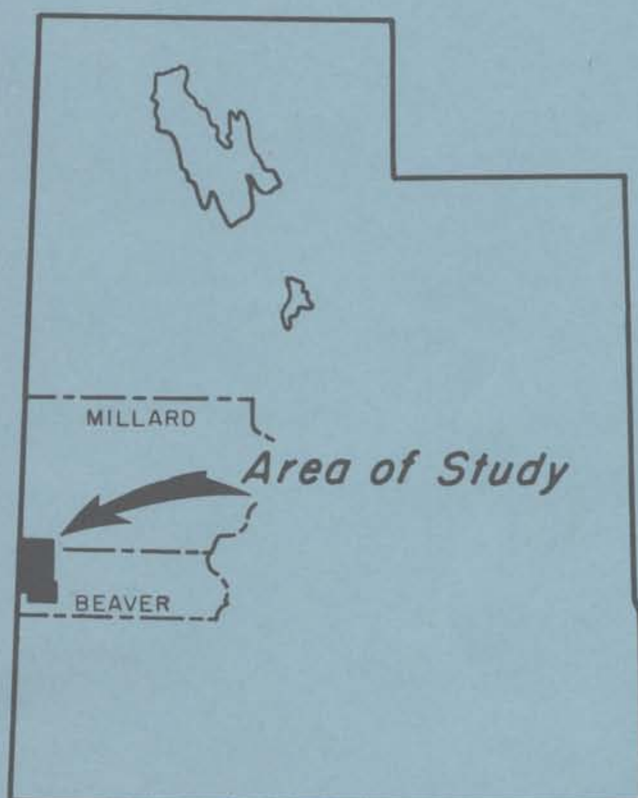
TERTIARY VOLCANIC ROCKS OF NEEDLES RANGE, WESTERN UTAH



Utah Geological and Mineralogical Survey
Special Studies 29

TERTIARY VOLCANIC ROCKS OF NEEDLES RANGE, WESTERN UTAH

by Omar G. Conrad

Southern extent of Sawtooth Peak, Sec. 14, T. 28 S., R. 17 W., type locality for the Sawtooth Peak Formation (Oligocene), probably equivalent to Cook's (1965) Windous Butte Formation.

UTAH GEOLOGICAL AND MINERALOGICAL SURVEY
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University of Utah, Salt Lake City, Utah

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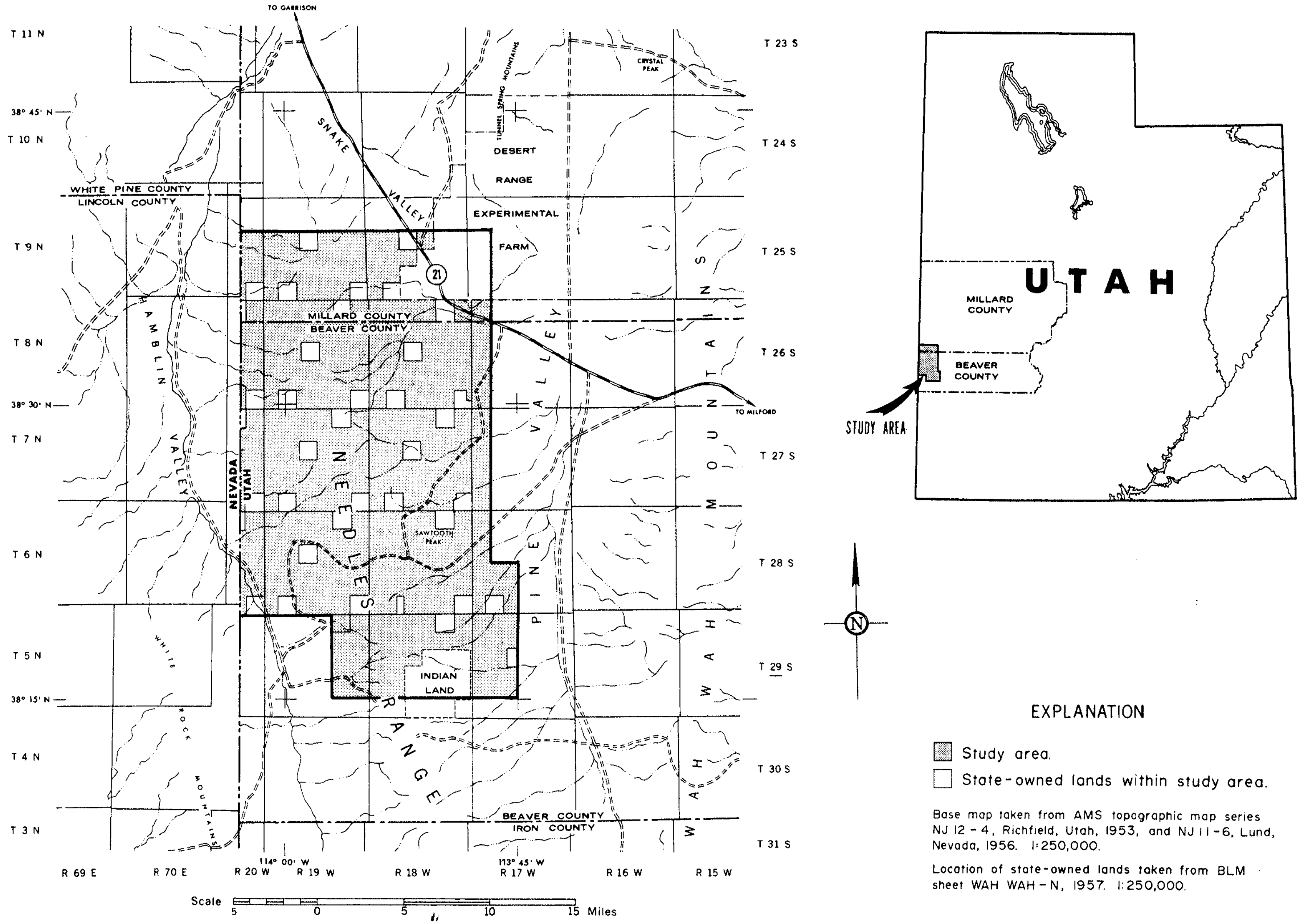

Figure 1. Index map showing area of investigation.

TERTIARY VOLCANIC ROCKS OF NEEDLES RANGE, WESTERN UTAH

by Omar G. Conrad[1]

ABSTRACT

The northern half of the Needles Range is an eastward-tilted, fault-block mountain range in the extreme western part of Utah. Detailed field study of ignimbrite layers shows three main units (herein named) beneath the well-known Isom and Needles Range formations: (from bottom to top) the Indian Peak Formation; the Sawtooth Peak Formation, probably equivalent to the Windous Butte Formation of east central Nevada; and the Beers Spring Formation. Using ignimbrite layers as stratigraphic units, events in regional structural development may be interpreted as follows: the southern part of the area began to subside during the late Eocene or the early Oligocene, shortly after initiation of ignimbrite-producing eruptions; subsidence became localized as an eastward-trending trough or graben, later filled by several successive ignimbrites; sinking continued intermittently throughout deposition of the Needles Range and Isom Formations during mid-Oligocene time. During late Oligocene time, major normal faults produced the northerly trend and easterly tilt of the Needles Range.

INTRODUCTION

Most of the Tertiary volcanic rocks overlying eroded edges of Paleozoic folded sedimentary rocks in the Needles Range of Millard and Beaver counties are shown as undifferentiated on the Geologic Map of Southwestern Utah (Hintze, 1963). While field mapping during the summers of 1964 and 1965, the author undertook to distinguish between the various volcanic units in the Tertiary sequence, and to show their distribution and structure in the northern part of the Needles Range, an area of approximately 200 square miles.

The Needles Range is a north-trending chain of mountains near the Nevada State Line, extending from the Escalante Desert northward about 70 miles to just north of Utah Highway 21 (fig. 1); it is bounded on the east by Pine Valley and on the west by Hamblin Valley. It lies on the north side of the broad belt of volcanic rocks that sweeps across southwestern Utah from Sevier, Piute, and Garfield counties, into southern Nevada. The Needles Range consists mainly of an eastward-tilted fault block, bounded on the west by one or more steeply dipping normal faults of several hundreds of feet of vertical displacement. Internally, the range contains numérous smaller normal faults that generally parallel the main faults.

The area of this report is restricted to the portion of the range south of Utah Highway 21 and north of Indian Peak, including the Piute Indian Reservation of Indian Peak. Within this area, the northern part consists mostly of early Paleozoic sedimentary rocks; Tertiary volcanic rocks are limited to a thin veneer capping the eastern foothills. To the south, the volcanic sequence thickens greatly, both in the number of units as well as in each unit, so that southward a progressively larger and larger portion of the range consists of volcanic rocks. A few miles north of Indian Peak, all of the Paleozoic rocks are buried and the volcanic rocks make up the entire range.

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Within the study area, volcanic rocks are almost entirely ignimbrites, with a few relatively thin lenses of tuffaceous sandstone intercalated. The regional continuity of some of the ignimbrite layers, particularly those stratigraphically higher in the study area, makes them ideal stratigraphic units; indeed, they are the key to the determination of Tertiary structural geology in the report area and in much of southwestern Utah and eastern Nevada.

PREVIOUS WORK

The Paleozoic sedimentary rocks of this region are shown on the Geologic Map of Southwestern Utah (Hintze, 1963) and have been described in detail by W. J. Gould (1959).

Most of the large-scale Tertiary features in western Utah were described by Mackin (1960). In a later paper (1963), Mackin specifically discussed the regional extent and importance of the Needles Range Formation, which he established as covering at least 10,000 square miles, including the area of the present study.

According to Cook (1965), who has worked extensively on the volcanic rocks of central and eastern Nevada, the Nevada ignimbrites, which predate the Needles Range Formation, are thickest in an area about 50 miles west of the Needles Range. These ignimbrites, he found, thin eastward to a feather edge near the Nevada-Utah border. The Needles Range, therefore, is at a point of transition between Cook's area, which contains mostly pre-Needles Range Formation units, and Mackin's area, which includes mostly Needles Range Formation and younger units. The writer's stratigraphic column is compared with those of Mackin and Cook in figure 2.

CHARACTERISTICS OF IGNIMBRITES

Definitions

Ignimbrites of the type found in western Utah are nearly perfect stratigraphic units, because of their wide lateral extent and the fact that they were essentially horizontal when deposited. For these reasons, it is possible to use them much like sedimentary strata, if certain precautions are kept in mind. The term "ignimbrite," as used in this paper and by most workers, refers to the ash-flow deposit of one or more volcanic eruptions of the nuée-ardente type. In the study area, each ash-flow unit is distinct from those adjacent to it, and composite ash-flows, or "cooling units" (Ross and Smith, 1960), are not common. Consequently, the term "single ash-flow units" is used here to designate deposits of one nuée-ardente eruption.

Induration

The ignimbrite can be indurated by fusion or devitrification. Materials may be fused into welded tuffs at high temperatures, or glass particles may be devitrified at lower temperatures, "growing" into a dense, hard tuff in time. Both types of induration are recognizable in thin section, although ignimbrites in the study area usually are fused. In certain vitric ignimbrites, such as the Isom Formation, fusion is so complete that some liquid or plastic flow may have taken place after the nuée-ardente stopped. Thin sections of these ignimbrites show extreme deformation of the glass shards.

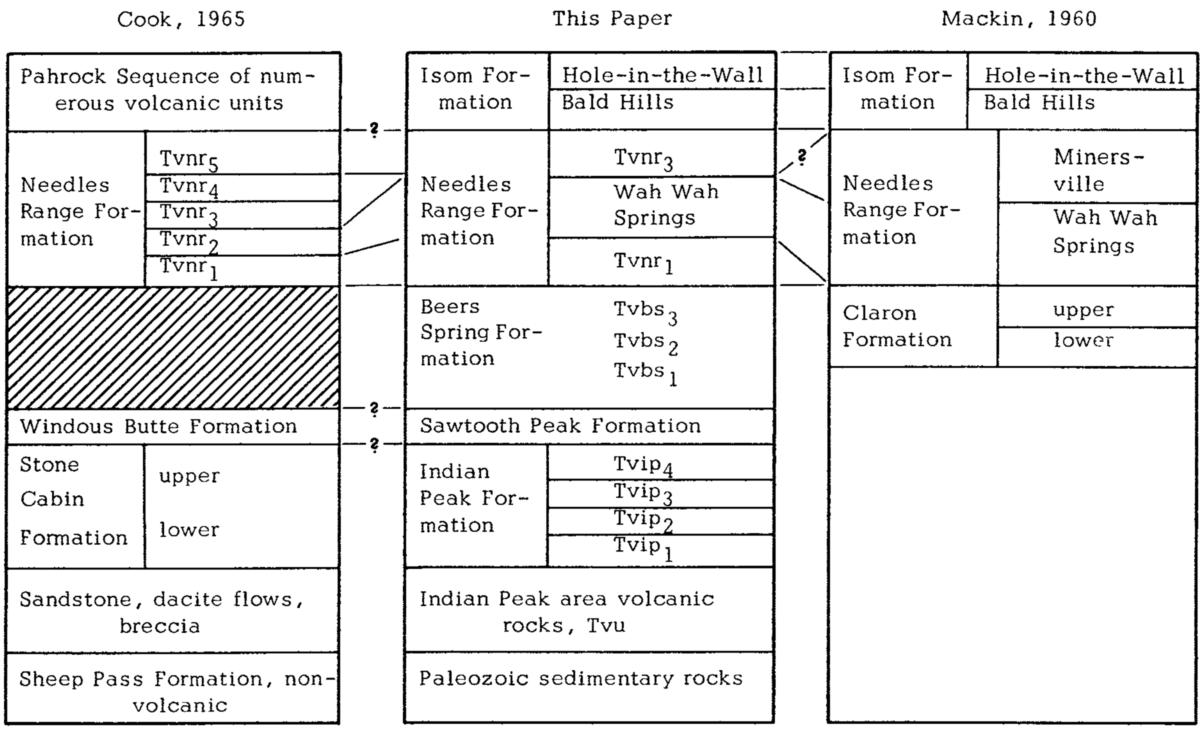


Figure 2. Stratigraphic sections: comparison of Cook (1965), Mackin (1960), and this paper.

Vertical Facies

Within a single ash-flow unit there may be considerable change in vertical facies. In the study area, most ignimbrites have three main layers. From bottom to top, these are the basal glass, the midportion, and the softer top. Generally, the bottom layer is a hard, dark-gray or black, glassy rock, mostly obsidian, a few inches to several yards thick. A soft ash layer commonly underlies this basal glass. In some places, the ash layer, which ranges in thickness from a few inches to a few feet, is the lowest portion of the pyroclastic flow, which during the eruption was cooled below fusing temperature by contact with the cooler ground. In other places, the ash is well stratified, which suggests it probably was ejected into the atmosphere and was deposited as air-fall tuff prior to the ash flow. Basal glass usually marks the base of an ash-flow unit, and because it shows up distinctly on aerial photographs, it is a valuable mapping aid.

A thin, transitional zone, generally only a few inches thick, separates the basal glass and the midportion. Less resistant to erosion than either the underlying basal glass or the overlying midportion, it erodes as a notch between them, and may thus be mistaken for a break between two different units.

The main part, or midportion, of the ignimbrite may be hundreds of feet thick. The amount of induration varies considerably, both vertically and laterally, but lateral differences are far less distinct. Texturally, the midportion of a single ash-flow unit is quite uniform, although the degree of welding ordinarily is slightly greater near the bottom. The midportion can be highly indurated through its entire thickness, as in the Isom Formation, or it may grade upward into tuff that exhibits less shard deformation and less induration.

The third main zone, or top portion, is almost never welded, and thus tends to be less resistant to erosion than the other portions; often part or all of it is missing. Consequently, an actual disconformity or even a slight angular unconformity exists between formations or between members of the same formation. Erosion channels occur in the tops of units, and material removed by erosion may be preserved as volcanic sandstone.

Lateral Variation

Lateral textural variations are difficult to observe unless one examines a wide outcrop area; thus they are not distinguishable in the restricted units below the Needles Range Formation. Within the Needles Range Formation, however, lateral variation can be determined by comparing samples from the study area with specimens from other areas. One member of the Needles Range Formation,[1] near Cougar Mountain in the Confusion Range some 60 miles to the north, has an appreciably lower crystal content; it is thinner and much less intensely welded than the same unit within the study area. These differences may reflect a lateral facies change in the size of the pyroclastic fragments produced when heavier crystal and lithic fragments settled closer to the source of eruption. The fact that welding is less complete suggests that the material was cooler when it was deposited, probably because it was farther from the source. The author plans a further paper examining this lateral variation in detail.

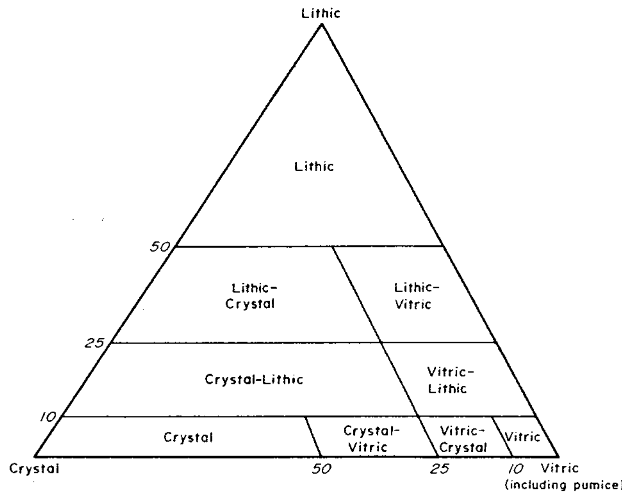


Figure 3. Textural composition triangle for determination of rock names.

Table 1. Composition of ignimbrites in the study area.

Formations	Member	Composition in percentages of phenocrysts: Groundmass	Quartz	Biotite	Plagioclase	Pyroxene	Amphibole	Magnetite	K-feldspar	Number of samples
Isom	Hole-in-the-Wall	91	0	0	7	1	0	1	0	2
	Bald Hills	84	0	0	12	1	0	2	0	2
Needles Range	$Tvnr_3$	69	4	4	20	tr	tr	3	tr	3
	Wah Wah Springs	58	4	5	24	1	6	1	1	11
	$Tvnr_1$	61	4	7	23	1	4	1	tr	11
Beers Spring*	$Tvbs_3$ mudflow	90	2	1	7	0	0	tr	0	1
	$Tvbs_3$ lithic tuff mudflow	75	0	1	22	0	1	1	0	1
	$Tvbs_2$ arenite									
	$Tvbs_1$ vitric tuff	92	0	0	6	tr	0	2	0	1
Sawtooth Peak*		55	15	3	24	tr	1	1	1	7
Indian Peak*	$Tvip_4$ upper tuff	87	tr	1	10	0	0	0	0	1
	$Tvip_4$ middle tuff	69	0	5	21	0	0	4	0	1
	$Tvip_4$ lower tuff	80	0	2	17	0	0	1	0	1
	$Tvip_3$ arenite									
	$Tvip_2$ vitric tuff	89	tr	5	5	0	tr	tr	0	4
	$Tvip_1$ crystal tuff	57	10	7	24	1	tr	2	0	1

* New names proposed in this paper
All compositions determined by thin section modal analysis of crystals.

Nomenclature

For a few of the upper stratigraphic units compositional names based on chemical analysis are available in the literature (e.g., Mackin, 1960). For most units, however, the author found a nomenclature system based on chemical analysis or refractive index to be impractical. For this reason, Cook's (1965) textural composition triangle (fig. 3) was used for lithologic naming purposes. Phenocryst content was determined by thin section modal analysis. The average phenocryst crystal count amounted to 20 to 30 percent of the sample by volume, and in no sample was the count as high as 50 percent. Since phenocrysts generally are plagioclase and biotite, most of the samples would be classifed as andesite, whereas published accounts using chemical analyses classify the

1. Here tentatively identified as the Wah Wah Springs Member.

higher units as dacitic. In view of the lack of knowledge of the composition of the glassy groundmass, the compositional name used herein is based on phenocrysts alone and the prefix "pheno" is added to the rock name (Cook, 1965), for example, phenoandesite.

Concerning the glassy groundmass, Cook (1965, p. 33) states: "In most of the Nevada ignimbrites in which quartz phenocrysts are sparse or absent, the index of the groundmass glass suggests a more acidic composition than do the phenocrysts."

It is probable that units in this study, which are very similar to those in Cook's sequence, are also more silicic than the phenocryst analysis would indicate (table 1).

STRATIGRAPHY AND PETROGRAPHY OF UNITS IN THE STUDY AREA

General Statement

Although about 8,000 feet of Paleozoic rocks, chiefly limestone and quartzite ranging in age from Middle Devonian to early Permian (Gould, 1959), are exposed in the area mapped, this report is confined to description and interpretation of the Tertiary volcanic formations, which are almost wholly ignimbrites. Units are described from the base upward. The Needles Range and Isom formations at the top of the sequence are of regional extent, but except for the Indian Peak Unit 2, lower units are of local extent.

Indian Peak Area Volcanic Rocks

Several undifferentiated volcanic units, herein designated Tvu, including tuffs, flows, and possibly even shallow intrusive rocks, are found in the region near Indian Peak, along with one or two isolated outcrops farther north. Except for a basalt just north of Sawtooth Peak, the rocks are primarily andesite. These Tvu units are unlike the ignimbrites and intercalated volcanic sandstones found elsewhere in the study area; they are more highly altered and the author has made no attempt to alter them. Grant (1969, in press) has described most of these units in his paper concerning the fluorspar deposits just south of Indian Peak at the Cougar fluorspar mine. Unit 4 of the Indian Peak Formation lies above the Tvu along the northeastern flank of Indian Peak; so at least some of the Tvu units predate the Indian Peak Formation.

Indian Peak Formation

The Indian Peak Formation (herein named) consists of four members, two lower ignimbrites (Indian Peak Units 1 and 2), a tuffaceous sandstone (Indian Peak Unit 3), and a third ignimbrite (Indian Peak Unit 4) at the top. It occurs at the base of the ignimbrite sequence just above the basement of Paleozoic rocks, except in the area near Indian Peak, where it rests on the undifferentiated Tertiary volcanics (Tvu) mentioned above. The type section is located in the southwestern portion of T. 29 S., R. 18 W. along the northeastern flank of Indian Peak. The four members occupy an area of about 25 square miles.

Indian Peak Unit 1

The lowest member, Indian Peak Unit 1, is a coarse-grained, red-brown to gray-green, vitric crystal phenodacite tuff with biotite books more than 5 mm wide and 3 mm thick. Unit 1 closely resembles the lower part of the Needles Range Unit 1, although it is coarser and has considerably more quartz visible in hand specimen. No basal glass nor

a. Indian Peak Formation, $Tvip_1$ (scale ½″ = 1.0 mm)

b. Indian Peak Formation, $Tvip_2$ (scale ¾″ = 0.5 mm)

c. Indian Peak Formation, $Tvip_4$, lower ignimbrite (scale ½″ = 1.0 mm)

d. Indian Peak Formation, $Tvip_4$, middle ignimbrite (scale ½″ = 1.0 mm)

Photomicrographs

soft, white top was found. The unit is best exposed on the west flank of the Needles Range. The type section for this member is in the SW$\frac{1}{4}$ Sec. 6, T. 28 S., R. 18 W., where it is approximately 125 feet thick. Microscopically, the groundmass is completely vitreous with little or no visible shard structure. The plagioclase crystals included are strongly sericitized, unlike the fresh crystals in younger ignimbrites (pl. 1a).

Indian Peak Unit 2

Indian Peak Unit 2 is the most extensive ignimbrite of the pre-Needles Range Formation units. In the northern two-thirds of the area and for at least 20 miles north of the area, it lies immediately beneath either Needles Range Unit 1 or Unit 2, the Wah Wah Springs Member. In the southern part of the area, however, nearly 1,000 feet of ignimbrite layers and tuffaceous sandstone lie between Indian Peak Unit 2 and the base of the Needles Range Formation.

Petrographically, Indian Peak Unit 2 is a vitric phenoandesite tuff; in a few outcrops it has sufficient lithic fragments to be called a vitric-lithic tuff. In thin section, there are sufficient crystals for it to be termed a vitric-crystal tuff, but the only crystals visible in most hand specimens are a few small biotite flakes. Megascopically, the crystal content appears to be less than 10 percent. Shard structure is well developed (pl. 1b), but shards are almost entirely undeformed, indicating the material was relatively cool when it was deposited. That it is an ignimbrite, rather than an air-fall tuff, is indicated by its great lateral extent, thickness, absence of air-fall stratification, and presence of a typical basal glass in a few outcrops, such as those at SW$\frac{1}{4}$ Sec. 26, T. 26 S., R. 18 W.

The lithic fragments in Indian Peak Unit 2 are of interest for two reasons. First, they are mainly pieces from sedimentary rocks like those of the Paleozoic deposits underlying the unit; and second, most of the fragments are surrounded for a fraction of an inch by a reaction rim or halo in the tuff. Generally, the reaction rim is more resistant to weathering than either the tuff or the fragment and tends to weather out in relief at the outcrop. Commonly, the rim is deep purple, in sharp contrast to the nearly white groundmass of the tuff. Halos around inclusions are typical of almost all exposures; so the field name halo tuff has been used (Mackin, 1960, and Conrad, this study) for this unit.

In aerial photographs, the white Indian Peak Unit 2 is similar to the white top of both lower members of the Needles Range Formation; careful field checking is necessary to prevent misidentification.

Indian Peak Unit 2 varies considerably in thickness from place to place, but maximum thickness is about 300 feet. The unit apparently filled in at least 200 feet of relief when it was deposited, and so thins over buried hills. It also thins toward the northern part of the study area, but it is still nearly 100 feet thick near Utah Highway 21. The type section for both Indian Peak Unit 2 and Unit 4 is in the S$\frac{1}{2}$ Sec. 31, T. 28 S., R. 19 W.

Indian Peak Unit 3

Indian Peak Unit 3 is a prominent volcanic sandstone, inclosing a thin ignimbrite that occurs intermittently at its base. The ignimbrite portion, which is no more than 20 feet thick, has an outcrop area of less than 1 square mile. The best exposure is the type section in the SE$\frac{1}{4}$ Sec. 5, T. 29 S., R. 18 W. about $3\frac{1}{2}$ miles north of Indian Peak. Petrographically, the ignimbrite is a lithic-vitric phenoandesite tuff, containing more than 25 percent lithic fragments and about 20 percent crystals, mostly plagioclase and biotite. Its striking orange color is mottled because of an abundance of varicolored lithic fragments, mainly volcanic rock pieces up to several inches in diameter. The undevitrified shards show moderate distortion due to compaction.

The main part of Indian Peak Unit 3 is a white, tuffaceous sandstone, rather similar to Beers Spring Unit 2. Petrographically, according to the Folk classification of clastic sedimentary rocks, the sandstone is a coarse, gravelly sand, or submature volcanic arenite. Few pebbles exceed 2 inches in diameter. Bedding is the coarse, torrential type. The sandstone attains a maximum thickness of 65 feet and covers an area of about 10 square miles.

Indian Peak Unit 4

The top member of the Indian Peak Formation is an ignimbrite triplet that has an outcrop area of about 15 square miles and is 110 feet thick in type section (S$\frac{1}{2}$ Sec. 31, T. 28 S., R. 19 W.). The lowermost unit of this triplet is about 12 feet thick and light gray. Microscopically, it does not show shard structure, but it does have a few vesicles. The middle unit is 28 feet thick, dark reddish gray, and is more vesicular than the lowest unit. Shard structure is well developed and shows strong distortion. The contact between the middle and lowest units in the triplet is gradational in some exposures; in others, it is much sharper, suggesting that the two may be a compound cooling unit. The two lower units, as a couplet, form a prominent cliff. Both are lithic-vitric phenoandesite tuffs containing fragments of lava-flow rocks similar to those south of Indian Peak and some sedimentary pebbles (pl. 1c and d).

The highest unit in Indian Peak Unit 4 is rather soft and contains many flattened pumice pieces and other lithic fragments. The rock, white with pink blotches and streaks, is a lithic phenoandesite tuff, 70 feet thick at the type section. Microscopically, the groundmass shows a slightly deformed shard structure, with some devitrification. In the type section, Indian Peak Unit 4 is overlain by the basal glass of the Wah Wah Springs Member of the Needles Range Formation.

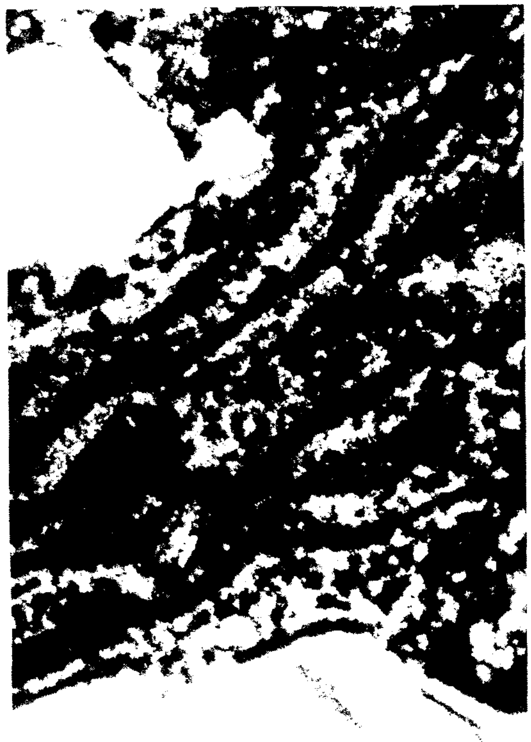
Sawtooth Peak Formation

The Sawtooth Peak Formation is a thick, persistent ignimbrite consisting of three or more similar units. The type section is at Sawtooth Peak, a small but prominent peak surrounded by alluvium in the northwestern part of T. 28 S., R. 18 W. The west edge of the peak is a fault scarp or a fault-line scarp. The east side of the scarp, which is upthrown and tilted to the east, forms the peak. The unit occurs in a large area of the Needles Range west of the type section.

Petrographically, the Sawtooth Peak Formation is a crystal-vitric phenodacite tuff, containing about 5 percent volcanic and sedimentary lithic fragments in about equal amounts. Its color is various shades of dull gray. The rock is moderately to strongly welded, and shows moderate shard distortion, as does the Needles Range Formation. Crystals make up 47 percent of the total rock, about 5 percent more than are contained in the members of the Needles Range Formation. The Sawtooth Peak Formation has the highest percentage of crystals of any rock in the area, and many crystals are 2 mm or more in diameter. Although texturally very similar to the Needles Range Formation, mineralogically the Sawtooth Peak Formation contains much more quartz (averaging 15 percent as compared with about 4 percent in the Needles Range Formation) and much less amphibole. The relative abundance of quartz is the best identifying feature in hand specimen.

At the type section, the formation consists of three distinct superposed units (pl. 2b, c, and d). The basal unit, which is about 100 feet thick, can be distinguished in hand speci-

a. Beers Spring Formation, $Tvbs_3$, upper ignimbrite (scale ½″ = 1.0 mm)



b. Sawtooth Peak Formation, lower ignimbrite (scale ½″ = 1.0 mm)

c. Sawtooth Peak Formation, middle ignimbrite (scale ½″ = 1.0 mm)

d. Sawtooth Peak Formation, upper ignimbrite (scale ½″ = 1.0 mm)

Photomicrographs

men by a low percent of lithic fragments and by pink feldspar crystals up to 4 mm long. A thin basal glass was found at only one locality approximately 2 miles northwest of the Sawtooth Peak. The middle unit is about 50 feet thick and has low resistance to erosion. White to gray feldspar crystals up to 3 mm in length are common, and the percentage of lithic fragments is high, especially near the top where they constitute nearly 50 percent of the rock. Almost half of the lithic fragments are flattened pumice, although fragments of both volcanic and sedimentary origin are present. The uppermost unit, which is up to 150 feet thick, is more vitric and has a smaller percentage of crystals than either of the two underlying units. Contacts are very irregular, in sharp contrast to the nearly planar contacts of other ignimbrites in the area, particularly the members of the Needles Range Formation. Such irregular contact may be due to erosion, to compaction of the ignimbrites during cooling, or to plastic flow during cooling.

Except for the high percentage of quartz, the Sawtooth Peak Formation looks much like the soft-gray to white top of either of the lower two members of the Needles Range Formation. Furthermore, where Beers Spring Unit 1, an Isom-like vitric ignimbrite, occurs above the Sawtooth Peak Formation (such as along one road in the N$\frac{1}{2}$ T. 28 S., R. 19 W.), the couplet, a vitric tuff over a crystal tuff, is strikingly similar to the Isom-Needles Range sequence. Careful checking of the stratigraphy above and below the Sawtooth is necessary to prevent confusion of these two sequences.

The Sawtooth Peak Formation at the type locality lies on Paleozoic rocks and is overlain by the Needles Range Formation. Further west, however, the Beers Spring Formation occurs between the two ignimbrites, indicating considerable time elapsed between emplacement of the two units.

The Sawtooth Peak Formation probably is an equivalent of Cook's (1965) Windous Butte Formation. Cook (p. 14 and 16) states the Windous Butte Formation consists of:

> ... two ignimbrites lithologically distinct but locally welded together and almost gradational. Petrographically similar, they may represent separate phases of one main eruption ... in some exposures the contact is a wavy surface; this irregularity may have been caused by some plastic flowage after deposition of the upper member.

He further describes the quartz crystals as large, up to 5 mm in diameter, embayed and angular in thin section. There are three units at Sawtooth Peak instead of two, but otherwise Cook's description fits outcrops of the Sawtooth Peak Formation in the Needles Range. Paul Williams, U. S. Geological Survey, and the late J. Hoover Mackin, William Stamps Farish professor of geology, University of Texas, who worked with Cook in central Nevada and were familiar with his stratigraphy, tentatively considered the Sawtooth Peak Formation an equivalent of Cook's Windous Butte Formation (1965, field trip). This tentative correlation is shown in figure 2. However, use of the separate formational names is retained until such time as the two units are proven to be equivalent.

The Sawtooth Peak Formation covers about 50 square miles of the study area. The author was able to find a thin basal glass in only one outcrop. Elsewhere the Sawtooth Peak Formation is a soft to relatively resistant tuff. Large fragments of the upper parts of the formation are incorporated in overlying volcanic sandstone, the Beers Spring Unit 2. Cook (1965, p. 16), quoting another source, gives early Oligocene ages, 32.0 and 32.6 million years (m.y.), to samples of the Windous Butte Formation.

Beers Spring Formation

The Beers Spring Formation lies immediately below the Needles Range Formation. In a composite section of 370 feet, it consists of tuff, tuffaceous sandstone, and mudflow. No single area presents a satisfactory section for all three members; so separate locations were chosen for the type sections. The name, Beers Spring, is taken from a well-known spring in Sec. 16, T. 26 S., R. 18 W.

Beers Spring Unit 1

The lowest member of the Beers Spring Formation is a thin (10 to 20 feet thick) but fairly persistent ignimbrite that covers an area of about 20 square miles west of Sawtooth Peak. The type section is in the SE$\frac{1}{4}$ Sec. 24, T. 28 S., R. 19 W.

Petrographically, the unit is a vitric phenoandesite tuff, with a crystal content just under 10 percent (table 1). Megascopically, Beers Spring Unit 1 is very similar to the Bald Hills Member of the Isom Formation. However, thin-section study of Beers Spring Unit 1 discloses numerous small vesicles filled with chalcedony, whereas the Bald Hills Member within the study area has few if any such vesicles. Beers Spring Unit 1 shows fusing and extreme shard deformation (pl. 3c), similar to that in the Isom Formation.

Beers Spring Unit 2

Beers Spring Unit 2 is a prominent volcanic sandstone. It forms a steep cliff at the type section (same locality as for Beers Spring Unit 1), where it has a thickness of about 75 feet. Petrographically, the sandstone is a coarse gravelly sand: submature volcanic arenite. Grain size of the matrix ranges from clay-size glass "dust" to shards and crystal fragments over 1 mm in the longest dimension. In the main, the matrix is composed of slightly devitrified angular to subrounded bits of volcanic glass, glass shards, and crystal fragments. Also within the matrix are numerous fragments of volcanic rocks, mainly ignimbrites (mostly of the Beers Spring Unit 1 and the Sawtooth Peak Formation), mixed with a few fragments of sedimentary rocks. At the type section some fragments are 2 feet in diameter, but most are only a few inches thick. Both the grain size of the fragments and the thickness of the unit decrease markedly to the east and to the north, indicating the source of detritus was a short distance south and/or west of the type section. Cross-bedding within the sandstone, of the coarse torrential type, dips eastward and strikes approximately N. 10° W. The type of bedding and the degree of sorting are similar to those of present-day alluvial fan deposits along the flanks of the Needles Range. Considerable relief would be required to produce the gradient necessary for deposition of such a coarse conglomeratic sandstone.

Beers Spring Unit 3

Petrographically, the uppermost member of the Beers Spring Formation can be separated into several different units, none of which has any appreciable lateral extent (fig. 4). At the type section in SW$\frac{1}{4}$ Sec. 10, T. 26 S., R. 18 W., the member rests on Indian Peak Unit 2, and is overlain by the lowest member of the Needles Range Formation. A dark-green volcanic rock of phenoandesite composition lies at the base of Beers Spring Unit 3. It may be completely fused tuff or a lava flow, but it is not possible to determine whether the prominent "flow structure" was caused by true liquid flowage or by extreme deformation of shards. There are no vesicles in the unit, which suggests it is a highly welded tuff. Maximum thickness of the unit at the type section is 15 feet. Apparently, the unit merely filled in the topography cut into the top of Indian Peak Unit 2; it has an outcrop of less than 1 square mile.

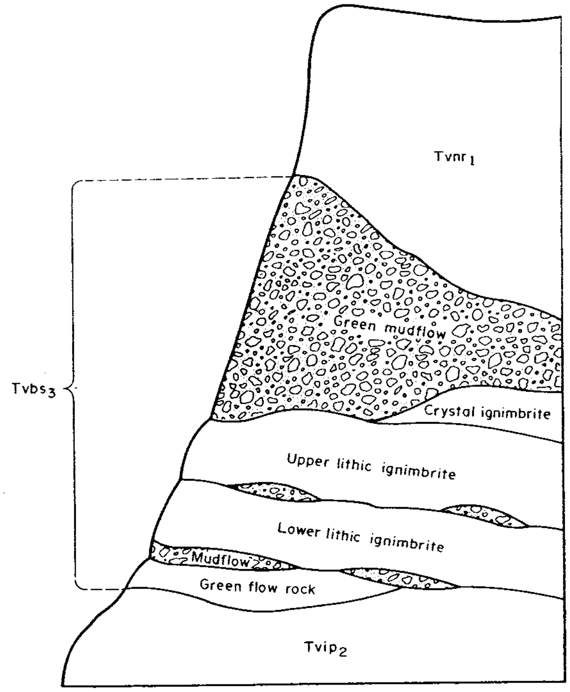


Figure 4. Internal stratigraphy of $Tvbs_3$ at the type section.

A thin green-gray conglomerate, consisting mainly of poorly rounded fragments of the underlying unit, lies above the green volcanic unit. Complete lack of sorting or bedding suggests a mudflow-type deposit. The conglomerate, which is discontinuous, ranges from a feather edge to several feet in thickness and has an outcrop area of only a few hundred square yards.

A couplet consisting of two ignimbrite layers, separated in a few places by a thin lens of green conglomerate similar to that described earlier, occurs above the greenish conglomerate. This couplet, the most persistent unit within Beers Spring Unit 3, may be traced over an area of several square miles; it crops out also in the cliff in Sec. 27, T. 26 S., R. 18 W., 3 miles south of the type section. The lower ignimbrite layer attains a maximum thickness of about 25 feet. It is a vitric-lithic phenodacite tuff, with approximately 20 to 25 percent lithic pieces loosely held in the matrix. These fragments, primarily of a reddish volcanic rock, are subrounded to angular and range from a fraction of an inch to several inches in diameter. Hand-specimen examination discloses that these fragments are similar to Beers Spring Unit 1. The matrix is soft, tan, and crumbles under the hammer so readily that it is difficult to obtain a specimen. The crystal fraction of the matrix, about 10 percent of the whole rock, contains appreciable quartz, a few scattered biotite flakes that are strongly altered to magnetite, and abundant plagioclase. The plagioclase crystals are unaltered, subhedral, and show typical albite twinning. Moreover, they are strongly zoned and show abnormal birefringence due probably to selective alteration of the more calcium-rich centers of the crystals. The excellent undeformed shard structure of the matrix is not devitrified, indicating that the material was relatively cool when deposited and that little or no welding occurred (pl. 3d).

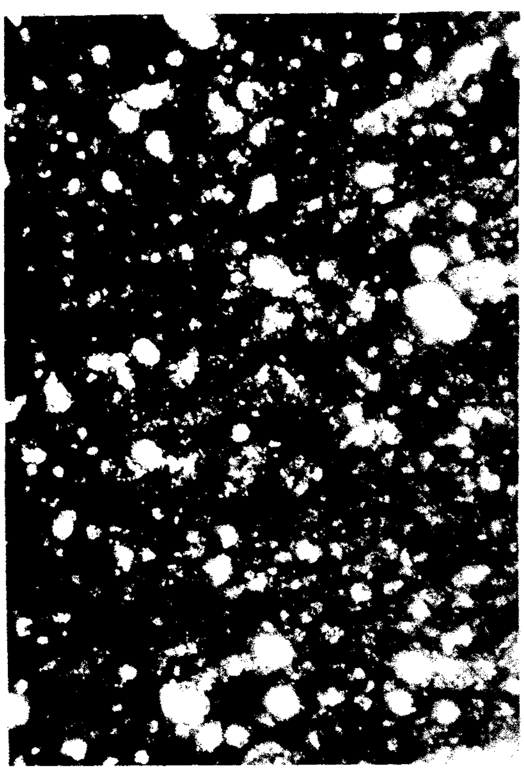
The upper ignimbrite is a crystal-lithic to vitric-lithic phenoandesite tuff, with lithic fragments similar in type and amount to those of the lower ignimbrite in the couplet. On weathering, the white matrix tends to color underlying units a dull white. Petrographically, the upper ignimbrite has essentially no quartz, but a high percentage of plagioclase crystals, some of which show the same abnormal birefringence as the unit below. There is also a trace of amphibole, probably oxyhornblende. The matrix shows no welding nor devitrification (pl. 2a).

A gray, crystal-vitric phenodacite tuff lies above the ignimbrite couplet in one small outcrop about 1 mile southwest of the type section for Beers Spring Unit 3. Crystal size is small, but in hand specimen, quartz can be recognized readily. The tuff splits in thin sheets parallel to the orientation of the biotite flakes. The entire outcrop is only 100 yards in length and the unit has a maximum thickness of 12 feet. The lowest member of the Needles Range Formation directly overlies the tuff.

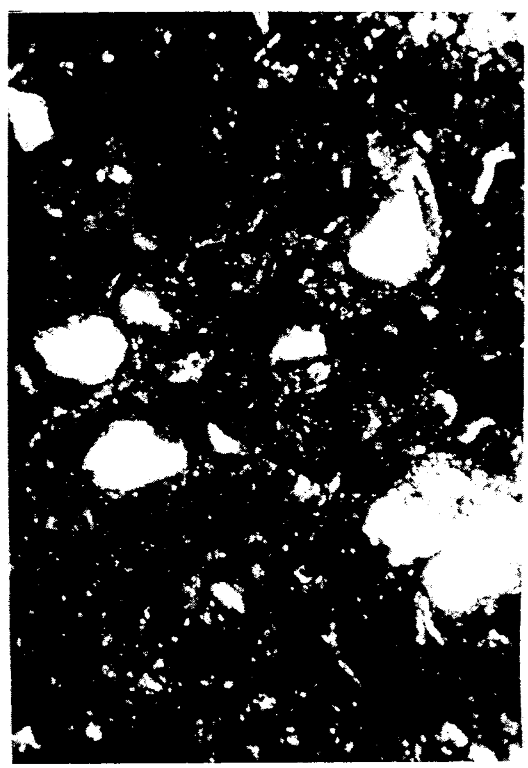
At the type locality, the topmost part of Beers Spring Unit 3 is a green conglomerate 110 feet thick, consisting of subrounded to angular rock fragments, almost entirely of volcanic origin. The unit probably is a volcanic mudflow; there is no trace of sorting or

a. Needles Range Formation, Wah Wah Springs Member, basal glass (scale ½″ = 1.0 mm)

b. Needles Range Formation, Wah Wah Springs Member, midportion (scale ½″ = 1.0 mm)



c. Beers Spring Formation, $Tvbs_1$ (scale ½″ = 1.0 mm)



d. Beers Spring Formation, $Tvbs_3$, lower ignimbrite (scale ½″ = 1.0 mm)

Photomicrographs

a. Isom Formation, Bald Hills Member (scale $\frac{1}{2}''$ = 1.0 mm)

b. Isom Formation, Hole-in-the-Wall Member (scale $\frac{1}{2}''$ = 1.0 mm)

c. Needles Range Formation, $Tvnr_1$, basal glass (scale $\frac{1}{2}''$ = 1.0 mm)

d. Needles Range Formation, $Tvnr_1$, midportion (scale $\frac{1}{2}''$ = 1.0 mm)

Photomicrographs

bedding. The conglomerate or mudflow, which thins rapidly to the east, south, and west, is capped by a thick, cliff-forming section of the lowest member of the Needles Range Formation.

Needles Range Formation

The Needles Range Formation is by far the most prominent volcanic unit in the area. In various places, it overlies each of the three major formations discussed above. In turn, it is overlain by the Isom Formation, which, while almost as widespread, is not anywhere near as thick as the Needles Range Formation. To the east of the study area, the Needles Range Formation intertongues with the upper part of the Claron Formation, the youngest essentially nonvolcanic unit predating wide-scale volcanic activity in southwestern Utah (Mackin, 1960). The Needles Range Formation was thick enough to bury all previously existing relief; thus the upper surface of each of the main members approximated a horizontal plane at the time of eruption. Consequently, units are excellent subjects for interpretation of structural events that have occurred since their deposition.

Within the study area, the Needles Range Formation consists of two prominent members, essentially continuous from Indian Peak to Highway 21, and a younger third member, restricted to the northern end of the area. Five members are recognized by Cook in east central Nevada, and Mackin shows two members throughout much of southwestern Utah (fig. 2).

Needles Range Unit 1

The lowest member of the Needles Range Formation ranges in thickness from a feather edge to over 200 feet. It is more sporadic in its occurrence than Needles Range Unit 2, but its outcrop area is several tens of square miles. The type section is in Sec. 32, T. 27 S., R. 16 W., where an unusually complete exposure of Needles Range Unit 1 is preserved beneath Needles Range Unit 2.

Petrographically, the lowest member is a crystal-vitric phenoandesite tuff, containing about 40 percent crystals, most of which are plagioclase and biotite. A relatively high percentage of hornblende (about 4 percent) also is included. Many plagioclase and biotite crystals exceed 4 mm in diameter. The latter are especially striking in hand specimen, and biotite books up to 4 mm thick are common. These large biotite crystals have led to the use of the term "Gross Biotite" as a field name for the unit. Microscopic examination indicates that welding of shards is essentially complete in the basal glass and lower midportion; shards are distorted and compacted, but not to the extreme degree found in the Isom Formation. In the lower two-thirds of the unit, there has been almost no devitrification of shards; fusing is so complete that it is difficult or impossible to identify individual shards. In the upper third, shards are less deformed and devitrification has occurred along the shard borders (pl. 4c and d).

The three-fold division of vertical facies described earlier is well developed. There is up to 15 feet of black glass at the base of the member. This glass crops out sporadically and is present at only about half of the localities where the base is exposed. The basal glass is overlain by a hard, deep-red midportion, up to 200 feet thick. In a few outcrops, such as at the type section mentioned above, a soft, whitish, unwelded top portion is present. The zone between the soft, white top and the red midportion is gradational; color change is spread through 50 feet or more of the unit. At the type section, the white top, which is about 100 feet thick, weathers into distinctive loaf-shaped mounds that constitute a distinctive pattern on aerial photographs.

No lateral variation of texture or composition within the study area was detected for Needles Range Unit 1, and except for the discontinuity of the basal glass, the member has a uniform mineralogy and texture throughout the area. Thickness varies considerably, because of erosion of the soft top after deposition and because the eruption filled numerous erosion channels that had been cut into the top of the next lower unit prior to that time of the eruption that produced the member.

Needles Range Unit 1 occurs as a few scattered outcrops in the Wah Wah Mountains 25 miles to the east, where it attains a thickness of only a few tens of feet and has a total outcrop area of a few square miles. Farther east and south, towards Cedar City, it is not found, and was not mentioned by Mackin when he divided the Needles Range Formation into two members (1960, p. 99); Mackin's lowest named member is the Wah Wah Springs Member, which in this study area is above Needles Range Unit 1. Cook (personal communication), after reading this manuscript, suggests that his $Tvnr_1$ is the equivalent of Needles Range Unit 1, although in his 1965 paper he shows his $Tvnr_1$ to be equivalent to Mackin's Wah Wah Springs Member. Comparative studies for the current report indicate that in the study area Needles Range Unit 1 probably is equivalent to Cook's $Tvnr_1$; Cook's $Tvnr_2$ is equivalent to the Wah Wah Springs Member as shown in figure 2. Some time elapsed between the eruption of the overlying Wah Wah Springs Member and that of the Needles Range Unit 1, for a coarse-grained volcanic sandstone, a few feet thick, crops out between the two members in a few areas.

Needles Range Unit 2, The Wah Wah Springs Member

The Wah Wah Springs Member of the Needles Range Formation, the dominant single volcanic unit in the area, is continuous along the eastern slope of the Needles Range. Thickness of the unit ranges from a few feet in erosion remnants to 300 feet in normal sections. The type section (Mackin, 1960, p. 99) is about 25 miles east of the Needles Range in a conical hill just south of Utah Highway 21 on the east flank of the Wah Wah Mountains. There the unit ranges in thickness from 700 to 800 feet.

Petrographically, the Wah Wah Springs Member is a crystal-vitric phenoandesite tuff. Mackin, apparently using the whole-rock analysis, states (1963, p. 71) that all the members of the Needles Range Formation that he studied are dacitic in composition. Visible crystals make up about 40 percent of the total rock, but they are definitely smaller than those in Needles Range Unit 1. The color ranges from reddish purple or reddish brown to reddish gray in the midportion, then gradually changes upwards to light gray and nearly white. Lithic fragments, several inches in diameter but only a fraction of an inch thick, are limited to disks of flattened pumice in the upper part. The main difference in composition between this member and the underlying Needles Range Unit 1 is that the Wah Wah Springs Member has considerably more amphibole (hornblende and oxyhornblende), which appears abundantly in thin section. A black, basal glass, a few feet to nearly 20 feet thick, is present wherever the base of the unit is exposed.

Microscopically, the texture is much like that of Needles Range Unit 1; fusing of the shards is complete in the basal glass and the lower two-thirds of the midportion. The few shards that are visible in the midportion are compressed and distorted. Devitrification is nearly absent (pl. 3a and b); internal zonation is like that of Needles Range Unit 1. The basal glass weathers into grayish-black plates parallel to the attitude of the unit. Biotite flakes in the basal glass are oriented roughly parallel to the platy structure. At the type section of the Wah Wah Mountains, a thick, white top is preserved beneath a lava flow, but little of the white top remains in the Needles Range. The white top of the

Wah Wah Springs Member weathers to soft, platy "pancakes" a few inches thick and up to a few feet in diameter, which are very similar to the white top portion of Needles Range Unit 1, both in hand specimen and on aerial photographs.

Needles Range Unit 3

The youngest member of the Needles Range Formation, shown as $Tvnr_3$ on the map and on the stratigraphic columns, was found only in the extreme northern part, where it has an outcrop area of but 1 or 2 square miles. It covers several erosion channels filled with fluvial sandstone cut into the upper midportion of the underlying Wah Wah Springs Member. The unit is 20 to 30 feet thick, and no basal glass nor white top was observed. Although the Needles Range Unit 3 lies between the Wah Wah Springs Member and the Isom Formation, it is lithologically so unlike the Minersville Canyon Member described by Mackin (1960, p. 99) that the two almost certainly are not equivalent. After reading the present paper, Cook expressed the opinion that his $Tvnr_5$ is probably equivalent to this author's Needles Range Unit 3, and is so shown in figure 2.

Petrographically, Needles Range Unit 3 is a red-brown, crystal-vitric phenoandesite tuff like the lower two members; however, it contains only a trace of the pyroxene and the amphibole so characteristic of the lower members. It is finer-grained than either of the two lower members, but large crystals exceed 1 mm in diameter. Biotite crystals are small, but have a distinctive reddish color even in fresh specimens. Visible crystal content is about 30 percent and welding is complete.

Isom Formation

The Bald Hills Member and the overlying Hole-in-the-Wall Member (Mackin, 1960, p. 98), which comprise the Isom Formation, are the youngest ignimbrites in the area.

Bald Hills Member

The Bald Hills Member occupies a few square miles in the southernmost portion of the study area near Indian Peak, where it is 30 to 35 feet thick. Petrographically, it is a completely welded, vitric-crystal to vitric-lithic phenoandesite tuff. Mackin (1960, p. 98) indicates that the Bald Hills Member is a latite tuff. Except for the black, basal glass, which appears sporadically, the color is dull gray to black. Thin-section study disclosed that the shards are highly deformed; in some thin sections, deformation is so extreme as to suggest that the material flowed plastically after the particulate flow ceased. The few biotite flakes are roughly aligned with the deformed shards and both are approximately parallel to the attitude of the unit. The unit weathers to nearly cubic, angular, pea-sized chunks. Lithic pieces are mostly thin flattened disks of pumice, 2 to 5 mm thick and several cm in diameter, which are parallel to the attitude of the unit. Other fragments include different types of tuff and a few sedimentary pebbles.

Hole-in-the-Wall Member

The more prominent Hole-in-the-Wall Member is exposed throughout the study area. Thickness ranges from 15 to 25 feet, except for a single 70-foot thick outcrop located southeast of Indian Peak, where the member caps a small mesa. There is no indication of a disconformity between the two members of the Isom Formation, which are parallel wherever they are found together. The contact is "tight"; there is no ash nor sedimentary material between the two members.

Petrographically, the Hole-in-the-Wall Member is a vitric to vitric-lithic phenoandesite tuff, containing less than 10 percent crystals. Whole rock analysis (Mackin, 1960, p. 99) indicates that this member is a latite. The member weathers to plates about an inch thick that nearly parallel the attitude of the unit. It is dark red to brown with white lithic fragments of pumice and sedimentary pebbles. Many white plagioclase crystals are visible in hand specimen also. Shards are highly deformed, and some liquid flow may have occurred (pl. 4a and b).

SEQUENCE OF EVENTS

Regional Setting

The area described in this report lies along the north side of a broad band of volcanic rocks that crops out across south central and eastern Nevada and southwestern Utah. Structurally similar to the east central Basin and Range province, this is a region of numerous fault-block mountain ranges, most of which trend north or northeast. These faults are mostly steeply dipping normal faults with upthrown east sides. As movement occurred along the faults, upthrown sides were tilted to the east; as a consequence, the overall structure is one of roughly parallel easterly tilted mountain ranges. Outcrop areas now are discontinuous, interrupted by basin-range faulting, erosion, and deposition of later sediments.

Conditions Prior to Volcanism

Paleozoic strata in the study area were deformed by the Laramide orogeny (Cretaceous) into a north-plunging asymmetrical syncline and anticline (Gould, 1959). The western limb was affected further by at least two episodes of thrust faulting and overturning. Following the folding and thrusting, the area was subjected to normal faulting, probably concurrent with the volcanic activity discussed in detail in this report.

The Claron Formation is found to the east of the study area, where it consists of up to 1,500 feet of fluvial and lacustrine sediments of late Eocene to early or middle Oligocene age. The lower part is devoid of volcanic detritus. The Claron Formation thickens rapidly eastward from the Wah Wah Mountains, but is not present in the area of this report. The earliest volcanic rocks filled in at least 200 feet of relief cut in the older Paleozoic sedimentary rocks, and these conditions suggest that the area that now is the Needles Range probably was a topographic high with considerable relief, forming a major source for the sediments of the Claron Formation.

The Needles Range Formation interfingers between the lower and upper portions of the Claron Formation near Cedar City. The upper part of the Claron Formation is tuffaceous; so extensive volcanism apparently began during the time represented by deposits of the Claron Formation.

These conditions are summarized by Mackin (1960, p. 102):

> . . . what are now the Great Basin in southwestern Utah and the southern High Plateaus were parts of a single fluvial and lacustrine depositional plain during Claron time, and continued through Needles, Isom, and part of Quichapa[1] time to be a single volcanic field

1. The Quichapa Formation, dated as late Oligocene (Cook, 1965, p. 8) is the next formation above the Isom Formation in the Wah Wah Mountains, from where it thickens rapidly to the south and east.

consisting chiefly of regional ignimbrites, surmounted in places by volcanoes and perhaps intrusive dome mountains.

Volcanic Events

Detailed mapping of the Tertiary volcanic units within the study area indicates the following sequence of events:

Indian Peak Volcanism

The ignimbrite eruptions that produced the Indian Peak Formation were preceded by extrusion of andesitic lava flows exposed in the vicinity of Indian Peak. Elsewhere this formation rests on the Paleozoic basement. Indian Peak Unit 1, the lowest ignimbrite, filled a few valleys in the prevolcanic topography and has slight lateral extent.

A persistent ignimbrite of regional extent, Indian Peak Unit 2, buried a topography of about 200 feet of relief (fig. 5), and is an excellent marker bed, showing up well on air photographs. Of interest is the fact that many hundreds of feet of volcanic units occur between Indian Peak Unit 2 and the Needles Range Formation in the southern part of the area, whereas the Needles Range Formation rests directly on Indian Peak Unit 2 over most of the northern part. After or contemporaneously with the deposition of Indian Peak Unit 2, the southern part of the area began to subside (fig. 5a), accompanied by channel erosion. Much of the eroded material may have been moved to the east and incorporated into the tuffaceous upper Claron Formation. Moreover, Indian Peak Unit 3, the tuffaceous sandstone in the southern part of the area, may represent material eroded from Indian Peak Unit 2 during subsidence. Nevertheless, Indian Peak Unit 2 and Unit 3 are essentially parallel to the overlying units.

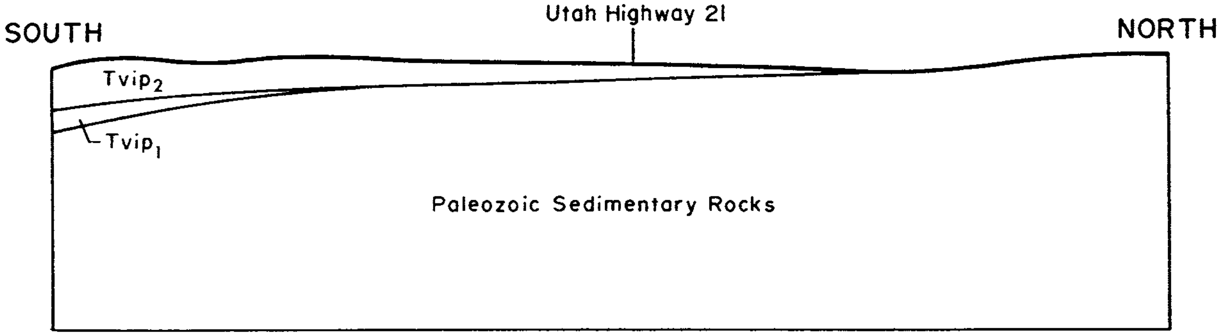
It is not clear whether subsidence of the southern part of the area took place as a monoclinal flexing of the zone, or because of movement along one or more faults trending east and downthrown on the south. Abrupt termination of some of the post-Indian Peak Unit 2 units, such as Indian Peak Unit 4, a prominent ignimbrite triplet uniformly distributed over the entire southern part of the study area, could be explained by a fault scarp of 100 feet or more along the northern edge of T. 28 S., which blocked the ash-flows from going further north. The termination could also be explained by a sharp flexure, or monocline, with the southern side downthrown. There is no direct evidence of either a flexure or fault, but, as there is no sign of any southerly tilted layers in this intermediate area, a fault scarp is the more likely possibility.

Sawtooth Peak Volcanism

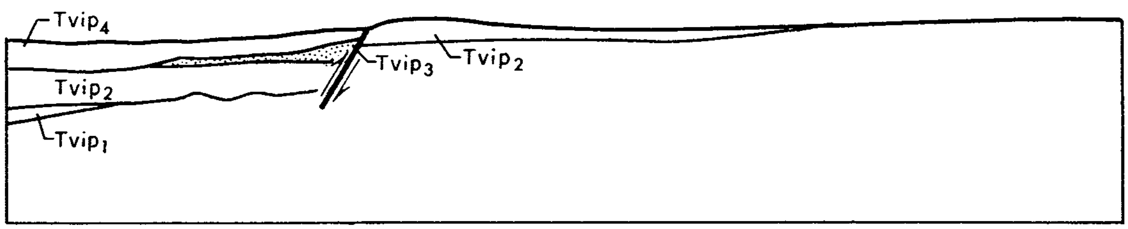
There is no evidence of any appreciable erosional interval preceding deposition of the Sawtooth Peak Formation. The unit, which is distributed throughout the southern part of the area, extends slightly farther north, but not as far south as Indian Peak Unit 4.

Beers Spring Volcanism

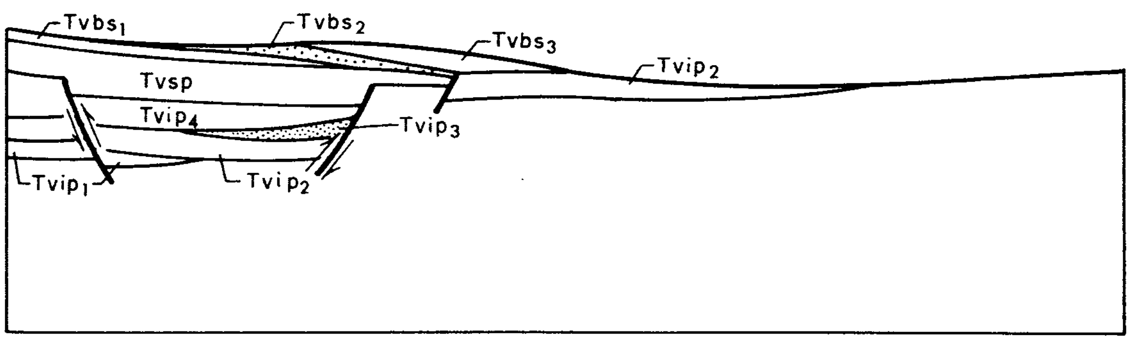
Beers Spring Unit 1 is generally uniform in thickness throughout its outcrop area, but it lenses out southward near Indian Peak as does the Sawtooth Peak Formation. This is interpreted to mean that at the time of eruption subsidence had been confined to an east-west trough or graben.



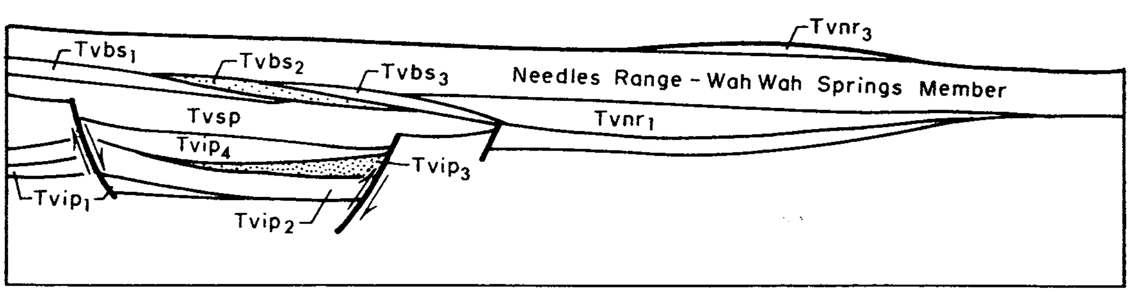
a. Eruption of $Tvip_1$ and $Tvip_2$.



b. Subsidence of southern area, erosion to produce $Tvip_3$, followed by eruption of $Tvip_4$.



c. Continued subsidence of southern area, forming a graben; eruption of Tvsp and Tvbs.



d. Faulting becomes more complex; southern area continues to subside; eruption of Needles Range Formation.

Figure 5. Structural development of Needles Range, southwestern Utah, through Needles Range time (early Oligocene). Probable north-south profiles during development of the volcanic stratigraphy from south of Indian Peak northward to the north end of Needles Range, looking west.

Eruption of Beers Spring Unit 1 was followed by a long period of erosion, during which all earlier units were incised by gullies. In the southern part of the area, this erosion surface was covered by an alluvial fan, Beers Spring Unit 2. The torrential bedding and the gradation from coarse to fine boulders indicate the source of the sandstone was to the west, probably outcrops of the Sawtooth Peak Formation. Distribution of Beers Spring Unit 2 is coincident with that of the Sawtooth Peak Formation, except that it extends slightly farther north. It seems probable that during or shortly after deposition of the Sawtooth Peak Formation, regional subsidence was accompanied by differential elevation and depression of sections of the Needles Range area along north-trending faults. Such movements could have produced the topography necessary for the Beers Spring Unit 2 alluvial fan to form. Some tilting may have occurred at this time, but for the most part the blocks remained essentially horizontal.

About the time Beers Spring Unit 2 was being formed by erosion of the Sawtooth Peak Formation in the south central Needles Range, Beers Spring Unit 3 was being deposited several miles to the north. Mudflows in Beers Spring Unit 3 probably came from a volcano slightly east or west of the present Needles Range and north of the type section of Beers Spring Unit 3 in the Pine Valley or Hamblin Valley areas now buried under late Tertiary and Quaternary sediments.

Needles Range Volcanism

The lowermost member of the Needles Range Formation, Needles Range Unit 1, spread over the faulted and eroded surface formed prior to and during deposition of Beers Spring Unit 2 and Unit 3. In most places, the Needles Range Formation overlies parts of the Paleozoic basement then exposed, Indian Peak Unit 2, and at several locations, Beers Spring Unit 3. Needles Range Unit 1 is a widespread, persistent unit in the central and northern parts of the area, but it is missing in the extreme southern part. Since an ignimbrite eruption tends to fill topographically low areas, it appears the southern part of the Needles Range, which had subsided as a topographic low previously, almost certainly had become a topographic high by the time of the eruption of Needles Range Unit 1. Subsidence apparently had ceased, and the area was beginning to break into independently acting fault blocks. Needles Range Unit 1 occurs continuously from a point just south of Sawtooth Peak northward for at least 40 miles. However, it stops abruptly at Sawtooth Peak, suggesting that a topographic barrier prevented it from extending further south.

A relatively short period of erosion modified the top of Needles Range Unit 1 slightly, permitting formation of a few small lenses of tuffaceous sandstone. This interval was followed by the largest single eruption to affect the area. The Wah Wah Springs Member of the Needles Range Formation erupted, blanketing the entire study area (and thousands of square miles beyond) with hundreds of feet of ignimbrite. The Wah Wah Springs Member at one place or another is in contact with each formation, and nearly every member of each formation, within the study area.

In some outcrops, particularly in the southern part of the area, there is a slight angular discordance, not exceeding 10 degrees, between the Wah Wah Springs Member and lower units. Compaction during cooling of an ignimbrite quite possibly could account for discordances of this magnitude. In other outcrops, the Wah Wah Springs Member appears to be parallel to all lower units down to and including Indian Peak Unit 2. Large-scale tilting of the range, then, had not occurred up through the time of the Wah Wah Springs eruption.

Deposition of the Wah Wah Springs Member in the Needles Range was followed by a period of erosion. Much of the soft, white top of the unit was eroded, particularly in the northern part of the area; erosion channels are common in the top of the unit. However, in the southern part of the area, the soft, white top commonly is present. During or following this period of erosion, an ignimbrite, Needles Range Unit 3, was deposited in the extreme northern part of the area near Utah Highway 21; it covers channels cut in the top of the Wah Wah Springs Member.

Isom Volcanism

The next event was the spreading of the Bald Hills Member of the Isom Formation over the relatively flat surface at the top of the Wah Wah Springs Member in the southern part of the area. The Bald Hills Member completely blankets the area near Indian Peak, but lenses out northward to a feather edge about 2 miles south of Sawtooth Peak. The implication is that the southern part of the area was a topographic low at the time.

The final recorded volcanic event was the deposition of the Hole-in-the-Wall Member, which spread almost uniformly over the entire area, although it lenses northward also and pinches out a few miles north of Utah Highway 21. The Bald Hills Member probably filled a depression in the southern part of the area, allowing the Hole-in-the-Wall Member to spread over an almost horizontal surface.

Post-volcanic Events

The present configuration of the Needles Range and its relation to Pine Valley and Hamblin Valley are the products of basin-range faulting, relative uplift and depression of blocks, eastward tilting, and erosion, which followed ignimbrite eruptions that occurred in Oligocene time. The map and sections (pl. 5) show the numerous faults and fault blocks within the range and the distribution of discontinuities and volcanic units.

In general, the Needles Range has been uplifted with respect to Hamblin Valley and tilted to the east, probably along a normal fault or system of faults concealed beneath alluvium at the east side of Hamblin Valley. Except in the area of Section B-B', uplift has elevated the Paleozoic basement on the west side of the range. As a consequence, much of the volcanic cover has been removed by erosion. However, the uplift was accomplished by adjustments along numerous breaks within the Needles Range, so that some portions were sliced downward to the west. For the most part, volcanic units slope eastward beneath the alluvial cover of Pine Valley. Mapping indicates that the normal faults within the range are discontinuous and that there is marked variation in the relative degree of uplift in a north-south direction, as well as a more consistent depression toward the west. Consequently, outcrops of Paleozoic rocks appear near the east side of the range, as along Sections B-B' and C-C'. The relative uplift and depression in the north-south direction probably occurred because of warping and tilting, but a few east-west normal faults were mapped. The most prominent of these, near the south edge of the area, separates Paleozoic rocks on the north from undifferentiated volcanic rocks (Tvu) on the south (the oldest in the sequence). The State Geologic Map (Hintze, 1963) does not show any emergence of the Paleozoic basement south of this fault. The area does not afford any direct evidence as to the age of basin-range faulting except that it is clearly post-Isom.

SUMMARY OF EVENTS

It is apparent from this study of the northern part of the Needles Range that a series of more local volcanic eruptions preceded deposition of the regionally widespread Needles Range

Formation and that this volcanic activity was accompanied by minor deformation and some erosion intervals. The distribution and relationships of these earlier volcanic units suggest that subsidence occurred in the southern part of the area, and that this was followed by minor faulting and relative elevation and depression of individual blocks. As contacts between succeeding layers are remarkably parallel, it does not appear that there was any marked tilting of blocks until post-Isom time. So far as can be judged, all the volcanic units and the deformation that accompanied their emplacement are of Oligocene age. Basin-range-type faulting and tilting in the study area is therefore late Oligocene or Miocene.

ECONOMIC GEOLOGY

In contrast to many other areas of Tertiary volcanic rocks in the Great Basin, including the Cougar Spar mine area immediately to the south, this part of the Needles Range contains no known deposits of economic importance. Several pits -- the largest of which is more than 30 feet deep -- expose the contact of the Sawtooth Peak Formation with underlying carbonate sedimentary rocks south of Sawtooth Peak. No minerals of economic interest were detected in the band of altered tuff near the contact.

A second area of prospect pits is halfway up the cliff in Sec. 28, T. 26 S., R. 18 W., where an adit has been driven more than 75 feet into the cliff along the contact of the Indian Peak Unit 2 and the underlying Paleozoic carbonate rocks. The lower margin of the tuff is altered to a greenish color. Considerable quantities of chalcedony and agate of moderately good quality cover the talus near the adit.

Grant (1969, in press) has a discussion of the fluorspar deposits at the Cougar Spar mine a few miles south of the study area.

CONCLUSIONS

Utilization of ignimbrites as stratigraphic units in determining the Tertiary structural geology in the east central Basin and Range province is highly successful. The ignimbrites serve as perfect horizontal marker beds, and, once the stratigraphy within an area is worked out, they allow the investigator to determine with considerable accuracy the sequence of events in that area.

ACKNOWLEDGMENTS

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REFERENCES

Armstrong, R.L., 1963, Geochronology and geology of the eastern Great Basin: Yale Univ. Ph.D. thesis, unpublished.

Cook, E.F., 1965, Stratigraphy of Tertiary volcanic rocks in eastern Nevada: Nevada Bureau of Mines Rept., no. 11, 61 p.

Gould, W.J., 1959, Geology of the northern Needles Range, Millard County, Utah: Brigham Young Univ. Geology Studies, v. 6, no. 5, 47 p.

Grant, S.K., 1969, Geology and ore deposits of the Indian Peak fluorspar district, Beaver County, Utah: Utah Geol. and Mineralog. Survey Special Studies, in press.

Hintze, L.F., 1963, Geologic map of southwestern Utah: Brigham Young Univ., Geol. Dept., 1/250,000.

Mackin, J.H., 1960, Structural significance of Tertiary volcanic rocks in southwestern Utah: Am. Jour. Sci., v. 258, no. 2, p. 81-131.

____________ 1963, Reconnaissance stratigraphy of the Needles Range Formation in southwestern Utah: Intermtn. Assoc. Petroleum Geologists, 12th Ann. Field Conf. Guidebook, p. 71-78.

Ross, C.S., and Smith, R.L., 1960, Ash-flow tuffs -- their origin, geologic relations, and identification: U. S. Geol. Survey Prof. Paper 366, 81 p.

Williams, P.L., 1960, A stained slice method for rapid determination of phenocrysts composition of volcanic rocks: Am. Jour. Sci., v. 258, no. 2, p. 148-158.

UTAH GEOLOGICAL AND MINERALOGICAL SURVEY

103 Utah Geological Survey Building
University of Utah
Salt Lake City, Utah 84112

THE UTAH GEOLOGICAL AND MINERALOGICAL SURVEY since 1949 has been affiliated with the College of Mines and Mineral Industries at the University of Utah. It operates under a director with the advice and counsel of an Advisory Board appointed by the Board of Regents of the University of Utah from organizations and categories specified by law.

The survey is enjoined to cooperate with all existing agencies to the end that the geological and mineralogical resources of the state may be most advantageously investigated and publicized for the good of the state. The *Utah Code, Annotated, 1953 Replacement Volume 5, Chapter 36, 53-36-2,* describes the Survey's functions.

Official maps, bulletins, and circulars about Utah's resources are published. (Write to the Utah Geological and Mineralogical Survey for the latest list of publications available).

THE LIBRARY OF SAMPLES FOR GEOLOGIC RESEARCH. A modern library for stratigraphic sections, drill cores, well cuttings, and miscellaneous samples of geologic significance has been established by the Survey at the University of Utah. It was initiated by the Utah Geological and Mineralogical Survey in cooperation with the Departments of Geology of the universities in the state, the Utah Geological Society, and the Intermountain Association of Petroleum Geologists. This library was made possible in 1951 by a grant from the University of Utah Research Fund and by the donation of collections from various oil companies operating in Utah.

The objective is to collect, catalog, and systematically file geologically significant specimens for library reference, comparison, and research, particularly cuttings from all important wells driven in Utah, and from strategic wells in adjacent states, the formations, faunas, and structures of which have a direct bearing on the possibility of finding oil, gas, salines or other economically or geologically significant deposits in this state. For catalogs, facilities, hours, and service fees, contact the office of the Utah Geological and Mineralogical Survey.

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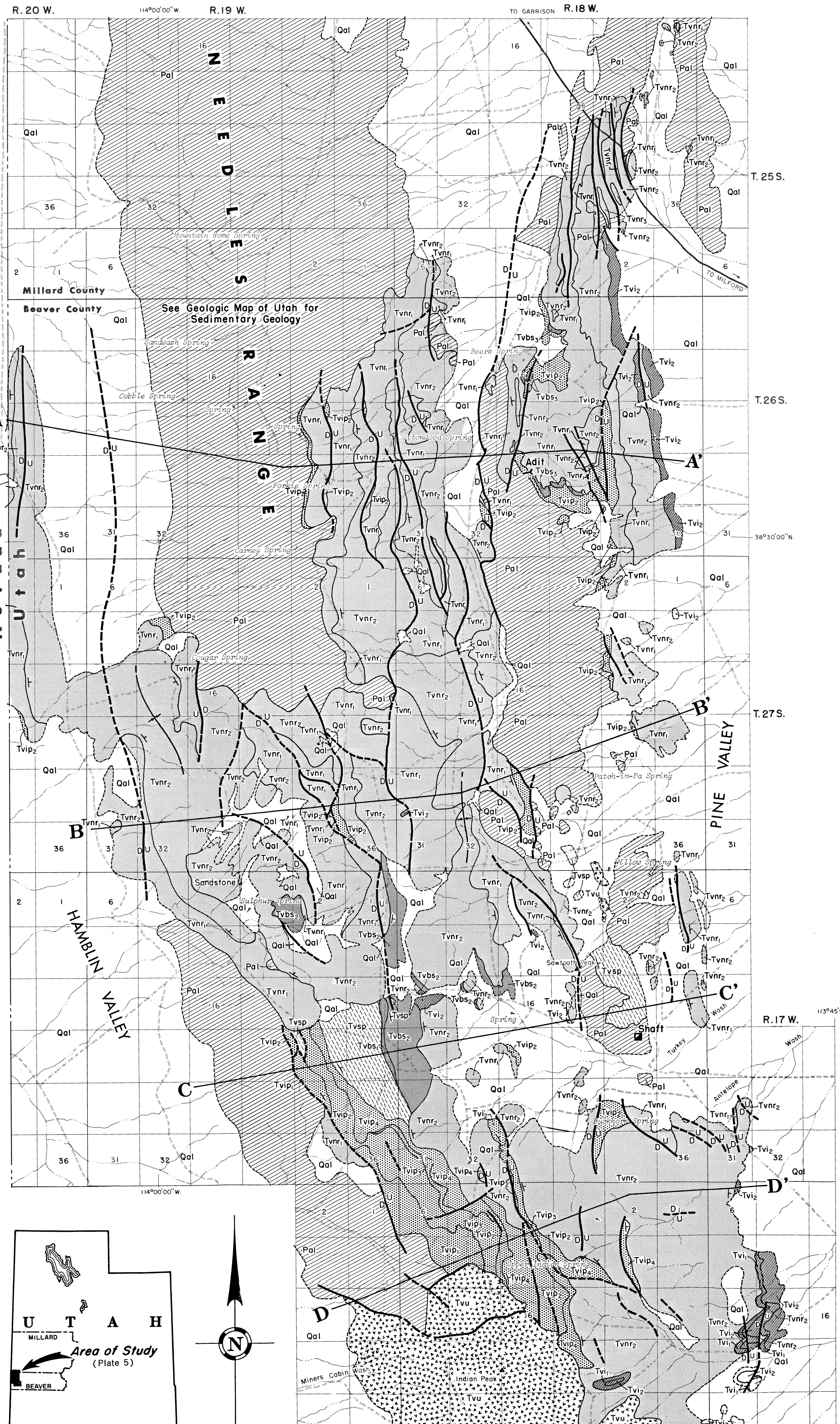
DIRECTORS:

William P. Hewitt, 1961-
Arthur L. Crawford, 1949-1961



INDEX MAP

EXPLANATION

Quaternary

Qal Alluvium

Oligocene

Isom Formation

- **Tvi2** Hole-in-the-Wall Member: *vitric to vitric-lithic phenoandesite tuff*
- **Tvi1** Bald Hills Member: *vitric crystal to vitric-lithic phenoandesite tuff*

Needles Range Formation

- **Tvnr3** *Crystal-vitric phenoandesite tuff*
- **Tvnr2** Wah Wah Springs Member: *crystal-vitric phenoandesite tuff*
- **Tvnr1** *Crystal-vitric phenoandesite tuff ("Gross biotite tuff")*

Beers Spring Formation

- **Tvbs3** *Multiple unit: base=phenoandesite tuff or lava flow with local conglomerate; mid=complex of vitric-lithic phenoandesite tuffs; top=greenish volcanic conglomerate*
- **Tvbs2** *Coarse gravelly sand: submature volcanic arenite*
- **Tvbs1** *Vitric phenoandesite tuff*

Sawtooth Peak Formation

- **Tvsp** *Crystal-vitric phenodacite tuff (may be equivalent to Windous Butte Formation)*

Indian Peak Formation

- **Tvip4** *Triplet of lithic to lithic-vitric phenoandesite tuffs, welded, gray to pink*
- **Tvip3** *Coarse gravelly sand: submature volcanic arenite; local lithic-vitric phenoandesite tuff at base.*
- **Tvip2** *Vitric phenoandesite tuff*
- **Tvip1** *Crystal-vitric phenodacite tuff*

Age relationship unknown

Tvu Undifferentiated Tertiary flows: *Mostly andesitic to latitic in composition, but at least one basalt is present; both lava flows and tuffs are found*

Paleozoic

Pal Undifferentiated Paleozoic rocks

SYMBOLS

Contact
Dashed where inferred

Fault
Dashed where inferred; D is on the downthrown block; U is on the upthrown block

Axis of syncline

Strike and dip of beds

Shaft

Adit

Line of section

Scale in Miles

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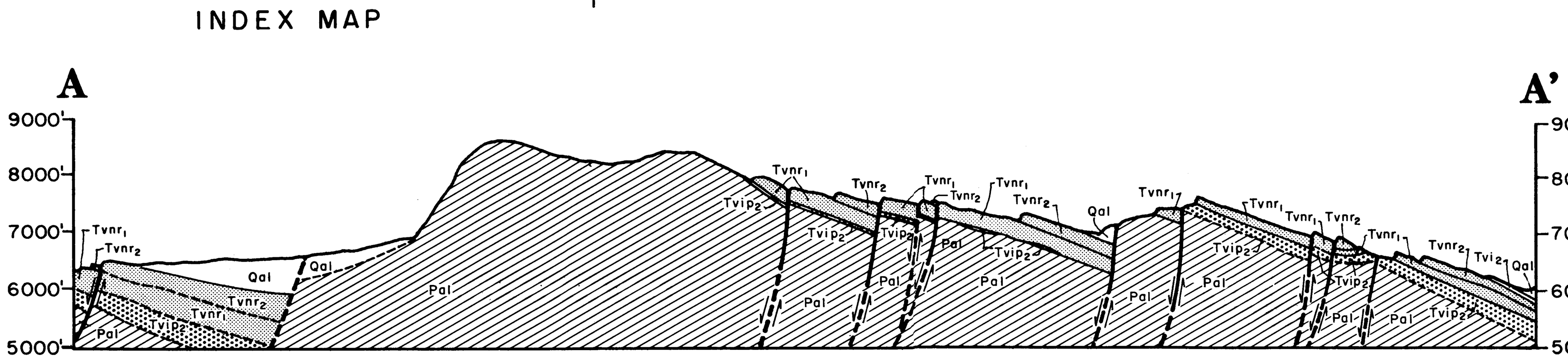
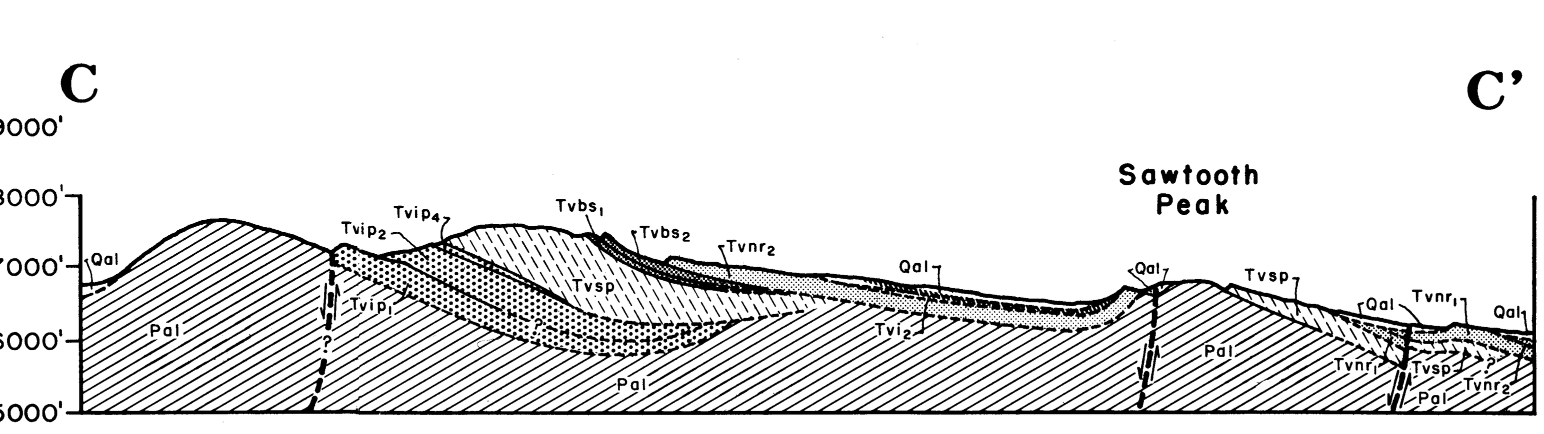
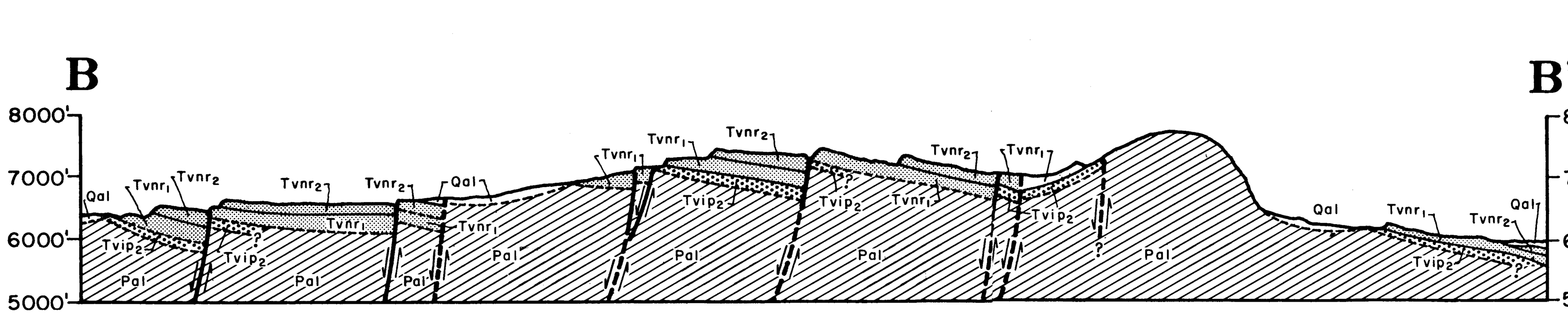
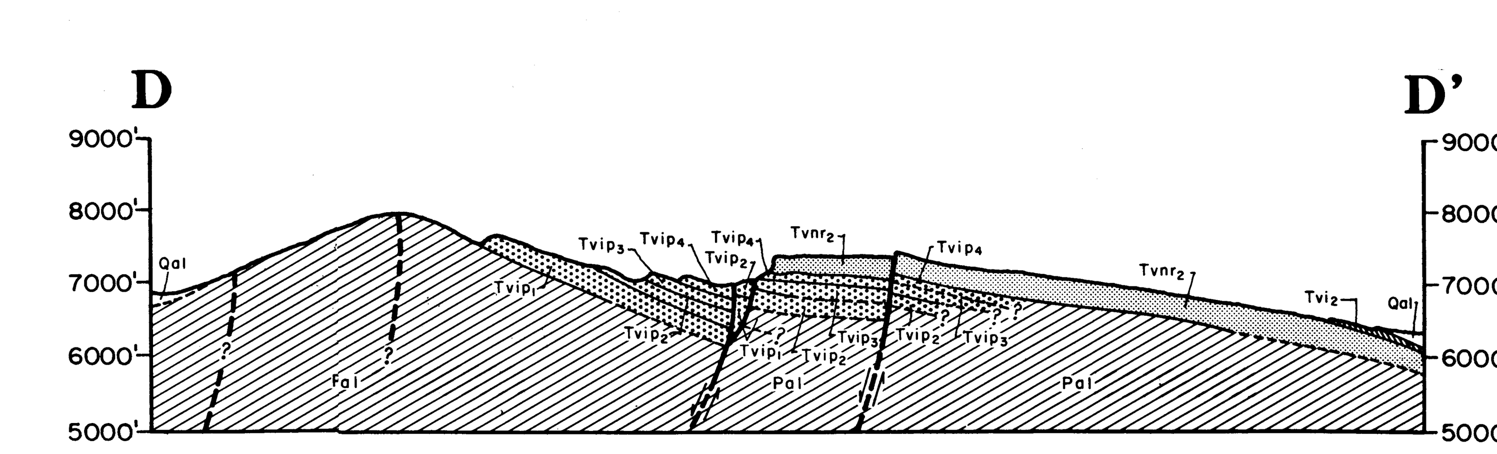
Base taken from Bureau of Land Management Grazing Service sheet – Hamblin Valley and Bull Springs Units, June 1961.

DRAFTED BY B. JONES, 1968









Elevations are approximate, taken from Geologic Map of Southwestern Utah, 1964 1:250,000.

TERTIARY VOLCANIC ROCKS OF THE NEEDLES RANGE, MILLARD AND BEAVER COUNTIES, UTAH

By
OMAR G. CONRAD

— 1968 —