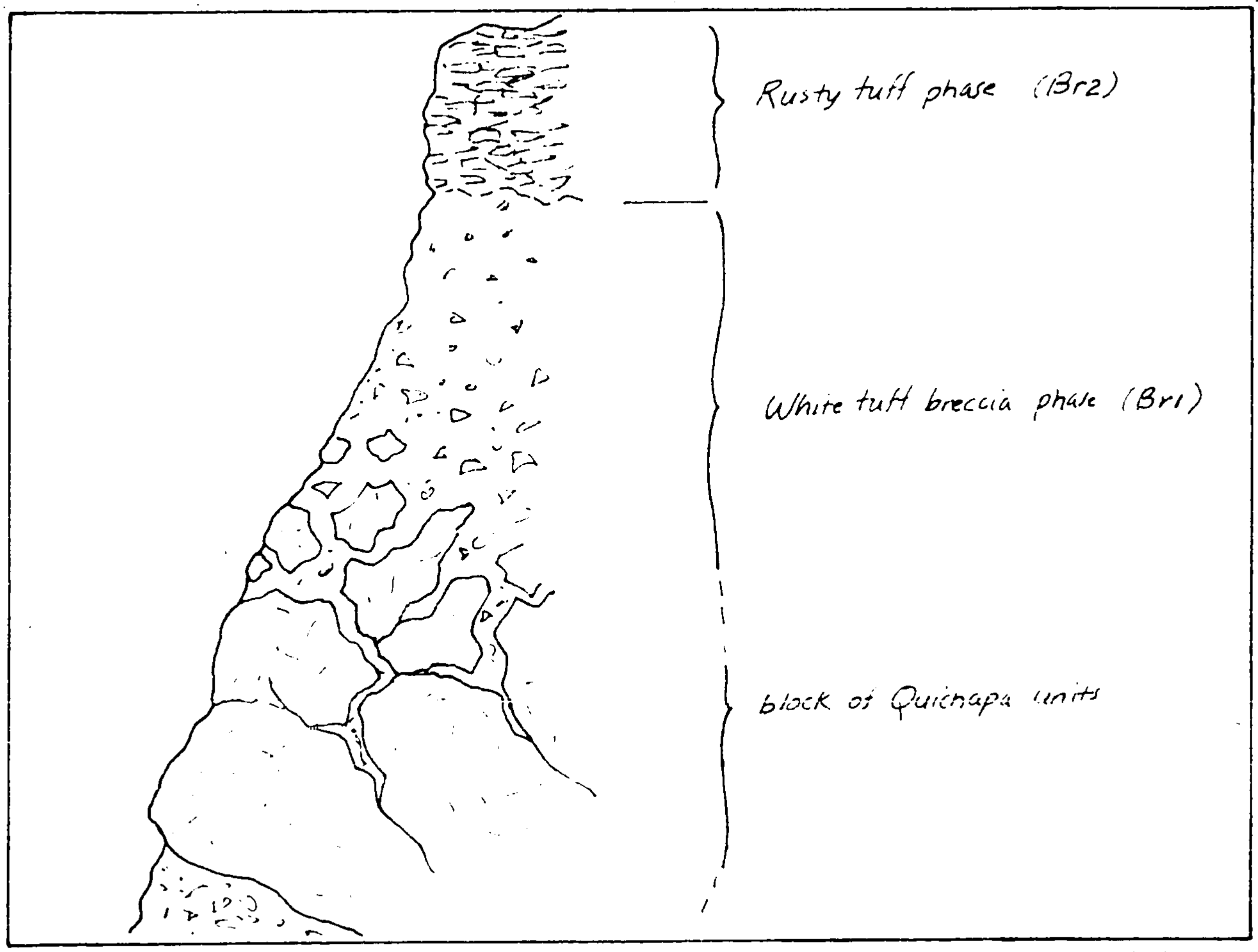


Figure 8. Diagrammatic sketch of block of Quichapa units in Rencher White tuff breccia phase, south of Garden Spring fault block--a locality analogous to (4), Figure 6. Block has disintegrated in upper portion; base rests upon Rencher latite.

somewhat darker and harder than the host rock and weather as subangular to subrounded ovoidal knobs. They probably represent liquid or plastic material not disrupted by explosive eruption and transportation; their origin is discussed more fully in a later section.

Rusty tuff phase (Br2). Overlying the White tuff breccia wherever that unit is distinguished is a rust-red, locally tan or gray, tuff-like latite porphyry mapped as the Rusty tuff phase of the Rencher formation. Excellent exposures of the contact have been observed in several localities. In some places it is abrupt (A, Plate 5, page 171), but elsewhere is apparently gradational within a few feet. It probably marks the boundary between deposits of a more violent, turbulent type of explosive eruption (the White tuff breccia) and a less violent but still explosive type (the Rusty tuff), which followed the first one very closely.

That the material composing the Rusty tuff phase issued from the core of the Bull Valley intrusion is established by tracing of outcrops continuously from typical Rusty tuff into rocks of the vent phase, as illustrated diagrammatically in Figure 6. The rock becomes increasingly tuffaceous away from the source area. At most places it is characterized by a type of brecciation wherein roughly rhomboidal, angular to sub-angular cognate inclusions are tightly packed together and eutaxitically aligned with the base of the unit. In some places these inclusions are subrounded; also, they may show a rude stratification. They are composed of dense, lava-like material, similar in appearance to the cognate inclusions of the White tuff breccia phase. Usually they are darker and more resistant than the enclosing matrix but the contrast is not always conspicuous; both contain abundant fragments of phenocrysts. The farther from the vent, the less conspicuous are the cognate inclusions, until at remote distances the rock is a massive crystal tuff. Typically it is moderately coherent as a result of welding of fragmental glass or devitrification following emplacement.

Cognate inclusions of another type are also observed in the Rusty tuff phase. In massive rock these appear as light-colored lenticules or discoids about one to four inches in diameter. They often weather out to form pock-marked surfaces showing strong eutaxitic structure. Petrographic study indicates that the discoids are cognate material which did not disintegrate during the eruption and contains no pyroclastic textures. Except for their lack of vesicularity, they are equivalent to the white pumice fragments common in many tuffs of the district. The same type of inclusions are present in the lava-like material near the vent and in the vent itself, although they may be less conspicuous there because of the dominance of other structures.

There is a strong resemblance between Rusty tuff remote from the vent and Harmony tuff of the Quichapa formation, particularly where the former is dark red or where either is altered. In a great many places identity was established only after laboratory examination. Generally, however, a distinction can be made in the field on the following bases:

(1) Mafic constituents of Rusty tuff are usually wholly or partially oxidized to a rust color; Harmony tuff mafics are commonly fresh and black.

(2) The feldspars of Rusty tuff appear to be less uniform in size and less euhedral than their counterparts in Harmony tuff; in the former they tend to blend with the groundmass material.

(3) Rusty tuff contains no phenocrysts of quartz whereas in Harmony tuff quartz phenocrysts are usually distinguishable from the feldspars upon close examination with a hand lens.

(4) Rusty tuff is usually a lighter color than Harmony tuff, and has fewer foreign fragments.

Undifferentiated extrusive phases (Br). Extrusive Rencher latites in much of the area mapped were not subdivided into White tuff breccia and Rusty tuff phases, in part because only one phase is present, and in part because of insufficiently detailed mapping.

On the crest of the Bull Valley-Big Mountain arch, most or all of the undifferentiated Rencher material undoubtedly is laterally equivalent to Rusty tuff, since it can be traced continuously into that phase. West and southwest of the Bull Valley intrusion and on the flanks of the arch, both the White tuff breccia and Rusty tuff phases are probably present.

Two occurrences of undifferentiated latite in the vicinity of the inferred vent are of particular interest--the first, because the latite demonstrates the transition from Rusty tuff to lava-like material of the vent, and the second, because it may have resulted from a different type of eruption than that which produced the Rusty tuff phase. Their positions with respect to the vent are both roughly analogous to locality (3), Figure 6.

(1) Between the Hardscrabble Hollow intrusion and material to the west mapped as vent phases (see geologic map), the Rencher formation comprises 500 to 1000' of dense, hard, purple to red latite porphyry of probable flow origin. It is typically brecciated in equant fragments a few inches to a foot in diameter, which lack a conspicuous orientation. Eastward, away from the probable source, the color lightens and the specific gravity appears to decrease; from lava-like, the material becomes tuffaceous. It is clear that the contact with known Rusty tuff is gradational rather than intrusive or depositional.

(2) On the ridge southeast of the Hardscrabble Hollow intrusion, Rencher latite consists of pink, gray and black glass breccia, in addition to purple and tan breccias of the type described above. The various glasses were not mapped separately and their mutual relations are not known. Some appear to be in the upper part of the formation; they consist of fragments of fresh latite vitrophyre several millimeters to a foot or so in diameter, which are identical in appearance to the basal glass of the White tuff breccia phase, set in an ashy, lighter-colored matrix. They may be agglomerates ejected slightly later than the principal

eruption of the Rusty tuff phase. Others occur at the base of the formation and were probably erupted with Rusty tuff as lava, which brecciated as it congealed.

In several places the basal portion of undifferentiated extrusive phases is composed of breccias of pre-intrusive rocks with a tan or yellowish latite matrix. Whether or not this material is equivalent to the White tuff breccia is not known. Underlying Rusty tuff at one location a short distance south of the Bull Valley intrusion is a very similar discolored heterogeneous breccia which is definitely the White tuff breccia phase.

Possible, probable and known intrusive and vent phases (Bri). Rencher latite is mapped as intrusive and vent phases in two general areas: in the center of and on the northeast side of the Bull Valley intrusion, and in the structurally complex area to the southwest (see geologic map).

The first area includes a major vent zone through which the Rencher magma erupted to the surface and a zone with rock of latite texture inferred to be in the core of the intrusion. The form of the vent is imperfectly known; boundaries sketched on the geologic map are largely diagrammatic, since the rock type of the vent intergrades with that of material mapped as undifferentiated extrusive phases. Two localities illustrative of the intrusive-extrusive relationship are described below.

(1) The mineralized area of the central part of the Bull Valley intrusion (see structure sections FF' and GG') is a vent or conduit through which at least a part of the Rencher erupted; it corresponds with locality (1), Figure 6. In a narrow zone less than 1000 feet across, and for a vertical distance of several hundred feet, the dense purple Rencher phase is highly charged with lighter-colored material in the form of lenticules, streaks, and irregular areas up to several inches in the longest dimension. The rock possesses steep to vertical foliation, with the proportion of light to dark material about 1:2. In thin section it is apparent that the light-colored material is holocrystalline, and lacks the pyroclastic textures of the host latite, nor is it as intensely altered. It seems to be the counterpart of light lenticules in extrusive phases--it had reached a more advanced state of crystallization prior to the eruption. Farther south and downslope or deeper within the intrusion than the mineralized zone, the foliated material grades into massive or brecciated rock whose texture is intermediate between latite and monzonite.

(2) At the eastern extremity of exposed Bull Valley quartz monzonite, a locality corresponding to (2), Figure 6, the Rencher material can be seen where it emerged from the vent as sketched in Figure 9, page 72. The layered latite is illustrated in A of Plate 5, page 171. Upper or lower contacts of the peripheral glass were not seen, but the

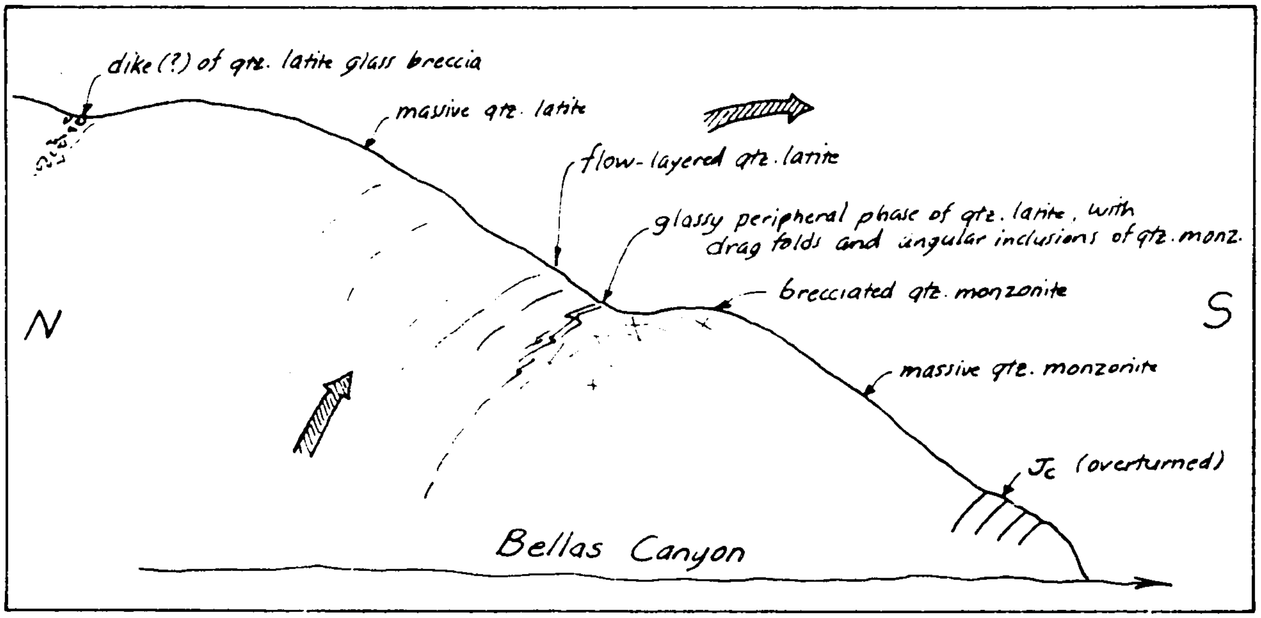


Figure 9. Latite-monzonite relationship at Bellas Canyon. Shaded arrows indicate inferred movement of Rencher magma during eruption to the surface.

monzonite must have been brecciated and scoured by the force of the eruption. In the limited exposure observed, the foliation dips about 60° to the north and flattens farther southward away from the vent. Progressively upslope (to the north), layering in the Rencher becomes less distinct, and tends to grade into the subrounded cognate fragments described previously, in Rusty tuff. The resemblance to Rusty tuff is striking in some places, especially where flow layering is pronounced, but higher in the section green, purple and reddish colors are predominant and the material is darker and denser than typical Rusty tuff. Adjacent to the inferred fault trending northwest-southeast in this vicinity (see geologic map), a black glass breccia occurs which is similar to the breccias southeast of the Hard-scrabble Hollow intrusion, a mile distant. It may possibly be a source dike for those deposits.

In the second general area where Rencher is mapped as intrusive and vent phases--southwest of the Bull Valley intrusion--there are a great variety of latite rock types and many structural complexities. The latite is bordered by brecciated and altered Quichapa volcanics and older rocks, but the nature of the contacts is not known. It may be intrusive into these rocks, or in conduits which led to the surface, or extrusive. Some of the latite resembles material of the White tuff breccia phase because of its color and a high content of foreign and cognate inclusions; elsewhere there are dense brown, red and purple latites with fluidal structures and textures transitional to quartz monzonite. A possible interpretation is that the rock comprises both early Rencher effusives (Br1) involved in deformation associated with later (Br2 or Br3) eruption, and the later eruptive material, which in this area was probably a lava flow.

<u>Upper phases on Cove Mountain (Br3)</u>. Southwest of the Bull Valley intrusion, on Cove Mountain, a two-fold sub-division of the Rencher formation has been made in several places (see geologic map). Neither unit is definitely cor-relative with the White tuff breccia or Rusty tuff phase. The upper unit consists of a variety of rock types not

encountered elsewhere; it may be younger than Rusty tuff and is therefore given a separate map symbol (Br3). Its maximum thickness at any locality is about 50'.

Material mapped as upper phases includes gray latite with fluidal structures, hard red-orange latite with pyroclastic structures, soft gray-bluish altered latite, and several occurrences of heterogeneous breccias with latitic matrix. No two isolated occurrences shown on the geologic map appear alike in the field nor under the microscope. The possibility that they are all laterally equivalent to Rusty tuff is seen in Figure 10, which illustrates diagrammatically their relation to other phases. In some places the upper

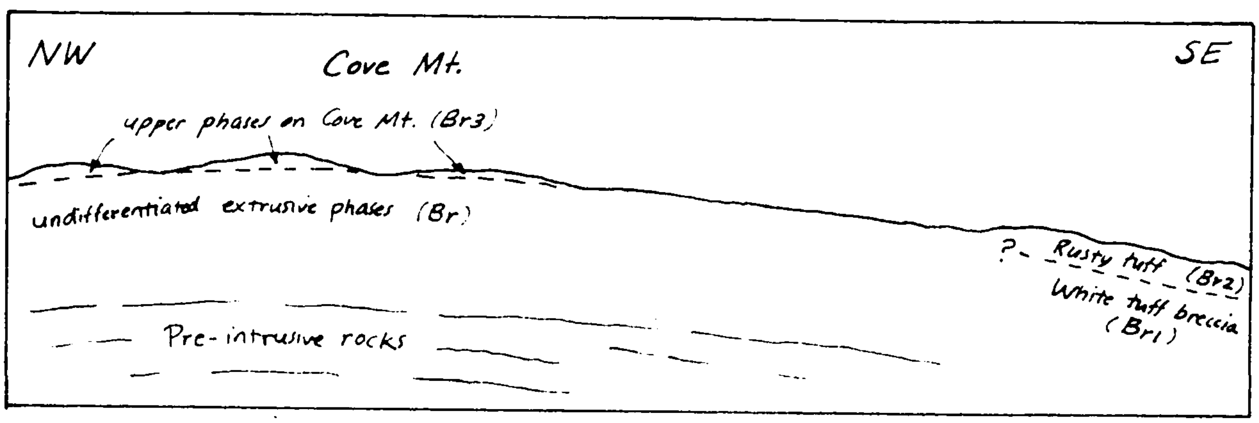


Figure 10. Diagrammatic section through Cove Mt. illustrating the relation of Br3 to other Rencher phases. Br3 may be laterally equivalent to Br2.

phases are separated from underlying Rencher material by about one foot of tuffaceous sandstone or air fall tuff of Rencher composition. This unit is locally the site of iron and silica deposition.

Altered rock with relict fragments (Ba). Intensively altered rock was mapped separately at several places on the western edge of the Bull Valley intrusion. It is light pink to reddish rock, usually with low density, abundant irregular cavities and relics of angular fragments. Much is strongly stained by hematite. In some occurrences the parent material is purple monzonite or latite porphyry--an extremely fine-textured phase which grades into the altered rock within the distance of a few tens of yards and is probably peripheral material of the Bull Valley intrusion. Elsewhere the altered rock consists of chunks of recognizable Quichapa units set in a pink, siliceous matrix.

The mode of origin of this altered rock remains unknown. At one locality it appears to have the form of a sheet dipping northwest away from the intrusion, but no contacts were seen which might indicate an intrusive or extrusive origin.

Petrography of the Bull Valley Suite

General statement. Because the Bull Valley suite embraces all rocks produced by a single episode of eruptive activity (including both hypabyssal intrusion and extrusion), its various phases share at least in part a common igneous history. Consanguinity is illustrated by the presence of certain mineralogical features characteristic of all units. Mineralogical, textural and structural variations are evolved during later igneous history, because of differing physical-chemical conditions in the hypabyssal environment and the effects of extrusion. Variations in initial composition of the parent magma from place to place may also account for some of the differences in rock type.

One hundred twenty thin sections and 500 thick sections of the Bull Valley suite were examined. Many of these were of specimens collected for stratigraphic purposes, but they include all known intrusive and extrusive phases. Photomicrographs of twelve thin sections are shown on Plates 1, 2, and 3, pages 167-9. Average composition of fresh specimens is represented by the histogram for the Rencher formation shown in Figure 3. The histogram is based on visual estimates of thin and thick section composition; a histogram for the holocrystalline phases is nearly identical. Real variations in most of the rocks exceed probable error of estimation.

Much intrusive and extrusive material is automorphically altered, the alteration being apparently related to the liberation and movement of volatiles in the magma. Furthermore, in many cases two or more textural types with differing degrees of alteration are present within a single thin section. Alteration effects and secondary minerals are discussed after description of the primary constituents; the section is concluded with a treatment of microtextures and structures.

In all but one or two exceptional cases, where the texture is seriate, the primary minerals of the rocks in the Bull Valley suite can be separated into those crystallizing earlier as phenocrysts and those crystallizing later as groundmass. Most phenocrysts are about 1 to 2 mm. long, but all sizes occur up to about one centimeter. They constitute from 25 to 40 per cent of the rock, averaging about 33 per cent, with the higher percentages occurring in the holocrystalline phases and in glassy or basal parts of the Rencher formation. Minerals crystallizing as phenocrysts are plagioclase, biotite, hornblende and augite; magnetite, apatite, zircon and, rarely, sphene are accessories; while quartz and potash feldspar are the major constituents of the groundmass.

Phenocrysts. Phenocrysts occurring in the rocks of the Bull Valley suite are described as follows:

(1) Plagioclase. Plagioclase, ranging in composition from An_{38} to An_{65}, but generally An_{45}-An_{55} (andesine-labradorite) is the most abundant mineral species. Usually it exhibits oscillatory zoning with a normal over-all trend (as many as 78 reversals were counted in one specimen); some show oscillatory zoning with reverse trends. Albite and Carlsbad twinning are common, frequently in combination, but other types of twinning were not observed. The habit is short prismatic. Prism terminae may be rounded by resorption, and in unusual cases there are embayments filled with turbid

material of the groundmass or tridymite(?). Inclusions of mafic materials are occasionally present, as well as small bleb-like inclusions of glass and/or tridymite(?), specks of opaque ore, dust and turbidity. One crystal was observed with vermicular inclusions of pyroxene.

Glomeroporphyritic clusters of plagioclase are not uncommon in phases of fluidal or intrusive origin; they consist of as many as a half-dozen crystals delicately intergrown. Plagioclase is also cumuloporphyritically intergrown with mafic minerals, especially biotite, of which it contains many inclusions. The feldspar seems to have been one of the earliest minerals to form and to have continued its growth during crystallization of the other phenocrysts.

(2) Biotite. Biotite is the most abundant mafic phenocryst, being present in all sections examined. Typically its pleochroism is tan-dark brown-opaque, or straw yellow-red-dark red. In a few sections shades of green are present; in others, the pleochroism is streaky or irregularly distributed.

Biotite in extrusive Rencher contains abundant inclusions of magnetite, often concentrated along cleavage directions; in other phases the magnetite inclusions are generally fewer, coarser and equant. Coarse biotite phenocrysts usually occur in thick books. The size of the crystals, particularly in Rencher phases, is roughly seriate down to microlite size and the books of intermediate and finer crystals are disproportionately thinner; they are often bent or otherwise distorted in extrusive (and even intrusive) phases. Also, the finer biotite crystals are typically much more automorphically altered than the coarser crystals.

(3) Hornblende. Hornblende occurs as medium to long prisms, up to about 1 cm. in length, the largest size attained by any phenocryst observed. The crystals are commonly tiwnned. As with biotite, they exhibit a variety of pleochroisms. Some have green pleochroism with Z to c extinction angles of about 12-25° (ordinary hornblende), whereas others have dark brown and red-brown pleochroism and extinction angles 0-12° (oxyhornblende). However, green and red-brown hornblende were not seen as discrete crystals in the same thin section.

Red-brown biotite and hornblende occur independently of the type of automorphic alteration to be discussed shortly, as they are often present in otherwise perfectly fresh specimens. The phenomenon of reddening has been studied by Kozu (1927), and Barnes (1930), who found that it results from oxidation of iron with concurrent loss of hydrogen from the mineral. Biotite begins to redden at 400-500° C and continues up to about 1000° C; hornblende becomes oxyhornblende at about 750° C (Kozu) or 800° C (Barnes) at a pressure of one atmosphere. In the Bull Valley suite holocrystalline phases contain low temperature forms, Rusty tuff contains high temperature forms, and the White tuff breccia contains both high and low temperature forms. Reddening is partially developed in undifferentiated Rencher near the vent, and in some Rencher mapped as vent phases (see Figure 6). Clearly oxidation of the pleochroic mafic minerals occurred during the process of extrusion.

Hornblende normally carries sparse inclusions of magnetite and plagioclase. Much hornblende may have formed early in the paragenetic sequence from augite, as the transition from augite to uralite can be found in all stages of development. Also the biotitization of hornblende is observed in different stages of development on the periphery of many phenocrysts.

(4) Augite. Augite is rare or absent in many thin sections, notably of Rusty tuff and upper Rencher phases on Cove Mountain. However, in some altered specimens of these rocks augite is the only mafic mineral, due to its apparent resistance to automorphic decay which has completely destroyed biotite and hornblende. The augite is colorless to faint green, with very weak pleochroism, and commonly has a short prismatic habit with occasional twinning. Extinction angles Z to c are about 45°. The outlines of phenocrysts are often rounded, presumably due to resorption by the groundmass. Although most augite is of normal phenocryst size, it also occurs in glomeroporphyritic clusters of crystals of smaller dimensions.

Inclusions of fairly coarse, euhedral to anhedral magnetite grains in the augite phenocrysts are typical. Many phenocrysts are stained a murky brown, in the core or in an intermediate zone, or exceptionally on the periphery. This is probably due to incipient uralitization--in some cases hornblende is partially developed from the brown staining. Although hornblende may be present in the core, there is no indication that augite has formed from hornblende. Pseudomorphs of augite after hornblende or vice versa were not noted.

Accessories. Magnetite, apatite and zircon are present as accessories in all sections studied of the Bull Valley suite. They appear to have had an early and possibly continuous history of crystallization, and occur both as inclusions in mafic phenocrysts and as discrete grains in the groundmass.

The most abundant accessory mineral is magnetite, which averages about 3 per cent of fresh rock, although the figure may include unrecognized ilmenite. It ranges in habit from euhedral or subhedral pyrogenic crystals up to 3/4 mm. diameter to late-forming minute specks in the groundmass. In extrusive phases, the magnetite grains are usually oxidized either entirely or peripherally and the specks in the groundmass are hematite. Even magnetite of holocrystalline phases almost always shows at least slight rimming by hematite. The oxidization, transportation and deposition of magnetite as a part of the process of automorphic alteration is discussed in the next section.

Apatite generally is present as fine clear rods or prisms, but coarser crystals in Rencher extrusive phases may have a pink, red or brown pleochroism. Such cases seem to occur where there is considerable automorphic alteration of the mafic constituents and oxidation of iron and it may be that development of pleochroism in apatite is some way related to that process. Apatite is also associated with mineralization.

Zircon is extremely fine, euhedral to subhedral, and sparse to rare.

In addition, sphene is present in a few sections, usually as anhedral interstitial grains in the groundmass, clearly postdating the crystallization of all other minerals. Like apatite, it is associated with alteration and mineralization.

Groundmass. The groundmass of the holocrystalline phases consists of microcrystalline anhedral to subhedral quartz and potash feldspar, the latter probably predominating, although some thin sections reveal almost none of one or the other. Lewis (1958, p. 12) reports a potash feldspar-quartz ratio of 38:17, or an almost eutectic proportion, in the Iron Mountain intrusion of the Iron Springs district, where the monzonite is nearly identical in chemical composition to that of the Bull Valley Mountains.

Apparently quartz and potash feldspar crystallized nearly contemporaneously, producing a characteristic xenomorphic granular texture in the groundmass, with quartz showing a slight tendency to be euhedral against potash feldspar.

In the Bull Valley and Hardscrabble Hollow specimens, as well as in all Rencher phases, the potash feldspar is sanidine (2V=0-20°) but in the Big Mountain intrusion both sanidine and orthoclase are present. This coincides with the presence of coarser groundmass textures in the Big Mountain rock and is probably due to the greater depth of burial at the time of final consolidation of the groundmass of that intrusion.

The groundmass constituents in Rencher phases of the Bull Valley suite are, by definition, for the most part too fine grained to determine under the petrographic microscope; textures are cryptocrystalline to holohyaline. Frequently, however, a set of microphenocrysts is more or less distinctly developed. These "second generation" phenocrysts are about the size of groundmass minerals in the holocrystalline phases, that is, average about 0.1 mm. in diameter, and consist chiefly of quartz and sanidine. The quartz, occurring as equant pseudomorphs after beta quartz, is often deeply embayed. Sanidine is less often embayed and commonly occurs as slender to short prisms, with or without conspicuous Carlsbad twinning. Plagioclase, hornblende, biotite and--in sections of vitrophyre--augite and hypersthene also occur as microphenocrysts.

Much clear, extremely fine-grained fragmental material with low to moderate negative relief is present in the groundmass. It appears to be fragmental glass, although in some cases a very weak birefringence is detectable with a gypsum plate. Because of the index of refraction of Rencher glass (1.490) it is often very difficult to distinguish from tridymite and cristobalite.

Secondary minerals and alteration. The alteration of mafic minerals in hypabyssal monzonite intrusions elsewhere in southwestern Utah has been described by Mackin (1947, p.45) and Cook (1957, p. 77). A similar breakdown of hornblende and pyroxene under conditions of decrease of pressure and slow cooling from a high temperature was reported by Mac Gregor (1938, p. 54) in the lavas of Montserrat.

Occurrences of rock in the Bull Valley district which have escaped this type of alteration are:

(1) Quartz monzonite in some places near the contact with Homestake limestone, north of Moody Wash.

(2) Basal glass of the White tuff breccia phase (Br1) and some zones in the upper part of that unit; glass breccia of undifferentiated Rencher (Br) southeast of the Hardscrabble Hollow intrusion.

(3) Basal portions of the Rusty tuff phase (Br2) or equivalent near or in the vent area, and irregularly elsewhere

in undifferentiated extrusive Rencher phases.

(4) Certain upper phases (Br3) on Cove Mountain, perhaps equivalent to (3).

In summary, all vitrophyric phases and some gray holocrystalline phases are fresh, while most other phases studied are more or less altered. The alteration may be described as automorphic, or deuteric, because it appears to be associated with the consolidation of the magma, or the imposition of a new set or sets of physical conditions upon a magma in the final stages of consolidation, whether it is intrusive or has been erupted to the surface. Phenocrysts, especially of the pleochroic (hydroxyl-bearing) mafic minerals, are transformed and replaced; iron oxides are redistributed and further oxidized; and secondary minerals appear in the groundmass. The type of alteration differs in intrusive and extrusive phases, but the two varieties intergrade in vent areas.

In the holocrystalline phases, automorphic alteration effects are as follows:

(1) Plagioclase is replaced along its periphery or internally by sanidine. In some cases the sanidine has evidently formed as an overgrowth on the rim during the consolidation of the groundmass, crystallizing in optical continuity with the plagioclase, but in specimens showing an advanced state of deuteric alteration it has grown by replacement of the plagioclase, both on the rim and in

cleavage or fracture directions within the crystal or in preferred composition zones.

In the Big Mountain intrusion some replacement potash feldspar is orthoclase instead of sanidine.

(2) Biotite and hornblende are wholly or partially replaced by fine aggregates of new sanidine and magnetite, both tending to be aligned along cleavage directions of the host. The hornblende sometimes appears to lose pleochroism as a first stage in this alteration, but the intermediate product is in very fine aggregates, and was not positively identified except in thin sections from Big Mountain, where it is actinolite-tremolite. In several instances quartz was found to be a constituent of the alteration aggregate.

(3) Augite is usually less altered than the other mafic minerals, although in exceptional cases the reverse is true. Partially altered augite is the only identifiable mafic remaining in some sections from the Bull Valley intrusion. The initial relative amounts of hornblende and biotite cannot be determined because there are no unaltered relics, and original crystal forms are obscured by the continued growth of sanidine, which in a few cases may reach the size of small phenocrysts. In general, the deeper within the intrusion, the coarser the sanidine aggregates--that is, the fewer discrete sanidine crystals replace a single mafic. Besides the usual transformation to sanidine and magnetite, augite of quartz monzonite and transitional Rencher rock in

the Bull Valley conduit breaks down into fine needles or slender prisms of secondary pyroxene. Similar material occurs as the product of incipient alteration on the rim of augite phenocrysts; as pseudomorphic aggregates after augite; as discrete anhedra to subhedra in the groundmass; and in zones of intense deuteric alteration, as crystals lining microcavities. It appears to consist of pyroxene ranging from augite through subcalcic augite to pigeonite, since estimated 2V's vary from about 60° positive to very low positive, approaching uniaxial. In one case a twinned crystal is half augite and half pigeonite, the twinning plane separating areas of different 2V. Morimoto and Ito (1958) have described a pseudotwin of augite and pigeonite and attribute it to exsolution.

Ionic substitution in the diopside-ferropigeonite series has been investigated by Kuno (1955), who found that a complete and continuous variation in composition from augite to pigeonite, passing through subcalcic augite, may occur under conditions of rapid cooling from a high temperature. Such conditions undoubtedly obtained at the site of the Bull Valley eruptions.

(4) Secondary magnetite is clearly formed as a result of the decomposition of mafic minerals. Some pseudomorphic aggregates contain as much as 60 per cent magnetite. In one section with only slightly decomposed pleochroic mafics, the least altered mafics have haloes of tiny magnetite grains.

It is possible that in some stage of the alteration process the mafic phenocrysts locally served as loci for the deposition of iron.

Where automorphic alteration is extreme, pyrogenic magnetite is usually completely destroyed, although commonly there are irregular concentrations of magnetite and hematite throughout the groundmass. Iron from the relatively coarse pyrogenic magnetite penetrates the surrounding groundmass as small fingers of ore between microgranular quartz and sanidine crystals. The breakdown of mafic minerals and pyrogenic magnetite appears to be contemporaneous.

In some specimens mafic phenocrysts are pseudomorphed by aggregates of sanidine only, and iron is conspicuously scarce in the groundmass. Thus, the automorphic process may result in a net enrichment or a net depletion of the iron in a given specimen.

Oxidation of, and concentration of, disseminated grains of iron ores in the groundmass is reflected in the color of the intrusive rock. Although no quantitative data are available it appears that purple and red zones contain relatively more finely disseminated magnetite and hematite, respectively. Oxidation and concentration of groundmass iron together with destruction of pyrogenic crystals seem to increase in the conduit area of the Bull Valley intrusion.

(5) Certain minerals present in the groundmass of automorphically altered rocks are evidently a product of the

alteration process, inasmuch as they are absent in fresh specimens. The only such minerals identified are sericite and chlorite. The former is common (to 5%) as very fine tabular plates with faint green pleochroism in the groundmass and also in some cases as a constituent of the pseudomorphic aggregate resulting from decomposition of a mafic mineral, hence probably as sericitized sanidine. Chlorite (pennine), and also fine-grained, late-forming phlogopite(?) were observed only in thin sections from Big Mountain. A tannish-green very fine fibrous secondary mineral with first order birefringence coats crystals and lines microcavities in some sections. Other sericitiform minerals may also be present.

In Rencher intrusive and vent phases the automorphic alteration is very similar to or identical with that of holocrystalline rock, but in extrusive phases there are significant differences. First, in the extrusive phases plagioclase is seldom rimmed or in any way altered except for occasional carbonatization. Secondly, pleochroic mafic minerals are transformed into fine aggregates of sericitiform material, and sanidine is subordinate. The iron oxides are in nearly all cases a mixture of magnetite and hematite distributed throughout the altered aggregate, forming a "boxwork." They do not occur as a few coarse crystals, nor are they ever missing, as they are occasionally in altered holocrystalline phases. The percentage of iron in the aggregate is consistently high.

The sericitiform mineral with a faint greenish or tannish pleochroism was identified in rare instances as sericite. It also occurs as fine shreds in the groundmass, commonly forming a halo around, or being concentrated irregularly in the vicinity of, the mafic which has undergone automorphic alteration. Likewise fine needles of a red opaque mineral (hematite?) are abundant in the vicinity of altered mafic phenocrysts. Thus at least a part of the alteration is post-emplacement, probably having occurred during exhalation of vapors while the deposited unit was cooling. However, the fact that some alteration occurred prior to final consolidation is indicated by the presence of bent aggregates pseudomorphic after biotite, which are found in some tuff specimens. If it be assumed that distortion of the biotite was effected during eruption, then at least at some places the sanidine replacing biotite had probably formed prior to eruption, since the individual grains of sanidine are also bent, and show strain extinction in regions of maximum curvature. The post-emplacement alteration was restricted to movement of iron from, and sericitization of, earlier-formed magnetite-sanidine pseudomorphic aggregates.

In Rencher extrusive rocks with less pronounced alteration, pleochroic mafics have undergone a hematization of the periphery, and also are surrounded by a halo of fine, discrete hematite(?) granules.

Deposition of silica also accompanied the movement of vapors through the cooling Rencher. A characteristic feature of all extrusive units except those with vitrophyric texture is the presence of minute spheroids of cristobalite(?). The spheroids have hollow centers, or have formed around a crystallite or microlite, or in still other cases have formed as hemispheroids on the faces of phenocrysts. Very fine tabular material of low to moderate negative relief and birefringence discernible only with a gypsum plate was in several instances identified as tridymite(?) by its low positive 2V.

Carbonatization is a type of alteration occurring in all phases of the Bull Valley suite, but is particularly common in intrusive and vent phases. The carbonate replaces phenocrysts and groundmass or fills cavities or fractures. Its presence in cognate inclusions in Rencher White tuff breccia phases probably indicates carbonatization prior to eruption.

Complete alteration to clay minerals and/or silica(?) is characteristic of the so-called "altered" phases (Ba); none of this material was identified. Other secondary minerals are associated only with iron mineralization.

Textures and structures. The rocks of the Bull Valley suite vary texturally from porphyritic seriate, in the deepest intrusion, to cryptocrystalline and holohyaline porphyritic in the effusive phases. It has been noted that the size of macrophenocrysts in all phases is approximately uniform, but that the crystallinity of the groundmass and the degree of development of microphenocrysts depends upon the magmatic history in a particular location subsequent to emplacement in the hypabyssal environment.

In addition, the rocks possess certain microstructures which may in some cases reflect this later history. They are described under the five general categories which follow; their genetic significance is discussed more fully in the next section.

(1) Fragmentation. Microfracturing of phenocrysts is usually present in all phases. Plagioclase is by far the most strongly affected mineral, although mafic minerals may be broken as well. Biotite (especially finer grains) is often distorted. Some grains show undulatory strain extinction.

Whether these structures resulted from forceful hypabyssal intrusion or sudden relief of pressure upon extrusion of Rencher is not known. That the shattering occurred in many cases prior to final consolidation is evidenced by the displacement of different pieces of a single crystal relative to one another as in a disturbed jigsaw puzzle, and by the presence of isolated crystal fragments, not only in the extrusive rocks but also in vent and holocrystalline phases. Extreme fragmentation when accompanied by intense alteration and turbulent fluidal structures in material which probably congealed from a melt, may indicate a violent distillation of volatiles from the liquid during eruption.

Broken phenocrysts and crystal fragments in the groundmass are very abundant in extrusive phases of the Rencher. Slightly separated pieces from which a parent crystal can be reconstructed are rare, and complex phenocryst intergrowths are virtually unknown. The two latter features in rocks of the Bull Valley suite may provide a measure of the violence of the eruption, as they would probably be destroyed under conditions of extreme turbulence.

No positively identified, typically curved glass shards were observed in any thin sections of the Bull Valley suite--that is, there are no definite fragmented vesicles. The groundmass of light latite at the base of the measured Rencher section in Moody Wash referred to earlier is packed with highly contorted outlines of either collapsed vesicles or glass shards, but the identity of most of these structures could not be established owing to devitrification, although some are clearly vesicles with hollow interiors. Dark red latite overlying the lowermost latite has wispy structures similar to those of the latter but again their identity is obscured by incipient devitrification. A thin section of black basal vitrophyre shows a groundmass consisting of patches of clear glass with perlitic cracks and strain fractures, little crystal debris, and possible compaction structures; and patches of altered, turbid glass with much crystal debris and possible shard structures. There is no positive evidence of fused or welded shards.

(2) Vesicles. With a few significant exceptions, vesicles in the Bull Valley suite are notably scarce. The occasional microcavities found in holocrystalline phases are irregular and seldom exceed 1/2 mm. in diameter. In Rencher phases the microcavities are usually smaller, less distinct, and are surrounded by a xenomorphic holocrystalline halo, suggesting post-emplacement crystallization effected by gases emanating from the cavity. Microcavities in monzonite may be lined or filled by quartz or chalcedony, while in Rencher, by quartz, colloform opal and tridymite.

One exception is the above-mentioned vesicular basal portion of the Rencher formation in Moody Wash. Whether or not those vesicles were ever disrupted is unresolved.

Another exception occurs in Rusty tuff, very close to its point of issue from the vent zone, a locality corresponding to locality (3) on the diagrammatic section (Figure 6). Thin sections from the dense base near the contact with Carmel limestone to the scoriaceous, frothy-appearing upper part in this locality demonstrate the intumescent character of the erupting material. The basal portion is largely cryptocrystalline with glassy patches, and contains numerous minute vesicles, usually irregular in shape but some roughly ovoidal, not conspicuously flattened. Although the plagioclase is highly shattered there are few crystal fragments in the groundmass. Several hundred feet higher, however, near the top of the section, there are highly vesicular areas with uniform cryptocrystalline porphyritic texture enclosed in a turbid cryptocrystalline to glassy groundmass, the latter containing broken crystals, turbid fragmental material, and crystallites. The contact between these two phases is highly irregular (see G, Plate 3, p. 169). The implication is that the vesicular type was exploding and expanding, and that in fact this vertical section represents a transition from basal lava-like material to higher tuffaceous material, through some agency of auto-explosion which is more effective in the upper part of the section. Such inclusions of one latite type in another (cognate inclusions) are discussed further on following pages.

(3) Foliation and fluidal structures. While it appears that no holocrystalline phases exhibit foliation of phenocrysts or groundmass constituents, such structures are usually present in Rencher phases. Foliation may result from compaction, as in White tuff breccia, or perhaps from a combination of compaction and flowage, which may apply to wilsonite zones in basal material. Foliation or lineation may also indicate liquid flow. In some of the sections of vitrophyre, such as the black glass breccia southeast of the Hardscrabble Hollow intrusion and certain upper phases on Cove Mountain (Br3), fluidal structure is indicated by

alignment of microphenocrysts, crystallites and microlites. Turbulence during emplacement probably accounts for vague convolute patterns of groundmass constituents often seen in other thin sections of Rencher.

Indistinct size layering in specimens of dense latite porphyry from possible vent phases west of the Bull Valley intrusion suggests fluidal structure rather than compaction foliation. The Rencher exhibiting this structure is probably either actual vent material or an extrusive lava flow. Foliated Rencher from a known conduit corresponding to Locality (1) on the diagrammatic section (Figure 6) is illustrated in photograph B, Plate 5, page 171.

(4) Devitrification structures. Spherulitic and subspherulitic devitrification structures have been observed in all extrusive Rencher phases. They are apparently not developed in latite of the Bull Valley conduit.

Some growths are especially spectacular in upper phases on Cove Mountain, where they are a shade of tan or orange in plane polarized light, showing several concentric growth stages, and are sufficiently coarse to be seen in hand specimens. Fine needles of hematite grow radially outward from the center. Areas between closely intergrown spherulites are commonly filled with magnetite and hematite; in other cases the interareas resemble collapsed vesicles with axiolitic devitrification such as that described in basal White tuff breccia material. Some plumose growths are observed to transect microlites. Hemispheres project into the groundmass from phenocrysts, and delicate "horsetails" of hematite have grown in like fashion.

Most of the spherulites probably consist of intergrown fibres of potash feldspar and tridymite. Other spherical structures were noted, however, which may be glassy beads similar to those described by Ross and Smith (1955), showing strain birefringence.

(5) Inclusions. Both holocrystalline and Rencher phases contain occasional inclusions of mafic clusters--cumuloporphyritic clusters composed predominantly of hornblende, augite, and biotite, but also of some plagioclase and euhedral pyrogenic magnetite. They reach a diameter of a centimeter or so but average about half that. Constituent grains are often about the size of microphenocrysts of Rencher phases--it is possible that dispersion of such clusters may have provided the mafic microphenocrysts noted in a few thin sections of Rencher. Some mafic aggregates have a well-defined internal structure, such as the following example: the core, an aggregate of very low birefringent pyroxene (hypersthene?), with irregular zones of magnetite subhedra and occasional hornblende and biotite, has a thick rim of closely packed and intergrown subhedra to anhedra of hornblende and some biotite. On this rim there is an irregular fringe of tightly packed euhedra of coarse augite with interspersed plagioclase laths. The maximum

diameter of the slightly ovate cluster is 3.5 mm.

Microscopic accidental inclusions of Quichapa and older rocks are largely confined to the White tuff breccia phase of Rencher. Rare insets of rounded quartz, and of ovoidal aggregates of xenomorphically intergrown quartz and sanidine, are found in holocrystalline phases and are probably xenocrysts.

Cognate inclusions, on the other hand, are present in many thin sections representing all Rencher units. In such cases the Rencher consists of an admixture of two types of rock: a lighter type of indistinct outline (the "cognate inclusions") enclosed by a darker type. Petrographic features distinguishing the two varieties are listed in Table II, page 99.

Megascopically the inclusions appear as light-colored lenticules in extrusive phases (Br, Br1 and Br2), from which there is apparently a continuous gradation to the holocrystalline lenticules in vent phases (Bri). Progressing outward from the vent the texture of the inclusions apparently changes abruptly from holocrystalline to cryptocrystalline or glassy; and pyroclastic structures and automorphic alteration effects become more pronounced in both inclusion and host.

Mode of Origin of the Rencher Deposits

General statement. Examples of hypabyssal intrusive bodies which broke their confining roofs and erupted to the

TABLE II

CONTRASTING FEATURES OF COGNATE INCLUSION AND HOST MATERIAL IN RENCHER FORMATION

Color	Lighter (inclusion)	Darker (host)
Vesicularity	More, where observed	Less, where observed
Phenocryst Clusters	More	Less
Texture of groundmass and spacing of phenocrysts	More uniform	Less uniform
Automorphic alteration and associated effects (sericitiform minerals in groundmass; dispersion and oxidation of iron in groundmass)	Less	More
Fragmentation of phenocrysts and associated effects (bending of biotite, amount of crystal debris and turbulence), ie., pyroclastic structure	Less	More

These contrasts may be either subtle or strong.

surface are known elsewhere in the Southwest. The "platy porphyry" which Cook (1957) has interpreted as a probable extrusive phase of the Pine Valley quartz monzonite laccolith, and the dacite dome of Mt. Elden in the San Francisco Mountains studied by Robinson (1913, pp. 78-84), were outwellings of a more or less viscous nature. In the Tintic district, several writers (Lindgren and Laughlin, 1919; Morris, 1947) have described stocks from which latite tuff and agglomerate were ejected, followed by extravasation of liquid phases.

That the material of the Rusty tuff phase of the Rencher formation is gradational with quartz monzonite in the core of the Bull Valley intrusion seems well established on the basis of field relations and corroborated by the petrographic studies. The evidence favors a similar location for the source of the White tuff breccia. Eruptive mechanisms by which these deposits might have been produced are now considered.

Mechanisms producing pyroclastic textures and structures. If the term "ignimbrite" is used to denote deposits intermediate in properties between ordinary lava flows and airfall tuffs, without implying a specific mode of origin, then the Rusty tuff and White tuff breccia phases of the Rencher formation may be called ignimbrites. Both have pyroclastic textures and structures and seem to require the operation of some sort of auto-explosive process during their emplacement.

The origin of ignimbrites has been treated extensively by many writers. Most concepts fall into one of two categories, both of which account for the pyroclastic structures of the resulting deposit: (a) the nuée ardente hypothesis (Marshall, 1935; Fenner, 1923, 1937, 1948); and (b) the collapsed froth flow hypothesis (Iddings, 1899; Grange 1934). In the first, ignimbrites are thought to be deposited from nuées ardentes, or "burning clouds," in which crystals, droplets of exploding liquid and accidental fragments are suspended in turbulent, rapidly expanding magmatic gas. Rapid passage of gas through discrete particles in a volcanic vent might be compared with the commercial process of "fluidization," as suggested by Reynolds (1954, pp. 580-582). The base of the cloud contains a higher proportion of solid and liquid matter and, upon moving away from the vent, behaves as a density flow. Small scale nuée ardente-type eruptions have been observed in several parts of the world in historical times. In the second hypothesis, the deposits are ascribed to mobile, vesiculating liquid which collapsed upon congealing.

The autobrecciation of lava flows may result in a third type of deposit with pyroclastic textures and structures. Curtis (1954), modifying the views of Durrell (1944) regarding brecciation in shallow intrusions, has proposed a mode of origin for pyroclastic debris in the Mehrten formation of California. According to his theory, viscous magma begins to vesiculate due to reduction of confining pressure as it approaches the surface. This process further increases the viscosity until the magma can no longer adjust internally by flow to the movement of the lava from behind, and it develops fractures along which differential movements may cause slight dilation. Adjacent semi-solid lava immediately spalls or explodes into these dilations. The process continues with additional movement, and may be climaxed by pulverization of the whole rock mass by attrition. The deeper the magma at the time of vesiculation, the more complete the brecciation and the smaller the size of the resultant pyroclastic structures.

A fourth possible way in which pyroclastic textures and structures are produced is by rapid boiling off of volatiles contained in a liquid. Separation of the component pieces of fractured phenocrysts and perhaps even shattering of whole crystals, destruction of delicate phenocryst intergrowths, bending of biotite, intense alteration, and turbulent fluidal structures in the residuum might testify to an earlier, violent passage of vapors through the liquid.

Proposed mode of origin. To some extent all of the processes mentioned above may have operative during the emplacement of the Rencher deposits; evidence presently available does not warrant definite conclusions. The hypotheses which follow are an attempt to explain not only textures and structures but also certain special features of these rocks such as the cognate inclusions, distribution of foreign fragments, brecciation structures, and vertical and lateral variations in lithology.

(1) White tuff breccia phase. The assumption is made that the entire White tuff breccia phase was deposited during a single eruption, and further, that the various types of basal material in this phase are laterally intergradational. The eruption is supposed to have been a nuée ardente of the Pelean type. Material initially merging from the vent contained a higher proportion of gas and of fragments of the roof of the intrusion, and was ejected with a greater violence and therefore to a greater height, than material subsequently emerging during the same eruption. The earliest material was finely "fluidized," whereas the later material was "fluidized" on a progressively coarser scale. Discrete particles in the upper part of the "burning cloud" presumed to have formed over the vent during the eruption were crystals, fragments of crystals, and very small fragments of the chilled groundmass, or glass, in addition to the relatively much less abundant cognate inclusions and exotic material. In the lower (and slightly later) part of the cloud, there was a high proportion of cognate inclusions of all sizes. Both portions moved away from the vent as a

density flow, but the lower part probably had less mobility than the material above--dense basal portions become less distinct with increasing distance from the source. That there was never complete mixing of upper and lower portions of the nuée ardente is strongly indicated by the comparative paucity of foreign fragments in the lower portion of the deposit.

The absence of vesicles, or shards indicating the former presence of vesicles, in the black basal vitrophyre described earlier is somewhat unexpected in view of the lateral gradation into material which is vesicular (whether fragmental or collapsed), and also when compared to the basal glasses of similar crystal tuffs such as Needles tuff and Harmony tuff. However, clear glass fragments in the matrix of the upper part of the deposit show no evidence of the typical cusps and curves betraying disrupted vesicles. Vesiculation must have occurred on a very fine scale, with shattering taking place before the vesicles appreciably enlarged. The glass of the vitrophyre is not the product of fusion of shards to the point of complete obliteration of shard structure, since there are no fragmental crystals in these areas of clear glass, in contrast to the fragmental, turbulent nature of the rest of the groundmass.

It might be argued that the basal vitrophyre is a discrete lava flow preceding the deposition of the remainder of the unit, and that partial microbrecciation occurred as the material was congealing in the manner described by Curtis. The apparent lateral transition into wilsonite, which is completely gradational with the overlying tuffaceous rock, renders this interpretation unlikely. Some relative movement between the material of the vitrophyre and overlying material may be necessary to account for the very sharp contact, but brecciation most likely occurred in the vent.

(2) Rusty tuff phase. The eruption of the Rusty tuff phase culminated with the congealing of material near and in the vent. The earliest material ejected--that deposited farthest from the vent--is typical crystal tuff, whereas the rock in the vent must have congealed from a liquid flow. Yet the two extremes are intergradational, and their petrographic characteristics are very similar; both bear a remarkable resemblance under the microscope to the material of the White tuff breccia phase. An hypothesis of the eruptive process which might have produced these rocks is set forth in the diagrams of Figure 11, page 106.

The eruption is supposed to have been less violent than that which resulted in the deposition of the White tuff breccia phase. It began, probably very soon after its predecessor (at least before much of the soft upper deposit of that eruption could be removed by erosion), with the emergence of a nuée ardente of Katmaian type from the vent of the Bull Valley intrusion. Comminution of the magma to produce the initial ejecta was effected by a "fluidization"

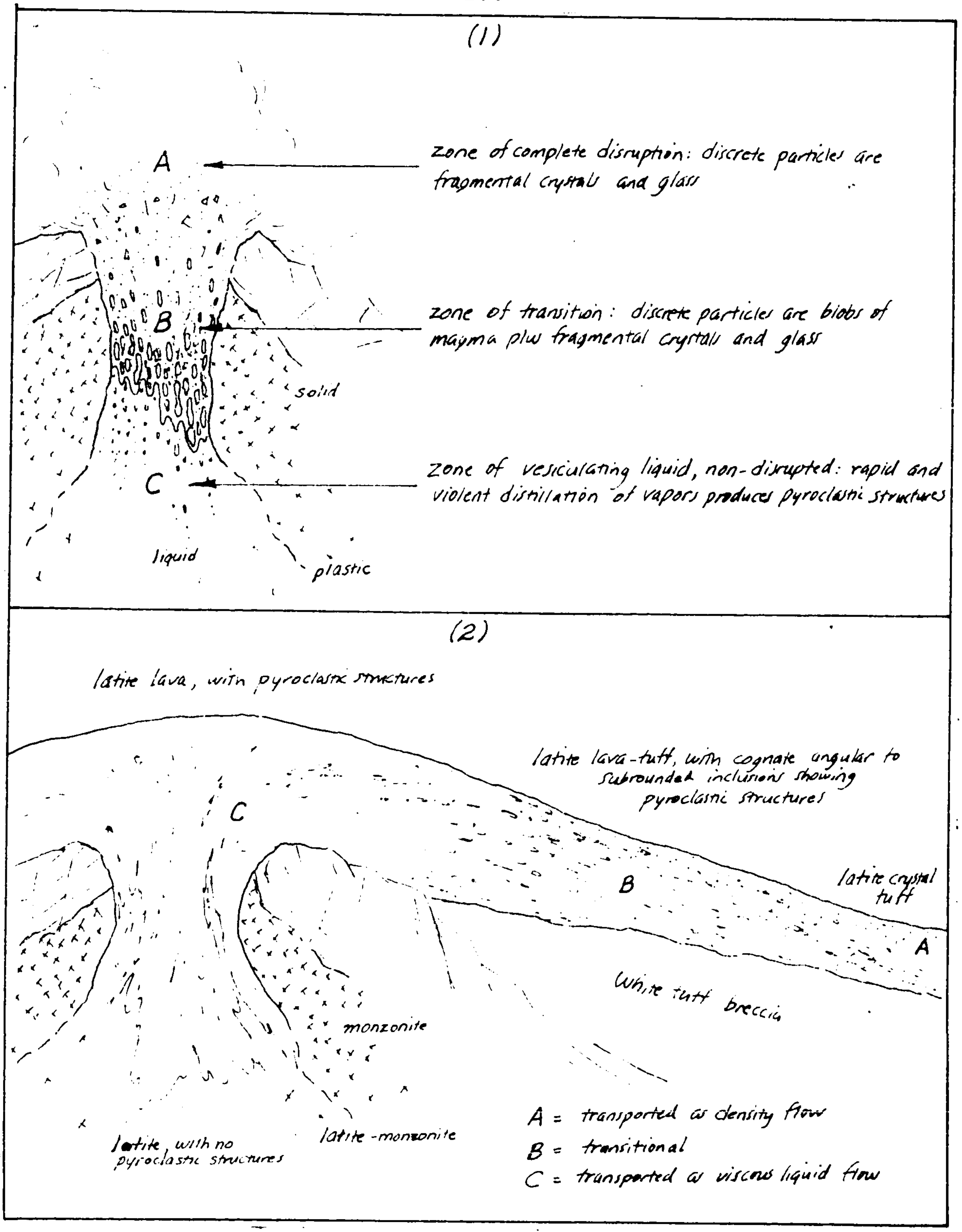


Figure 11. Diagrammatic sections through the Bull Valley intrusion illustrating mode of origin of the Rusty tuff phase, (1) at the beginning of the eruption of the Rusty tuff phase, (2) immediately after the eruption of the Rusty tuff phase.

process of the type discussed above; the material began to move away from the source as an "incandescent sand flow" or density flow of discrete particles in turbulent gas. However, the gas effecting fluidization may be envisioned as originating not only from explosion of the material being fluidized, but also from boiling of the liquid below in the vent, and rapid, turbulent upward passage of those vapors through the liquid to the position in the vent at which the magma solidified and disrupted. Three zones are illustrated in the upper diagram of Figure 11: (A) a zone of complete disruption, (B) partial disruption and (C) no disruption, of liquid in the vent. The products of all three of these zones are illustrated in the lower diagram. The latite crystal tuff found at points distant from the source grades laterally and vertically into lava of the vent, and all the material is characterized by pyroclastic structures regardless of the mode of emplacement. However, one important petrographic difference is observed--the groundmass of the vent material is cryptocrystalline because of incipient crystallization from a melt and contains no fragmental glass.

The light-colored lenticular inclusions in the Rusty tuff are completely gradational with the holocrystalline inclusions in the vent, and display all textures from glassy to holocrystalline. They are material which was ejected without disruption and through which there has never been turbulent passage of vapors; their texture depends upon the rate of cooling. At or near the vent there is much material in addition to the inclusions which lacks pyroclastic structures, as, for example, the latite at the base of the section corresponding to locality (3), Figure 6, described earlier. Such material may or may not be noticeably vesicular. Lavas with and without pyroclastic structures are intergradational. None of the latite in the interior of the Bull Valley intrusion assumed to be adjacent to, but not in, the vent, has those structures.

Geothermometry. A rough estimate of magma temperature prior to and during eruption may be made on the basis of the mineralogy of the Rencher effusives. Sanidine, according to Laves (1952) and others, forms only above a temperature of 700° C, and beta-quartz, between 573° C and 870° C. Thus the temperature during the formation of microphenocrysts was between 700° C and 870° C, assuming a pressure of one atmosphere (although the actual pressure must have been higher). At the time of eruption of the Rusty tuff phase, the temperature was not below 750° C as shown by the reddening of hornblende in the vent.

Middle Volcanic Group

Shoal Creek Breccia (S)

The episode of monzonite-latite eruptive activity was apparently followed by a considerable period of erosion, during which much of the Rencher formation and some Quichapa material were removed from the western portion of the district. Resting upon an erosion surface cut on weathered Rencher and Quichapa rocks at various places in the west, from Cove Mountain to Flattop Mountain, are the dark-colored, intermediate to basic volcanic deposits here designated the Shoal Creek breccia. The name is taken from exposures of breccia flanking Shoal Creek in the northwest corner of the area mapped, since these and similar breccias comprise the major thickness of the formation.

The breccias are dark, varicolored, massive to rudely bedded monolithologic deposits extending southward into the district from the low hills northwest of Enterprise, where they attain a thickness much greater than the maximum of 200' or so exposed in the map area. Constituent fragments are hypersthene-augite-hornblende andesite(?), of modal composition given in Figure 3. The hornblende phenocrysts reach a length of 1/4 inch in some phases; in others, the phenocrysts are uniformly fine-grained.

Thin sections show an intergranular to interseral groundmass texture, with laths of plagioclase in random orientation with rods and prisms of pyroxene, hypersthene and augite, and tiny grains of magnetite.

South of Maple Ridge the breccias include occasional fragments of holocrystalline porphyry, probably the Bull Valley quartz monzonite. Gray or green colors predominate, but various shades of brown, red and purple are also common. At some localities the monolithologic breccia is overlain by a red clastic breccia containing several different volcanic rock types.

As far as is presently known, the Shoal Creek breccia rests on no unit older than the Little Creek breccia, from which it is distinguishable in the field only with difficulty. It may be present in the structural complex west of the Spine.

An isolated erosional remnant of an amygdaloidal olivine basalt flow north of the Manera Wash fault on Cove Mountain was mapped as Shoal Creek breccia because of similar stratigraphic position. Its composition approximates that of the Pilot Creek unit, to be described shortly.

Maple Ridge Porphyry (M)

The Maple Ridge porphyry is a dark biotite-augite andesite(?) flow unit constituting most of Maple Ridge, at the west central border of the Bull Valley district. It evidently represents the frontal lobe of a lava flow which entered the district from the west or northwest. The thickness on Maple Ridge is estimated to be a maximum of about 300'. A second occurrence, with considerably less outcrop area, is on the north flank of Flattop Mountain North. There the base of the unit is concealed by alluvium, but it is inferred to rest upon Shoal Creek breccia, as it does on

Maple Ridge; it is a flow breccia of the type commonly occurring in the Little Creek member of the Quichapa formation.

Unusually large plagioclase phenocrysts--occasionally as long as one centimeter--which are set in a dark red-brown to purple groundmass, give the rock a distinctive appearance in hand specimen. Its composition was determined in thin section to be calcic andesine to sodic labradorite. Other phenocrysts are red-brown biotite, augite, red-brown oxyhornblende, magnetite, a few crystals of rounded and embayed quartz, and sparse altered olivine. Relative proportions of these constituents are shown in Figure 3. The groundmass consists of subtrachytically aligned microlites of feldspar, with dusty, turbid glass in interspaces, and considerable fine-grained iron oxide.

Cove Mountain Formation

General statement. The Cove Mountain formation comprises all rocks younger than the Maple Ridge porphyry and older than Ox Valley tuff, a sheet-like ignimbrite present in most of the district which serves as an excellent stratigraphic marker. It is divided into four members, which are, from the base upwards: (1) Willow Spring member, (2) Racer Canyon tuff, (3) Pilot Creek basalt, and (4) Cedar Spring member. In most places the middle two members are greatly predominant; the top and bottom units consist largely of volcanic sediments and airfall tuffs of lesser thickness and more limited distribution. Representatives of all members are well exposed on Cove Mountain, southwest of the Bull Valley intrusion, whence the formation derives its name.

Willow Spring member (Cw). Deposits of volcanic-derived material known or inferred to postdate the Maple Ridge porphyry, and upon which rest the tuffs of the Racer Canyon member, have been mapped separately where sufficiently thick and are designated the Willow Spring member of the Cove Mountain formation. At the type locality in Willow Spring Draw, north of the Bull Valley intrusion, these rocks have a thickness estimated at about 50'; they consist of white or gray cross-bedded tuffaceous sandstone, reddish volcanic breccia of possible mudflow origin, ash deposits, and volcanic pebble conglomerate.

In the absence of Maple Ridge porphyry at the base and/or Racer Canyon tuff at the top of these deposits, their stratigraphic position cannot be precisely defined. The former unit is not present in Willow Spring Draw but fragments of it are contained in the breccia between there and Maple Ridge.

Volcanic-derived sediments beneath Racer Canyon tuffs on Cove Mountain contain detrital pieces of iron ore, demonstrating that the basal units of the Cove Mountain formation postdate mineralization.

Racer Canyon tuff (Crc). The Racer Canyon tuff is a succession of rhyolite ignimbrites and associated tuffaceous interbeds unconformably overlying older rocks in the western and northwestern portion of the map area. Its maximum thickness is about 1500'. The number of individual ignimbrites composing the member is not known; there probably are at least four, all very similar in megascopic and microscopic characteristics. These rocks are particularly well exposed in the vicinity of Racer Canyon, northwest of the Bull Valley intrusion. Equivalent deposits occur in the Iron Springs district, where they have been designated the Kane Point tuff (Mackin, in press); in the Pine Valley mountains; and in the vicinity of Modena, about twenty miles north of the Bull Valley district. The tuffs have been traced on aerial photographs westward at least as far as the Nevada state line.

The rock of the Racer Canyon ignimbrites is white, gray or pinkish to yellowish, nonwelded to moderately welded, vitric-crystal tuff, which commonly weathers in spectacular, massive "hoodoos" (typical outcrops are illustrated by photographs D and F, Plate 6, page 172. Red or purple lithic fragments generally are abundant and conspicuous. In both composition and megascopic appearance the rock bears a striking resemblance to the Leach Canyon tuff of the Quichapa formation, from which it may usually be distinguished on the basis of its lighter color, lower degree of welding, higher biotite content and more prominent compaction foliation. Also, the Racer Canyon tuff in many places contains devitrification structures about the size of golf balls, and shows rude stratification--characteristics nowhere observed in the Leach Canyon unit.

At only one locality was a basal glass found in any Racer Canyon ignimbrite; this occurrence is puzzling because it is near the southeasternmost extent of the unit, where depositional thinning is suggested by the predominantly nonwelded nature of the deposits. A decrease in degree of welding, thickness, and number and size of foreign fragments normally occurring in a south and southeasterly direction implies increasing distance from the source, as in the case of the White tuff breccia phase of the Rencher formation.

Tuffaceous sedimentary interbeds about six feet in thickness are exposed between the uppermost two ignimbrites of the Racer Canyon member east of Grassy Flat, on the north side of Racer Canyon. They are composed of volcanic pebbles and pumice fragments in a tuffaceous matrix, with little or no sorting. Although rapidly accumulated, they reveal at least a brief erosional interval between two nuée ardente eruptions of apparently identical composition.

In the vicinity of Flattop Mountain, the Racer Canyon tuff has been subdivided into upper (Cru) and lower (Crl) units as indicated on the geologic map. The lower tuffs are gray to purplish or grayish pink, with conspicuous biotite; they are definitely correlative with Racer Canyon ignimbrites mapped elsewhere. With the upper subdivision, however, the correlation is less firm. These rocks may include equivalents of the uppermost (Cedar Spring) member of the Cove Mountain formation and also, where Ox Valley tuff is not observed, of even younger material (Reservoir formation). They comprise beds from several inches to several feet thick of buff to yellowish tuffaceous sandstone and conglomerate, above which rests nonwelded massive tuff highly charged with red and purple lithic fragments and yellowish pumice. Mafic minerals are locally absent from the tuffs or are much less conspicuous than in the lower unit. But except for a yellowish coloration and the mafics, there are no obvious differences between these rocks and those of Racer Canyon tuff farther south in the district. The underlying tuffaceous sediments appear to be correlative with those interbedded with ignimbrites east of Grassy Flat, although much thicker. Anomalous characteristics of the upper tuffs may be entirely due to weathering effects or to hydrothermal alteration associated with the Flattop Mountain eruptive episode.

The bulk mineralogical composition of Racer Canyon tuff (exclusive of upper units on Flattop Mountain) is shown by the histograms of Figure 3. There appear to be two distinct varieties present, but as in the case of the Leach Canyon tuff, it is not clear whether the variation is due to lateral changes within individual ignimbrites, or the presence of two or more ignimbrites with differing compositions.

A photomicrograph of a typical specimen of the tuff is shown in C, Plate 4, page 170. Quartz, statistically the most abundant phenocryst, is commonly slightly rounded and embayed. Sanidine has irregular crystal outlines. Plagioclase (An 35 - An 45) often shows faint oscillatory zoning and pronounced albite twinning.

Mafic constituents are predominantly biotite, which has brown-red-opaque pleochroism (or, occasionally, green), and is usually fine and scrappy rather than in thick books; and hornblende, in some sections nearly equal in abundance to biotite but absent in others. The hornblende has green to brown or reddish-brown pleochroism and extinction angles between 5^{o} and 15^{o}. Magnetite is an abundant accessory, commonly very fine and equant, and peripherally oxidized to hematite. Other accessories identified in thin sections are sphene (rare), apatite (a few coarse euhedra per section), and zircon (abundant but extremely fine). In addition, augite and hypersthene were noted in a thin section of the basal glass.

In most cases, the matrix of the Racer Canyon tuff is turbid and cryptocrystalline as a result of devitrification; clear glass from the basal vitrophyre has an index of refraction of 1.501. Relict shard structure may often be seen in plane polarized light. The shards do not generally exhibit appreciable distortion or flowage structures. Some appear to be enveloped by a rim of pinkish tridymite(?). Fragmental phenocrysts and foreign fragments are common.

Pilot Creek basalt (Cp, Cpi). Resting upon an erosion surface cut on Racer Canyon tuff and older rocks in many parts of the Bull Valley district is a member of the Cove Mountain formation designated the Pilot Creek basalt, for typical exposures in the gorge of Pilot Creek, north of the northwest corner of the Bull Valley intrusion. In that locality the unit consists of about 200' of dark-colored flow overlain by a similar thickness of flow breccia, which contrasts sharply with the underlying white tuffs of the Racer Canyon member. The basalt is generally red-purple and dense near its base, becoming brown or black and vesicular in the upper portion; except for the type locality only one flow is present in any one section. In hand specimen the material is characterized by numerous fine red or rust-color phenocrysts of altered olivine.

Occurrences of the Pilot Creek basalt known or inferred to be intrusive are designated on the geologic map by the symbol "Cpi." A major eruptive center for this unit is present near the northern border of the Bull Valley intrusion, where intrusive contacts are seen with the lower members of the Cove Mountain formation. The basalt is varicolored in the vicinity of the vent, probably due to hydrothermal alteration; some is gray or pink and readily confused with the Racer Canyon tuff which has been intruded and altered. At several other localities an intrusive origin is inferred but not proved.

The average estimated modal composition of several thin sections of Pilot Creek basalt is shown by the histogram in Figure 3. Textures vary from porphyritic to seriate; the histogram is intended to represent the composition of the entire rock including the principal finer constituents. Photomicrograph D, Plate 4, page 171, shows a typical thin section.

Plagioclase, of composition estimated to be labradorite on the basis of refractive index, rarely occurs as distinct phenocrysts but constitutes the bulk of the finer crystals, as thin laths or prisms approaching phenocryst size. Augite and olivine are the principal minerals occurring as phenocrysts. The pyroxene has a positive 2V of 30° to 60° and may be in part pigeonite. It is clear to very pale gray-green; the grains are generally subrounded anhedra with a maximum diameter of about one millimeter. Olivine has a 2V of about 90° and a maximum diameter of 2 mm. Most is altered to bright red iddingsite, with corroded, hematitized rims, or in some cases to a brownish serpentine(?) mineral. Both olivine and the pyroxene also occur as fine granules in the groundmass. Magnetite is the next most abundant constituent, dispersed throughout the groundmass as fine, equant grains. One thin section contains 3-5 per cent of coarse (to 2mm.) hypersthene, and a few slender prisms of oxyhornblende. All sections contain some unidentified cryptocrystalline material. Groundmass textures are highly variable, ranging from hyalopilitic to intersertal, intergranular, trachytic and pilotaxitic. Irregular vesicles constitute 0-30% of the rock volume.

Cedar Spring member (Ccs). Between the Pilot Creek basalt and suprajacent Ox Valley tuff there are at most places a few tens of feet to about 300' of volcanic conglomerate, clastic breccia, airfall tuff and ash, collectively designated the Cedar Spring member, for the occurrence at a locality by that name in the southern part of the district. The composition of the unit varies radically, depending upon location. The thickest deposits are loosely consolidated, massive to thick-bedded conglomerates and breccias composed almost entirely of material derived from the Pilot Creek member. Some of this material may have originated by explosion from a volcanic vent without subsequent stream action (agglomerate). Elsewhere, notably on or near the Bull Valley-Big Mountain arch, the chief detrital constituents are monzonite and latite probably derived from erosion of the Bull Valley intrusion.

A soft, pink massive airfall tuff, 10-20' thick, overlain by about the same thickness of white airfall tuff, characteristically constitutes the uppermost part of the Cedar Spring member. This sequence is widespread throughout the district and provides a useful stratigraphic marker. In places either or both tuffs contain abundant fragments of basalt.

A thin (6-15'), highly welded rhyolite tuff of a type very similar to Bauers tuff is also commonly present within the Cedar Springs member, occurring near the base of the marker sequence. It is designated the Lower Moody tuff (Ccsl), and is distinguished separately on the geologic map wherever encountered.

The Lower Moody unit is a chocolate or tan to purplish, but most commonly drab green, vitric tuff characterized by long, perfectly euhedral prisms of sanidine showing eutaxitic alignment. There is an almost total absence of mafic phenocrysts. If the ignimbrite ever had a "fluffy" or nonwelded top it was removed by erosion prior to deposition of the marker tuffs. Relict vitroclastic texture is clearly seen in thin section, although the shards have been devitrified to a cryptocrystalline aggregate of unidentified material. The phenocrysts are chiefly sanidine and quartz, in proportions indicated by the histogram of Figure 3. Abundant, very fine needles of hematite(?) are present in the groundmass, as well as fine grains of magnetite. Several crystals of a green pleochroic pyroxene were also noted.

<u>Ox Valley Tuff (O)</u>

The Ox Valley tuff is a rhyolite vitric-crystal tuff, named for typical occurrences on the hills overlooking Ox

Valley. It is widely distributed in the Bull Valley district, and because it is easily identified, serves as an excellent stratigraphic reference. The maximum thickness attained is about 400'. Although the source of the unit is not definitely established, the striking petrographic similarity to other rocks of the Flattop Mountain suite and an apparent thinning away from Flattop Mountain suggest that the tuff was erupted from that center.

At the time of emplacement of Ox Valley tuff, the Bull Valley-Big Mountain arch no longer formed a topographic barrier of great magnitude--not only had it been much eroded but the low area to the northwest of it had been largely filled by material of the Cove Mountain formation. The Ox Valley tuff probably completely covered the arch except for Big Mountain. It rests variously upon members of the Cove Mountain formation or Rencher latites. West of Flattop Mountain the unit is missing, either because of non-deposition or erosion; units of the Flattop Mountain suite rest directly upon the Cove Mountain formation. It was not found in reconnaissance of areas adjacent to the Bull Valley district on the north and east, but has been identified in the vicinity of Motoqua, 15 miles southwest of its probable source in the Flattop Mountain complex.

The tuff is light grayish-blue to pink or purple, lightly to moderately or highly welded, and contains very sparse lithic fragments. It is characterized by the presence of clear phenocrysts of sanidine showing blue iridescence, a feature which usually serves to distinguish it readily from all other rocks of the district with the exception of certain units of the Flattop Mountain suite. A basal glass phase of the Ox Valley tuff was not observed, but the lower part of the unit is darker and conspicuously more welded than the upper portion, weathering to cliffs and bold ledges (see photograph C, Plate 6, page 172). Where exposed near the summit of Flattop Mountain, the tuff is light and ashy and lacks a harder basal phase.

Silicified joints are occasionally found in the Ox Valley tuff; these may weather as sharp, prominent vanes. The tuff is commonly laced with fine veinlets of silica.

Quartz, sanidine and plagioclase are the principal constituents of the rock, in average proportions represented by the histogram of Figure 3. All leucocratic constituents are characterized in thin section by irregular, highly resorbed borders, more pronounced in feldspars than in quartz (see E, Plate 4, page 170). Quartz is usually embayed, often by finger-like aggregates of tridymite(?). Sanidine generally shows Carlsbad twinning. Plagioclase is absent in some sections; it usually has coarse, ill-defined albite twinning, is fractured, and is finer than quartz or sanidine. It was found in the centers of some sanidine crystals. No reliable determinations were made of the composition, but it seems to be in the oligoclase-andesine range. Many plagioclase phenocrysts show oscillatory zoning.

Mafic minerals comprise as much as 5% of the rock in thin section. Generally they are fine and scrappy, and often they are completely altered to roughly pseudomorphic aggregates of hematite, magnetite, and a sericitiform mineral. Red-brown oxyhornblende is the most common species; red biotite is abundant in some thin sections. Accessory minerals are magnetite, as euhedra or fine specks sprinkled throughout the groundmass (partially altered to hematite), and rarely apatite and zircon.

A section from a dense, reddish basal phase contains devitrified relics of shards, which are somewhat distorted and show a rude microeutaxitic alignment. Fragmental crystals and turbid cryptocrystalline material constitute the groundmass of most sections. Vague, sub-aligned aggregates of tridymite and potash feldspar may be devitrified pumice fragments. Some clear glass occurs, in minute patches, but an attempt to isolate this material for index determinations was unsuccessful.

Flattop Mountain Suite

General Statement

The "Flattop Mountain suite" comprises all rocks produced during a general period of activity of the younger of the two principal eruptive centers in the Bull Valley district, located in the northwestern portion of the map area. The rocks range in composition from highly siliceous rhyolite to rhyodacite. It is inferred that most occur as stock-like intrusive bodies, or plugs, and that some were erupted to the surface as lava flows. Units of the suite are shown diagrammatically in the restored section of Figure 12.

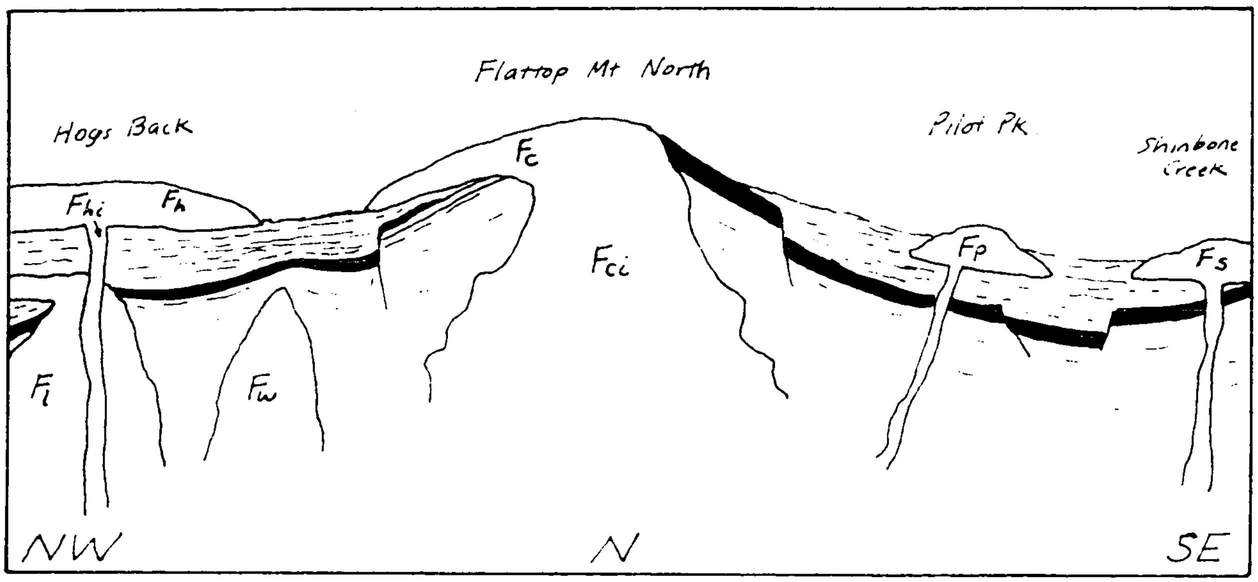


Figure 12. Diagrammatic restored section of northwestern part of Bull Valley district at close of Flattop Mt. silicic eruptive episode, showing units of the Flattop Mt. suite. Fl=Little Pine Creek rhyolite; Fh, Fhi=Hogs Back fm.; Fw=white siliceous rock; Fc, Fci=Cow Creek rhyolite; Fp=pilot Peak rhyolite; Fs=Shinbone rhyolite. Ox Valley tuff, shown in solid black, is overlain by Reservoir fm. Deposition of Reservoir units was probably contemporaneous with eruptive activity but continued afterwards until domal structure of Flattop Mt. area was completely buried.

Because the Flattop Mountain eruptive center was less extensively studied than its precursor, the Bull Valley complex, and the associated rocks are petrographically more diverse, the order of treatment does not follow that for the earlier suite. Each of the six units mapped is described in turn; there is no unified discussion of mode of origin or petrography. A sequence of events in the history of the complex is given at the conclusion of the section on structural geology.

Shinbone Rhyolite (Fs)

The Shinbone rhyolite is a unit of very limited distribution resting unconformably upon Ox Valley tuff and the Rencher formation in the vicinity of the mouth of Shinbone Creek, northeast of Ox Valley (see geologic map). It has a probable maximum thickness of about 400'.

The rock is light tan to gray, or purplish, and exhibits a wide variety of megascopic and microscopic properties. It strongly resembles Ox Valley tuff where it overlies that formation, but farther north, especially in the gorge of Bullrush Creek north of Tom Springs, it more closely resembles other Flattop Mountain units. In these places the rock sometimes exhibits contorted flow layering, and weathered surfaces occasionally have ovoidal "pocks," some of which contain crumbly, holocrystalline cognate inclusions. The material is believed to have boiled as it erupted to the surface, with peripheral phases having been deposited under conditions of high turbulence and mobility in contrast to the comparatively viscous central part of the mass. Peripheral rock is lighter and more tuffaceous.

The phenocrysts are plagioclase, sanidine, and pink quartz, with a few scattered mafic minerals, in proportions varying widely in the rock slices examined. A typical histogram is given in Figure 3. Felsic constituents range in size from microlites up to 3 or 4 mm. Quartz is sometimes embayed, as are plagioclase and sanidine to a lesser degree, and coarsely fractured; but any of these may be perfectly euhedral or subrounded and anhedral in the same section. Plagioclase, which occurs both as discrete phenocrysts and in the cores of a few sanidine crystals, sometimes shows oscillatory zoning with a normal over-all trend from calcic to sodic andesine. The mafic constituents are much finer, consisting chiefly of green to red-brown biotite, with lesser amounts of red-brown oxyhornblende. Magnetite, zircon, apatite and sphene occur as minor accessories in that order of abundance.

No vitroclastic structures were observed in the groundmass. Generally it consists of clear glass, of refractive index 1.504. The glass is somewhat turbid and dusty in places due to incipient devitrification, and elsewhere has devitrified in perfectly developed spherulitic structures with several concentric growth zones. In one thin section where the groundmass consists of alternating clear and altered bands of glass, the latter contain conspicuous amounts of fragmental phenocrysts.

A thin section of a specimen from the periphery of the deposit near its contact with Ox Valley tuff has a groundmass of irregular subparallel vesicles, each embraced by a halo of altered glass, into which extend filaments of opaque material. The vesicles are partly filled with colloform silica(?).

Little Pine Creek Rhyolite (F1)

Rock mapped as Little Pine Creek rhyolite occurs west of Flattop Mountain in the vicinity of the Enterprise reservoirs, where it intrudes tuffs and tuffaceous sediments of the Reservoir formation. Except for certain peripheral phases in which devitrification structures are strongly developed, and peripheral glass breccias, the rock is extremely dense and hard; it has provided an excellent foundation for the reservoir dams. Most typically it is dark bluish-purple and massive. In some exposures in Little Pine Creek, north of the lower Enterprise reservoir, the rock is light gray and has prominent, grossly contorted flow layers. Gray glass breccia and bluish-gray rock with crumbly, berry-sized devitrification spherulites are associated with the darker rock at the lower dam site.

Phenocrysts in Little Pine Creek rhyolite are rare. They consist almost wholly of sanidine, which occasionally shows the blue iridescence characteristic of Ox Valley tuff. The histogram of Figure 3 shows the average composition of several thick sections, but cannot be considered an accurate representation because of the very small number of phenocrysts observed. In addition to sanidine there are rare phenocrysts of plagioclase and green amphibole(?). The groundmass is composed of fluidally sub-aligned laths of sanidine, cryptocrystalline material charged with fine xenomorphic equant quartz rich in inclusions, and scattered microlites of unidentified opaque minerals and mafics. Quartz also occurs, as very fine interlocking anhedra fading into the groundmass. In thin sections of peripheral breccia the groundmass is slightly altered vesicular glass of refractive index 1.499.

The intrusive origin of the Little Pine Creek rhyolite in the area mapped is inferred from (1) observation of the rhyolite-sediment contact at the northernmost occurrence in Little Pine Creek, which is crenulate in detail; (2) the geometry of the outcrops, which are apparently small bulbous domes, and (3) silicification of suprajacent tuffaceous sediments, and the presence of numerous veinlets of chalcedonic silica which seem to emanate from the rhyolite mass. In some cases the contact is probably an intrusive fault, as, for example, at the upper Enterprise reservoir dam just west of the map area. The units intruded are not conspicuously deformed.

A few miles to the west of the Bull Valley district the Little Pine Creek rhyolite is a lava flow resting upon a nonwelded tuff or agglomerate highly charged with material of the same composition. The vent through which the rhyolite was erupted is probably very close to the western border of the district.

The Little Pine Creek unit may have been emplaced contemporaneously with Cow Creek rhyolite, to which it is closely related petrographically and bears a strong megascopic resemblance.

Cow Creek Rhyolite (Fc, Fci)

The name "Cow Creek rhyolite" is applied to siliceous rocks of the central part of the Flattop Mountain eruptive complex, for occurrences in the vicinity of Cow Creek on the east side of Flattop Mountain North (see geologic map). Rocks comprising this unit have been divided into an inferred intrusive phase (Fci) and an inferred extrusive phase (Fc), which has a maximum thickness of about 300'.

Cow Creek rhyolite of probable intrusive origin occurs in Cow Creek Canyon, in Black Canyon to the south, and on the west central side of Flattop Mountain across the divide from Cow Creek. The rock is light gray or tan to blue-purple and chocolate-brown, and extremely dense and hard. It has an aphanitic to glassy groundmass, with sparse phenocrysts of quartz, sanidine, plagioclase and occasional biotite. In some specimens the sanidine displays a blue iridescence as in Ox Valley tuff and Little Pine Creek rhyolite. An intrusive origin for this rock is considered probable on the basis of (1) the structure of Flattop Mountain, (2) a single observed contact with pinkish tuffaceous sediments underlying the Ox Valley tuff, in which the Cow Creek rhyolite is brecciated and the sediments are baked and silicified in the vicinity of the contact, and (3) brecciation and silicification of Ox Valley tuff resting directly upon the Cow Creek unit.

Where the Cow Creek rhyolite is inferred to be an extrusive flow rock it is generally lighter in color and has fewer phenocrysts than the inferred intrusive phase, and commonly weathers in slabby, phonolitic plates. The vent outlined is diagrammatic; the entire unit may be intrusive.

In many places the Cow Creek rhyolite consists of glassy breccias and/or rock exhibiting strongly developed devitrification phenomena nearly identical to those of the Little Pine Creek rhyolite. Typical megascopic devitrification spherulites are shown in photograph C, Plate 7, page 173. Such areas of brecciation and devitrification usually occur at the peripheral contacts both of rock mapped as intrusive and as extrusive phases. In Cow Creek Canyon, a glass breccia occurs as a layer about 20' thick in massive rhyolite. Fragments of the breccia are generally gray and highly vesicular, but they may also be pink and gray with a meaty texture, or dense black; they are always set in a lighter colored ashy matrix of the same composition.

It is apparent from the histogram of Figure 3 that the composition of the phenocrysts approximates that of Ox Valley tuff. By contrast, however, the phenocrysts in Cow Creek rhyolite seen under the microscope have sharper outlines; there are fewer mafics; and fewer crystal fragments are present in the groundmass.

Felsic constituents are frequently embayed and subrounded (see photomicrograph A, Plate 4, page 170). No satisfactory determination of plagioclase composition was made in the several thin sections studied but the refractive indices indicate a range of oligoclase to andesine; oscillatory zoning is common. Mafic minerals are generally fine grained and constitute less than 1% of the phenocrysts. They consist predominantly of red or brown biotite, and to a lesser extent, of pyroxene and magnetite. Sphene was observed in most sections, often as very coarse euhedra. There are also a few crystals of a green-brown amphibole (ferrohastingsitic hornblende?). Apatite and zircon are additional rare accessories.

In thin sections of the peripheral breccias, the groundmass is clear glass of index 1.504, with perlitic fractures. Abundant trichites and globulites display fluidal alignment; microlites of feldspar and opaque minerals may also be present. Inferred intrusive rhyolite most commonly has a patchy cryptocrystalline to glassy groundmass. Spherulitic devitrification structures are common (see photomicrograph A, Plate 4, page   Some phenocrysts are fragmental, and biotite is occasionally distorted. Vesicles, where present, are in some cases filled with tridymite, opal, and chalcedonic quartz.

Pilot Peak Rhyolite (Fp)

The several sharp peaks and knobs south and southeast of Flattop Mountain, including Windy Peak and Pilot Peak, are composed of rock similar to that mapped as extrusive Cow Creek rhyolite. Because this material does not appear to be a product of the central eruption, it is distinguished separately on the geologic map and designated the Pilot Peak phase of the Flattop Mountain suite. Rhyolite at Pilot Peak, and to the north and south, has about the same mineralogical composition as the Cow Creek unit. Windy Peak, however, is composed of rock completely devoid of mafic minerals. It is light bluish-gray to purplish rhyolite porphyry with an aphanitic to glassy groundmass, and a phenocryst composition represented by the histogram in Figure 3. Columnar jointing is strongly developed near the contact with Ox Valley tuff and in some places there is conspicuous flow layering.

These bodies are probably plug domes and associated lava flows satellitic to the principal Flattop Mountain eruptive center. Tuffaceous sediments of the Reservoir formation at a locality about a mile east of Windy Peak are laced with veinlets of black glassy rhyolite, but no other intrusive (or extrusive) contacts were observed.

Hogs Back Formation (Fh, Fhi)

The high smooth-topped hills flanking Little Pine Creek north of the lower Enterprise reservoir, locally known as "the Hog's Back," are composed chiefly of two eruptive units collectively mapped as the Hogs Back formation. They appear to have intruded the Little Pine Creek rhyolite and to have reached the surface through a vent near the reservoir damsite, where the rock is designated on the geologic map by the symbol "Fhi," spreading out horizontally as viscous lava flows over the tuffaceous sediments and agglomerates of the Reservoir formation. The Hogs Back rocks extend westward an unknown distance from the district; the maximum thickness of extrusive phases (Fh) in the area mapped is about 500'.

Upper and lower members of the formation have certain lithologic features in common but differ sharply in others. Both are gray, tan, and red or purple in their basal portions, with black, brown, pink or gray glass breccia locally present at the basal contact. They have about the same ratio of leucocratic to mafic phenocrysts, and in each member the principal mafic, biotite, is fresh, abundant and conspicuous. The upper part of the lower unit shows very strong flow layering in exposures near the vent on the west side of Little Pine Creek (photograph B,

Plate 6, page 172). It is commonly a light color in this vicinity and bears a pronounced resemblance to Shinbone rhyolite.

The contrast in phenocryst composition of the two members is illustrated by the histograms of Figure 3. In the lower member (histogram A), quartz and plagioclase are the only leucocratic constituents. Quartz is usually highly rounded, occurring in some instances as perfect spheres, some of which are embayed. Plagioclase occurs as coarse to fine euhedra, frequently highly corroded but unbroken; its composition was not accurately determined but is estimated as calcic oligoclase to sodic labradorite in zoned crystals. In addition to brown-opaque biotite, there are a few scattered crystals of oxyhornblende and magnetite.

The groundmass of this member is clear or turbid glass of index about 1.510. It contains microlites of mafic minerals and feldspar laths which, along with the phenocrysts, commonly show fluidal alignment. There are no crystal fragments. Vesicles are numerous and are partly filled with tridymite(?). Cristobalite(?) is also present as minute spheroids. A high potassium content of the groundmass is evident in stained sections.

In the upper member (histogram B), quartz phenocrysts are rare, but sanidine is an important constituent. Plagioclase is zoned and has about the same composition range as in the lower unit. Brown-opaque biotite and oxyhornblende (ferrohastingsitic?) are the principal mafic minerals. Magnetite, apatite and zircon are minor accessories. The groundmass is similar to that described for the lower unit, with the glass having about the same index, 1.510.

As indicated by the composition of phenocrysts and by a chemical analysis for the upper member (see Table I, page 36), the rock of the Hogs Back formation is less siliceous and more calcic than any other unit of the Flattop Mountain suite. It is probably best classified as rhyodacite.

<u>White Siliceous Rock (Fw)</u>

A low hill west of the mouth of Little Pine Creek, in the extreme northwest corner of the district, is composed entirely of very dense, white siliceous material mapped as a separate phase of the Flattop Mountain suite. It is surrounded by dark flow rocks of the Shoal Creek unit, but no contacts were observed. On the opposite side of Little Pine Creek a similar but much less silicified type of rock occurs over a smaller area. There the unit is overlain by bedded tuffaceous sediments of upper Racer Canyon tuff, which it seems to intrude. Material adjacent to the contact is highly decomposed.

The rock of the principal (western) occurrence is difficult to break with the geologic hammer. It weathers in gnarly, roundish knobs, white except where stained by limonite, or faint purple where hematite or magnetite is present. A thin section shows a composition almost entirely of cryptocrystalline silica, with fragmental and deeply embayed quartz phenocrysts, relics of mafic minerals, and a few grains of zircon associated with the relict mafics. Rock of the eastern occurrence is generally soft to the dig of a pick. It is highly charged with relict fragments of altered porphyritic material. In thin section the composition is seen to be cryptocrystalline silica and clay, with abundant specks of hematite. A sericitiform mineral is commonly present in aggregates pseudomorphic after biotite.

The rhyolite resembles the Mt. Belknap rhyolite of the Marysvale district, described by Callahan (1939) and Kerr, et al (1957), and also rhyolites of the Wah Wah Range. Its age is unknown, but most probably it intrudes both Shoal Creek breccia and Racer Canyon tuff, and was emplaced during the general episode of Flattop Mountain eruptive activity. A dike of similar material intrudes Claron sediments east of the Black Hills.

Upper Volcanic Group

Enterprise Basalt

Olivine basalt flows nearly identical with Pilot Creek basalt but younger than Ox Valley tuff occur both in the Flattop Mountain area and in the southern part of the district. They rest upon an erosion surface cutting various rocks ranging in age from the Racer Canyon tuff to rhyolites of the Flattop Mountain suite and upper units of the Reservoir formation. The number of individual flows is not known, nor are the relative stratigraphic positions, but all are collectively designated on the geologic map as Enterprise basalt, after a flow near the town of Enterprise.

The basalt capping Flattop Mountain is not known with certainty to be the same flow as that of the type locality, although outcrops can be traced continuously in a descent from the flattish surface of the mountain to the elevation of Enterprise. It seems likely that the basalt filled an erosional topography on an older Flattop Mountain to a near-uniform level and then spilled down towards Enterprise. Structural implications regarding this and alternative explanations are discussed in the final section. The maximum observed thickness of the basalt in Flattop Mountain is about 300'; it is considerably thinner at Enterprise.

In the southern part of the district, Enterprise basalt rests upon tuffaceous sediments of the Reservoir formation or directly upon Ox Valley tuff, but is overlain by later Reservoir deposits, as illustrated in Figure 13, page 138. Intertonguing of Enterprise basalt with the Reservoir formation in this area contrasts with the Flattop Mountain area where basalt overlies the youngest known Reservoir units. No evidence was found of an erosion surface at the base of the basalt in the southern part of the district; the accumulation of Reservoir material seems

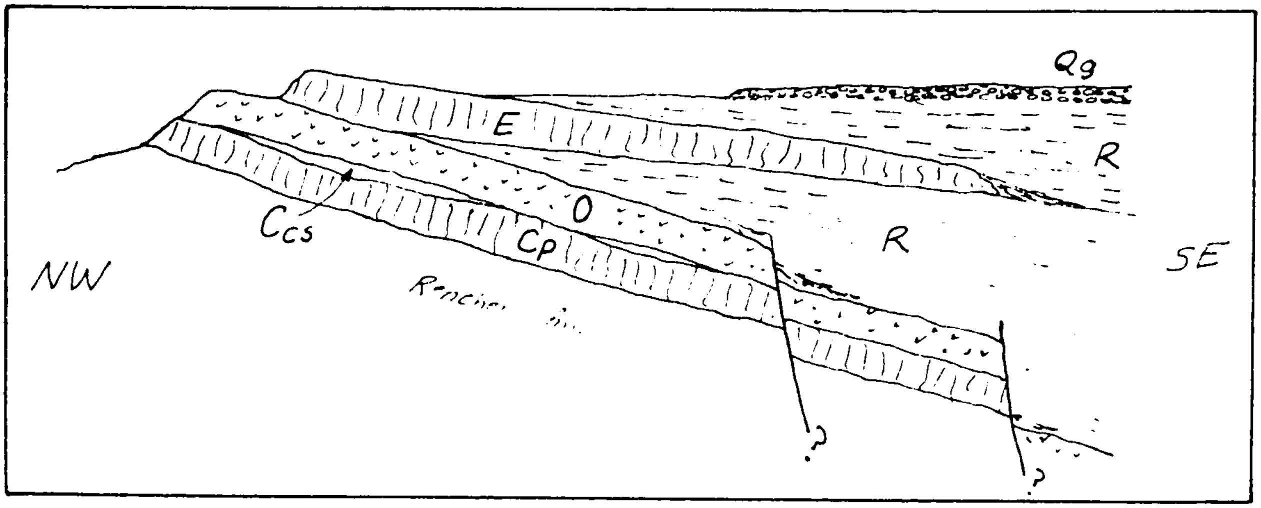


Figure 13. Diagrammatic section showing relationship of Enterprise basalt to older and younger units in southern part of the Bull Valley district. Cp=Pilot Creek basalt; Ccs=Cedar Spring member; O=Ox Valley tuff, R=Reservoir formation; E=Enterprise basalt; Qg=older gravel.

to have continued uninterrupted. Possibly the flow here is considerably older than that capping Flattop Mountain, although such an assumption is not necessary.

Basalt forming the caprock of Gum Hill, north of Big Mountain, is tentatively assigned to the Enterprise flows, but no data has been obtained with which to establish its stratigraphic position.

The material of the Enterprise flows is brown to bluish-black, or dark bluish-gray on some fresh surfaces. In neither hand specimen nor thin section can it be distinguished from Pilot Creek basalt with confidence, although the average modal composition (estimated from thin sections) is somewhat different, as shown by the histogram of Figure 3.

Black Hills Basalt

The Black Hills basalt flows are the youngest igneous rocks in the Bull Valley district, forming a pile with a thickness of up to 600' in the north-central part of the map area. At least the youngest of the flows clearly issued from a vent near the north flank of Ox Valley Peak, a cinder cone of the same material, and moved generally north towards Enterprise as indicated by the symbol showing position of flow furrows on the geologic map. The basalt is jet black, and is characterized by sparse euhedral to anhedral phenocrysts of plagioclase up to about 4 mm. in diameter, in an aphanitic matrix.

The youngest flows have blocky tops, on which are trenches 20-50' deep with flat, dirt-filled bottoms. Whether these were furrowed by surface streams of lava or are collapsed flow tunnels, they clearly delineate the direction of flow. From these features, the lack of vegetation on most areas of the flows, and the still unadjusted drainage derangement, it is concluded that the basalts are of Recent age and probably were erupted within the last several thousand years.

Phenocrysts of the Black Hills basalt are plagioclase, hypersthene, and augite, in proportions represented by the histogram of Figure 3. The composition of the plagioclase is estimated from relief in thin section to be in the andesine-labradorite range. It occurs as nearly equant and highly rounded crystals generally showing a high degree of fracturing with subsequent rehealing. Normal zoning is prevalent, with rims altered to an unidentified turbid aggregate. Hypersthene phenocrysts are more numerous and finer than plagioclase. There are a few phenocrysts of augite, but this mineral occurs chiefly in the groundmass. Oxyhornblende is a rare accessory.

The groundmass is pilotaxitic, with fluidally aligned microlites of plagioclase ranging from fine needles to about the length of hypersthene prisms, and small granules and prisms of hypersthene and augite. The remaining interspaces are occupied by dusty, glassy to cryptocrystalline material and uniformly fine grains of magnetite.

Dikes

Dike rocks mapped in the Bull Valley district are divided into the two general categories of andesite-basalt and rhyolite. They appear on the geologic map in the central and western part of the district, in most cases following well-defined structural trends.

The andesite-basalt dikes are composed of dark purple to brown, or less commonly, gray-green aphanitic rock with minute rust-colored specks of altered olivine and occasional pyroxene phenocrysts. They intrude the Racer Canyon tuff and form sharp ridges in that unit as a result of differential erosion. Some of the material is petrographically indistinguishable from Pilot Creek basalt; some appears to be of more intermediate composition. Rhyolite dikes are usually a very light bluish-gray or tan color in outcrop. They are petrographically very similar to units of the Flattop Mountain suite, and may have been intruded during that period of eruptive activity. East of Maple Ridge a rhyolite dike transects an older dike of andesite-basalt. None of the dikes in either category has produced alteration of the host other than a slight discoloration.

Probable feeder dikes for Enterprise basalt, and for the vesicular flow of the Isom formation, occur in the southern part of the district but are insufficiently extensive to show on the geologic map. Orange-pink sandstone dikelets, planar or convoluted, a few inches to about a foot thick, are present in several of the tuff deposits. A black vitrophyric dike of latite composition intrudes Rencher latite tuff south of Mountain Meadow.

Although some aplitic material was found with altered rock of the principal Rencher conduit area, no dikes of any kind are known to be directly associated with the Bull Valley intrusion.

STRUCTURAL GEOLOGY

General Statement

The Bull Valley district is at the western margin of a so-called transition zone between the Colorado Plateau and Basin-Range types of tectonic environments (Dobbin, 1939, p. 125; Cook, 1957, p. 87). As far as is known, the relatively mild structure produced by Laramide orogeny is strikingly similar to that of the Iron Springs district. Deformation is less intense to the east, in the Pine Valley Mountains, and much more intense a few miles to the southwest, where there is major Laramide thrusting (see index map, Figure 1, page 2).

Most of the structural features of the Bull Valley district are associated directly or indirectly with eruptive igneous activity. Because the district was the site of intermittent volcanism from early Tertiary time until the Recent, it is difficult or impossible to isolate the structures associated with any one particular eruptive episode. There was more than one episode of high-angle faulting and many faults were repeatedly reactivated. Volcanic deposits were in many places spread over surfaces of considerable relief, but whether this was erosional or fault relief is generally not clear.

The structural features of the district are discussed in the present section according to whether they are

(1) pre-intrusive, (2) associated with the Bull Valley eruptive complex, (3) associated with the Flattop Mountain eruptive complex, or (4) antithetic strike faults which are eruptive-tectonic in nature but are not specifically related to any of the preceding categories. These remarks are intended chiefly to emphasize and explain the prominent features seen on structure sections accompanying the geologic map.

Pre-Intrusive Structures

As noted earlier, the lithology and thickness distribution of the Claron formation on and adjacent to the Bull Valley-Big Mountain intrusive arch indicate that the arch approximately coincides with a post-Iron Springs, pre-Claron flexure, which was partially eroded and then completely buried beneath lacustrine sediments prior to initiation of volcanism. This feature constitutes the oldest structure recognized in the district; it is regarded as "Laramide," following common terminology for structural deformation during latest Cretaceous to early Eocene time in that area. It is largely inferred by analogy with the Iron Springs district, where the Claron-Iron Springs relation is much better exposed, the horizon of intrusion is the same and the emplacement of monzonite magma was clearly localized along the axial plane of a Laramide fold--the Iron Springs Gap anticline (Mackin, 1947a). Much of the intervening terrain between the Bull Valley and Iron Springs districts is known or inferred to be underlain by intrusive rock (Figure 1, page 2); it is possible that the intrusions have been emplaced along the axial part of a structure which was continuous between the two districts. Whether the Laramide structure in the Bull Valley district involved faulting as well as folding is not known. Its form cannot be inferred from the evidence available.

Bull Valley Eruptive Complex

Bull Valley-Big Mountain Arch

General statement. The proposition that the Bull Valley-Big Mountain arch has a core of intrusive rock is supported by (1) the continuity of post-Claron structures between Bull Valley and Big Mountain, with intrusive rock exposed at either end and in the middle; and (2) the presence of a magnetic anomaly extending from Bull Valley to Big Mountain. At either end of the arch, the anomaly is much more pronounced than at intermediate points, presumably because of a greater volume of quartz monzonite at higher elevations. The Hardscrabble Hollow intrusion between Bull Valley and Big Mountain produces no appreciable maximum on the general anomaly, as it should were this a body not contiguous with the other known intrusions. Although the position of neither the monzonite intrusion nor the pre-intrusive (Laramide) structure is sharply defined, the approximate general coincidence of the two suggests that in some way the Laramide structure acted as a zone of weakness guiding the emplacement of the magma.

Big Mountain. At the Big Mountain end of the arch the intrusion is probably laccolithic, with a concordant roof of Homestake limestone. The roof is observed where monzonite is exposed south of the Majestic fault (see geologic map) and also in several drill cores from sites about a mile northeast in the vicinity of the Snow fault. Locally the monzonite appears to cut across the Homestake and invade Cretaceous rocks. The floor of the laccolith is a matter of speculation, since it has nowhere been seen or penetrated by drilling; it must be Navajo sandstone or perhaps the lowermost units of the Carmel.

Yielding in the Big Mountain area took place essentially by doming. A very large mass of the roof, constituting most of what is now Big Mountain, was uplifted like a trapdoor. The Big Mountain fault, on the west and south, is nearly a line of maximum differential movement. Movement along that fault increases from a few hundred feet north of Utah Highway 18 to perhaps 2000' at the crest of the arch, and decreases again where the trace of the fault is east-west.

The Snow fault is extended to the eastern side of Big Mountain on the basis of a line appearing on the aerial photographs; displacements along this part of the fault, if any, are small in comparison with those of the Big Mountain fault. The Majestic and Ucon faults are for the most part transverse to the axis of the arch. Some movement on them may have occurred in this area after the deposition of Rencher latite, as it seems to be cut by the faults, but the point is not well established.

All of these faults are probably high angle. The inferred relations are shown in Figure 14, which represents

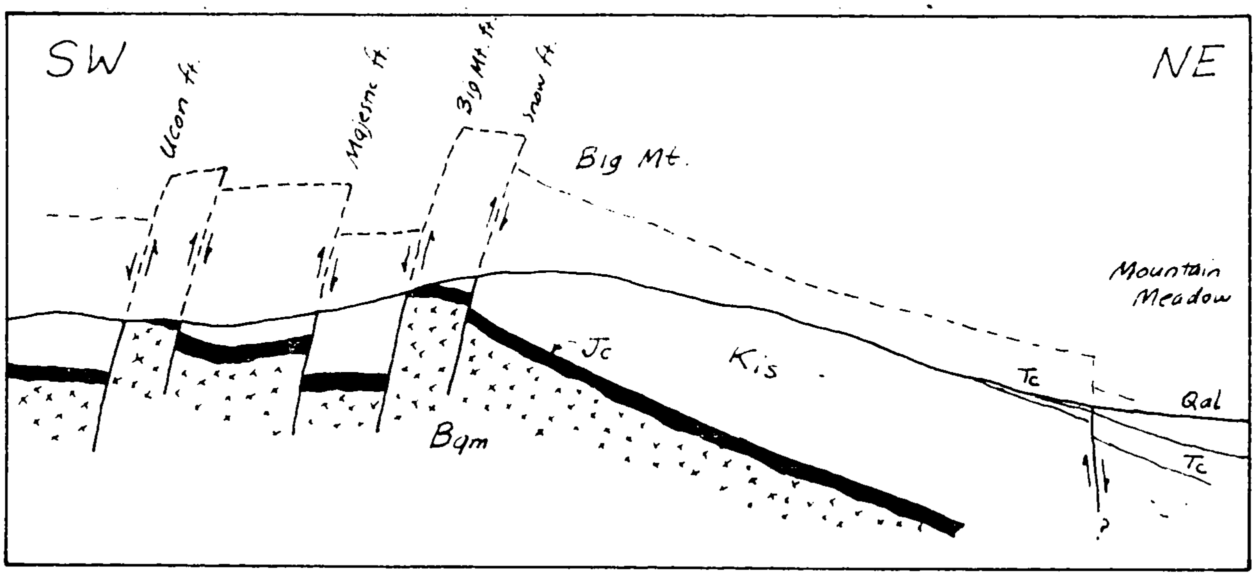


Figure 14. Diagrammatic section through Big Mt. illustrating principal transverse faults. Carmel fm. shown in solid black. Kis=Iron Springs fm.; Tc=Claron fm.; Qal=alluvium; Bqm=Bull Valley suite, quartz monzonite.

a southwest-northeast section through the summit of Big Mountain approximately in the axial plane of the arch. Section MM' accompanying the geologic map is a transverse (east-west) section through the summit.

The Big Mountain uplift appears to have near its center a shallow synclinal dish which plunges to the north or northeast. The west limb rolls over between Big Mountain and Gum Hill (shown on the geologic map three miles north of the summit of Big Mountain) and becomes an anticline plunging northward--a broad structure whose axis is not indicated on the geologic map. Likewise, the east limb becomes an anticline near Mountain Meadow on the east side; a combination of folding and downfaulting places Claron limestone at the level of the valley alluvium, some 1000' below Cretaceous rock on the crest of the mountain (see section MM').

West of Big Mountain and the Big Mountain fault the structures are much more complex (see section NN'). Claron and Quichapa units were not uplifted in large blocks, but were deformed and jostled about in small independently moving units. The faulting is almost certainly associated with the emplacement of the Big Mountain intrusion. Some material is microbrecciated and resembles material mapped as gravity slides by Mackin in the Iron Springs district, but no gravity slides were conclusively demonstrated in the area. The West fault system, about a mile and a half west of the summit of Big Mountain, marks an approximate western limit of intrusive uplift.

Between Big Mountain and Hardscrabble Hollow, the intrusive arch can be traced in a general way but details of the structure are not understood. Steep and overturned dips on the southeast limb of the arch and more gentle dips on the northwest, in the Cretaceous rocks, indicate an asymmetry of structure which increases southwest from Big Mountain and reaches a maximum in Bull Valley. Section LL' depicts the deformation of Cretaceous rocks diagrammatically; the faults on the crest of the arch are inferred from photointerpretation.

Hardscrabble Hollow. The Hardscrabble Hollow intrusion is probably a cupola on the main body of the Bull Valley-Big Mountain intrusion. Its Jurassic and Cretaceous sedimentary cover has been arched asymmetrically to the southeast, but again, the orogenic versus intrusive origin of the structure cannot be resolved without more information on the Claron-Iron Springs relationship than is presently available. Only a slight unconformity is indicated on section KK'.

Whereas on the southeast side of the intrusion the Carmel formation contains both Homestake limestone and the Moody Wash limestone, and possibly the siltstone member, the Carmel section dipping gently away from the intrusion on the north and northwest side is much thinner, and the Moody Wash member appears to be absent. Yet this member is present immediately northeast of the exposed intrusive rock in a tightly-folded anticlinal(?) structure. The reason for the anomalous abrupt disappearance of Moody Wash limestone is not known but may involve post-Carmel, pre-Iron Springs faulting and erosion, as suggested by relations in the Iron Springs district (Mackin, 1954, Fig. 2).

The anticline can be traced as far towards Bull Valley as the vicinity of Garden Spring, or about a mile southwest of the Hardscrabble Hollow intrusion. Here the southeast limb is not well-defined; the entire structure is probably modified by faulting accompanying the extrusion of material of the Rencher formation. About a mile southeast of Garden Spring, Claron and Cretaceous beds dip northwest towards the intrusive arch in a structure interpreted tentatively as shown in section JJ': a unit titled "Garden Spring Fault Block" is inferred to have moved downward away from the crest of the arch on a low angle normal fault now covered by Rencher deposits. This implies that some deroofing of the arch occurred by gravity-type faulting following oversteepening by intrusion of the monzonite. At the northeast end of Hardscrabble Hollow, where Hardscrabble Creek emerges from a narrow slot in the Rencher formation, Claron limestone dips toward Cretaceous rocks and borders them with a probable fault contact that may be of the same type as postulated above.

Little is known of the structure on the northwestern limb of the intrusive arch between Bull Valley and Big Mountain. Several gentle flexures are present, probably related to intrusive arching. There is no direct evidence that they are underlain by intrusive rock, although the aeromagnetic anomaly indicates a more gentle dip of the surface of the monzonite in the northwest than southeast.

Bull Valley. Of much greater intensity is deformation associated with the Bull Valley intrusion, where the magma eventually erupted to the surface. Whatever pre-intrusive structures existed there have been completely modified by eruptive activity; the only evidence of such structure is an angular unconformity between the Claron and Iron Springs formations of 15 to 30 degrees. Jurassic and Cretaceous rocks which formed an early cover for the monzonite intrusion in the Bull Valley area have been folded back, overturned, and brecciated, presumably in large part due to the extravasation of material of the Rencher formation. The relationship of these structures to the ones discussed above, farther east, is obscured by thick deposits of Rencher latite forming the ridge between Garden Spring and Bellas Canyon. Peripheral areas of the Bull Valley intrusion--Bellas Canyon, on the south; The Spine, on the west; and Willow Spring Draw, on the north side--are next discussed in detail.

(1) South: Bellas Canyon area. Yielding along two major faults, here designated the Bellas Canyon and Little Spring faults, appears to have accompanied the rise of the monzonite-latite magma. That the major movement of the Little Spring fault predated extrusion of the Rusty tuff

phase (Br2) of the Rencher formation is demonstrated by the fact that north of the fault this phase rests directly upon the sedimentary rocks, while south of the fault it overlies White tuff breccia (Br1). However, recurrent movement occurred in post-Ox Valley tuff time. These relations may be seen by reference to section II' and the geologic map.

Figure 15, page 152, shows four postulated stages in the growth of the Bull Valley intrusion, culminating in the eruption to the surface of the Rencher magma. According to this interpretation the intrusion was initially concordant, as in (A), but with continued rise of the magma further yielding occurred by asymmetric upturning of the cover and intrusive faulting. The intrusive structure formed an oversteepened topographic high which was rapidly eroded concurrently with its rise and from which segments of the roof material must have been sloughed by gravity sliding, so that the upper, already solidified, quartz monzonite was bared or nearly bared by the time of the initial eruption of Rencher. Final destruction of the roof of the intrusion probably occurred during extravasation of the Rusty tuff phase; latite of this eruption rests directly on brecciated monzonite.

Limestone resting on steeply dipping Cretaceous rocks and capped by Rencher, as seen in section HH' and

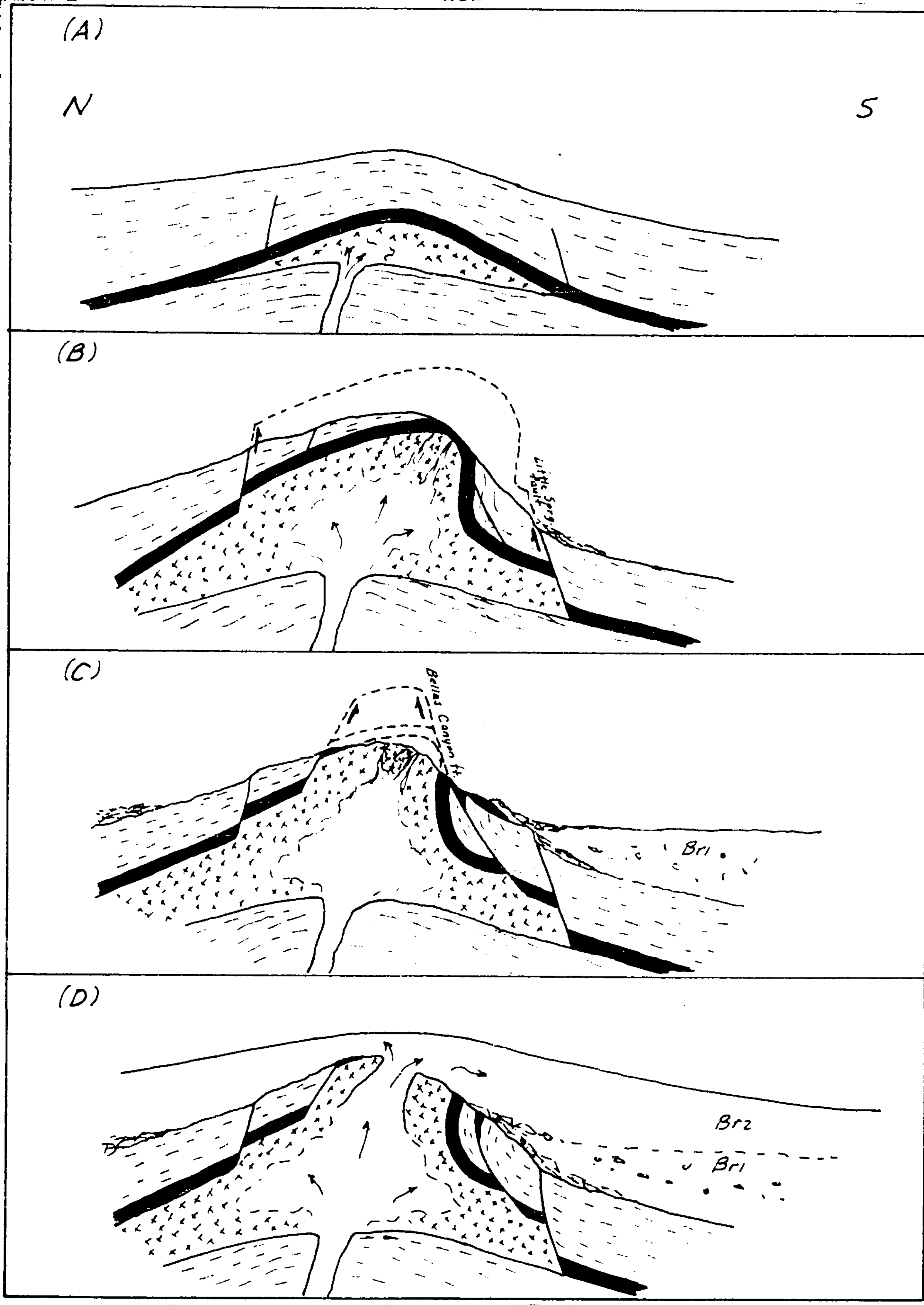


Figure 15. Diagrammatic sections in Bellas Canyon area showing postulated stages in growth of the Bull Valley intrusion. Carmel formation is indicated by solid

black. In (A), quartz monzonite porphyry is concordantly emplaced along the axis of a Laramide flexure. In (B), continued magmatic pressure has resulted in sharp flexing of the roof and further uplift by intrusive faulting--the Little Spring fault on the south side of the intrusion. Rapid denudation of the sedimentary and volcanic cover has occurred, largely through gravity sliding. Movement along another intrusive fault--the Bellas Canyon fault--is imminent, as is additional sliding. (C) depicts the structure a short time later than (B). The White tuff breccia phase (Br1) of Rencher latite has been ejected from the core of the intrusion. The roof is further raised along the Bellas Canyon fault, concurrently with additional gravity sliding, and will be largely destroyed during the eruption of the Rusty tuff phase (Br2) which ensues immediately. In (D) the eruptive episode has just concluded. Structures on the south flank have been overturned; a small relic of the upraised roof is present north of the vent.

II', is represented in (C) as a gravity slide. No fossils were found in the limestone shown in HH' and therefore its identity (Claron or Homestake) is unknown, but that in II' is Homestake. Fragments of quartz monzonite have been ground into the brecciated limestone on its apparent upper surface, which may indicate a former monzonite-limestone contact overturned while moving down from the arch.

(2) <u>West: The Spine and vicinity</u>. At the western border of the Bull Valley intrusion, the sedimentary and volcanic cover was deformed as indicated in section GG'. The Spine fault, shown in section FF', may mark the approximate western margin of the Bull Valley intrusion. The most recent movement of this fault is post-intrusive and results in juxtaposition of Racer Canyon tuffs and quartz monzonite;

at the same location the tuffs rest upon cryptocrystalline latite-monzonite (mapped as Rencher) in what is clearly a depositional contact. The initial movement was probably opposite in direction--the fault seems to have had upthrow on the east, raising the intrusive mass of The Spine. South of The Spine, the pre-intrusive rocks were folded back as indicated in section GG'.

The area west and southwest of The Spine is a structural complex characterized by intensive faulting, brecciation, and alteration. These effects are largely a result of the emplacement of the Bull Valley intrusion and subsequent eruption of material of the Rencher formation, but again some of the faulting postdates deposition of the Racer Canyon tuffs; it may be related to later eruptive-tectonic adjustments. The situation is further complicated by intrusion of Pilot Creek and possibly Little Creek material in the same general vicinity.

Latite of the Rencher formation in this complex includes intrusive, extrusive, and/or vent phases; its mode of origin has not been determined. The two smallest outcrop areas appearing on the map are in gullies cut in altered Quichapa rock, and the material, though mapped as Rencher, is intermediate in texture between latite and monzonite, and may be intrusive. Farther south the base of the Rencher is black vitrophyric latite. At several other places where contacts of Rencher with older rocks are exposed, both

Rencher and the contiguous rock are highly sheared and altered. The geologic cross sections constructed through this area depict a repetition of extrusive Rencher by high angle faulting, rather than an intrusive origin of the Rencher, but it is emphasized that this is only one of several interpretations considered equally possible in the light of the evidence presently available.

(3) North: Willow Spring Draw and vicinity. A part of the northern contact of the Bull Valley intrusion is shown on the geologic map as an intrusive fault which, as in the case of Spine fault, has had recurrent movement in post-Racer Canyon time. No direct evidence was found for the existence of the fault east of Willow Spring Draw. Outcrops of altered Quichapa units west of the draw and data from diamond drill holes east of the draw indicate that the roof of the intrusion north and west of the vent was Quichapa, or locally, Isom and Claron units. However, by reference to diagrams (C) and (D) of Figure 15, it is seen that any pre-intrusive unit may be in contact with monzonite on the north flank of the intrusion, depending on the geometry of the inferred intrusive faulting.

The form of the north side of the Bull Valley intrusion is obscured by the effects of intrusion of Pilot Creek material. Intrusive contacts of this rock with tuffs and tuffaceous sediments of the Racer Canyon unit are exposed north of Willow Spring Draw. The center of the eruption is believed to be north of the western bend of the draw. It seems likely that the site of emplacement and eruption of Pilot Creek magma was controlled by earlier faulting of the Bull Valley eruptive episode.

Two bodies of massive blue-gray limestone partly replaced by iron ore are shown on the map at the contact between monzonite and latite south of Willow Spring Draw. No fossils were found in the limestone; megascopically it more closely resembles typical Homestake than Claron. These bodies may be erosional remnants of the original roof of the intrusion. Although highly deformed, they appear to have a general northwesterly dip, as shown on the geologic map. A thin bed of sandstone and siltstone up to about two feet thick occurs between monzonite and latite at many places in the vicinity of the limestone bodies; if the limestone is Homestake, this is probably the underlying siltstone member. .

Soft Iron and Manera Uplifts

Slightly more than a mile south of the apex of the Bull Valley intrusion is a fault-bordered updome of Claron and pre-intrusive volcanic rocks, designated the Soft Iron uplift (section GG'), after the name of a group of mineral claims. The rocks are highly deformed and in some places weakly mineralized. The uplift is believed to have formed by emplacement of monzonite at depth. Although there is no direct evidence in support of this hypothesis, it is favored by the presence of probable intrusive monzonite breccia at some places in the Soft Iron East fault zone, which borders the easternmost Claron rocks exposed in the uplift, and also by the presence of a small magnetic anomaly.

Several miles farther south is another, broader domal area designated the "Manera uplift" (section 00'), in the center of which are the southernmost exposures of the Claron formation mapped in the district. Rocks mapped as Claron are chiefly massive conglomerates and possibly include uppermost Cretaceous conglomerates. Although details of the structure are not known, it is essentially a broad dome with minor flexures and an asymmetry to the southwest, where yielding occurred by complex faulting. Neither the age nor the cause of the deformation is known. That a topographic high existed before deposition of the Rencher latite is indicated by the presence of Rencher apparently resting unconformably upon Claron rock at the southeastern border of the uplift; the actual contact was not seen and may be a fault. At least one major fault predates Rencher. The latest fault movements, however, involve units of the Cove Mountain formation and Ox Valley tuff, and have accentuated any earlier structure.

A monzonite intrusion may have produced the Manera structure but such a body is not indicated by the aeromagnetic data, so that it would necessarily be at great depth. Intrusion of rhyolite or similar material of low magnetic susceptibility is another possible cause of the uplift. A zone of hydrothermal alteration in rocks of the northeastern part of the structure suggests association with an intrusive body.

The Soft Iron and Manera uplifts are roughly aligned with the western borderof the Bull Valley intrusion, the major structural elements of all three areas striking about N. 20° W. This trend may reflect a major fault predating the Bull Valley eruptive episode.

Claron Exotics

Claron and possibly also Iron Springs rocks occur in a number of places on the southeast flank of the Bull Valley-Big Mountain arch in what are thought to be exotic blocks removed from the roof of the arch during Rencher eruptive activity. Some of these demonstrably rest upon material of the White tuff breccia phase and are overlain by Rusty tuff; others appear to be completely engulfed in the latter phase. The largest block observed is about 800-1000' in length and probably has a thickness of over 100'. Limestone, siltstone, and sandstone composing the blocks are finely brecciated and rarely form outcrops; usually the blocks are traced by patches of red-orange soil. They are depicted in structure sections JJ', KK', and NN', diagrammatically in the case of those shown as completely subsurface.

The blocks may have resulted from gravity sliding from the steepening intrusive arch during the interval between eruption of the White tuff breccia and Rusty tuff phases. They may also have been rafted out over the earlier latite deposits during eruption of Rusty tuff, when the roof of the Bull Valley intrusion was apparently completely disrupted. Similar exotic blocks are present in the eruptive complex at Marysvale.

Chaotic Areas

In some parts of the map area, extremely close-spaced faulting resulting in an apparently chaotic distribution of lithologies has made it impossible to differentiate the various rock units on the scale of mapping employed. These are designated on the map as "chaotic areas." They do not necessarily present a distinct structural contrast with adjacent complex areas nor are they sharply defined. Usually only Quichapa, but occasionally Isom and Claron and rarely Rencher units are involved. In many places the material is finely brecciated.

The maximum distance of any of these zones of "chaotic" structures from the intrusive arch is three to four miles. It is thought that they were produced because of the rise of the Bull Valley-Big Mountain intrusive arch, probably as gravity slides from its crest and flanks.

Much of the pre-intrusive terrain south of Mountain Meadow is chaotic. Exposures in Magotsu Wash suggest that

Little Creek breccia intruded older volcanic units in this area, possibly resulting in large-scale brecciation of host rocks, but since Harmony tuff also appears to be involved in the complex it does not seem likely that intrusion of Little Creek material is the sole cause of the chaotic structure.

Flattop Mountain Eruptive Complex

Reservoir Trough

The broadly arcuate trend of the Bull Valley-Big Mountain intrusive arch is roughly paralleled on its concave northwest side by a major structural feature referred to as the "Reservoir trough," which extends across the map area from the vicinity of the Enterprise reservoirs, on the western border, to the town of Enterprise. There it becomes very broad and merges with the Escalante basin (see Figure 1, page 2). The trough is largely filled with tuffs and volcanic sediments of the Reservoir formation, coarse gravel deposits, and basalt flows. It was formed at a time later than the emplacement of Ox Valley tuff, probably by a combination of faulting and downwarping associated with the intrusive uplift of the Flattop Mountain eruptive center; it may be a collapse feature resulting from the movement of magma at relatively shallow depth. The major eruptive activity of the Flattop Mountain area appears to have roughly coincided with the filling of the trough. This intimate association of collapse, fill, and eruption is analogous to the Pliocene-Pleistocene volcanic history of the southern part of El Salvador, recently described by Williams and Meyer-Abich (1955).

Flattop Mountain

The Flattop Mountain structural high is probably a result, at least in part, of the emplacement of rhyolite magma. The "high" is relative to the Reservoir trough only, which encircles it on the south and east. On the north the structure apparently is bounded by a constructional dome of Shoal Creek breccias, although very little of that area has been visited by the writer and its relation to the Flattop Mountain complex is not known.

Four geologic cross sections (AA', BB', CC', and DD') depict the structure of the Flattop Mountain area as inferred from the present study. Interpretations are regarded as tenatative only; relationships are obscured by many problems, roughly divisible into three principal categories:

(1) Stratigraphic. Assignment of soft, pinkish tuffaceous sediments to the Cedar Spring member of the Cove Mountain formation or to the Reservoir formation, and yellowish-gray bedded tuffs to upper Racer Canyon tuff or to the Reservoir formation, cannot in many cases be made with certainty because of the similar lithologies of these units; the problem is paramount where Ox Valley tuff is not

observed. In addition, bedded material of the Reservoir formation which postdates the silicic eruptive episode is apparently identical in many places to older Reservoir units. And finally, Ox Valley tuff is so highly silicified in the vicinity of Cow Creek on Flattop Mountain that it is difficult to distinguish from Cow Creek rhyolite in the field, although the identification can be made in thin section.

(2) Nature of the rhyolite contacts. Whether the occurrences of silicic rock of the Flattop Mountain suite--particularly the Cow Creek unit--are extrusive deposits or intrusive into contiguous rocks is usually not clear. Only one contact of Cow Creek rhyolite was seen in the field; this was interpreted as intrusive. Other contacts of rhyolite with host rock are probably intrusive faults.

(3) Structural significance of the Enterprise basalt. On the assumption that the basalt forming the flattish surface of Flattop Mountain is the same as material 1500' lower at the town of Enterprise, it must be postulated either that the basalt flowed down from the surface of Flattop Mountain to Enterprise, or that the difference in elevation of the two occurrences was caused by deformation subsequent to spreading of the basalt. The first alternative is the more attractive in view of the supposed association of the uplift of Flattop Mountain with rhyolite intrusion, which almost certainly predated the basalt

eruptions, probably by a considerable length of time. The presence of the Enterprise cinder cone testifies to the existence of a vent near Enterprise, but this may indicate only that the flows on Flattop Mountain and near Enterprise had different sources.

Extrusion of Enterprise basalt is thought to be in no direct way related to the earlier episode of rhyolite eruptive activity; Pleistocene and Recent cinder cones and lava flows of similar composition occur sporadically thoughout southwestern Utah. The Enterprise basalt has, however, participated in some faulting on Flattop Mountain. At several places on the periphery of the central mass the basalt is downdropped or warped. Some of these structures may be slumps.

An inferred succession of events in the development of the Flattop Mountain structural complex is illustrated by the restored sections of Figure 16, page 164.

Antithetic Strike Faulting

Close-spaced high angle normal strike faults characterize the structure of the western part of the Bull Valley district, resulting in persistent moderate northerly dips of the volcanic deposits and numerous repetitions of lithology. The dips of the rock units generally vary between 10 and 45 degrees north, averaging about 30 degrees; and the fault planes where observed dip 60-90 degrees south.

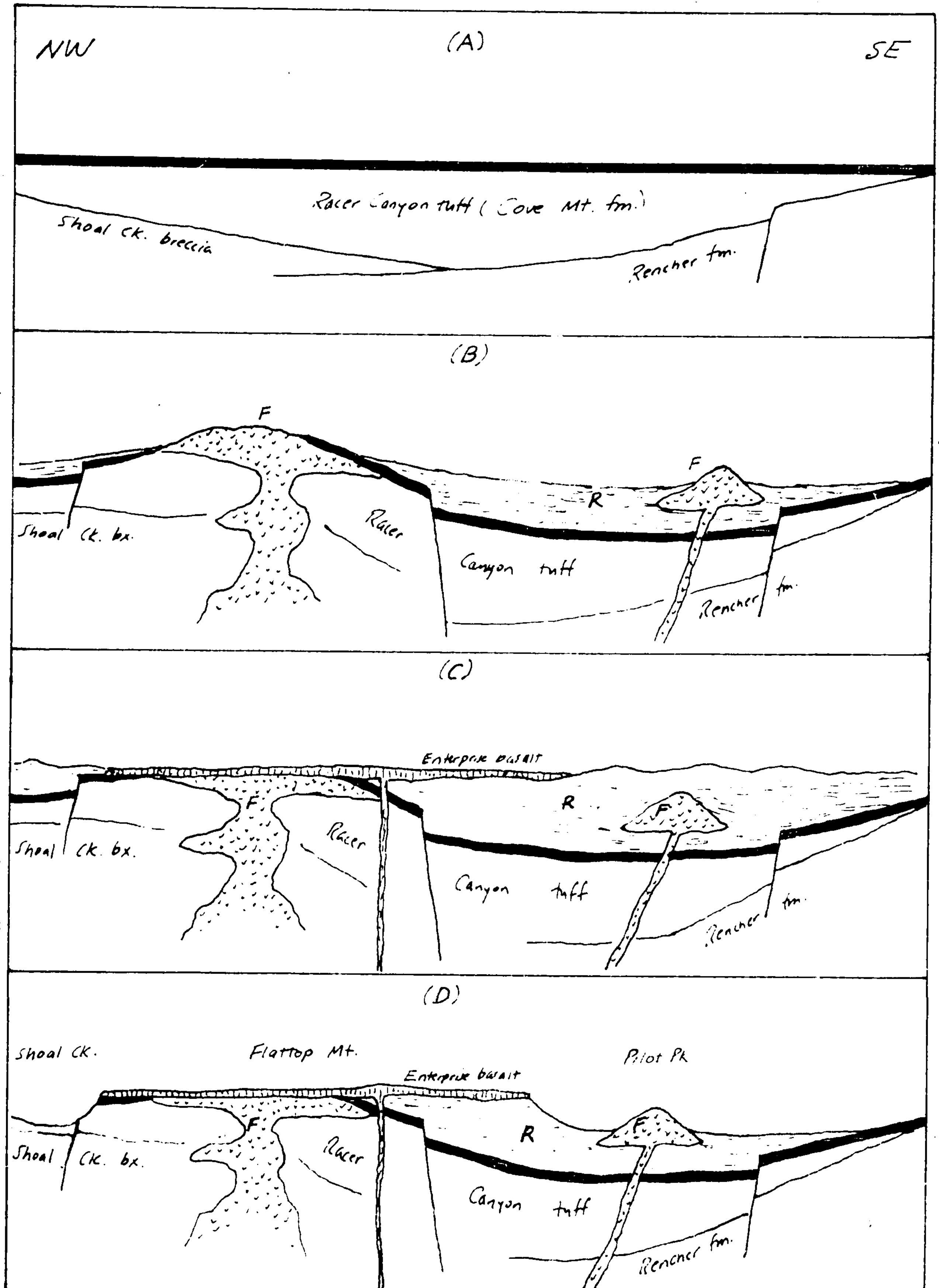


Figure 16. Restored sections showing postulated events in history of Flattop Mt. complex. R=Reservoir fm.; F=units

of Flattop Mt. suite; Ox Valley tuff is indicated by solid black. In (A), volcanic deposits of Middle Volcanic group fill a depression northwest of the Bull Valley-Big Mt. arch. In (B), Flattop Mt. has been uplifted by rhyolite intrusion contemporaneously with collapse of Reservoir trough; the trough is partly filled with material of the Reservoir fm., and rhyolite plugs have been emplaced in the fill. (C) shows the area after close of the rhyolite episode--the area between Flattop Mt. and the Bull Valley-Big Mt. arch has been completely filled with later Reservoir deposits. Enterprise basalt is extruded onto an erosional surface cut on the fill and rhyolite. In (D), inversion of topography has been effected by further erosion, forming the present Flattop Mt.; rhyolite plugs are partly exhumed.

Racer Canyon tuff is repeated more than a dozen times between Tobin Wash, at the southwestern edge of the district, and Racer Canyon.

Several of the most prominent strike faults are given names as indicated on the geologic map. The Cove Wash fault, one of the most conspicuous, may be seen where it parallels the Enterprise-Veyo road in Cove Wash; white Rencher latite abuts against the dark Little Creek flows. The Bull Mountain South fault, to the north and east, has had vertical movement of 1500-2000' as estimated by the displacement of Ox Valley tuff. It cuts bedded conglomerates of the Reservoir formation at Moody Wash, but is believed to be concealed beneath upper units of that formation farther east.

None of the strike faults can be traced across the complex structures associated with the western border of the Bull Valley intrusion, nor across the Manera uplift to the south. Most of this faulting probably occurred during and after the Flattop Mountain activity, although in many cases it must have been guided by earlier faults or zones of weakness developed during previous eruptive episodes.

Plate 1

A. Rencher fm., vent phase (Bri), from upper part of Bull Valley vent. Contains fragment of quartz monzonite. Plane polarized light.

B. Same as A, crossed nicols.

C. Rencher fm., vent phase (Bri), from deeper in Bull Valley vent. Light area in center of picture is holocrystalline lenticule; alignment of lenticules gives rock near-vertical foliation. Plane polarized light.

D. Same as C, crossed nicols.

E. Material of texture intermediate between monzonite and latite, from drill core in heart of Bull Valley intrusion, beneath specimens of photomicrographs A.and C. Mafic phenocrysts in upper left complete replaced by aggregates of sanidine and magnetite. Small needles of secondary pyroxene in right center. Plane polarized light.

F. Same as E, crossed nicols.

G. Quartz monzonite (Bqm) of Bull Valley intrusion, near contact with overturned Homestake limestone. Fresh, low temperature pleochroic mafic minerals. Hb=hornblende, A=augite; biotite not labeled. Plane polarized light.

H. Same as G, crossed nicols.

PLATE 1

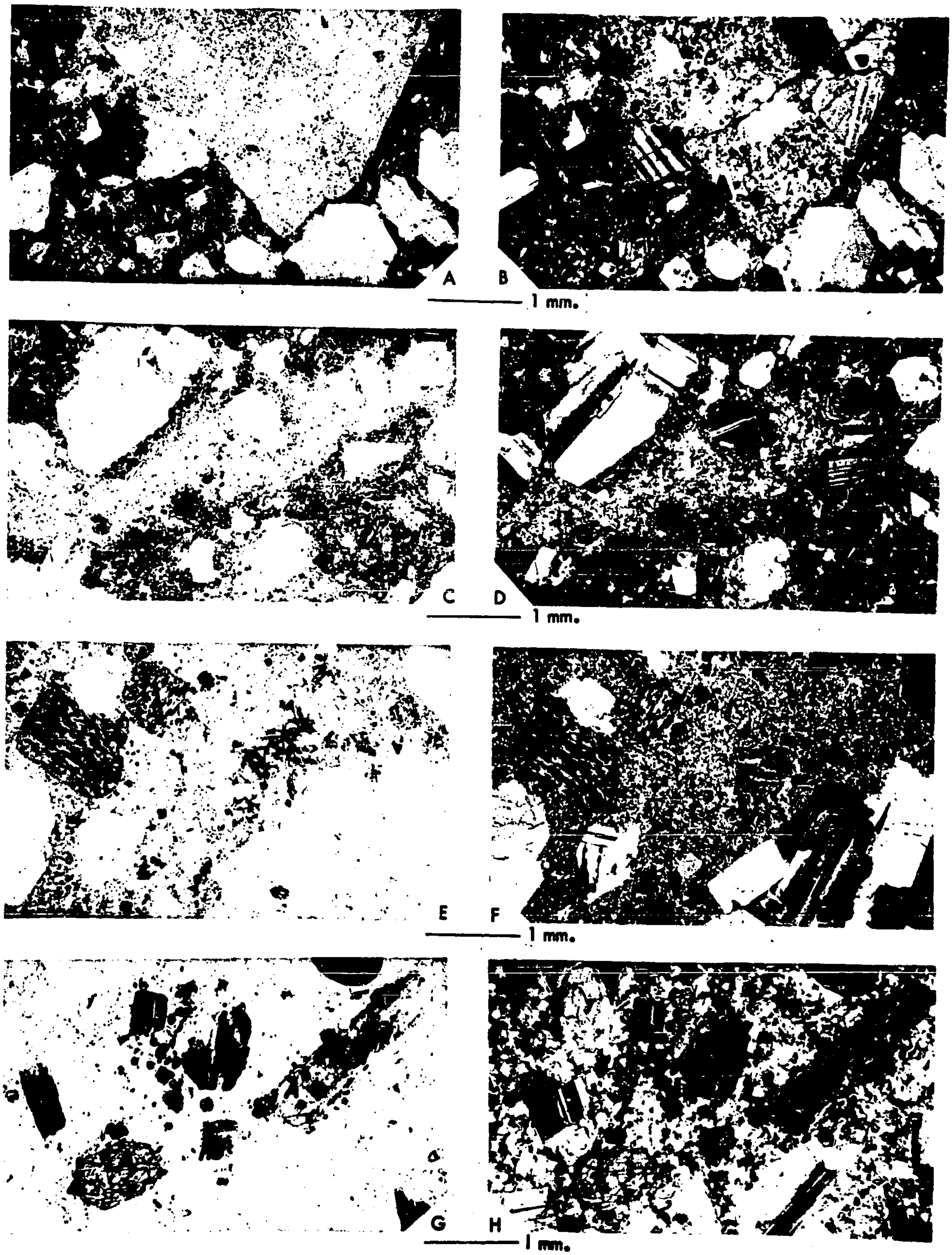


Plate 2

A. Rencher fm., Rusty tuff phase (Br2), from Rencher section in Moody Wash, 2 miles south of Bull Valley intrusion. High temperature mafic minerals hematitized on periphery. Plane polarized light.

B. Same as A, crossed nicols.

C. Rencher fm., White tuff breccia phase (Brl) from same stratigraphic section, several hundred feet lower, showing advanced automorphic alteration. Coarse biotite phenocryst in upper left partly replaced by aggregate of magnetite, hematite, sericite(?) and sanidine. Note abundance of hematite flecks in groundmass. Plane polarized light.

D. Same as C, crossed nicols.

E. Rencher fm., White tuff breccia phase (Brl), vitrophyre from base of section in Moody Wash near localities of A and C. Clear glass contains fewer fragments of phenocrysts and shows some compaction(?) structures. Sub-turbid glass, appearing slightly darker in upper left, contains many small fragments of phenocrysts and some possible shards. Plane polarized light.

F. Same as E. crossed nicols.

G. Rencher fm., White tuff breccia phase (Brl), light tan latite from base of stratigraphic section in Moody Wash from which specimens of photomicrographs A and C were taken. Fresh, high temperature mafic phenocrysts. Faint wispy structures possibly are devitrified shards. Plane polarized light.

H. Same as G, crossed nicols.

PLATE 2

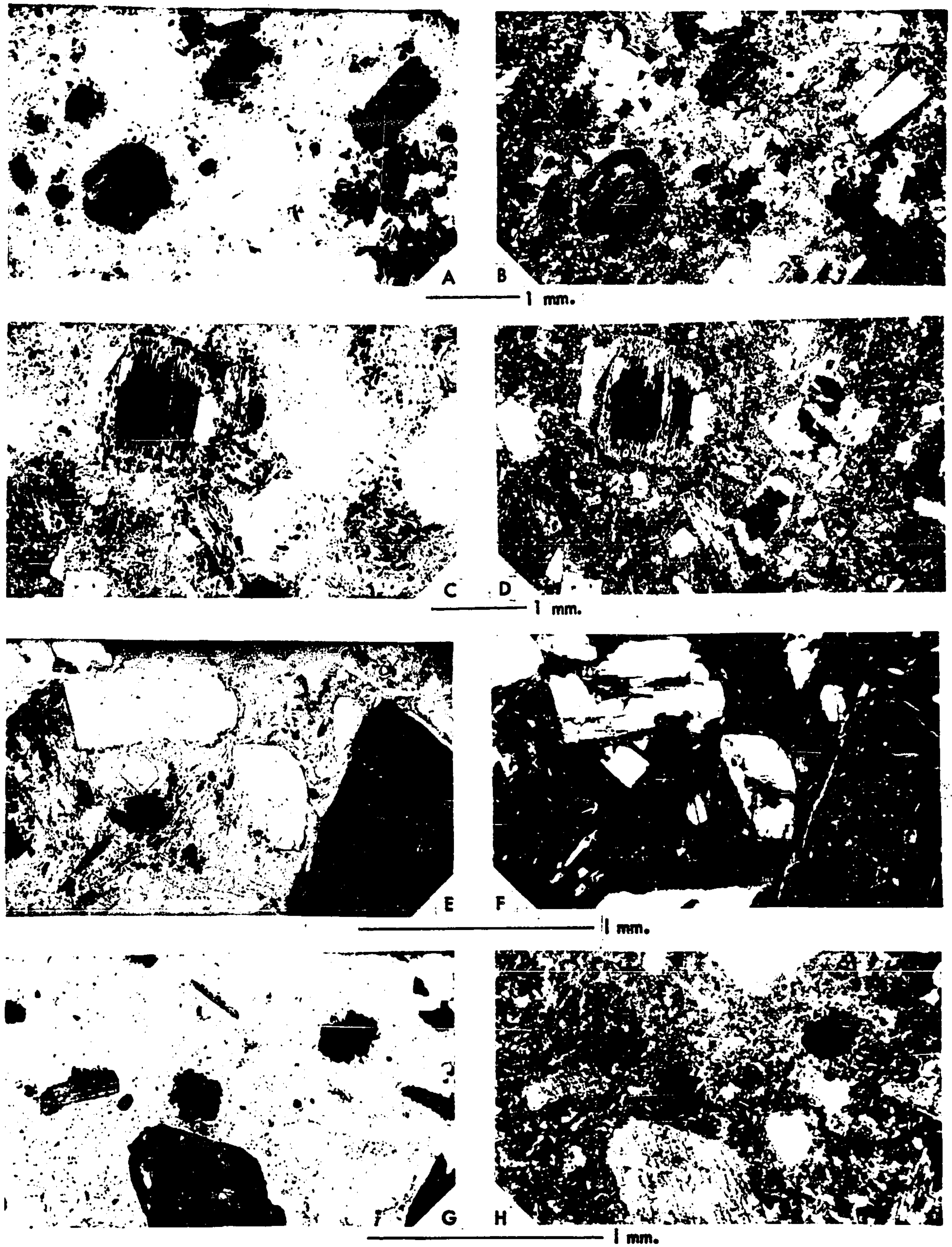


Plate 3

A. Quartz monzonite (Bqm) near periphery of Bull Valley intrusion. Mafic phenocryst completely replaced by pseudomorphic aggregate of sanidine and magnetite. Texture of groundmass is holocrystallinexenomorphic microgranular (quartz and sanidine), but elsewhere in same thin section there are patchy areas of cryptocrystalline texture. Plane polarized light.

B. Same as A, crossed nicols.

C. Rencher fm., undifferentiated extrusive phase (Br), from 3-4 miles north of Bull Valley vent. Laterally equivalent to Rusty tuff. Portion in right with lighter colored groundmass is cognate inclusion; portion to left is typical host.

D. Same as C, crossed nicols.

E. Rencher fm., possible intrusive or vent phase (Bri), southwest of Bull Valley intrusion. Indistinct size layering and fluidal alignment of phenocrysts across photograph from left to upper right. Plane polarized light.

F. Same as E, crossed nicols.

G. Rencher fm., undifferentiated extrusive phase (Br), from $\frac{1}{2}$-1 mile south of Bull Valley vent, laterally equivalent to Rusty tuff. Light colored vesicular cognate inclusion in right, which lacks pyroclastic structures and has cryptocrystalline groundmass. Material to left vitrophyric and has pyroclastic structures. Note irregular contact between types. Rock in this vicinity appears scoriaceous in outcrop. Plane polarized light.

H. Same as G, crossed nicols.

PLATE 3

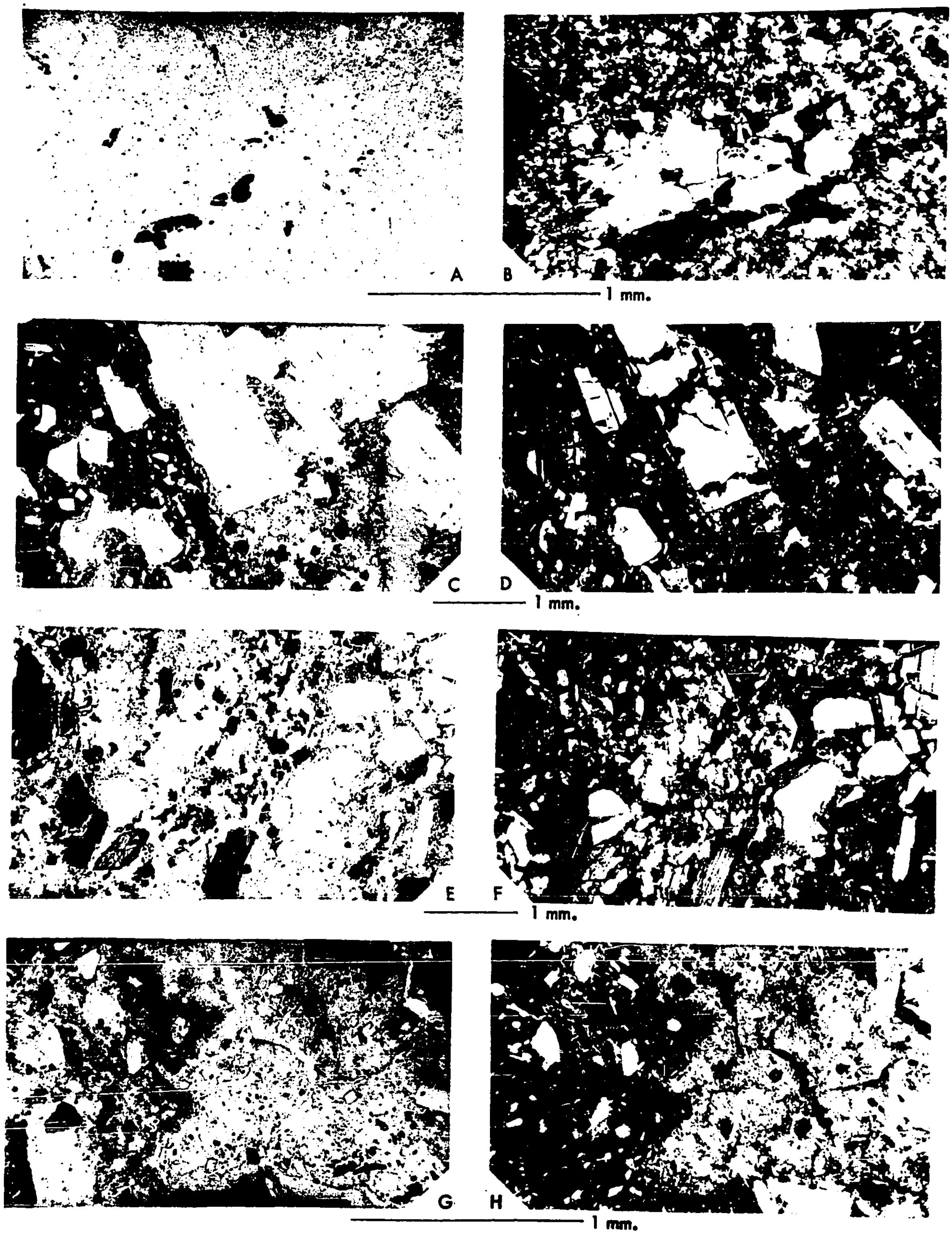


Plate 4

A. Cow Creek rhyolite of Flattop Mt. suite, inferred intrusive phase (Fci), showing devitrification spherulites. S=sphene; B=biotite; K=potash feldspar (sanidine). Plane polarized light.

B. Same as A, crossed nicols.

C. Racer Canyon tuff of Cove Mt. fm. (Crc). Q=quartz; P=plagioclase; K=potash feldspar (sanidine); mafic phenocrysts are biotite. Plane polarized light.

D. Pilot Creek basalt of Cove Mt. fm., intrusive phase (Cpi). Dark phenocrysts are olivine, largely altered to iddingsite and hematite; most of rock composed of augite, plagioclase, and smaller grains of olivine. Plane polarized light.

E. Ox Valley tuff (O). Q=quartz; P=plagioclase; K=potash feldspar (sanidine); mafic phenocrysts are highly hematitized biotite. Plane polarized light.

F. Same as E, crossed nicols.

G. Little Creek breccia of Quichapa fm. (Qlc), thin section cut across megascopic devitrification spherulite. Center of spherulite to right, not visible in photomicrograph. Dark area in right half of picture is devitrified portion, in which hypersthene (Ha) is altered to serpentine(?), while augite (A) remains fresh. Lighter area in left half contains fresh hypersthene (H) and augite. Textural contrast in groundmass not conspicuous at this magnification. Note plagioclase phenocrysts across devitrified-nondevitrified boundary. Plane polarized light.

H. Same as G, crossed nicols.

PLATE 4

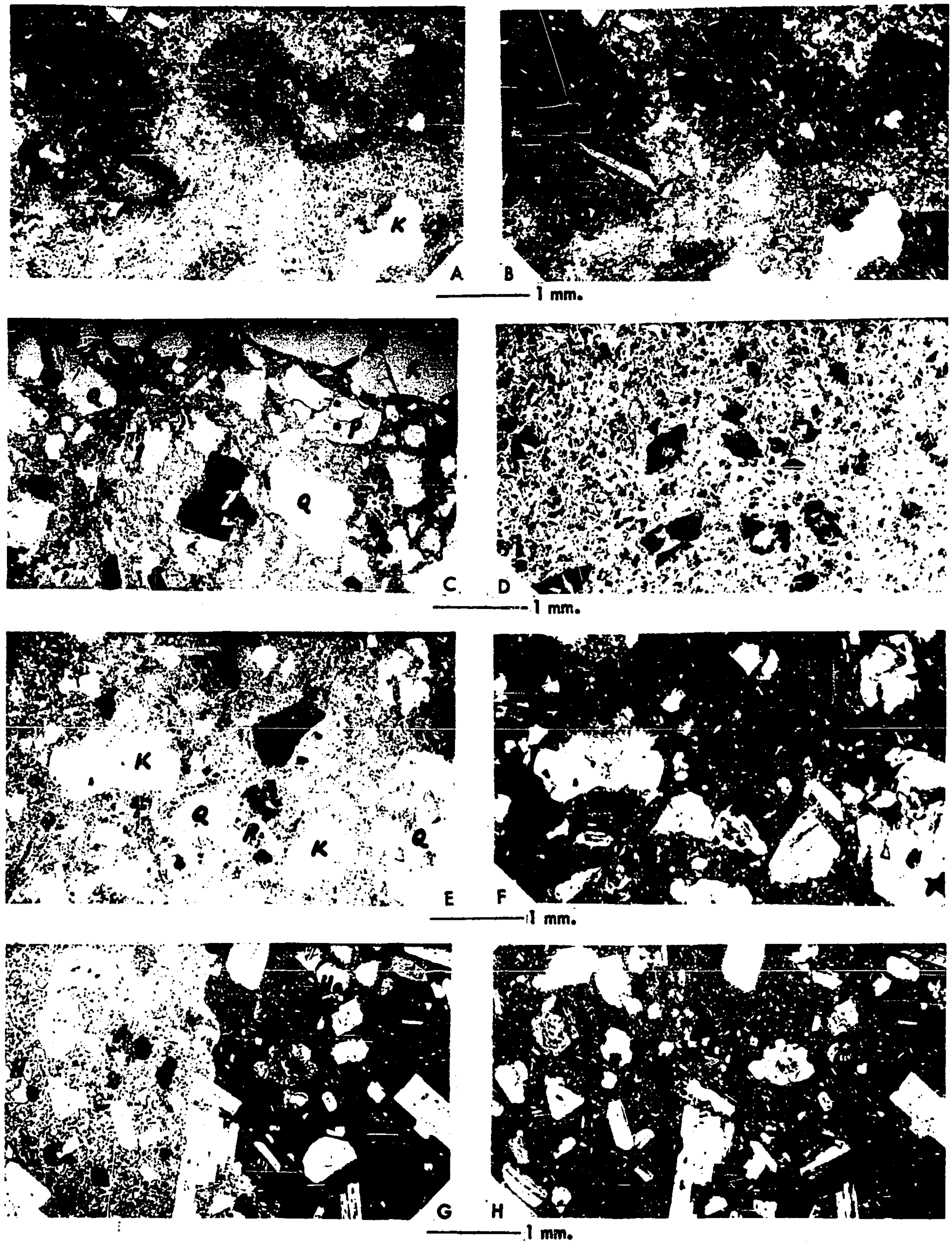


Plate 5

A. Rencher fm., Rusty tuff (Br2) - White tuff breccia (Brl) contact one mile southeast of Bull Valley vent. Note cognate fragments and rude stratification in Rusty tuff. Approximate scale shown at bottom of photograph.

B. Rencher fm., vent phase (Bri) at top of Bull Valley vent near contact with quartz monzonite, showing steep-dipping flow layering. Material can be traced laterally into Rusty tuff of photograph A.

C. Rencher fm., basal portion of White tuff breccia phase (Brl) in Moody Wash, two miles south of Bull Valley intrusion. Light-colored latite makes sharp contact with black basal vitrophyre. Circled figure gives scale.

PLATE 5

A

B

C

Plate 6

A. View to north from Cove Mt. in southwestern part of Bull Valley district, showing Flattop Mt. in center distance. Two sharp peaks to right of Flattop Mt. are Windy Peak and Pilot Peak, rhyolite plugs (Fp) emplaced during Flattop Mt. eruptive episode.

B. Flow layering or sheet jointing in rhyodacite of Hogs Back fm. (Fh), near vent in canyon of Little Pine Creek, north of lower Enterprise reservoir.

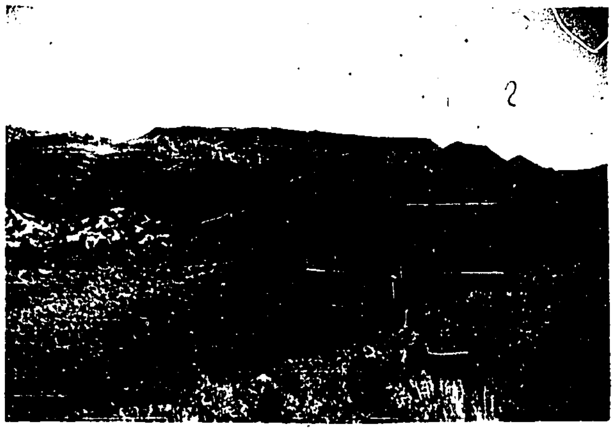
C. Ox Valley tuff (O) overlying Racer Canyon tuff (Crc) north of Racer Canyon.

D. Closer view of Racer Canyon tuff, lower in section, showing rough surface and rude stratification. Windy Peak in distance.

E. Typical exposures of Little Creek breccia (Qlc). Dark, sub-rounded fragments of andesite(?) are enclosed in lighter-colored, ashy matrix of same composition.

F. View to north across upper Racer Canyon, showing white-gray ignimbrites of Racer Canyon tuff at type locality. Darker material on skyline is Ox Valley tuff.

PLATE 6

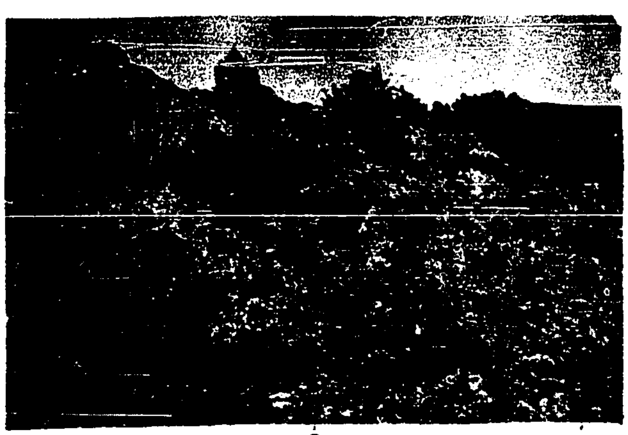


A

B

C

D



E

F

Plate 7

A. "Hoodoos" formed by weathering and erosion of non-welded tuff and tuffaceous sediments of Reservoir fm. (R), east of Enterprise reservoirs. Material very similar to that of Racer Canyon tuff.

B. White airfall tuff overlying soft pink airfall tuff in Reservoir deposits (R) northwest of Ox Valley. Similar sequence occurs on Cedar Spring member of Cove Mt. fm.

C. Dark red devitrification spherulites in gray glassy matrix of Cow Creek rhyolite (Fc), west flank of Flattop Mt.

D. Devitrification structures in Little Creek breccia (Qlc) south of Mountain Meadow. Dark layers are devitrified portions. Distinct layering grades into breccia at left side of picture.

E. Gray thick- to thin-bedded Claron limestone (Tc) in vicinity of Soft Iron uplift.

F. Claron-Iron Springs contact in Cottonwood Canyon north of Big Mt. Coarse cobble conglomerate of Claron fm. (Tc) rests upon interlensing sandstone and conglomerate of Iron Spring fm. (Kis) with angular unconformity of about 15 degrees.

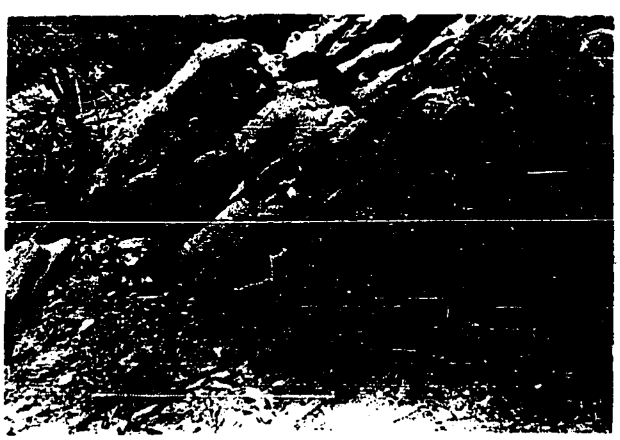
PLATE 7

A

B

C

D



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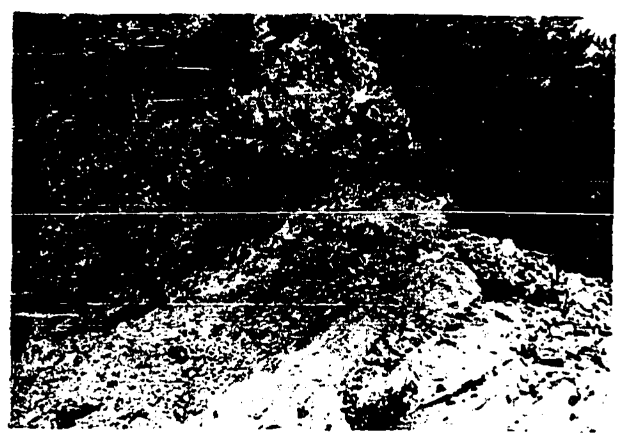

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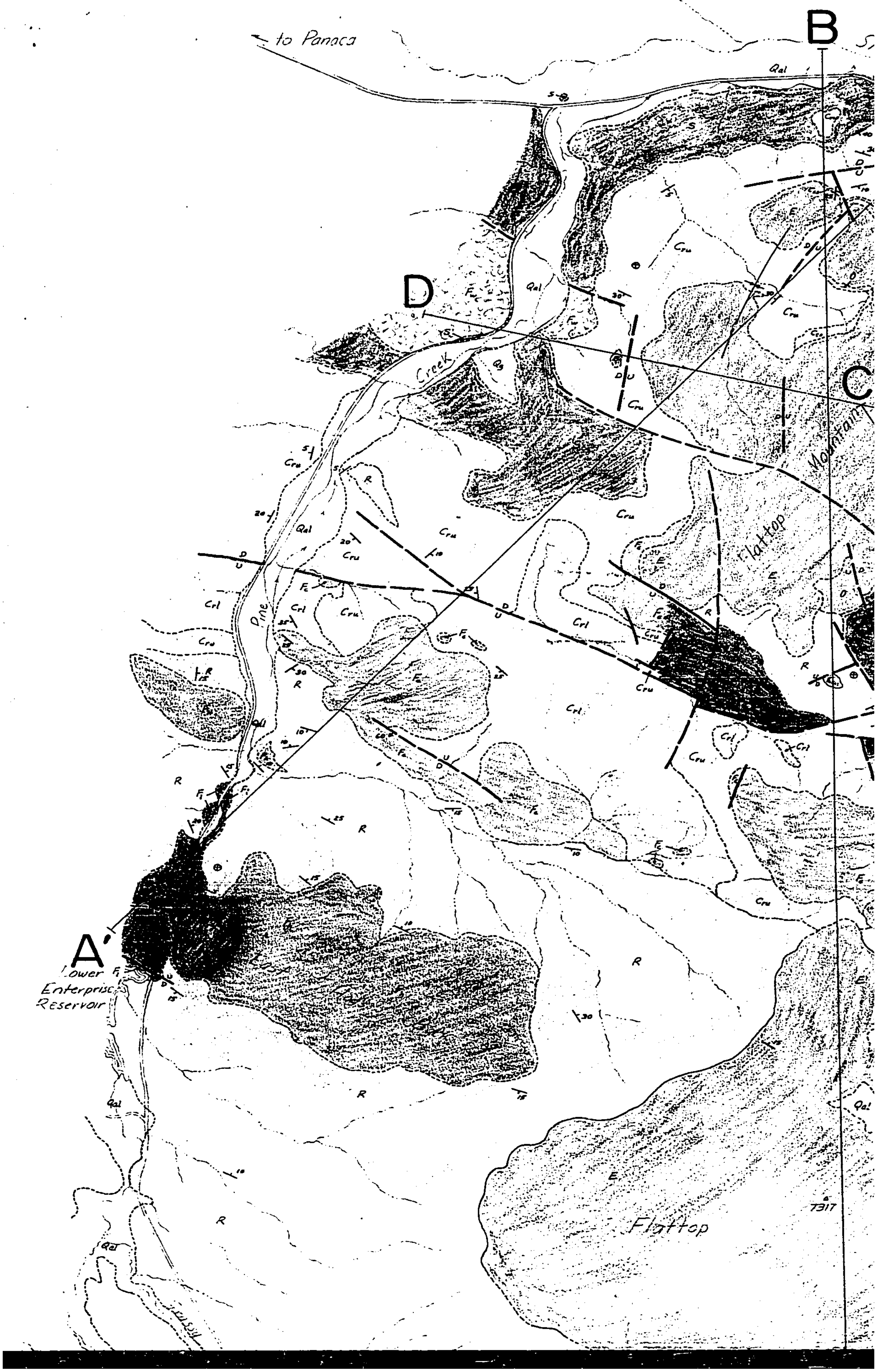
VITA

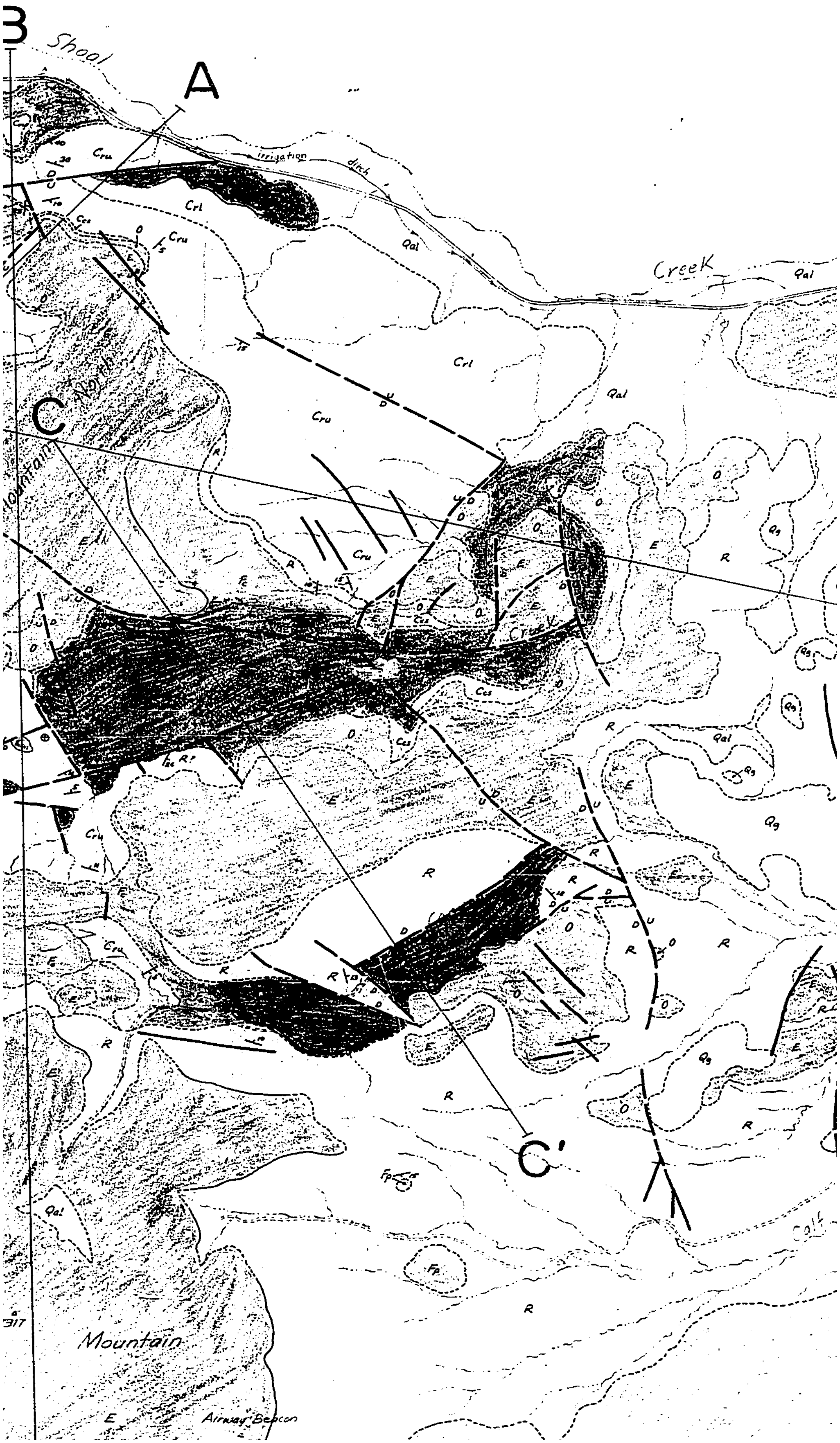
Horace Richard Blank, Jr., was born in New York City on April 27, 1929, the son of Horace Richard and Marjorie Ferguson Blank. He received a B. S. in physics from Southwestern University (Texas) in 1948, and an M. S. in physics from the University of Washington in 1950. Prior to entering the U. S. Marine Corps in 1952, he also studied geophysics and geology at U. C. L. A. and the Colorado School of Mines. In 1956 he resumed graduate work in geology at the University of Washington.

GEOLOGIC M

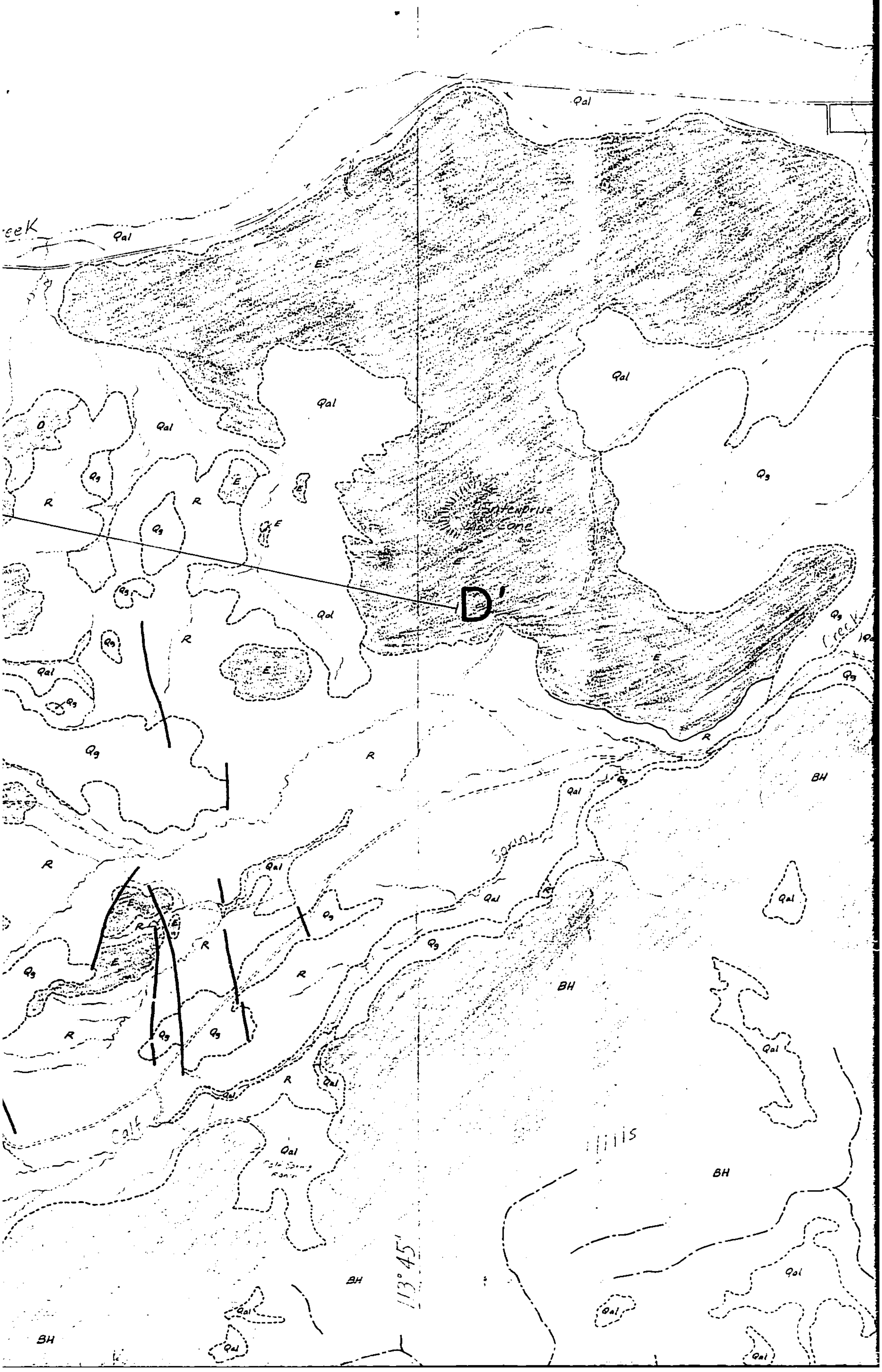


B
to Panaca
D
C
A'
Pine Creek
Flattop Mountain
Lower Enterprise Reservoir
Flattop
7317

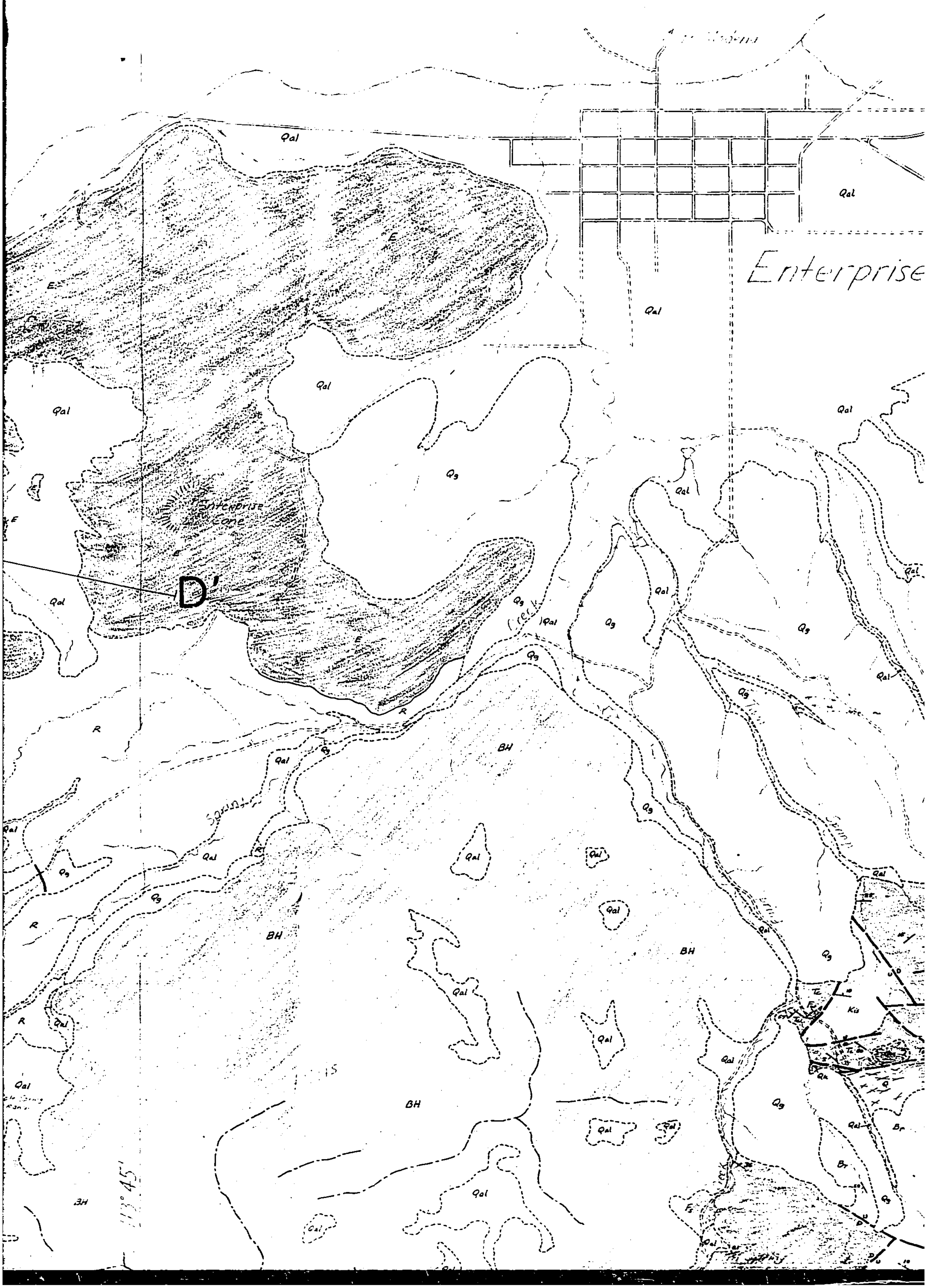
MAP OF THE BULL V



LL VALLEY DISTRICT



EY DISTRICT WASH



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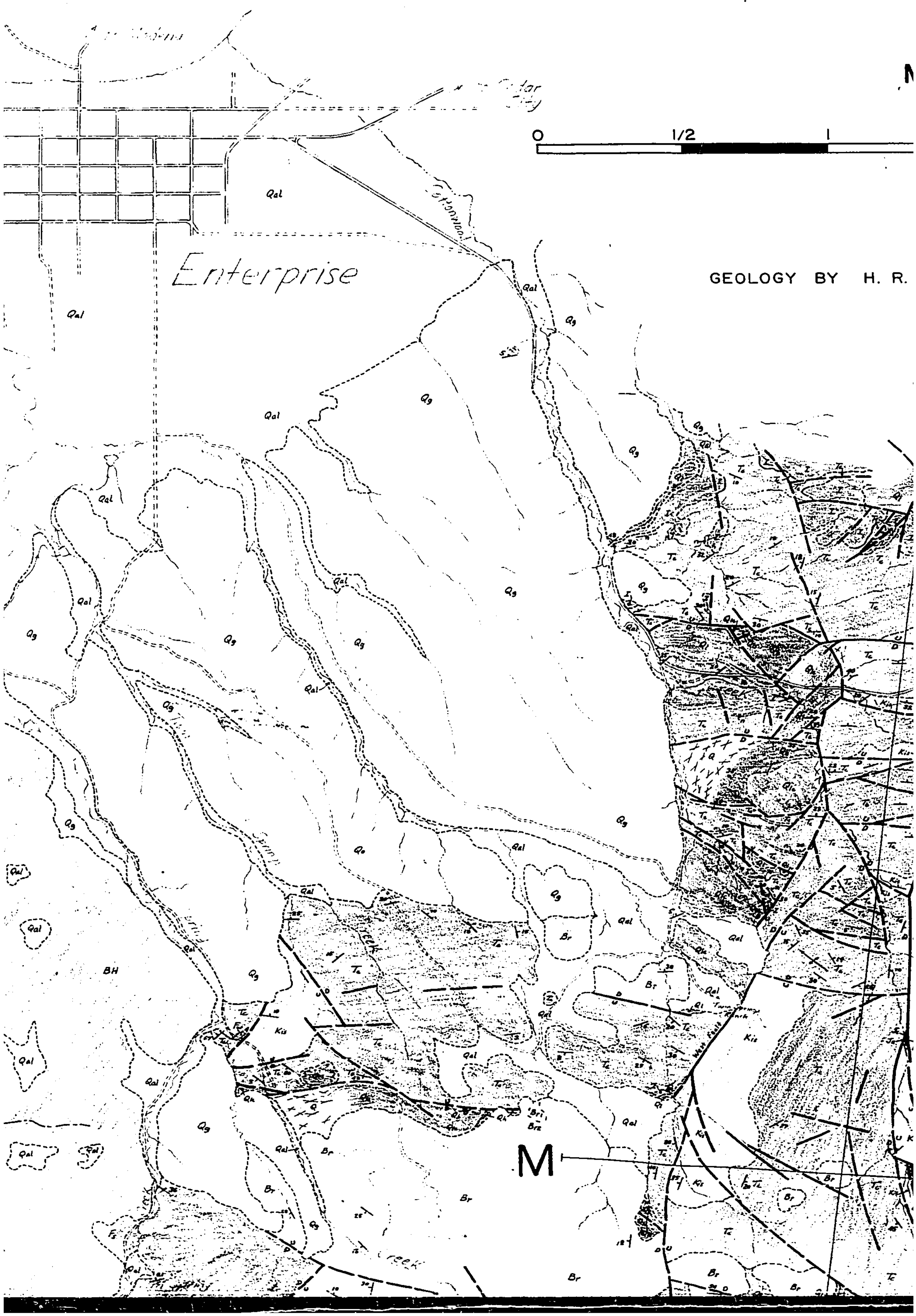

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MILES

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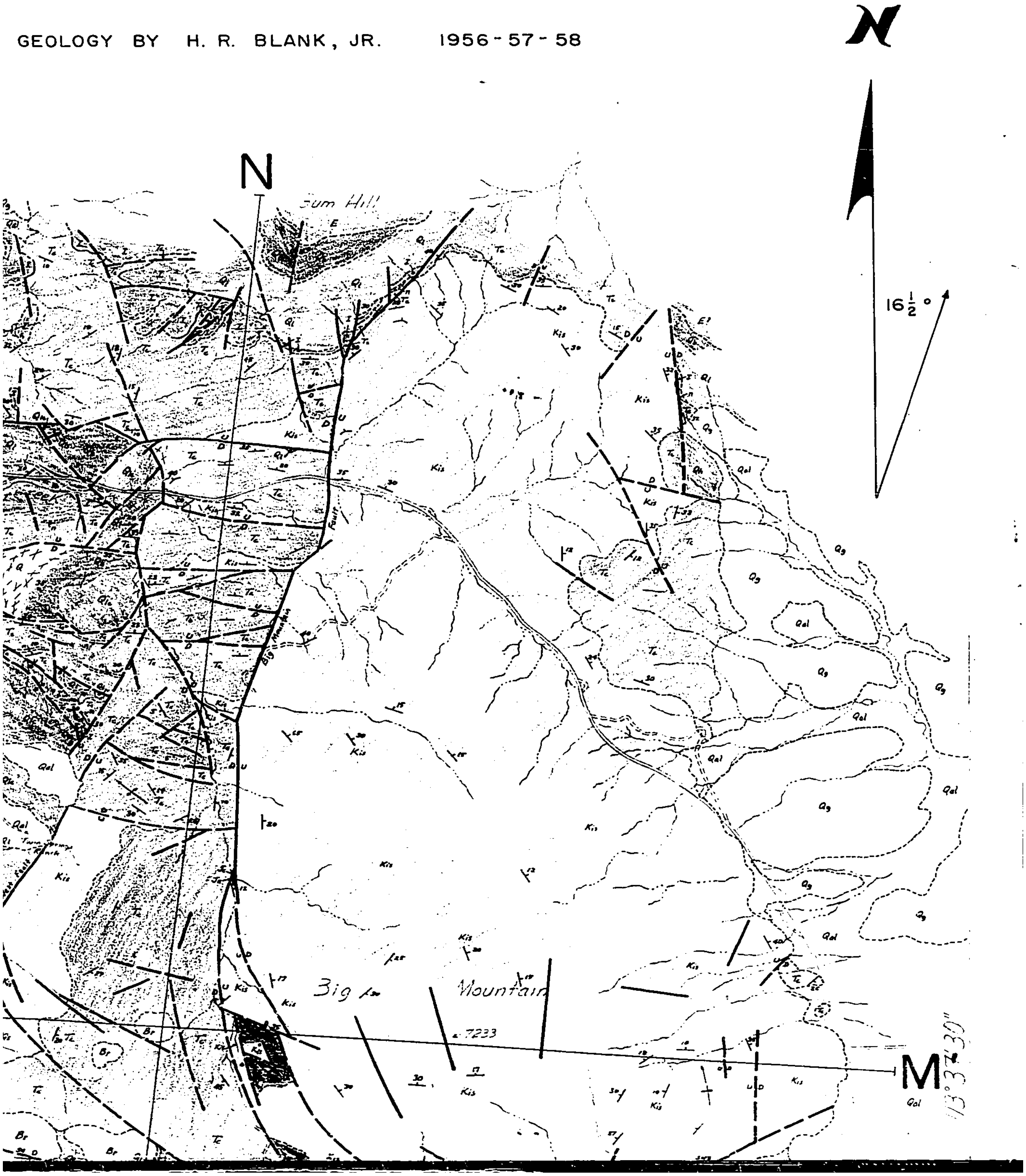
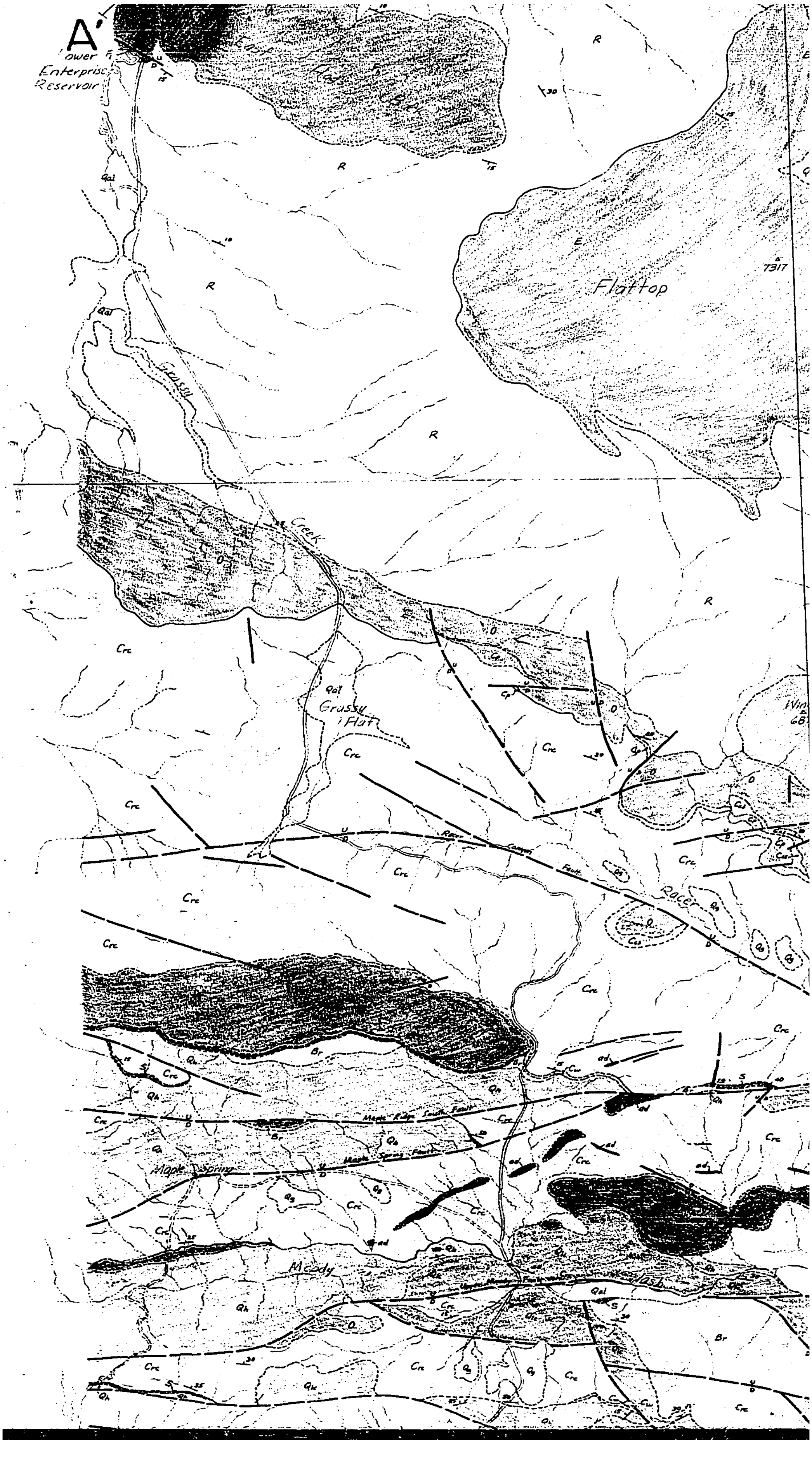
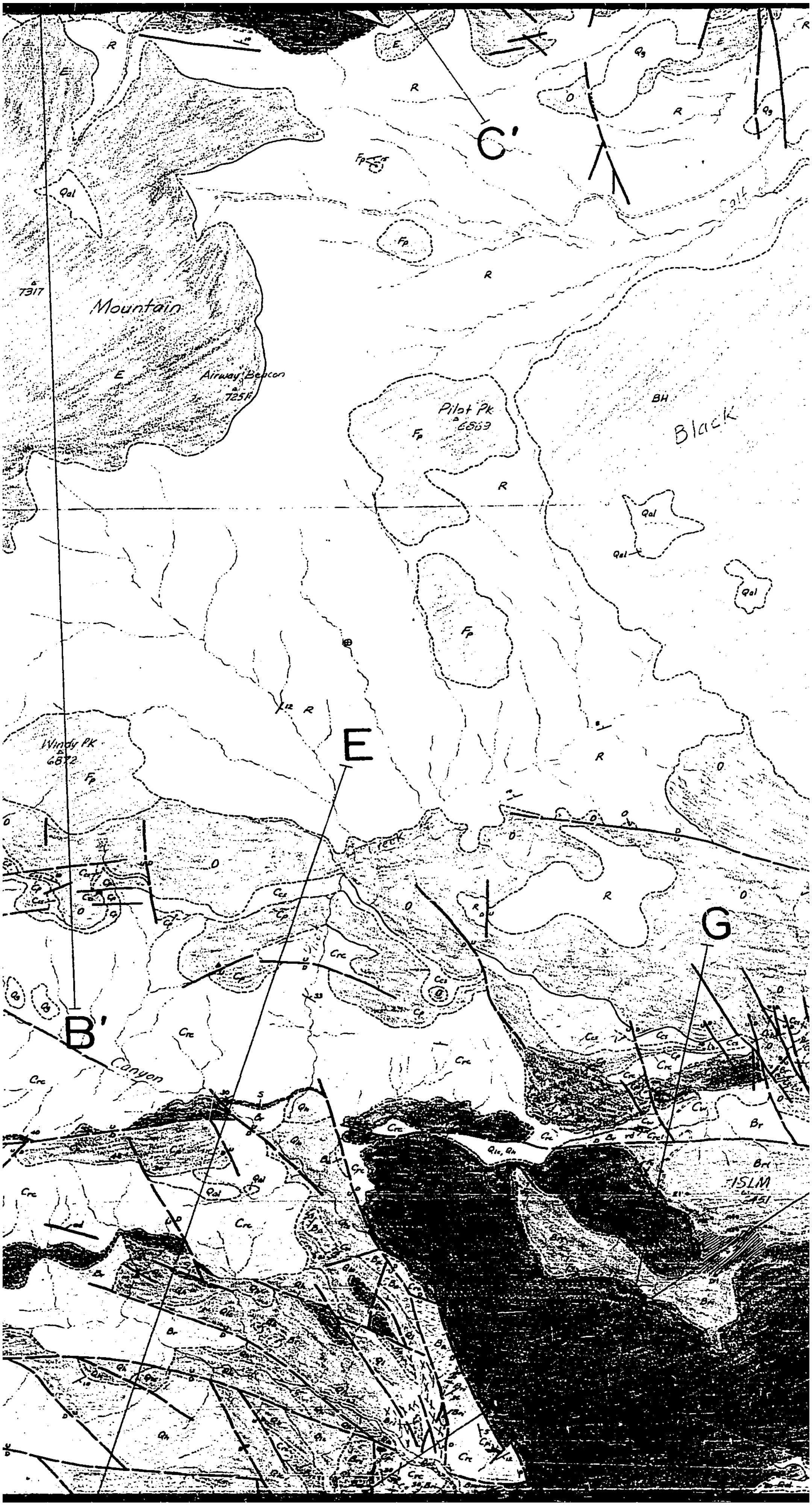
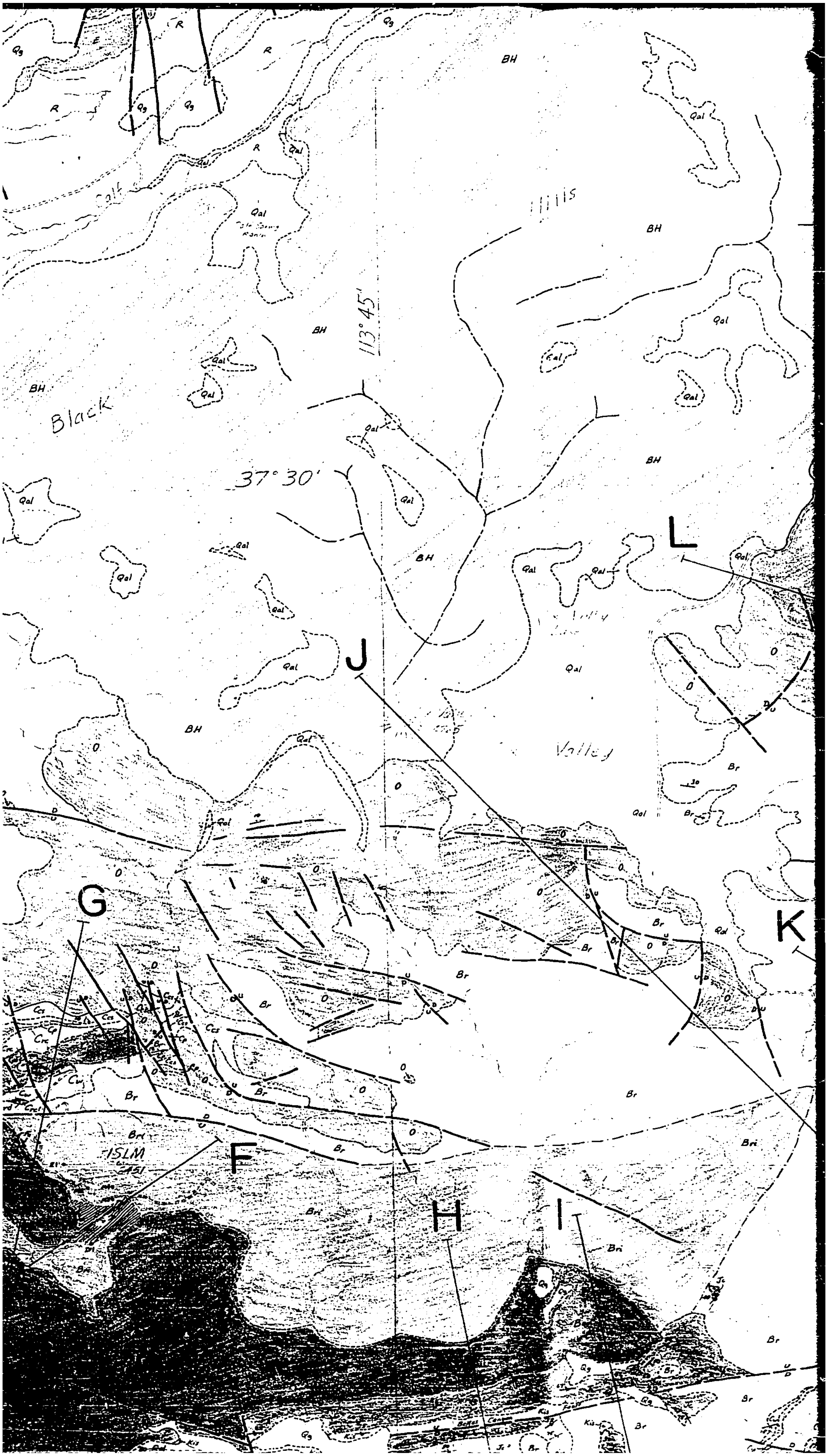
GEOLOGY BY H. R. BLANK, JR. 1956-57-58




A'
Lower Enterprise Reservoir
East Pass Bay
R
Qal
Grassy
E
7317
Flattop
Creek
O
Crc
Grassy Flat
Racer Canyon Fault
Racer
Br
Maple Ridge South Fault
Maple Spring Fault
Maple Spring
ad
Moody Wash
Qal


C'
Mountain
7317
Airway Beacon
Pilot Pk
6863
Black
BH
Windy Pk
6872
E
Creek
G
B'
Canyon
ISLM



BH
Qal
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113° 45'
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Hills
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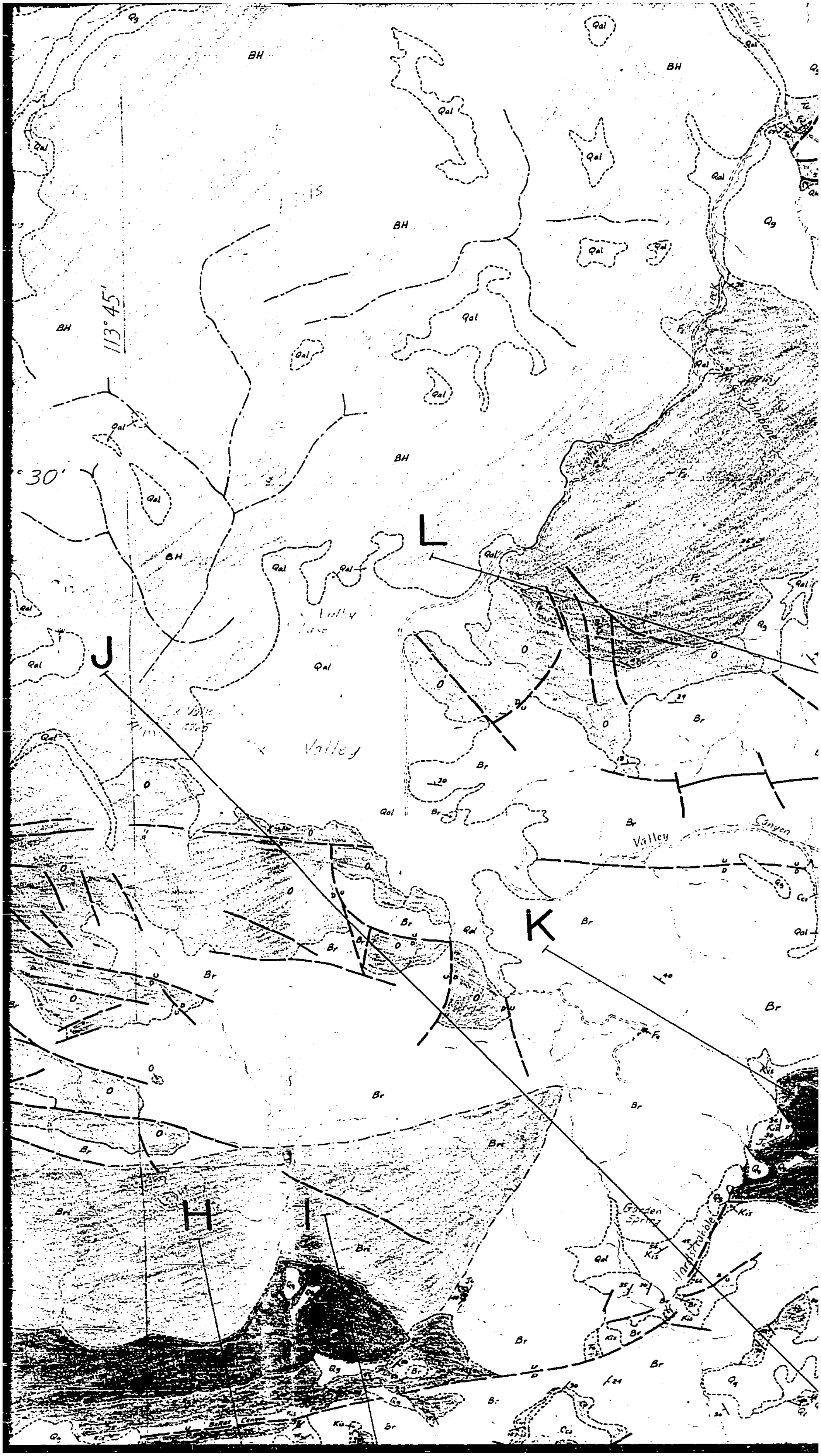

113°45'
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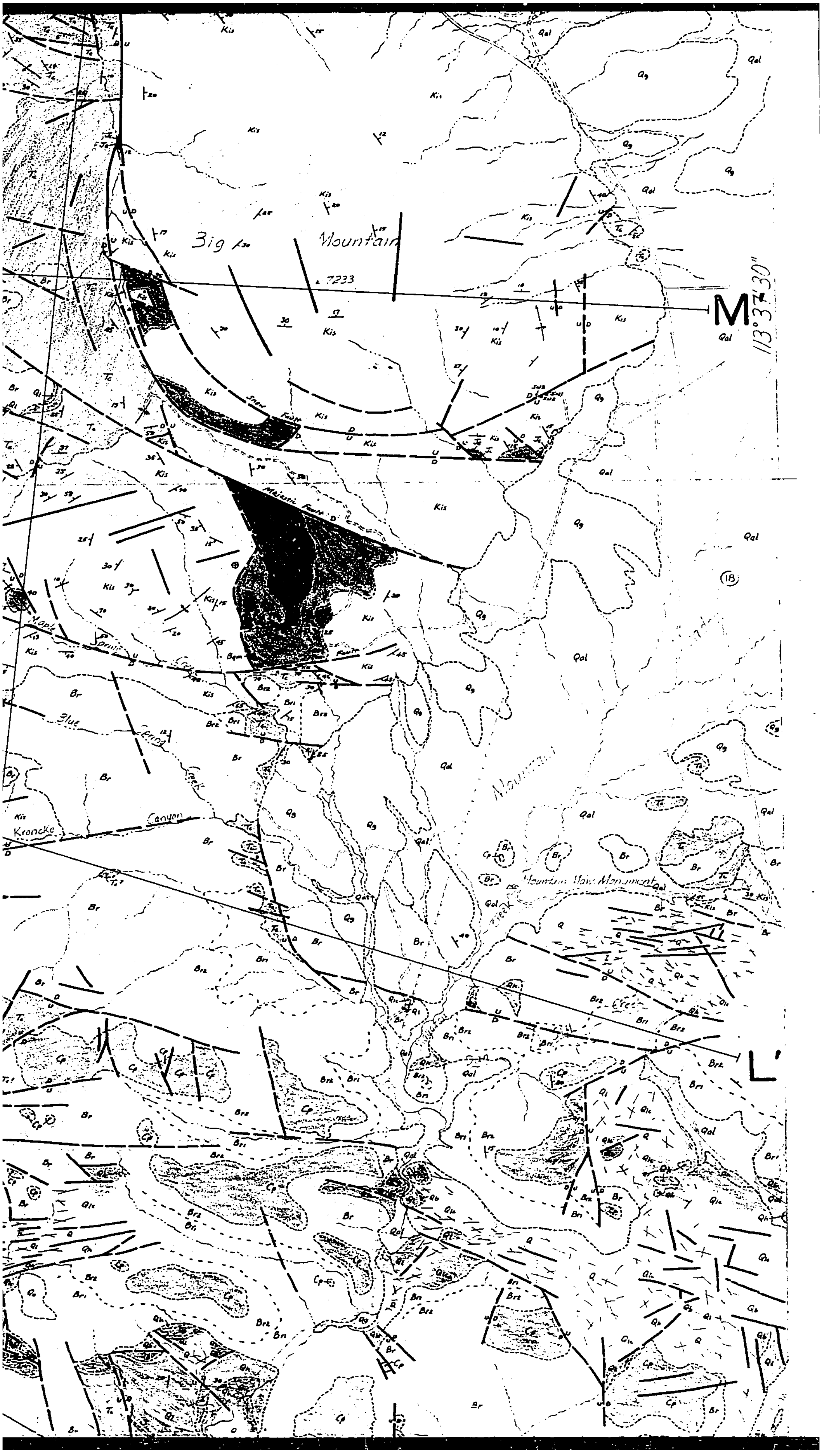
Big Mountain
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113°37'30"
Kroncke Canyon
Mountain View Monument
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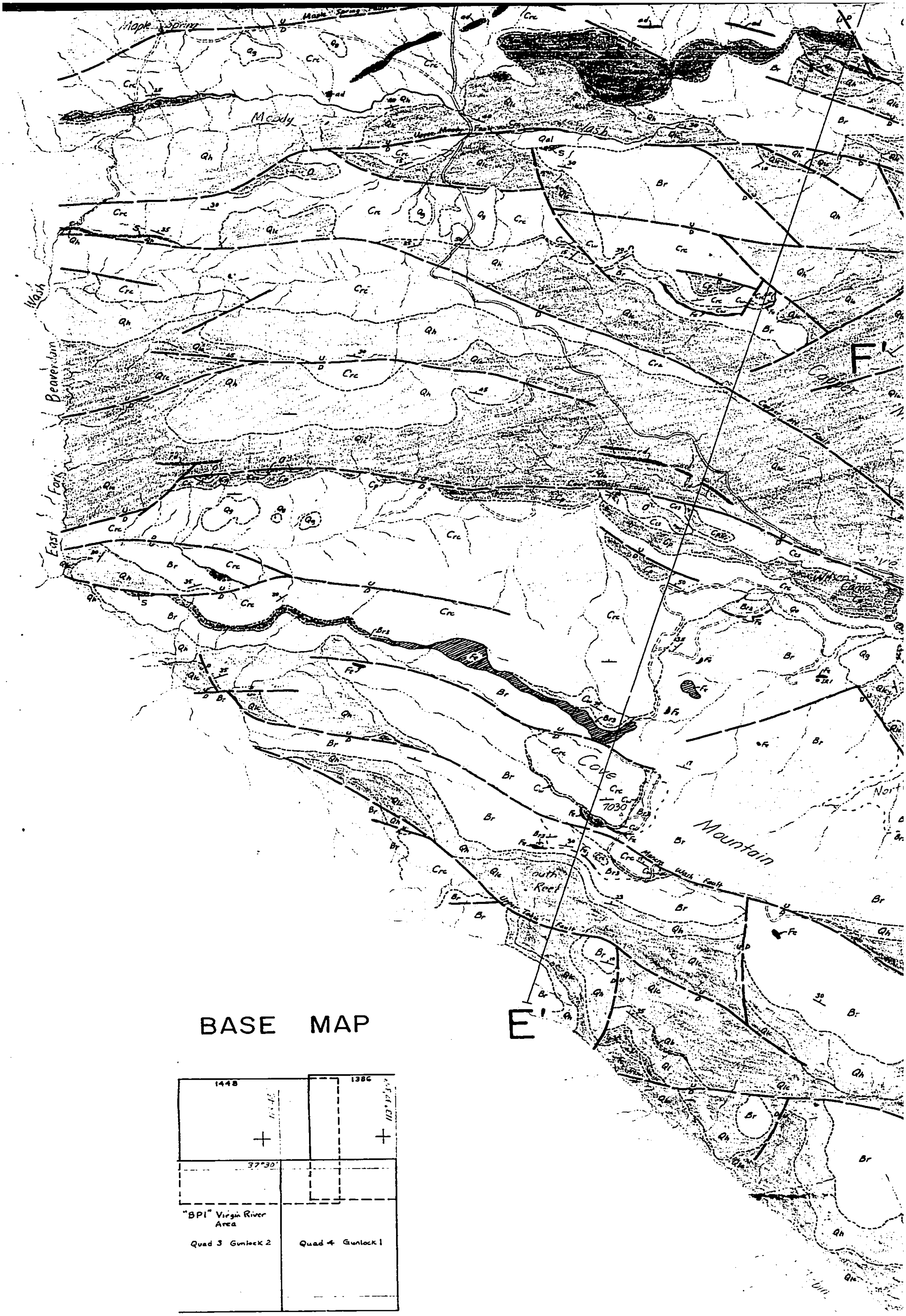
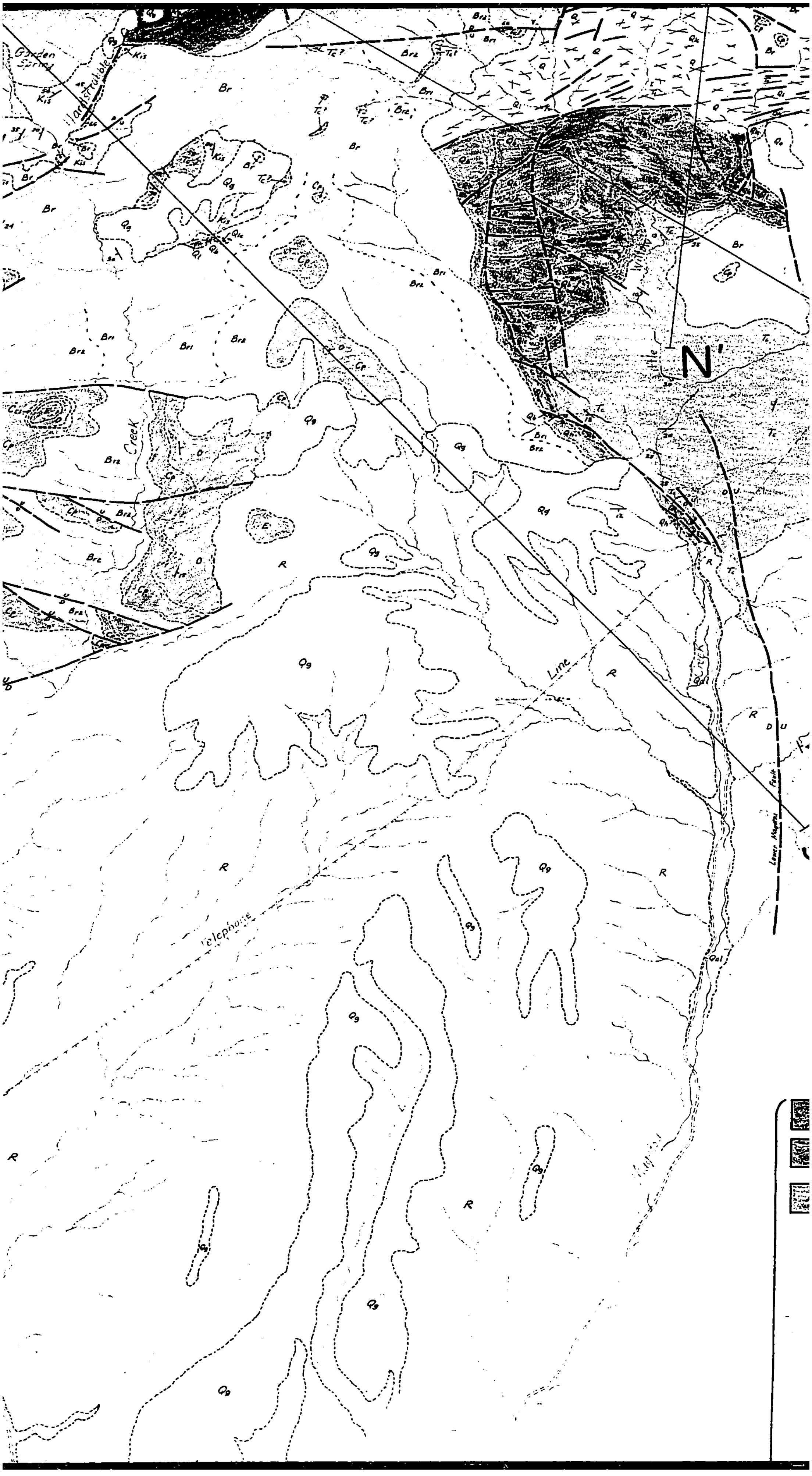


Two high alt. photos. U.S.G.S. Proj. G.S.-126 AN f = 6" 1953


F'
G'
Copper
Mountain
Bull
Mount
North
Mountain
Muddy
Cove Wash Fault


H
I
H'
I'
G'
O
Bull
Mountain
Bull Mt. South Fault


H
I
H'
I'
O
Garden Spring
Creek
Garden
Ridge



Garden Spring
N'
Creek
Line
Telephone

IGNEOUS ROCKS

UPPER VOLCANIC GROUP

Quaternary
- BH — Black Hills basalt
- Enterprise basalt

FLATTOP MT. SUITE

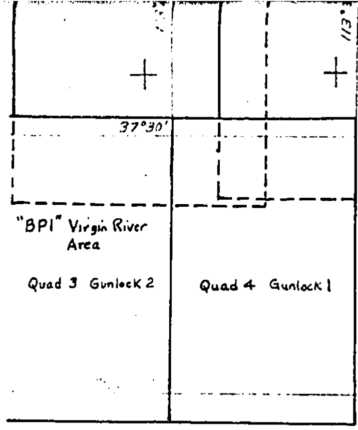
- Hogs Back fm.
  - Fhi, intrusive and vent phases
- Shinbone rhyolite
- Cow Creek rhyolite
  - Fci, intrusive and vent phases
- white siliceous rock
- Little Pine Creek rhyolite
- Pilot Peak rhyolite

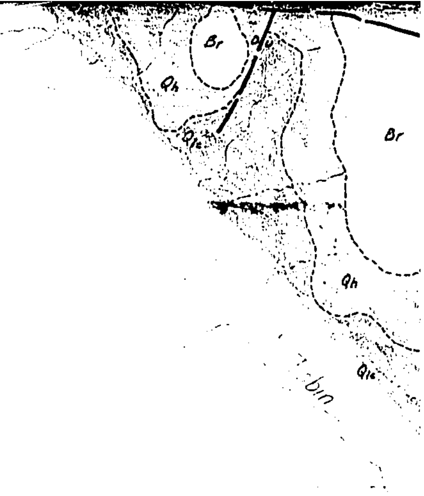
MIDDLE VOLCANIC GROUP

- Ox Valley tuff

Cove Mt. fm.

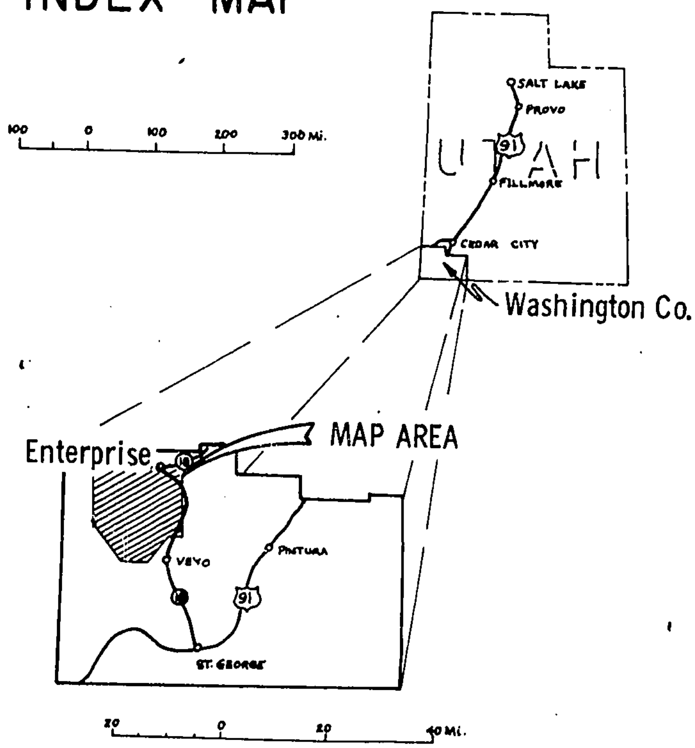
- Ccs — Cedar Spring member
  - l, Lower Moody tuff
- Cp — Pilot Creek basalt
  - Cpi, intrusive and vent phases

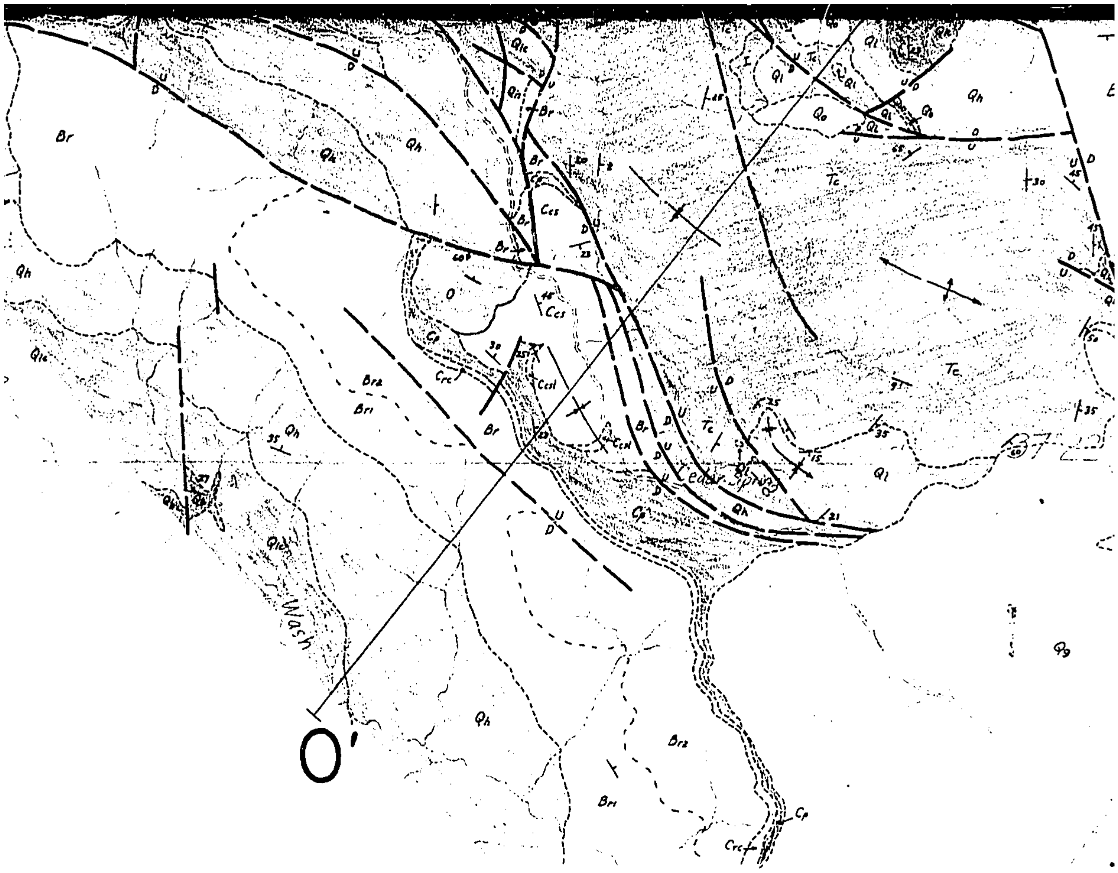




Two high alt. phot's. U.S.G.S. Proj. G.S.-126 AN f = 6" 1953
Parts of semi-controlled aerial mosaics Utah 329, 330 U.S.D.A., SCS

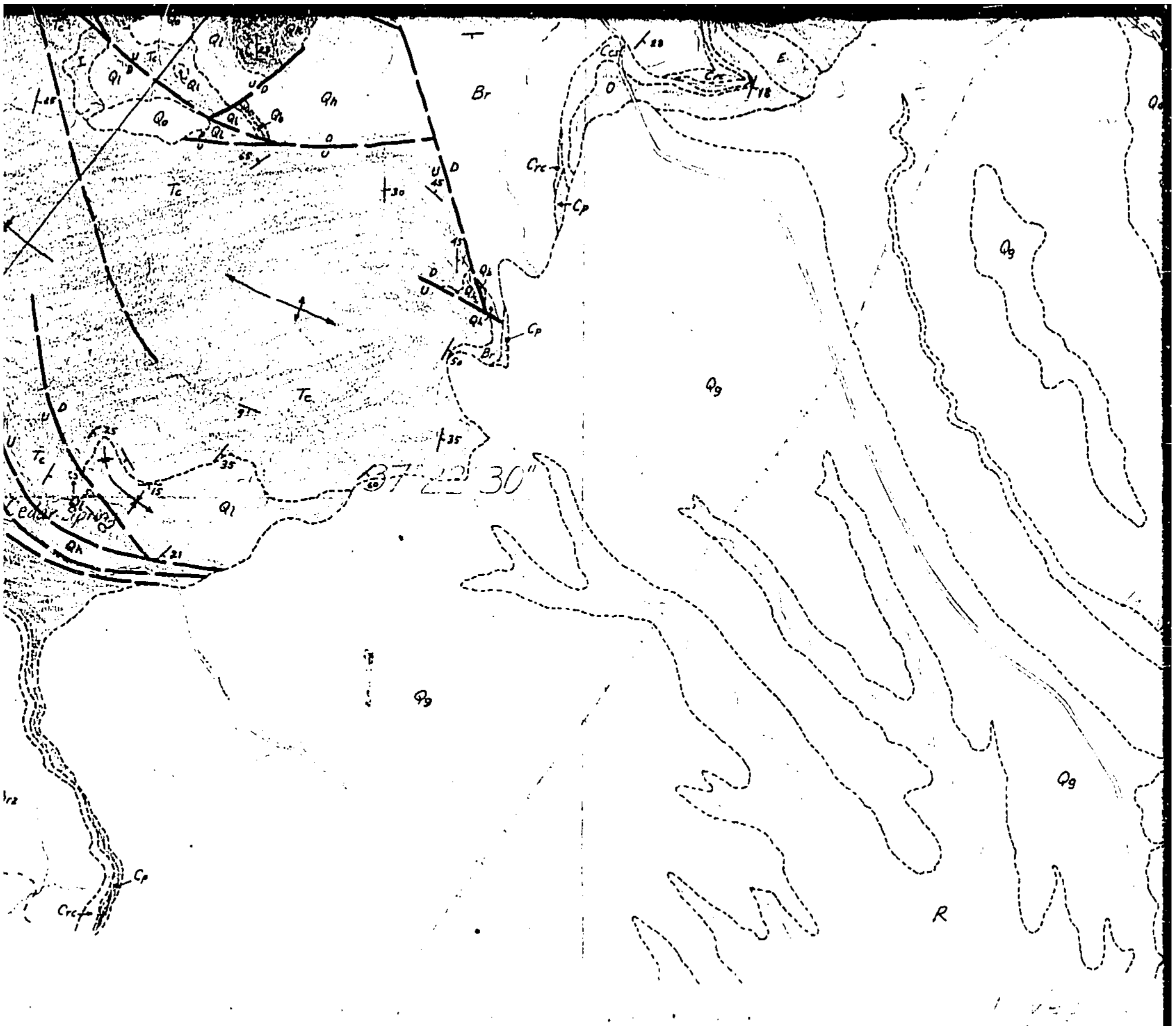
INDEX MAP





SYMBOLS

- Contact, dashed where inferred or not well located
- Interphase contact (within Rencher fm.)
- Fault or fracture, dashed where inferred or not well located
- Trace of inferred periphery of eruptive vent
- Axis of flow furrow (in Black Hills basalt)
- Chaotic area; symbols denote units involved
- Crestal trace of plunging anticline, dashed where not well located
- Crestal trace of plunging syncline, dashed where not well located
- 35 Strike and dip of planar structure (measured)
- Strike and dip of planar structure (generalized)
- 70 Strike and dip of overturned beds
- Generalized strike and dip of contorted bedding
- Strike of vertical beds
- Horizontal beds
- ∘ Mt Diamond drill hole



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bedding

SED

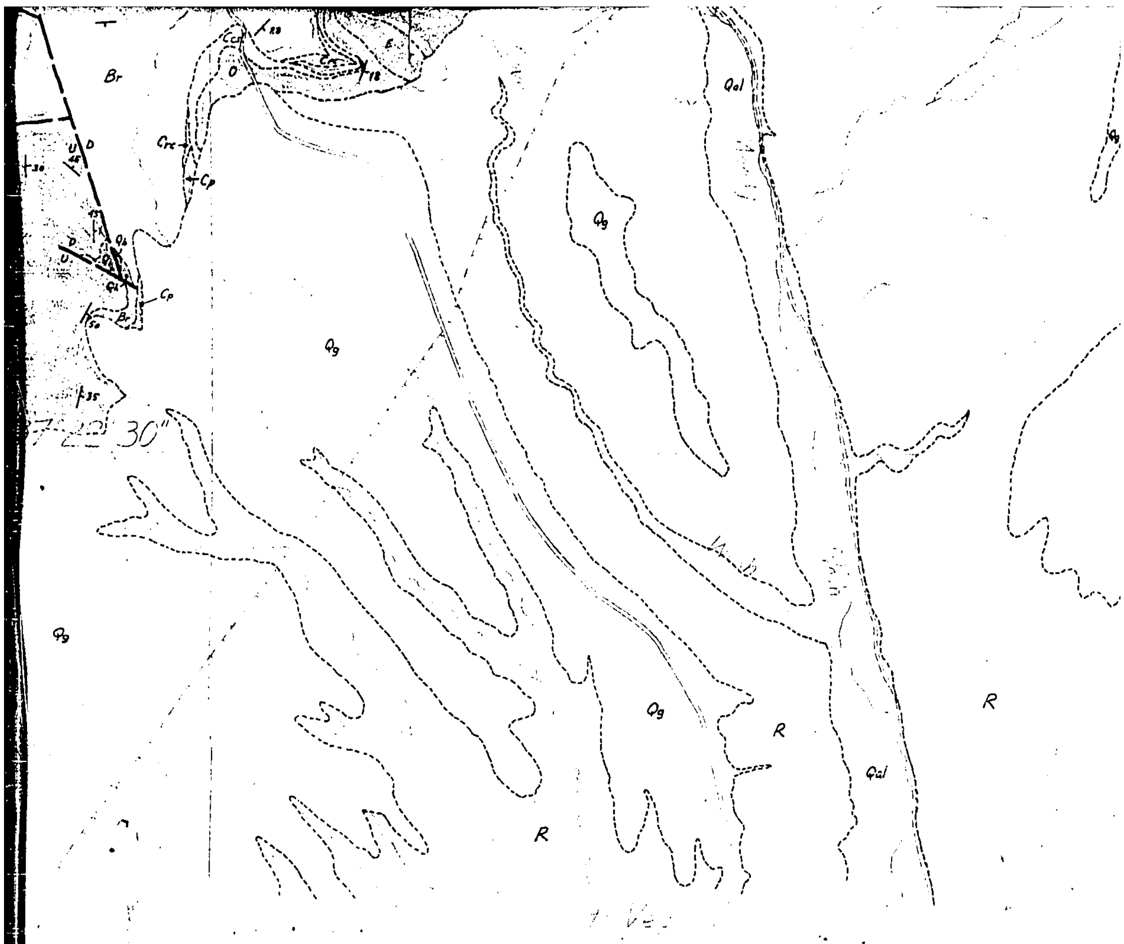
Quaternary

Pliocene(?)-
early Quate

upper Cretaceou
Eocene

upper Cretaceou

Jurassic



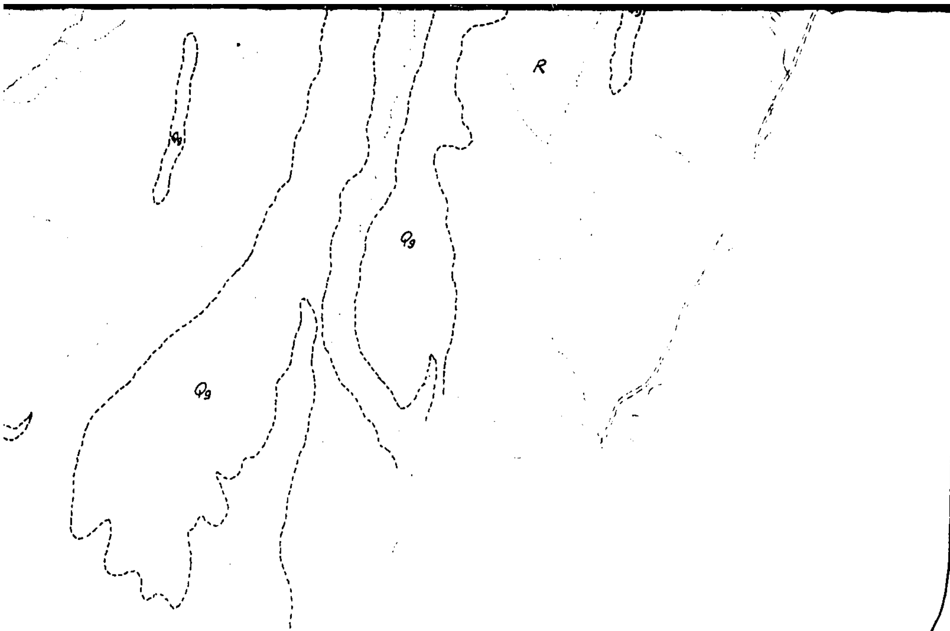
SEDIMENTARY ROC

LARGELY POST-VOLCAN

Quaternary	Qal	alluvium
	Qg	gravel and older
Pliocene(?)-early Quaternary	R	Reservoir fm.

PRE-VOLCANIC

upper Cretaceous(?)-Eocene		Claron fm. n, Needles tuff
upper Cretaceous	Kis	Iron Springs fm.
Jurassic		"Entrada" fm.
		Carmel fm.



Tertiary

RY ROCKS

Y POST-VOLCANIC

alluvium

gravel and older alluvium

Reservoir fm.

CANIC

Claron fm.

n, Needles tuff

ron Springs fm.

Entrada" fm.

armel fm.

DIKES

Cow Creek rhyolite
Fci, intrusive and vent phases

Pilot Peak rhyolite

MIDDLE VOLCANIC GROUP

Ox Valley tuff

Cove Mt. fm.

Cedar Spring member
l, Lower Moody tuff

Pilot Creek basalt
Cpi, intrusive and vent phases

Racer Canyon tuff
Cru, upper units on Flattop Mt.
Crl, lower units on Flattop Mt.

Willow Spring member

Maple Ridge porphyry

Shoal Creek breccia

BULL VALLEY SUITE

Rencher fm.
Br3, upper phases on Cove Mt.
Br2, Rusty tuff phase
Br1, White tuff breccia phase
Bri, intrusive and vent phases

iron deposits; shading denotes mineralized zone

altered rock with relict fragments

quartz monzonite porphyry

LOWER VOLCANIC GROUP

Quichapa fm.
Q, undifferentiated

Harmony Hills tuff

Little Creek breccia

Bauers tuff

Leach Canyon tuff

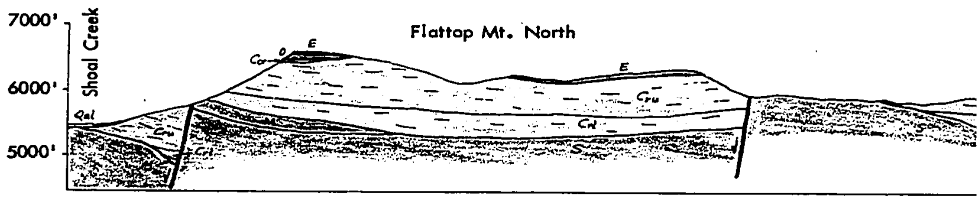
Isom fm.

IKES

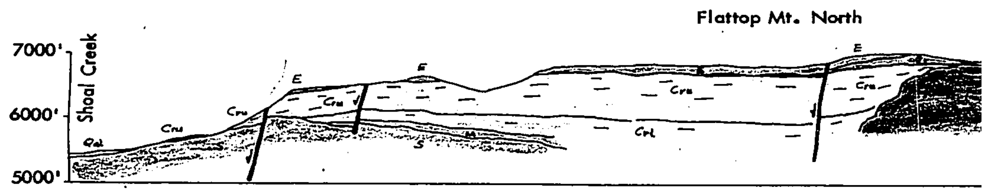
rhyolite dikes

andesite-basalt dikes

A


7000'
6000'
5000'
Shoal Creek
Flattop Mt. North

B


7000'
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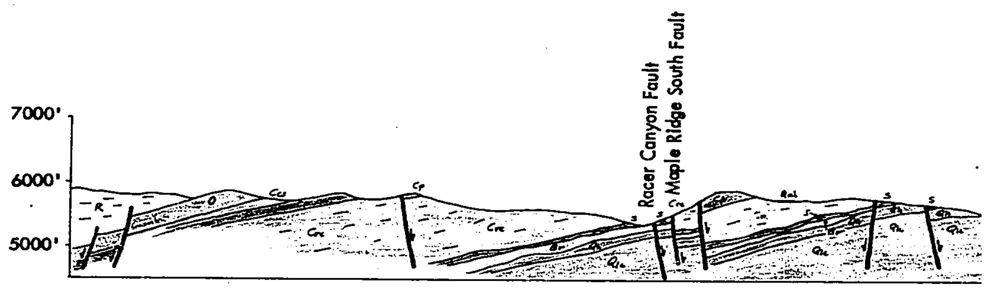
Shoal Creek
Flattop Mt. North

E


7000'
6000'
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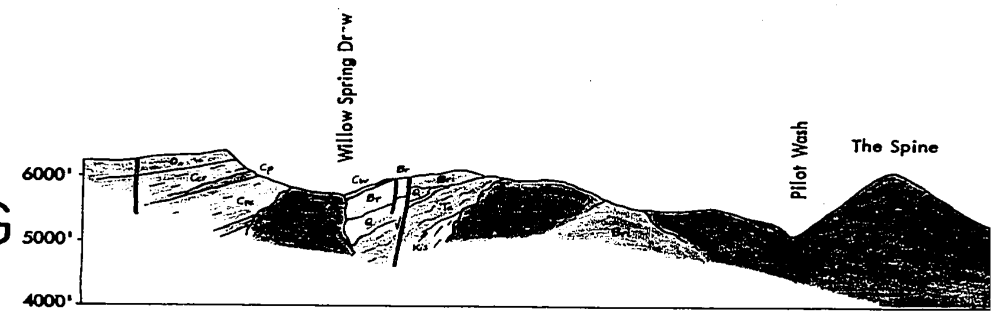
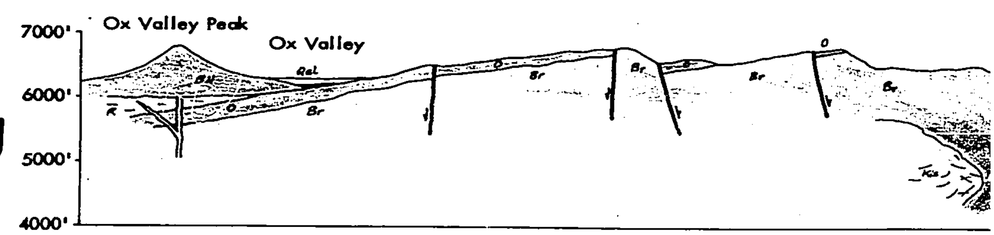
Racer Canyon Fault
Maple Ridge South Fault

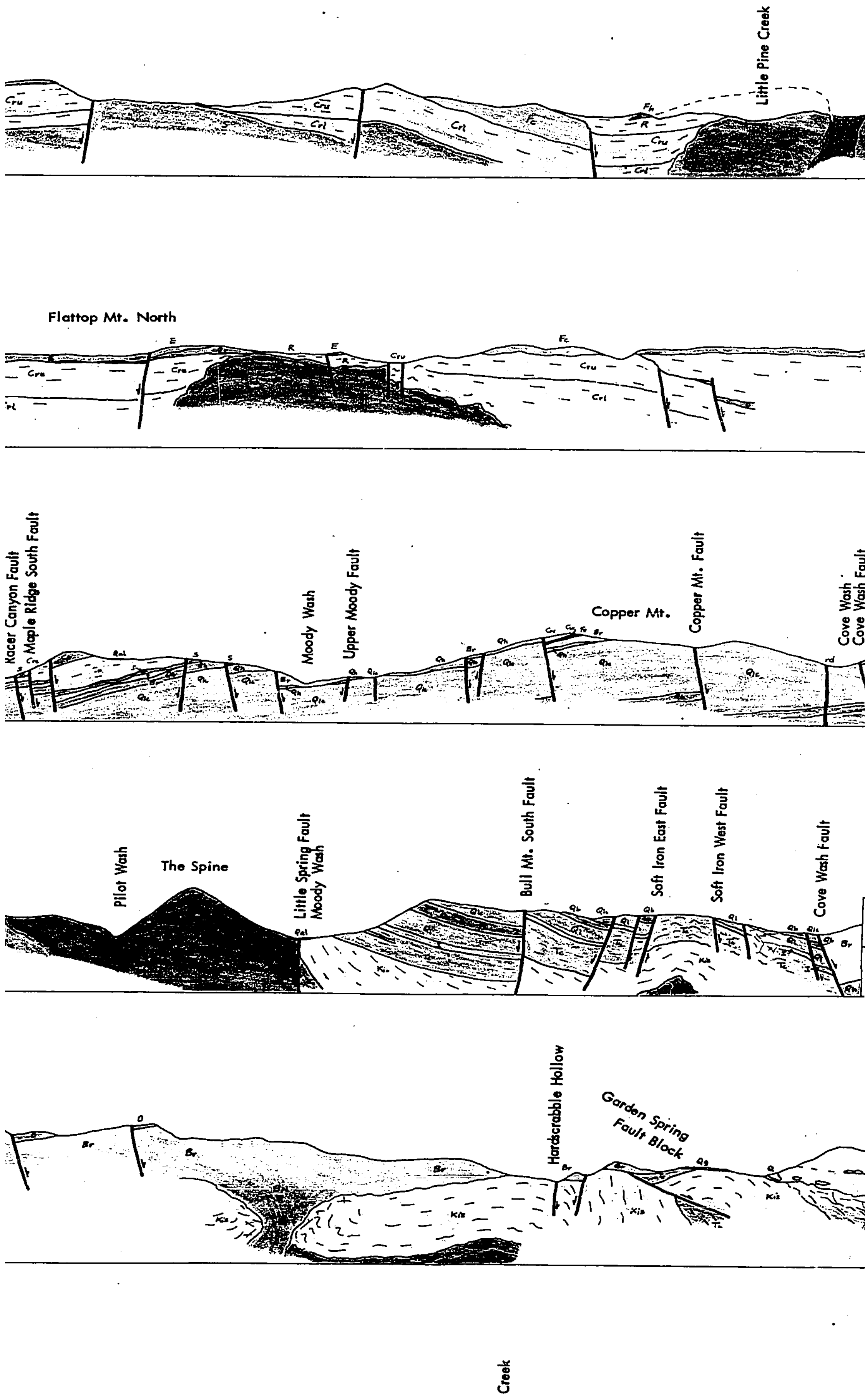
G


6000'
5000'
4000'
Willow Spring Dr-w
Pilot Wash
The Spine

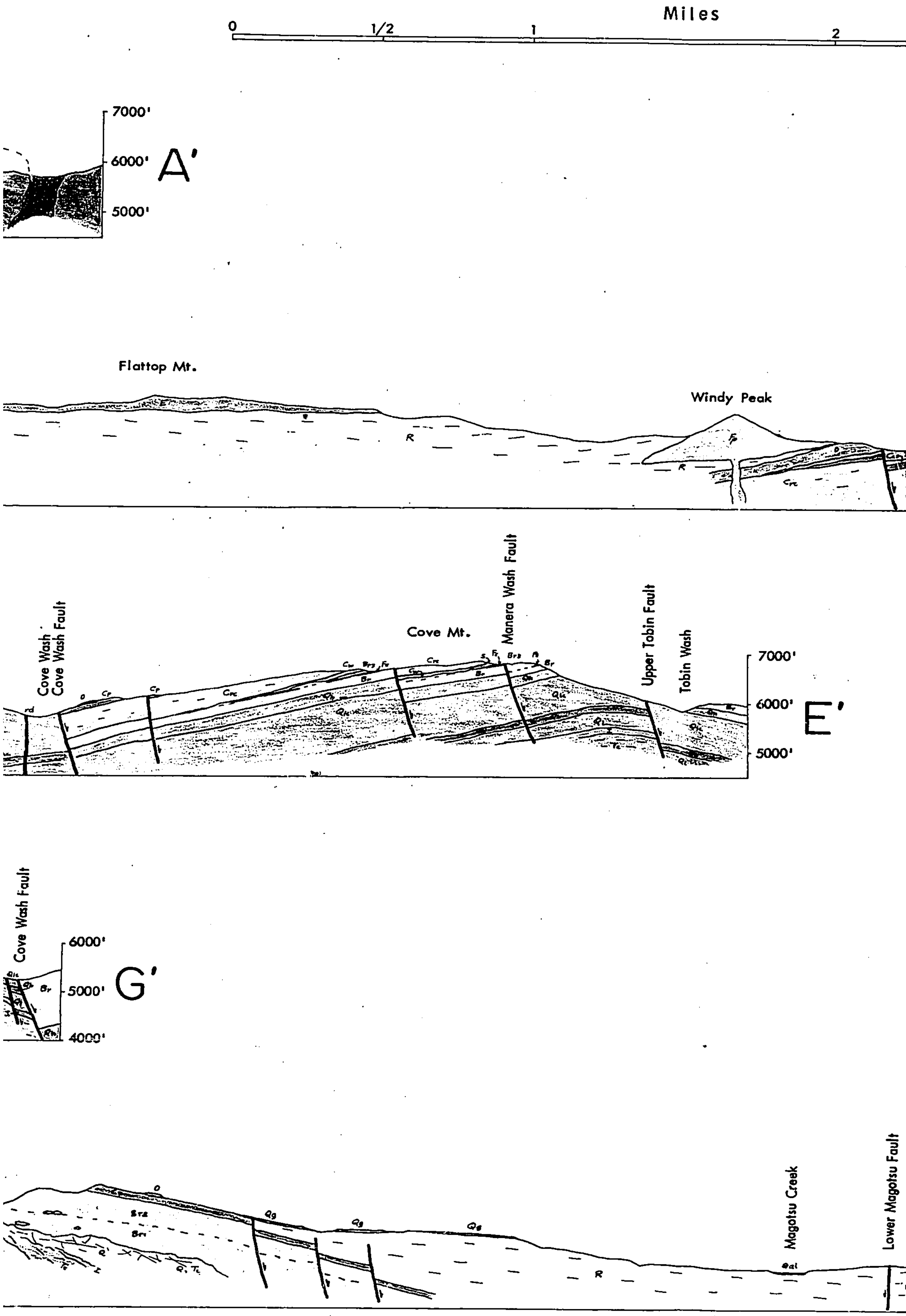
J


7000'
6000'
5000'
4000'
Ox Valley Peak
Ox Valley

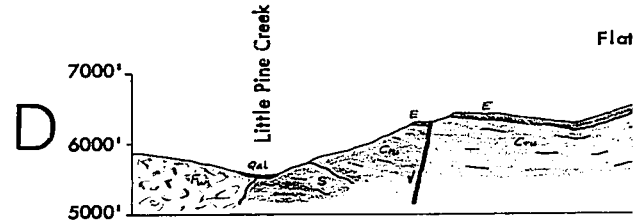

crabble Hollow

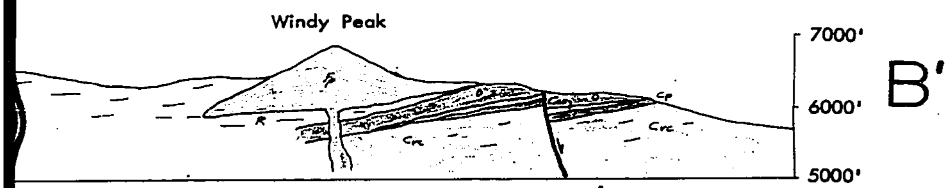

Little Pine Creek
Flattop Mt. North
Kacer Canyon Fault
Maple Ridge South Fault
Moody Wash
Upper Moody Fault
Copper Mt.
Copper Mt. Fault
Cove Wash
Cove Wash Fault
Pilot Wash
The Spine
Little Spring Fault
Moody Wash
Bull Mt. South Fault
Soft Iron East Fault
Soft Iron West Fault
Cove Wash Fault
Hardscrabble Hollow
Garden Spring Fault Block
Creek

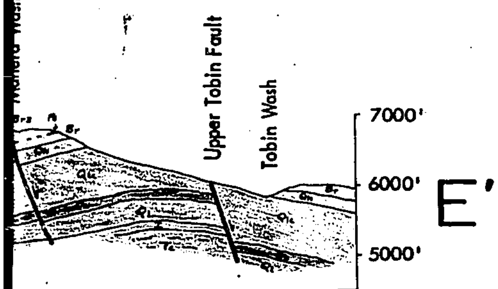
RUCTURE SECTIONS ACCOMPANYING GEOLOGIC MAP O

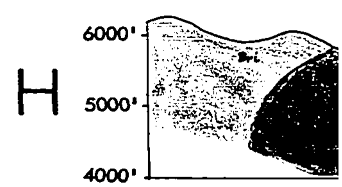


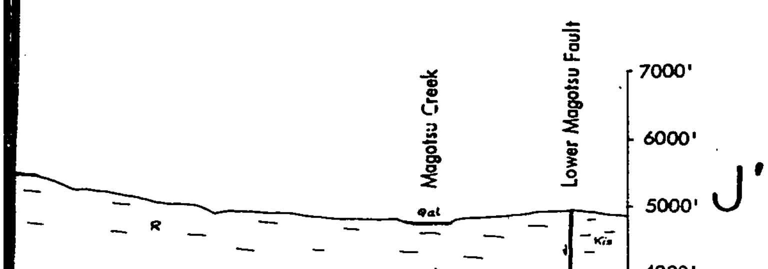
ING GEOLOGIC MAP OF THE BULL VALLEY DISTRICT











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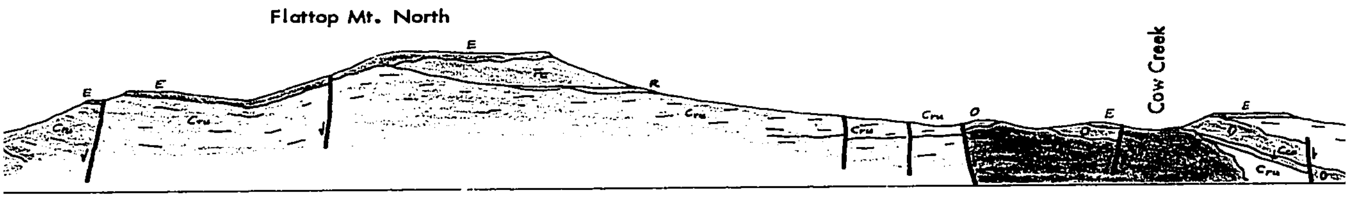

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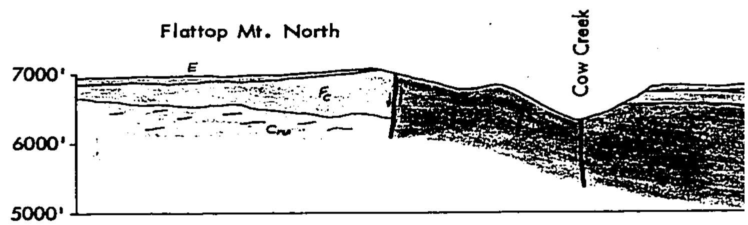
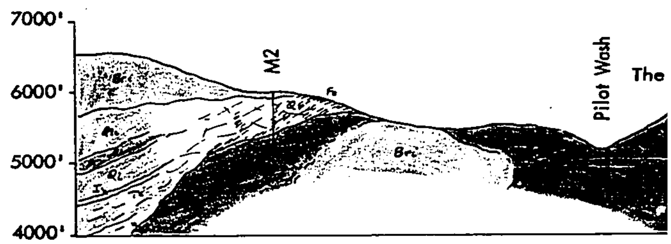


F



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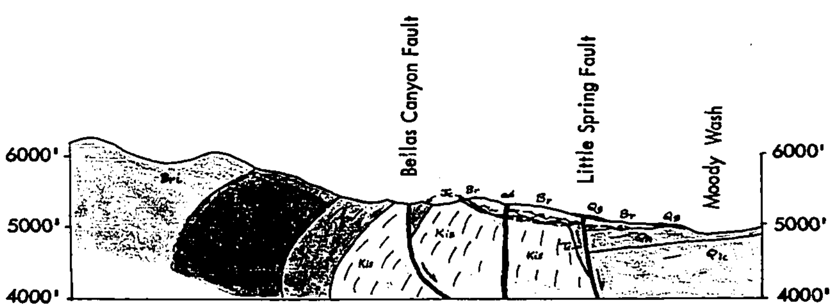
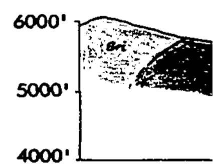
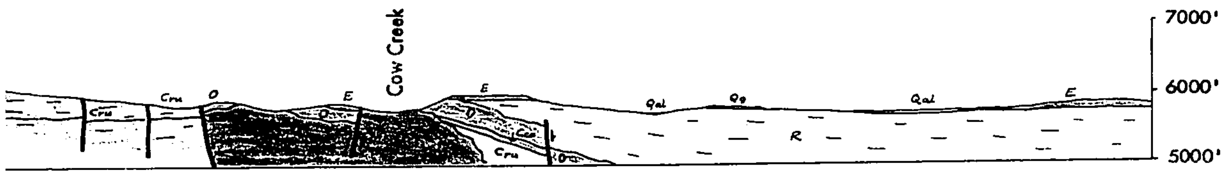


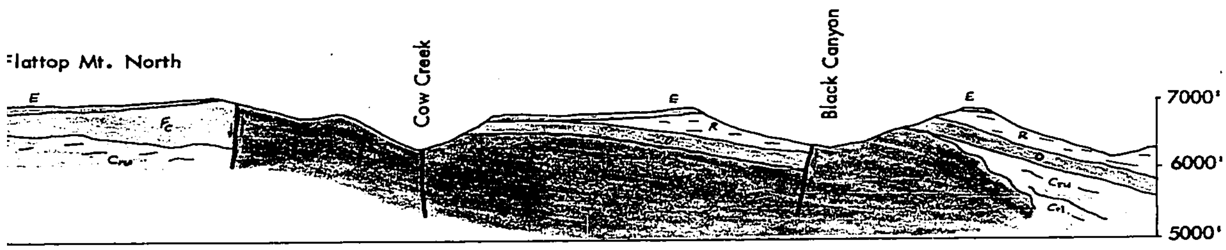
H'

I

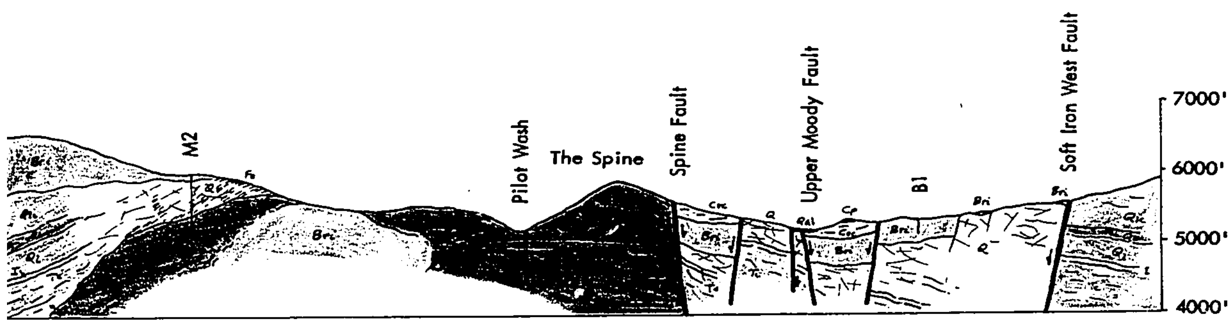



Cow Creek
7000'
6000'
5000'

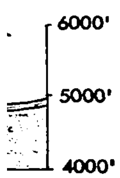
D'


Flattop Mt. North
Cow Creek
Black Canyon
7000'
6000'
5000'

C'

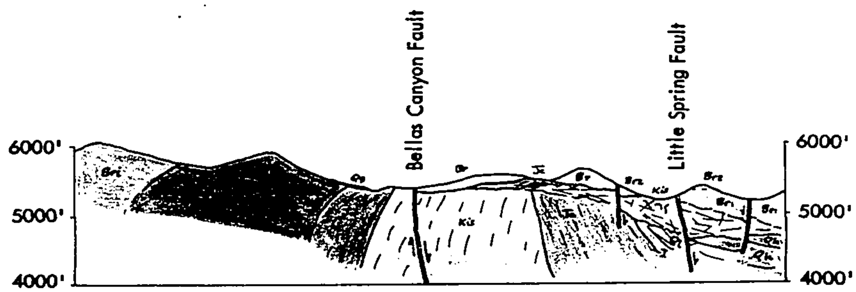

M2
Pilot Wash
The Spine
Spine Fault
Upper Moody Fault
B1
Soft Iron West Fault
7000'
6000'
5000'
4000'

F'

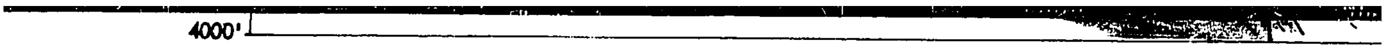

6000'
5000'
4000'

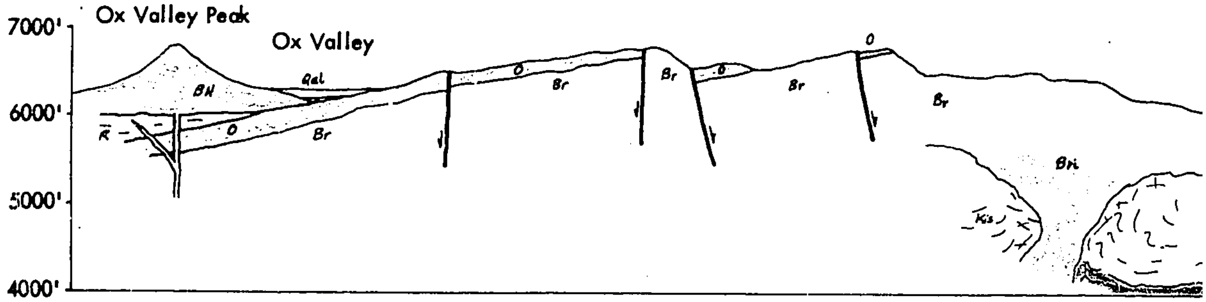
H'

I

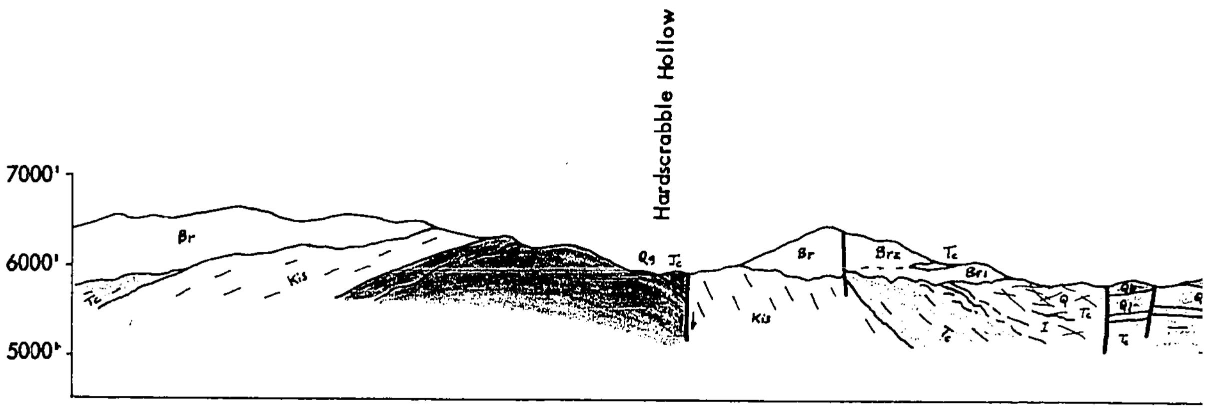

6000'
5000'
4000'
Bellas Canyon Fault
Little Spring Fault
6000'
5000'
4000'

I'

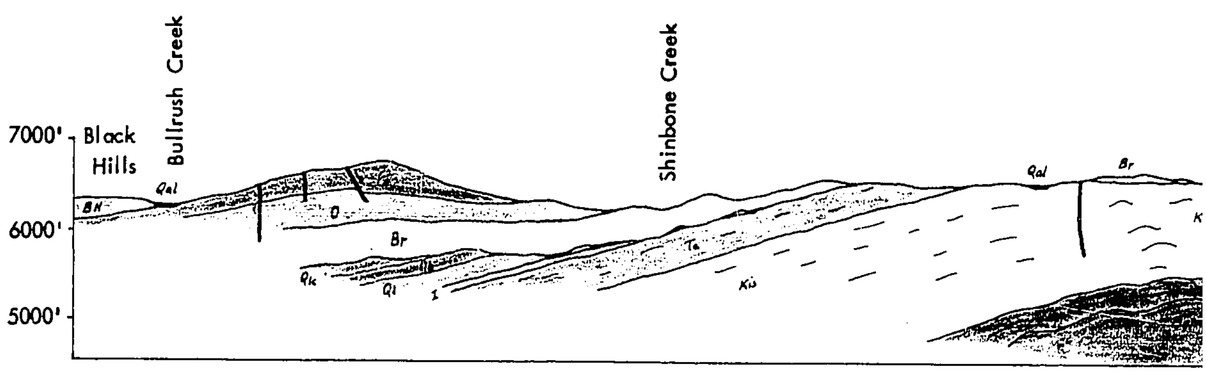

4000'


7000'
6000'
5000'
4000'
Ox Valley Peak
Ox Valley
Qal
BH
O
Br
Bri
Kis

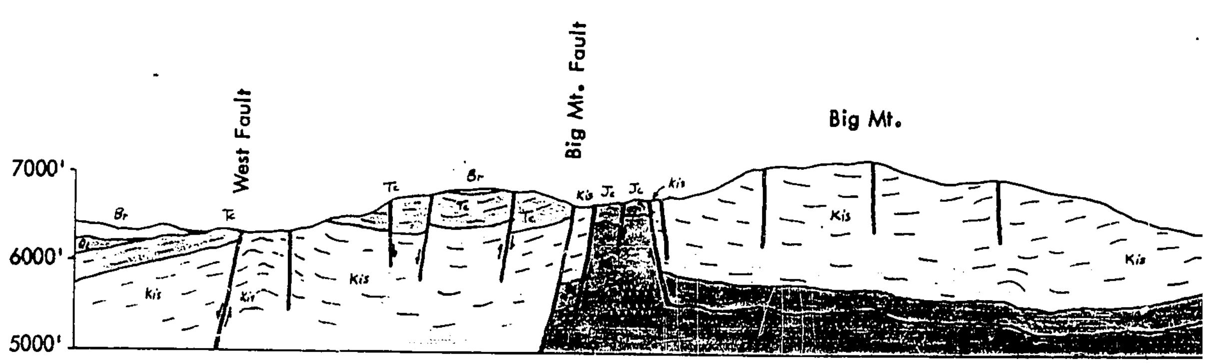
J


Hardscrabble Hollow
7000'
6000'
5000'
Br
Kis
Tc
Qg
Jc
Brz
Bri
Q
I

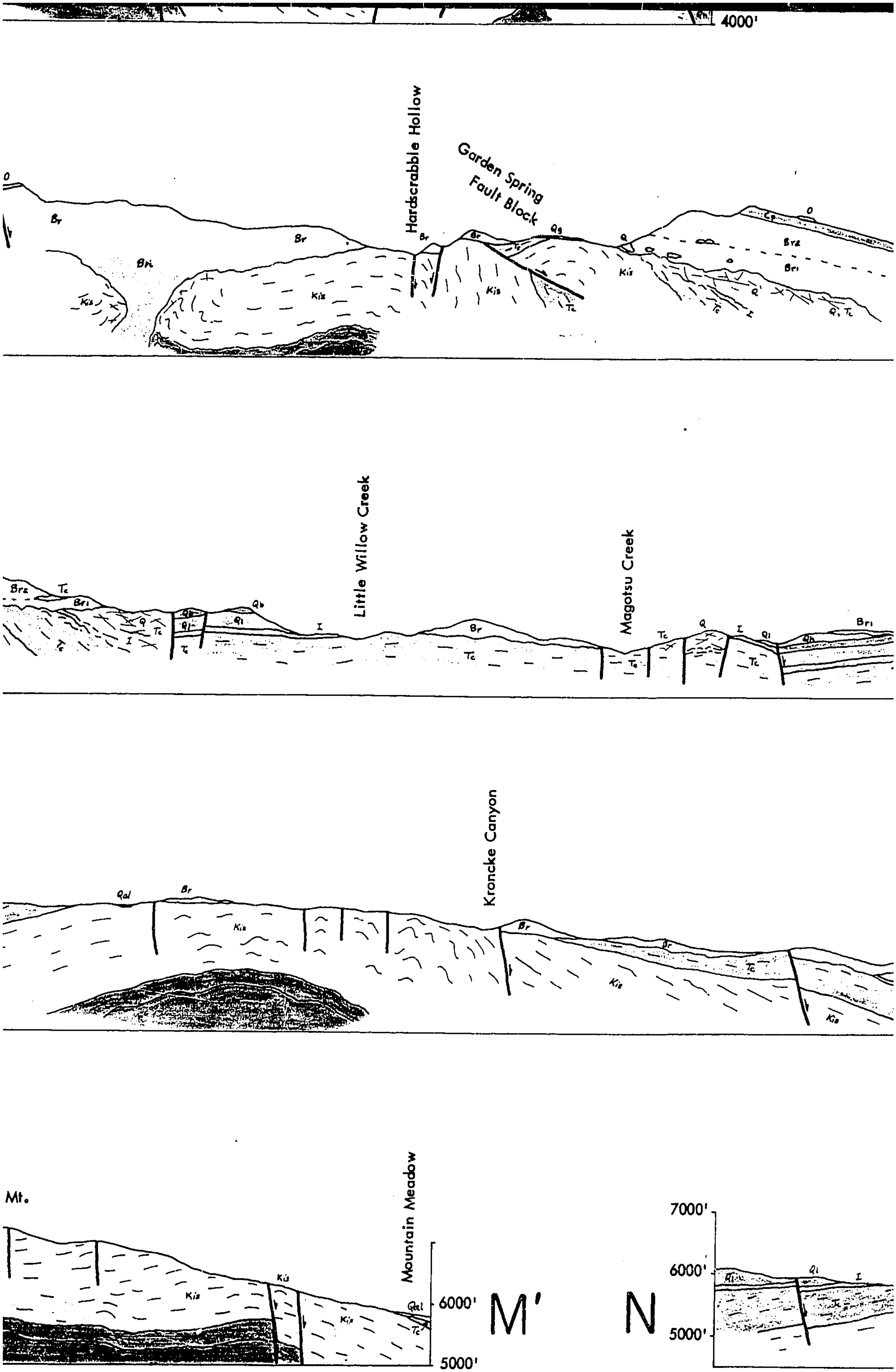
K


Black Hills
Bullrush Creek
Shinbone Creek
7000'
6000'
5000'
BH
Qal
O
Br
Qk
Ql
I
Tc
Kis

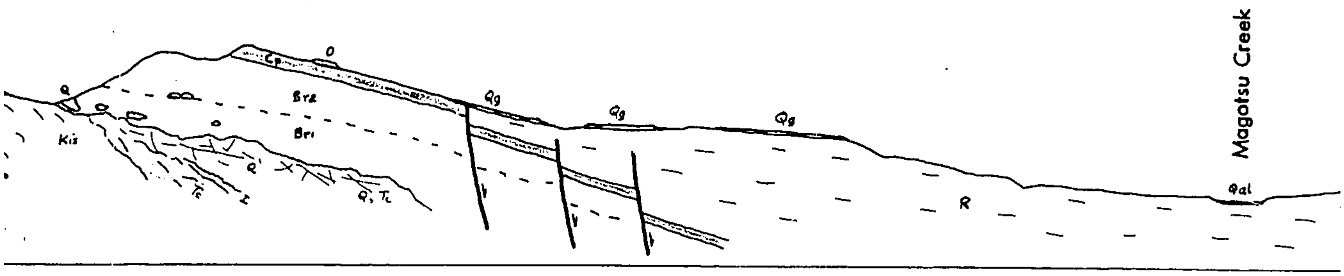
L

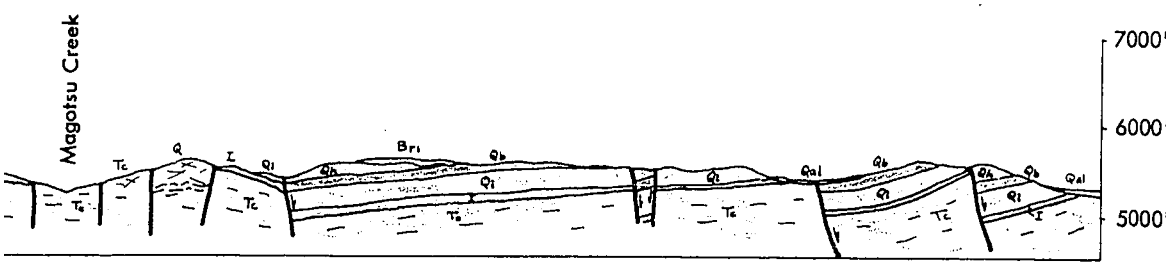

West Fault
Big Mt. Fault
Big Mt.
7000'
6000'
5000'
Br
Tc
Kis
Jc
Ql

M

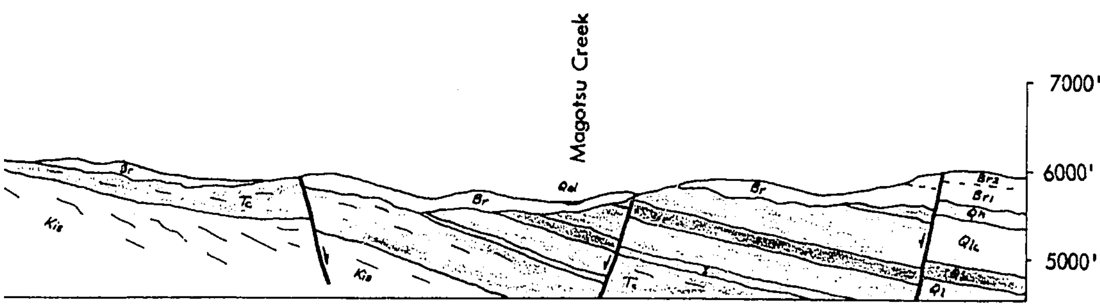

4000'
Hardscrabble Hollow
Garden Spring Fault Block
Little Willow Creek
Magotsu Creek
Kroncke Canyon
Mt.
Mountain Meadow
6000'
5000'
M'
N
7000'
6000'
5000'

4000


Magotsu Creek
Cp
Br2
Br1
Kis
Qg
Qg
Qg
R
Qal

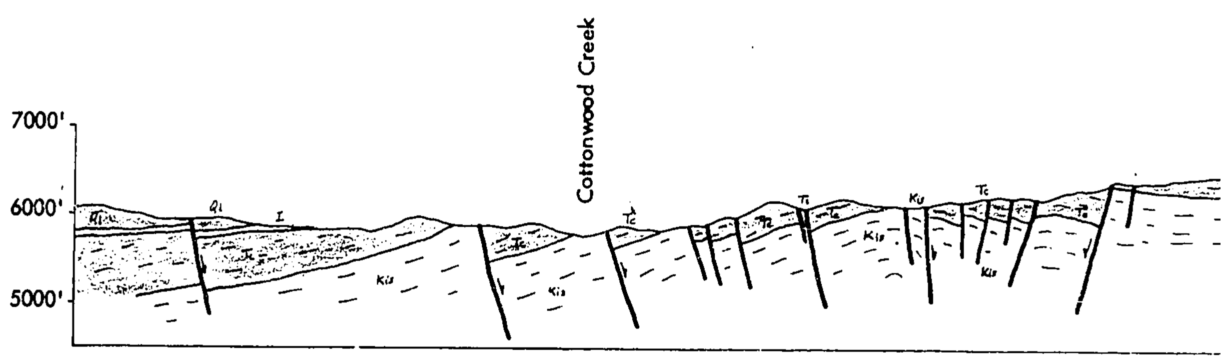

Magotsu Creek
7000'
6000'
5000'
Tc
Q
I
Ql
Qb
Br1
Qb
Ql
Ql
Qal
Qb
Qb
Ql
Qal
Tc

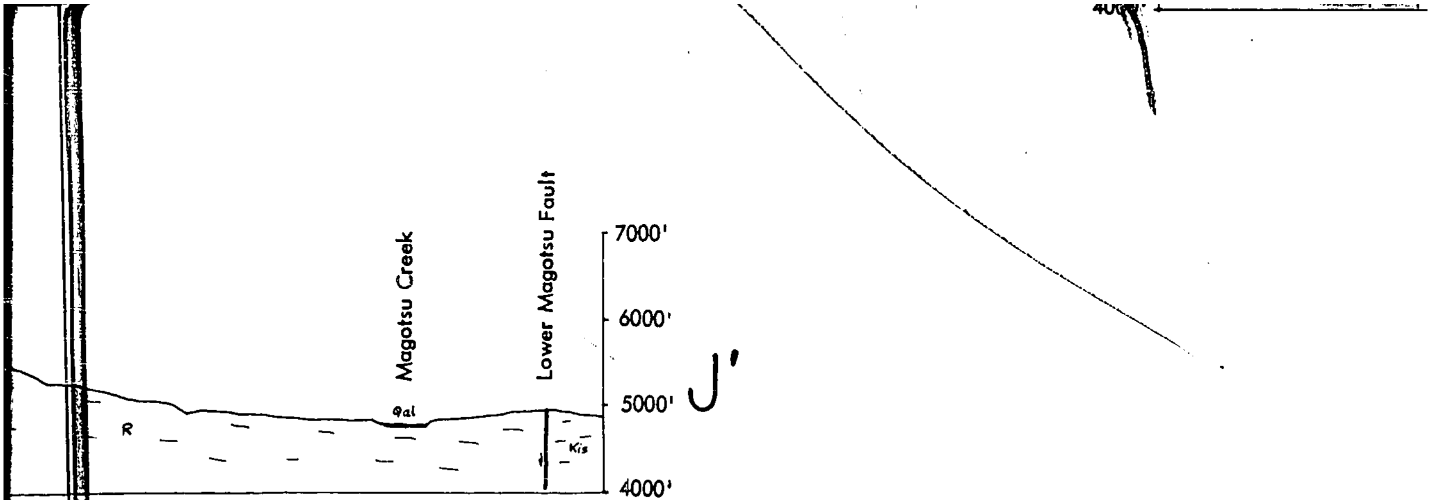
K'

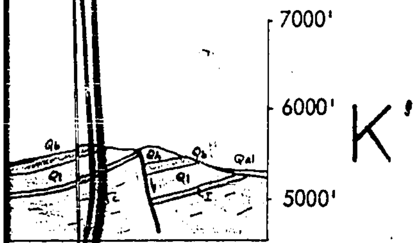

Magotsu Creek
7000'
6000'
5000'
Br
Tc
Kis
Br
Qal
Br
Br2
Br1
Qh
Qlc
Ql
Kis
Tc

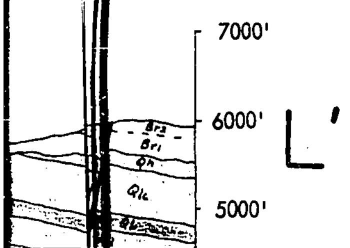
L'

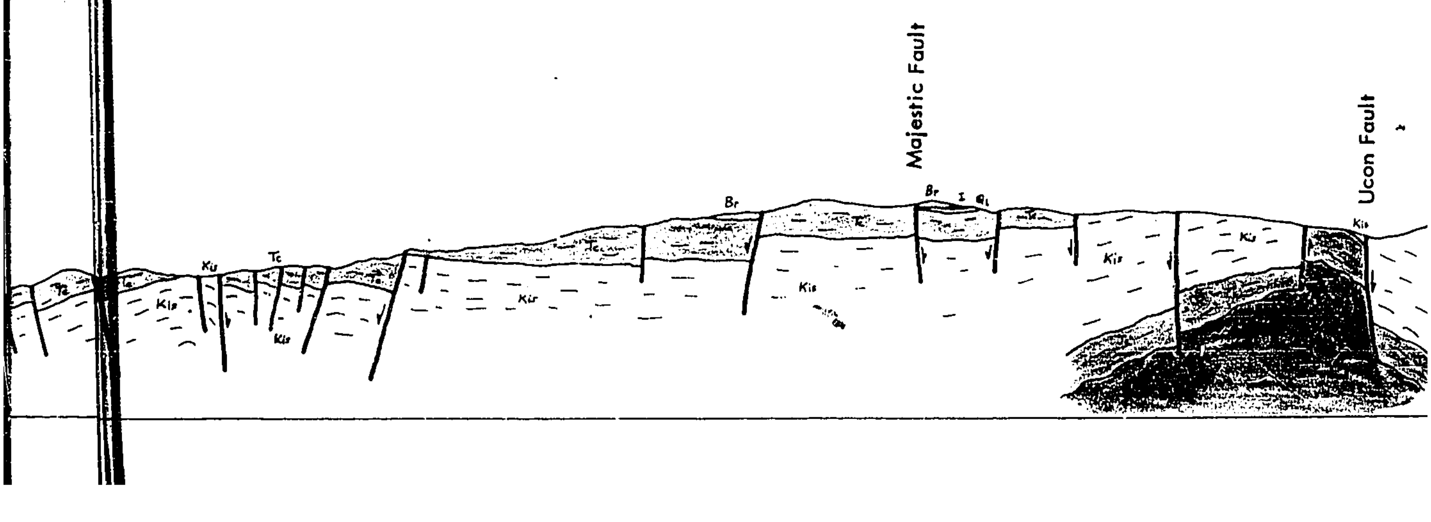
N

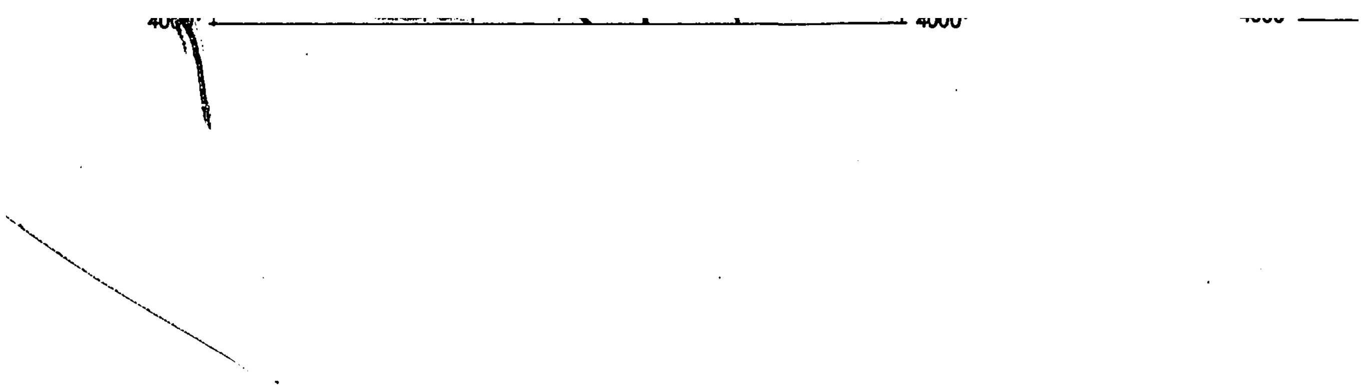

Cottonwood Creek
7000'
6000'
5000'
Ql
Ql
I
Kis
Kis
Tc
Kis
Tc

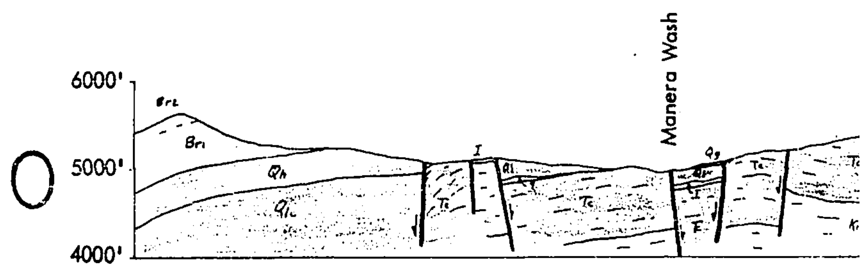

Magotsu Creek
Lower Magotsu Fault
7000'
6000'
5000'
4000'
J'
Qal
R
Kis

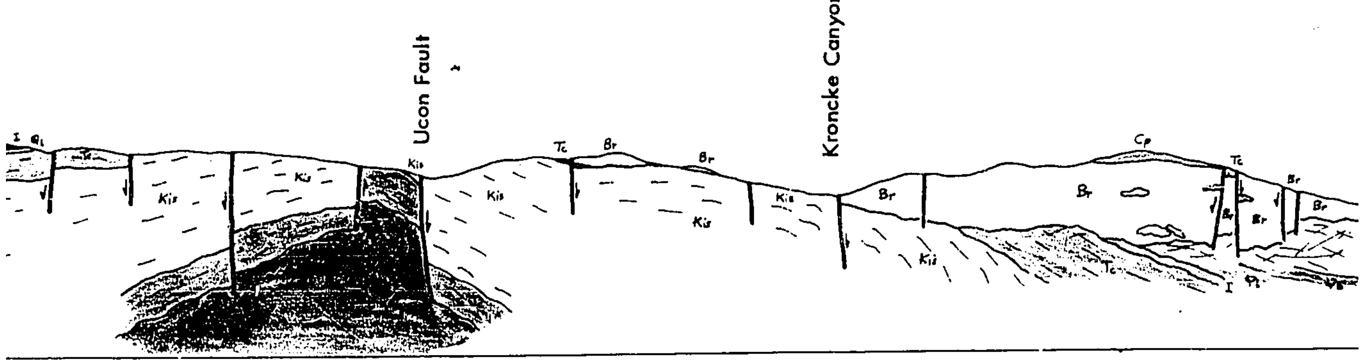

7000'
6000'
5000'
K'
Qb
Ql
Qal

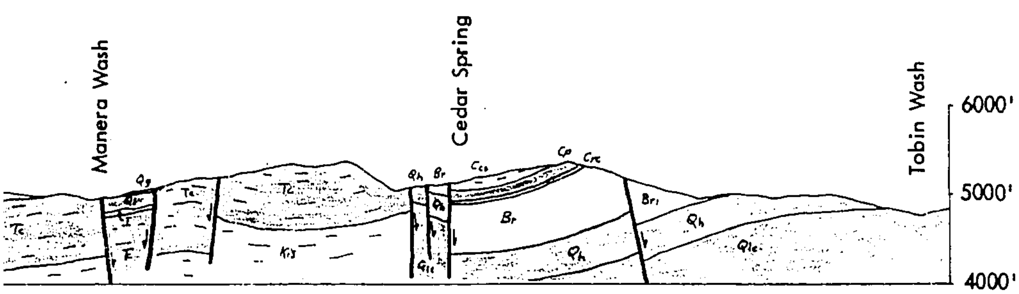

7000'
6000'
5000'
L'
Br2
Br1
Qh
Qlc


Majestic Fault
Ucon Fault
Br
Kis
Tc


4000'
4000'

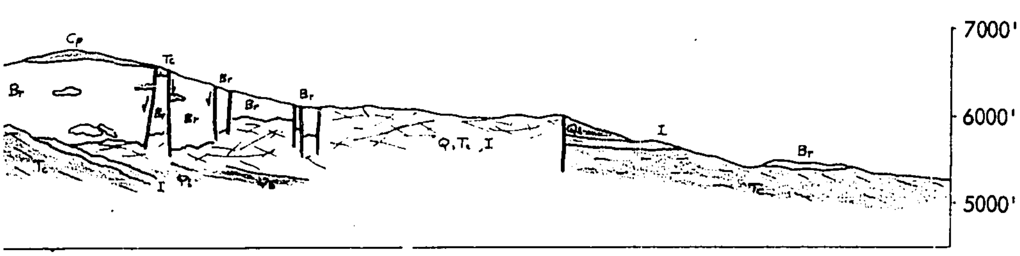

6000'
5000'
4000'
Manera Wash
Qh
Tc


Ucon Fault
Kroncke Canyon
Kis
Tc
Br
Cp



Manera Wash
Cedar Spring
Tobin Wash
6000'
5000'
4000'
Qg
Tc
Br
Qh
Ccs
Cp
Crc
Br1
Qlc
Krj

O'



7000'
6000'
5000'
Cp
Tc
Br
I
Q, Tc, I

N'