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Contents

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Pre-Needles Range Silicic Volcanism, Tunnel Spring Tuff, (Oligocene), West-Central Utah

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ABSTRACT.—In west-central Utah the rhyolitic Oligocene Tunnel Spring Tuff (new name) rests on erosional surfaces cut in Paleozoic sedimentary rocks and is overlain by the Needles Range formation. It is a white, unsorted, nonwelded, friable ash-flow tuff that weathers in a cavernous fashion. Numerous carbonate xenoliths, pumice fragments, and phenocrysts of quartz, plagioclase, sanidine, and biotite characterize the unit. Field, depositional, and structural features of the Tunnel Spring Tuff indicate an ash-flow mode of emplacement, filling topographic lows. Pre-Tunnel Spring Tuff topography consisted of at least 350 meters of relief. Local conglomeratic, fluvial, and lacustrine deposits were derived from the pre-Tunnel Spring Tuff erosional surface. Postemplacement faulting of the Tunnel Spring Tuff follows north-south Basin and Range trends. The Tunnel Spring Tuff is similar in composition to other pre-Needles Range volcanic units in eastern Nevada and southwestern Utah.

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*A thesis presented to the Department of Geology, Brigham Young University, in partial fulfillment of the requirements for the degree Master of Science, 20 April 1973.

INTRODUCTION

The Tunnel Spring Tuff (new name) is one of many Oligocene volcanic deposits which rests upon erosional surfaces cut in Paleozoic sedimentary rocks (Text-fig. 1). The purpose of this study is to determine (1) the stratigraphic relations of the Tunnel Spring Tuff and associated Tertiary deposits, (2) the depositional and structural features of the tuff, (3) possible mode of emplacement of the Tunnel Spring Tuff, (4) the pre-Tunnel Spring Tuff topography and environment, and (5) the nature of subsequent block faulting.

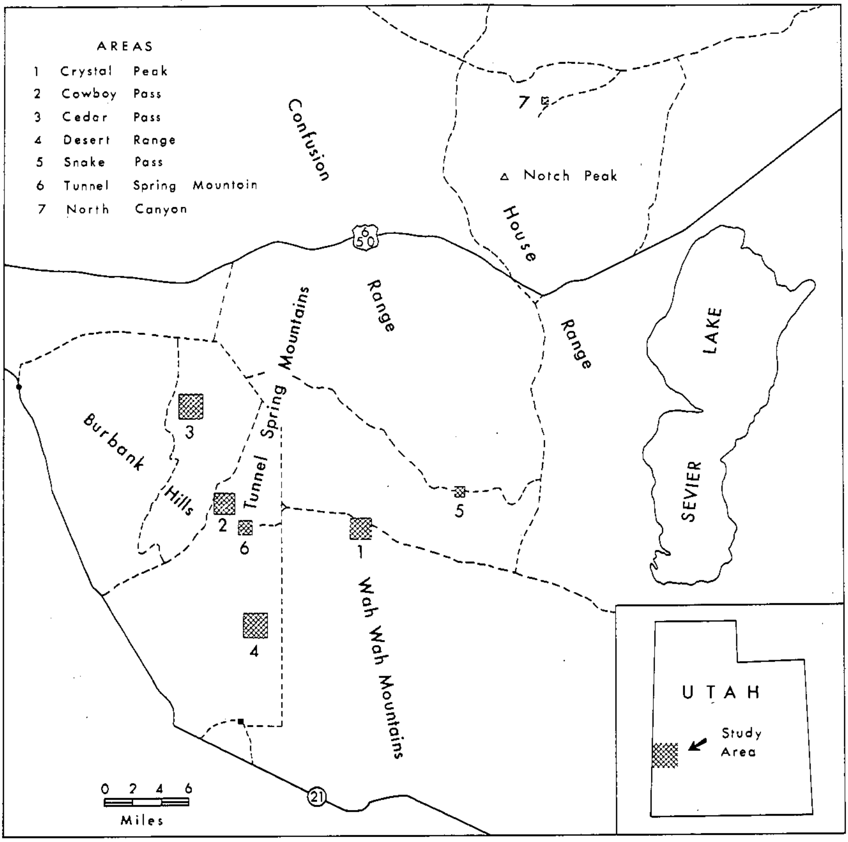
Mackin (1954, 1960, 1963), Cook (1960, 1965), and Armstrong (1968, 1970) have described many of the mid-Tertiary volcanic rocks in southwestern Utah. Dunn (1959) was one of the first to describe the Tunnel Spring Tuff that constitutes Crystal Peak (Text-fig. 5). He believed the peak to be the result of two separate periods of activity, an early extrusive phase and a later hypabyssal intrusive phase. Dunn also proposed a definite genetic relation between brecciation of adjacent Paleozoic rocks and the formation of the peak. The present study has resulted in modification of some of Dunn's views.

Regional stratigraphic studies (Mackin, 1960; McKee, 1971) of the widespread volcanic rocks of Tertiary age in the Great Basin showed that some individual units are hundreds of feet in thickness and cover areas of many thousands of square miles. Most of these great sheets represent explosive ash-flow eruptions of many hundreds of cubic miles of magma. The total volume of Tertiary silicic volcanic rocks in the Great Basin is on the order of 50,000 cubic miles (Mackin, 1960).

The widespread Needles Range Formation, dated at 29.7 $\pm$ 0.9 million years (Oligocene) by means of the K-Ar method (Armstrong, 1970; McKee, 1971), is found directly over the Tunnel Spring Tuff in most locations. In some areas the Tunnel Spring Tuff and Needles Range Formation are separated by a tuffaceous conglomerate.

ACKNOWLEDGMENTS

The writer wishes to thank Myron G. Best and Lehi F. Hintze, who helped



TEXT-FIGURE 1.—Index map, showing location of study area.

develop the study and criticized the manuscript. Appreciation is expressed to my wife, Gene, for her patience and understanding.

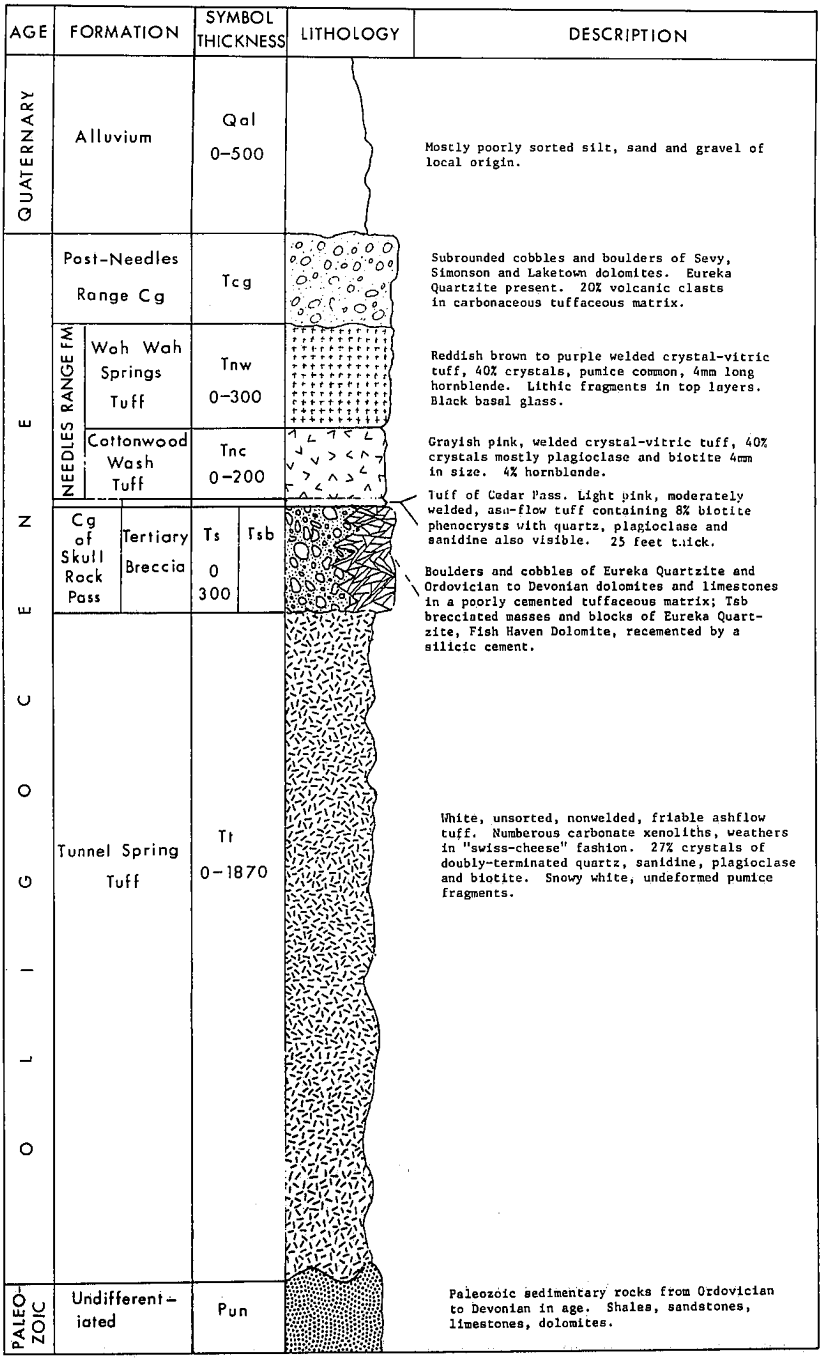
STRATIGRAPHY

A stratigraphic column for the Tunnel Spring Tuff and associated units in Millard County, Utah, is presented in Text-figure 2.

ORDOVICIAN TO DEVONIAN SYSTEMS

Paleozoic Rocks Undifferentiated

The Paleozoic sequence consists of Ordovician to Devonian limestones, dolomites, shales, and sandstones. The 1,000-meter-thick Pogonip Group, Lower Ordovician to Middle Ordovician, consists of the House Limestone, Fillmore Formation, Wahwah Limestone, Juab Limestone, Kanosh Shale and Lehman Formation (Hintze, 1951). The House Limestone is a finely crystalline, medium gray limestone that erodes to slightly massive ledges. The Fill-



TEXT-FIGURE 2.—Stratigraphic column for the Tunnel Spring Tuff and associated rock units in Millard County, Utah.

more Formation is a medium gray intraformational conglomerate that consists of flat pebbles of silty to quartzose, fine-grained sandy limestone in a matrix of muddy limestone. The talus from the intraformational conglomerate covers the interbeds of yellowish gray shale which comprise much of the formation. The Wahwah Limestone and Juab Limestone are medium gray silty limestone units that are ledge and slope forming. The Kanosh Shale is a light olive gray, fissile shale interbedded with thin fossiliferous calcarenite and yellow brown siltstone beds. It weathers to a prominent slope and often covers itself over large intervals. The Lehman Formation is bluish gray, thin bedded, silty limestone interbedded with cross-bedded quartzite layers. Few if any of the Pogonip Group rocks are resistant enough to become major pebble constituents of the Skull Rock Pass conglomerate.

The Middle Ordovician Watson Ranch Quartzite (Webb, 1958) is 55-60 meters in thickness and is a quartz sandstone that weathers to a dark reddish brown color and contains silty partings and distinctive fucoidal markings. The Middle Ordovician Crystal Peak Dolomite (Webb, 1958) consists of 27 meters of medium to finely crystalline, thin bedded dolomite that weathers to a distinctive olive gray color.

The Middle Ordovician Eureka Quartzite (Webb, 1958) is an easily identified unit often observed. It is 140-170 meters thick and is a medium- to fine-grained, white to light gray quartz sandstone. It contains numerous spherical pockmarks and weathers reddish brown. Eureka Quartzite boulders are easily identified in the Skull Rock Pass conglomerate by their reddish brown color and spherical pockmarks.

The 185-meter-thick Upper Ordovician Ely Springs Dolomite (Budge, 1972) is a dark brownish gray, cherty dolomite interbedded with medium to light brownish gray dolomite.

The 200-meter-thick Silurian Laketown Dolomite (Budge, 1972) is a dark gray, massive, cherty, cliff-forming dolomite with a marker bed near the top of coarsely crystalline pinkish gray dolomite that contains silicified brachiopods and a coral fauna.

The 400-meter-thick Devonian Sevy Dolomite (Hose, 1966) is a dense homogenous, medium gray, finely crystalline dolomite. It weathers to low rounded slopes with no conspicuous cliffs. Its dolomites are easily identified as pebbles in the Skull Rock Pass conglomerate.

The Devonian Simonson Dolomite (Hose, 1966) consists of alternating medium to coarsely crystalline beds of dark brownish gray and light gray laminated dolomite. The total thickness is 165-210 meters.

The basal member of the Guilmette Formation (Hose, 1966) is 185 meters thick, Devonian in age, and consists of a dark gray finely crystalline massive limestone that forms rounded cliffs. In many places this unit consists of a breccia of angular limestone blocks cemented within a dense matrix of the same kind of limestone. The upper member of the Guilmette Formation is 600 meters thick and is composed of gray limestone and dolomite in ledge- and slope-forming beds a few meters thick.

TERTIARY SYSTEM

Tunnel Spring Tuff

Lithology.—The Tunnel Spring Tuff (new name) is a white, unsorted, non-welded friable ash-flow tuff. Numerous carbonate xenoliths are found in the

Tunnel Spring Tuff: some are baked white; others contain coarse green calc-silicate alteration minerals; and still others show no alterations.

The Tunnel Spring Tuff weathers in a "Swiss-cheese" fashion that characterizes the tuff in all locations. White, undeformed and unaltered pumice fragments averaging 0.5 cm in diameter are abundant.

Phenocrysts of quartz, sanidine, plagioclase, and biotite make up 27 percent of the Tunnel Spring Tuff and are easily identifiable in hand sample. The quartz phenocrysts average 3mm in size and are doubly terminated, smoky gray crystals. Sanidine phenocrysts are identifiable with a hand lens by their cleavage and clear appearance. Plagioclase appears as small, milky white, subhedral laths that are slightly fractured. Small black flakes of biotite are conspicuous.

The matrix of the Tunnel Spring Tuff is composed of angular glassy shard fragments that have been slightly devitrified. On weathered surfaces the glassy matrix erodes easily, leaving the phenocrysts standing in relief and giving the tuff a sugary texture.

In several locations bedding is found in the Tunnel Spring Tuff—the result of the sorting of phenocrysts, xenoliths, and pumice fragments. The bedding may or may not be highlighted by a slight reddish pink color change.

Petrology.—The Tunnel Spring Tuff is in the rhyolite compositional range and is similar in composition to other pre-Needles Range silicic volcanic tuffs found in eastern Nevada and southwestern Utah (Cook, 1965; Armstrong, 1970). The Tunnel Spring Tuff fits nicely into the pre-Needles Range silicic volcanic classification of Armstrong (1970) of Tertiary volcanism in the Great Basin.

Type Section.—The name "Tunnel Spring Tuff" is taken from the Tunnel Spring Mountains located in T. 23 S., R 17 W. of the Burbank Hills and Crystal Peak Quadrangles of Utah. Exposures of the Tunnel Spring Tuff occur on both east and west sides of the Tunnel Spring Mountains at localities 2 and 6 of Text-figure 1. The Crystal Peak area is designated as the type section (Text-fig. 5 A and B) and is located in sections 23, 24, 25, and 26 of T. 23 S., R. 16 W. of the Crystal Peak Quadrangle.

Distribution.—The Tunnel Spring Tuff is exposed in the Confusion Range, Wah Wah Mountains, Tunnel Spring Mountains and the Burbank Hills (Text-fig. 1), which are all northerly trending basin-range blocks that consist almost entirely of Paleozoic strata.

All studied exposures of the Tunnel Spring Tuff, except at North Canyon (Text-fig. 1) are located within an area of 29 by 32 kilometers. Three areas of the Tunnel Spring Tuff, at Crystal Peak, Snake Pass, and North Canyon, are found in inverted valleys. The remaining exposures are found on the flanks of basin-range blocks. Relief on the Tunnel Spring Tuff varies from 350 meters at the Crystal Peak area to barely visible exposures in the Desert Range and Snake Pass areas. The amount of relief is controlled by depth of erosion of the many small washes that flow from the ranges.

Contact Relations.—Osmond (1960) has shown that the beginning of Tertiary igneous activity in the Great Basin postdates the close of the Laramide deformation long enough for erosional beveling of Laramide structures. The Tunnel Spring Tuff lies unconformably on Paleozoic sedimentary rocks in several locations (Text-figs. 5A and 11), indicating deposition into eroded lows.

In several areas the Tunnel Spring Tuff underlies the Skull Rock Pass Conglomerate (Text-figs. 6B, 7 and 11), and in others it lies conformably below the Cottonwood Wash Member of the Needles Range Formation (Text-figs. 5, 6, 8, and 9). The apparent variation in the stratigraphic position of the Tunnel Spring Tuff is the result of differing topographic and depositional relations at the time of deposition of the Skull Rock Pass Conglomerate and Cottonwood Wash Tuff Member. In all locations where the Tunnel Spring Tuff is exposed, highly brecciated blocks of Eureka Quartzite too small to be mapped are invariably found lying on the tuff. Apparently the Eureka Quartzite boulders were left as tuff residue when erosion transported the finer material away.

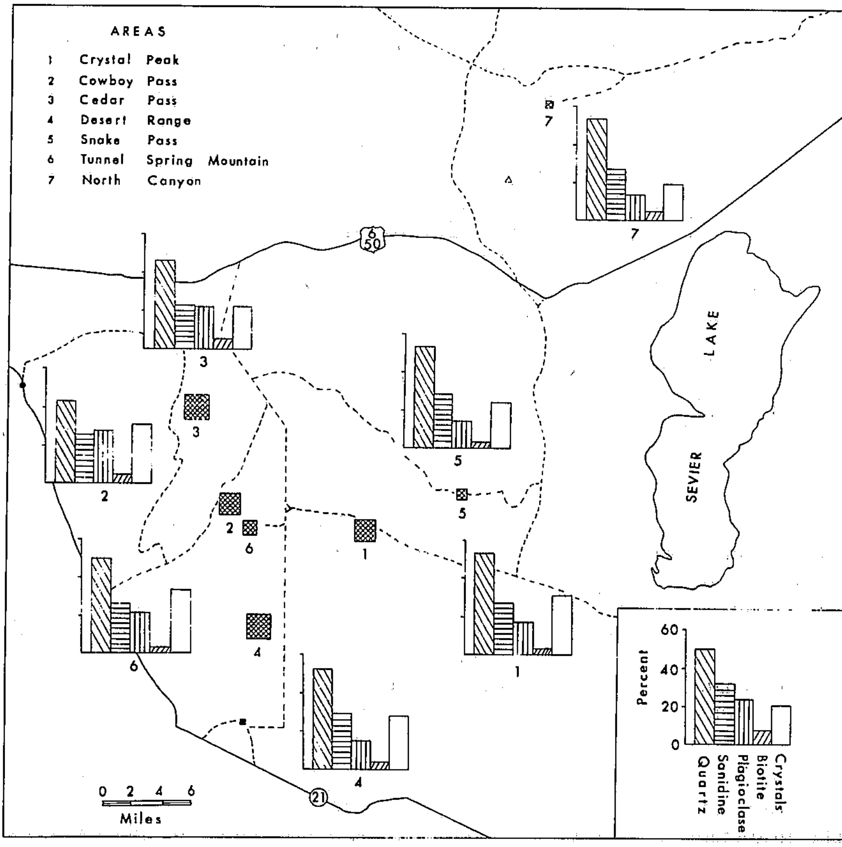
Thickness.—The variation in thickness of the Tunnel Spring Tuff is a product both of the topographic relations at the time of deposition and of the mode of emplacement. The greatest measurable thickness of the Tunnel Spring Tuff is found at Cowboy Pass area (Text-fig. 6A and B), where it is 570 meters thick. The exposed thickness at the Crystal Peak area is 350 meters. In the remaining areas the Tunnel Spring Tuff shows only a few meters of relief.

Overall Appearance.—The Tunnel Spring Tuff is white, unsorted, nonwelded, friable, and massive, except where bedded. Numerous randomly altered carbonate xenoliths are always present along with undeformed and unaltered pumice fragments. All areas of the tuff weather in a characteristic "Swiss-cheese" fashion, and in hand sample the phenocrysts stand in relief from the fine-grained matrix. Abundant, small, doubly terminated, smoky quartz crystals are characteristic of the tuff in all locations, with easily identifiable lesser amounts of sanidine, plagioclase, and biotite. The overall similarity of the tuff in all areas strongly indicates a sure correlation.

Phenocryst Correlation.—The histogram map (Text-fig. 3) compares phenocryst varieties of the Tunnel Spring Tuff from the seven localities studied. The histograms (Text-fig. 3) show that the concentration of phenocrysts of a particular mineral remains relatively constant in all seven areas. The unexplained high percentage of plagioclase in the Cowboy Pass area is the single exception. Total phenocryst percentages of the areas vary from 33 percent at the Tunnel Spring Mountain area to 19 percent at the North Canyon area. The proportion of phenocrystic phases in each area strongly suggests that the tuff described in the seven areas is indeed the same.

Thus phenocryst correlation studies, together with overall petrographic similarity and stratigraphic position of the Tunnel Spring Tuff, leaves little doubt as to the correlation of the seven areas studied.

Radiometric Dating.—Armstrong (personal communication to L. F. Hintze, 1970) dated the Tunnel Spring Tuff at Crystal Peak by the K-Ar method at 33.7 $\pm$ 0.7 million years. McKee (personal communication to L. F. Hintze, 1971) dated the Tunnel Spring Tuff in two different areas by the K-Ar method. At the Crystal Peak area the Tunnel Spring Tuff is dated at 32.7 $\pm$ 1.3 million years, whereas at the North Canyon area a date of 30.9 $\pm$ 1.2 million years was obtained. The Armstrong and McKee dates for the Crystal Peak area compare favorably; however, the date obtained at North Canyon is not within the same range. This discrepancy in the age of the Tunnel Spring Tuff may be because the biotite used in dating the tuff under-



TEXT-FIGURE 3.—Histogram index map, showing phenocryst percentages of the seven areas studied.

went degradation by groundwater during devitrification. It is possible, as suggested by total phenocryst percentages, that the tuff found at North Canyon is an earlier tuff unit very similar in composition and texture.

Any alteration of biotite could result in losses of potassium and/or argon used in dating the tuff. Sampling and different laboratories used in dating the Tunnel Spring Tuff could produce margins of error.

Mode of Emplacement of the Tunnel Spring Tuff.—Recognition of the Tunnel Spring Tuff as a volcaniclastic rock instead of an intrusive rock, as suggested by Dunn (1959), is based on the following field and textural characteristics of the Tunnel Spring Tuff: (1) Volcaniclastic rocks are composed of volcanic ejecta made up of vitric, crystalline, and/or lithic fragments. (2) The vitric nature of the tuff is demonstrated by the wide size range of nearly equidimensional pumice fragments and the glassy shards of the fine-grained matrix. (3) The wide size range of fresh and altered accidental xenoliths indicates an explosive mechanism.

A pyroclastic origin for the Tunnel Spring Tuff is demonstrated by the abundant pumice fragments resting in a matrix of glass shards and crystals of essentially the same composition.

Recognition of the Tunnel Springf Tuff as an ash-flow tuff is based on the following field and microscopic characteristics as described by Ross (1955) and Ross and Smith (1961) for ash-flow deposits: (1) The presence of a wide size range of nearly equidimensional pumice fragments serves as an important clue in interpreting the mode of emplacement. (2) Pumice fragments, nonsorting, and the nonbedded nature of the Tunnel Spring Tuff are characteristic of ash-flow deposits. (3) The wide size range of fresh and altered accidental xenoliths found in the tuff is indicative of a pyroclastic ash-flow origin. (4) The overall uniformity in composition and petrographic characteristics of the Tunnel Spring Tuff over a widespread area demonstrates an ash-flow depositional origin.

Some ash-flows remain entirely unconsolidated and nonwelded, typifying the nature of the Tunnel Spring Tuff. Some type of jointing is usually present in ash-flow deposits, generally a four-sided checker-board pattern, a characteristic displayed by the Tunnel Spring Tuff. The "Swiss-cheese" erosional cavities of the tuff are characteristic of unaltered and nonwelded ash-flow tuffs.

The above textural characteristics provide compelling evidence for accepting an ash-flow deposit as the mode of emplacement for the Tunnel Spring Tuff, and they strongly discount an hypabyssal intrusion as the mode of origin of Crystal Peak, as suggested by Dunn (1959).

An alternate mode of emplacement is possible for the Tunnel Spring Tuff. Bedding dipping under Crystal Peak is suggestive of a volcanic crater into which ash-fall material settled, with later ash-fall eruptions depositing the massive and unsorted tuff.

Paleogeography of Predepositional Topography.—Because of its mode of emplacement, the Tunnel Spring Tuff provides possible information on the paleogeography of southwestern Utah in pre-Oligocene times. Ash-flow deposits normally result in extensive and initially flat sheets that fill topographic lows to a common level. The resulting deposit is thickest in preexisting topographic lows and little if any is deposited on topographic highs. Sheets of essentially uniform thickness are deposited where the preexisting surface has little relief.

The early Tertiary history of southwestern Utah has been discussed by Mackin (1963). East of the Wasatch Line in west-central Utah the volcanic rocks of early Tertiary age rest in most places on Claron sediments, and the Claron rests unconformably on Paleozoic sediments. The Claron Formation is mainly a freshwater sandy limestone varying from white and gray to pink, red, and purple (Leith and Harder, 1908). West of the Wasatch Line the volcanic rocks of early Tertiary age rest on a surface, with about 150 meters of local relief, cut in Paleozoic sedimentary rocks. This relationship indicates that just prior to the beginning of Tertiary eruptive activity material eroded from highlands west of the Wasatch Line was deposited on the fluvial and lacustrine Claron plain to the east.

Where the Needles Range Formation rests on the Claron Formation in the Iron Springs district, approximately 90 kilometers south of my area of study, it is generally less than 30 meters thick. In the Wah Wah Mountains and in the Confusion Range area, the Needles Range Formation is 300 to 350 meters thick and lies on a mature erosional surface. The Claron Formation is absent.

Because Claron sediments were derived from the west, it is believed that the topography in the Wah Wah Mountains and Confusion Range area during Claron time must have stood above the Claron depositional plain. Since in all areas the Needles Range Formation overlies the Tunnel Spring Tuff instead of the Claron Formation, the pre-Tunnel Spring Tuff was probably deposited on an erosional surface cut in a topographic high.

Cotton (1952) has provided some criteria for recognition of inverted valleys of volcanic origin. Inverted valleys are usually bounded by escarpments and stand above the present drainage and topography. Stream valleys are generally found on either side of the inverted valley because the original stream channel is blocked. Gravels are commonly found at the base of inverted valleys. Most of these characteristics of inverted valleys are recognized in three areas where the Tunnel Spring Tuff is exposed: Crystal Peak, Snake Pass, and North Canyon.

The beginning of Tertiary igneous activity in the Great Basin postdates the close of the Laramide deformation long enough for erosional beveling of Laramide structures (Mackin, 1960). Osmond (1960) has shown that north-south trending regional faulting of post-Oligocene age has deformed the pre-Oligocene topography. The illustrations shown in Text-figure 4 indicate both the deposition of the Tunnel Spring Tuff into an eroded low and the manner in which subsequent block faulting and erosion has developed an inverted valley at Crystal Peak. The thickness of the Tunnel Spring Tuff at Crystal Peak indicates original topographic relief of at least 350 meters. An ancient valley, filled with the Needles Range Formation and known as the Red Tops, is located in the House Range east of Snake Pass.

The Tertiary breccia found in several areas where the Tunnel Spring Tuff is exposed suggests possible gravity-slide blocks from topographic highs (Hintze, 1972) implying mountainous or cliffy topography.

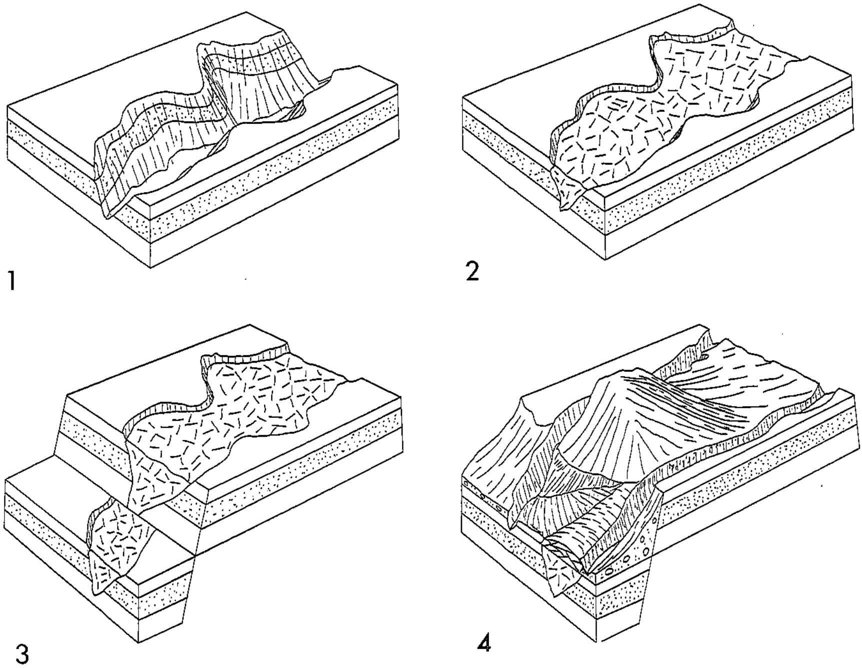
The well-known fact that ash-flow depositional units fill topographic lows suggests that where tuff thickness is large, paleovalleys once existed.

Evidence points to a pre-Tunnel Spring Tuff topography with relief of at least 350 meters and with an environment capable of producing large, conglomeratic fluvial and lacustrine deposits.

Postdepositional Faulting and Erosion.—North-south trending regional normal faulting of post-Oligocene age deformed the pre-Tunnel Spring Tuff surface in southwestern Utah (Osmond, 1960).

The Crystal Peak area has been faulted and uplifted so that the deposit, viewed from the west, indicates an inverted valley (Text-fig. 4). Erosion has since removed large amounts of the soft Tunnel Spring Tuff and accentuated the jointing of the Peak. The Cowboy Pass area shows postdepositional faulting (Text-fig. 6A and B), because the Needles Range Formation is downfaulted on the west into contact with the Tunnel Spring Tuff; northern exposures are much broken with numerous small faults.

Exposures of Tunnel Spring Tuff in other areas also indicate postdepositional faulting because all are found to dip significantly from an original horizontal position characteristic of ash-flow deposits. All areas are found in or near Great Basin "block-fault" ranges that were faulted during development of Basin and Range structure. Drainage from the ranges has cut



TEXT-FIGURE 4.—Sequence of events that formed Crystal Peak: *A*. Stream valley; *B*. Ash-flow tuff fills stream valley; *C*. Block faulting of filled stream valley; *D*. Subsequent erosion and exposures of faulted stream valley.

small valleys in the Tunnel Spring Tuff, and removal by erosion is well advanced.

Tuff of Cedar Pass

Cowboy Pass and Cedar Pass areas (Text-figs. 6B and 7) contain an ash-flow unit 8 meters in thickness between the Cottonwood Wash Tuff and the Tunnel Spring Tuff. Map scale makes it impossible to show and it is mapped as part of the Tunnel Spring Tuff.

The tuff of Cedar Pass is best exposed just north of the Cedar Pass area (Text-fig. 7) below the prominent ridge of the Cottonwood Wash Tuff. In the Cowboy Pass area (Text-fig. 6B) the bottom 2 meters of the unit are bedded indicating a preceding air-fall eruption.

The tuff of Cedar Pass is moderately welded, light pink and essentially intermediate in composition between the overlying Cottonwood Wash Tuff and the underlying Tunnel Spring Tuff. It is distinguished from the Tunnel Spring Tuff by its welding and higher amount of biotite.

Conglomerate of Skull Rock Pass

The conglomerate of Skull Rock Pass, ranging in thickness from 0 to 90 meters, consists of boulders and cobbles of Eureka Quartzite, Sevy Dolomite, and other Ordovician to Devonian dolomites and limestones. The matrix is seldom seen, but when visible it is tuffaceous. Weathered sections of the

Skull Rock Pass conglomerate consist of residual boulders and cobbles that armor the exposed areas of the conglomerate.

The diameters of clastic debris of the Skull Rock Pass conglomerate vary from blocks of 7-8 meters at the North Canyon area (Text-fig. 11) to smaller rounded boulders and cobbles in the Cowboy Pass area (Text-fig. 6A and B). Bedding of the Skull Rock Pass conglomerate is rarely exposed.

Tertiary Breccia

The Tertiary breccia (Text-figs. 5A and B, 8, and 10) is characterized by highly brecciated, nearly coherent blocks of mainly Eureka Quartzite, Fish Haven Dolomite, and Sevy Dolomite. The breccia is found as isolated blocks that rest on the Tunnel Spring Tuff and alluvium.

Dunn (1959) considered the breccia to be the result of the explosive activity that deposited the Tunnel Spring Tuff. He believed the overlying Paleozoic sediments were brecciated as the tuff was erupted at Crystal Peak. This idea would require that the large brecciated blocks be found throughout the Tunnel Spring Tuff instead of resting on top of the tuff as shown in Text-figures 5A and B and 8. Hintze (1972) has suggested that the brecciated Paleozoic masses are landslide deposits triggered by explosive events accompanying final deposition of the Tunnel Spring Tuff.

It appears from map relations that the Tertiary breccia is younger than the Tunnel Spring Tuff and that downward settling as erosion removed material has left the breccia resting on the tuff. Different landslide events are suggested because a breccia appears to rest on the Needles Range Formation in the Cedar Pass area, as shown on Text-figure 8.

Needles Range Formation

Cottonwood Wash Member.—The Needles Range Formation is one of the most extensive Tertiary ash-flow deposits found in the Great Basin. The Cottonwood Wash Tuff Member (Best, personal communication, 1973), the lowest member of the Needles Range Formation, ranges in thickness from 0 to 55 meters, and conformably overlies the Tunnel Spring Tuff in several locations (Text-figs. 5A, 6B, 8, and 9). The Cottonwood Wash Tuff Member is a grayish red welded crystal-vitric tuff that contains 40 percent phenocrysts by volume of plagioclase and biotite and is often identified in the field by the presence of large books of biotite, commonly 6 mm across. Crystals of quartz and amphibole are commonly found in hand sample or thin section.

Flattened pumice and xenolith fragments are found in a lower basal gray vitrophyre. Most of the tuff is moderately welded and compacted; however, the top, where exposed, is white, soft, and porous.

Confusion may occur in distinguishing the top of the Cottonwood Wash Tuff Member from the Tunnel Spring Tuff. The top of the Cottonwood Wash Tuff Member, where exposed, weathers in a "Swiss-cheese" fashion and is commonly bedded, soft, and finely sorted. The Cottonwood Wash Tuff Member can be distinguished from the Tunnel Spring Tuff by the high percentage of biotite and plagioclase, welding, and very low percentage of quartz. The Tunnel Spring Tuff is identified in the field by its lack of welding, abundance of doubly terminated quartz crystals, and low biotite content.

Wah Wah Springs Member.—The Wah Wah Springs Tuff Member, conformably overlies the Cottonwood Wash Tuff Member in several locations (Text-figs. 6B, 8 and 9) and varies in thickness from 0 to 95 meters. The base of the Wah Wah Springs Tuff Member is an intensely welded black vitrophyre. Size of the biotite books is smaller than those in the Cottonwood Wash Tuff Member; and the presence of amphibole, conspicuous in hand sample, serves as a major means of identification.

Pumice fragments are more abundant and crystal size is smaller in the Cottonwood Wash Tuff. Crystals of biotite and hornblende make up 40 percent of the reddish brown to purple, welded crystal-vitric tuff.

Post-Needles Range Conglomerate

A post-Needles Range conglomerate, ranging in thickness from 0 to 180 meters, is found in the Tunnel Spring Mountain, Cowboy Pass, Cedar Pass, and Snake Pass areas and consists of predominantly subrounded cobbles and boulders derived from Sevy, Simonson, and Laketown dolomite. Boulders of the Eureka Quartzite are also present. The matrix is usually weathered away; but where found, it is a limy, tuffaceous matrix. The constituents of the post-Needles Range conglomerate are smaller than those of the Skull Rock Pass Conglomerate. Clasts of the Needles Range Formation in the post-Needles Range conglomerate distinguish the Skull Rock Pass Conglomerate from the post-Needles Range conglomerate. The post-Needles Range conglomerate overlies or surrounds the Needles Range Formation in the areas listed above (shown on Text-figs. 6B, 7, 9 and 10).

QUATERNARY SYSTEM

Surfical Deposits

The surfical deposits of the study area consist of alluvium, dune sand, tuffaceous sand, and poorly sorted silt, sand, and conglomeratic deposits of local origin. Dune sand, derived from the numerous Tertiary tuffaceous volcanic rocks found in the area, has accummulated at the base of bedrock hills. The tuffaceous sand is poorly consolidated and consists mostly of quartz crystals but includes some biotite, feldspar, glass, and pumice fragments.

REGIONAL GREAT BASIN VOLCANIC SEQUENCES

Cenozoic volcanism of the Great Basin described in recent years by Armstrong, 1970; McKee, 1970, 1971; Lipman et al., 1972; Lipman, 1970; Gilluly, 1965; and Christiansen and Lipman, 1972, can be summarized as follows:

A major pulse of volcanism began in the Eocene and early Oligocene and was concentrated in the northern part of the Great Basin. Rocks erupted during the Eocene and early Oligocene were mainly andesite and latite but with some basaltic andesite and low-silica quartz latite.

In the middle Oligocene and early Miocene the nature of volcanic activity changed dramatically as widespread rhyolitic and quartz latitic ash-flow tuffs succeeded the earlier andesite, latite lava, and related plutonic rocks. Mafic and intermediate rocks are uncommon.

A period of relative quiescence in volcanic activity occurred during the middle Miocene, although locally erupted volcanic rocks are found in the southern Great Basin.

In the late Miocene and Pliocene times, silicic volcanism ceased, and basaltic volcanism began and shifted to the margins of the Great Basin.

The history of Cenozoic volcanism is essentially a two-stage activity involving a regime of calc-alkaline volcanism that lasted until middle Cenozoic time (Lipman, 1970; Lipman, Steven, and Mehnert, 1970) and was followed by fundamentally basaltic volcanism that has lasted until the present time (Christiansen and Lipman, 1972).

Pre-Needles Range volcanic tuffs are found in several places in eastern Nevada. Cook (1965) has correlated many of the tuffs in eastern Nevada with those in southwestern Utah on the basis of phenocryst percentages. In the Grant and Egan Ranges in eastern Nevada, the Stone Cabin and Windous Butte volcanic tuffs underlie the Needles Range Formation. The oldest is the Stone Cabin Formation, approximately 33-34 million years in age, consisting of rhyolitic crystal-vitric tuffs (Cook, 1965). The Windous Butte Formation, approximately 30 million years in age, is a rhyodacite, highly to moderately welded, crystal-vitric tuff. The dacitic Needles Range Formation overlies the Windous Butte Formation in this area.

In the Fortification Range in eastern Nevada, a series of dacitic crystal-vitric, vitric-lithic, and crystal-lithic tuffs (Cook, 1965) underlie the Needles Range Formtaion.

In the Wah Wah Mountains and Needle Range of southwestern Utah, the pre-Needles Range volcanics are mostly vitric-crystal tuffs that are rhyolitic and latitic in composition (Mackin, 1963). The Windous Butte and Stone Cabin formations are similar in composition and may be the same age as the pre-Needles Range units in Utah (Mackin, 1963).

The Tunnel Spring Tuff which underlies the Needles Range Formation in the Wah Wah Mountains area is within the rhyolite compositional range.

Armstrong (1970) has classified volcanism in the Great Basin into three regions as follows: (1) Pre-Needles Range silicic volcanic rocks in east-central Nevada and in the Wasatch region of Utah, (2) Needles Range and younger tuffs in an arc around the east-central Nevada core-zone extending from southwestern Utah across Lincoln and northern Nye County in Nevada, and (3) volcanic rocks 6-17 million years in age in a zone surrounding and locally overlapping the older volcanic rocks across northern Nevada and northwestern Utah and, sporadically, in southwestern Utah and southern Nevada.

The Tunnel Spring Tuff fits nicely into the classification of Armstrong (1970) as a pre-Needles Range silicic ash-flow tuff and is similar in composition and age to other pre-Needles Range volcanic tuffs found in eastern Nevada and southwestern Utah.

DESCRIPTION OF LOCALITIES

Seven occurrences of the Tunnel Spring Tuff (Text-fig. 1) will be described, in order of apparent significance, as follows: (1) Crystal Peak, (2) Cowboy Pass, (3) Cedar Pass, (4) Desert Range, (5) Snake Pass, (6) Tunnel Spring Mountain, and (7) North Canyon.

CRYSTAL PEAK AREA

Field Relations

The Crystal Peak area is easily reached on the Garrison-Black Rock Road (Text-fig. 5A and B). The exposed thickness of the massive part of the tuff at Crystal Peak is 350 meters. Bedding near the base of the tuff is rarely exposed; but where seen, it consistently dips under Crystal Peak.

The topographic relief and exposures in the Crystal Peak area are superior to those of any other locality. Small patches of the Tunnel Spring Tuff protrude through the alluvium west of Crystal Peak and to the east the tuff underlies the relatively flat valley floor.

The base of the Tunnel Spring Tuff is exposed and lies unconformably on the sides of the paleovalley that was filled by the tuff, but in most places it is concealed by talus and surfical deposits. The bottom of the inverted valley is not exposed; thus, a total thickness of the tuff cannot be determined. The conglomerate of Skull Rock Pass, Tertiary breccia, and alluvium all unconformably overlie the tuff. On the western flank of Crystal Peak the Cottonwood Wash Tuff Member is possibly in fault contact with the Tunnel Spring Tuff and Tertiary breccia.

Petrography

The Tunnel Spring Tuff in Crystal Peak is unsorted, nonwelded, and friable and contains numerous xenoliths.

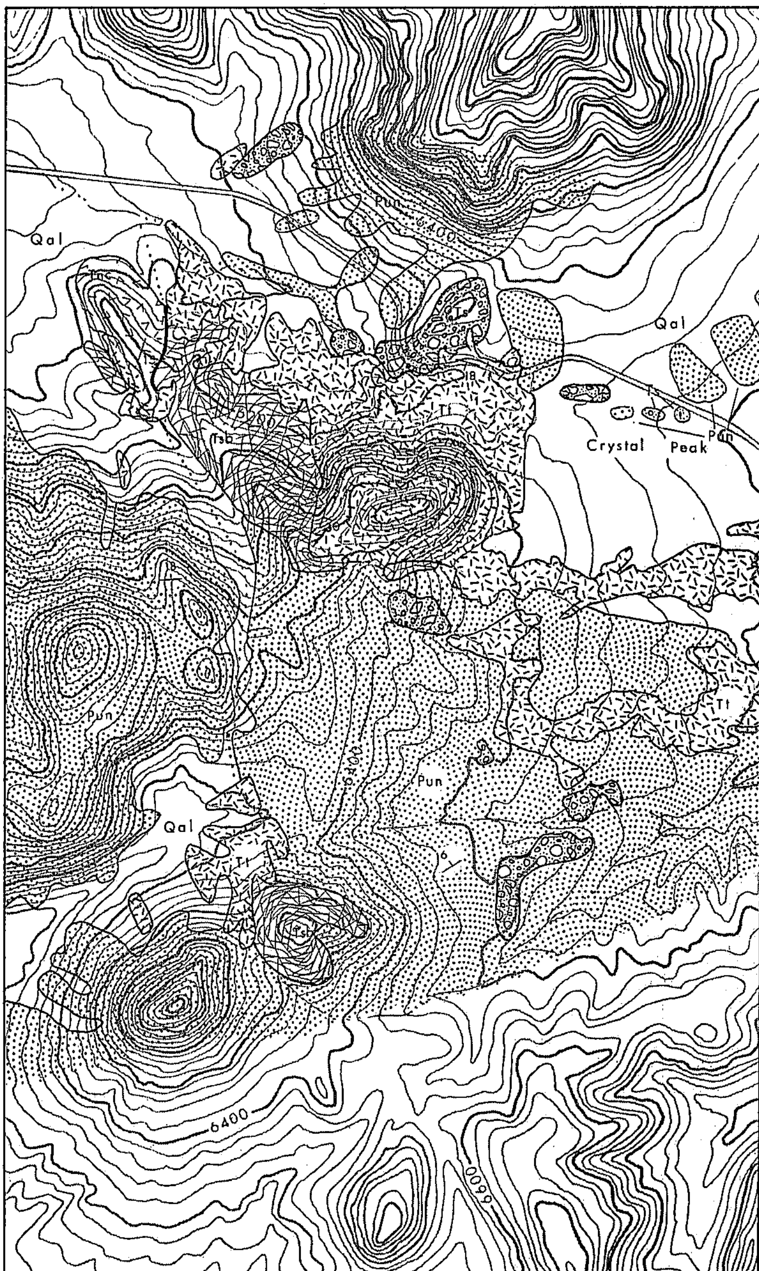
Numerous subhorizontal cavities in the Peak cause a resemblance to Swiss cheese. This "Swiss-cheese" appearance may begin to form because of inequalities in the Tunnel Spring Tuff, especially where pumice fragments occur. Wind and rain, acting on the porous, nonwelded, and unaltered tuff, remove the less resistant areas selectively, producing the cavities. Case hardening along joint fractures may likewise leave the interjoint areas comparatively less resistant.

Abundant, small, doubly terminated smoky quartz crystals averaging 3 mm are easily identified and occur together with lesser amounts of clear sanidine. Plagioclase is not as readily observed, but under the hand lens it appears as small, milky white, subhedral laths that are slightly fractured. Small black flakes of biotite are conspicuous. On weathered surfaces these phenocrysts stand out in relief from the fine-grained matrix.

Numerous randomly distributed angular xenoliths, mostly Ordovician carbonates (although fragments of Eureka Quartzite are common), are characteristic of the Tunnel Spring Tuff in the Crystal Peak area. The xenoliths range in size from 0.2 cm to 2 meters in diameter. Some of the carbonate xenoliths are bleached white; others appear unaltered; and still others contain coarse green calc-silicate minerals. Most of the large xenoliths, particularly those of Eureka Quartzite, are located within the top 60 meters of the Peak.

Alteration of the xenoliths appears to be as random as their distribution. Some show signs of thermal metamorphism with rims of garnet and diopside (Dunn, 1959); others appear unaltered. The larger the xenolith, the less likely is alteration to occur; but locally, large carbonate xenoliths weathered from the tuff leave behind thin, white, altered carbonate shells. As expected, the carbonate xenoliths are most easily altered, whereas the xenoliths of Eureka Quartzite show virtually no alteration.

Phenocryst percentages were determined by a modification of the stained-slab method developed by Williams (1960). A flat slab 2 cm thick was cut from a hand specimen and then impregnated with epoxy under vacuum to prevent plucking of the phenocrysts during subsequent polishing on a 15 micron diamond lap. After being thoroughly dried, the slab was immersed for 10 seconds


Qal
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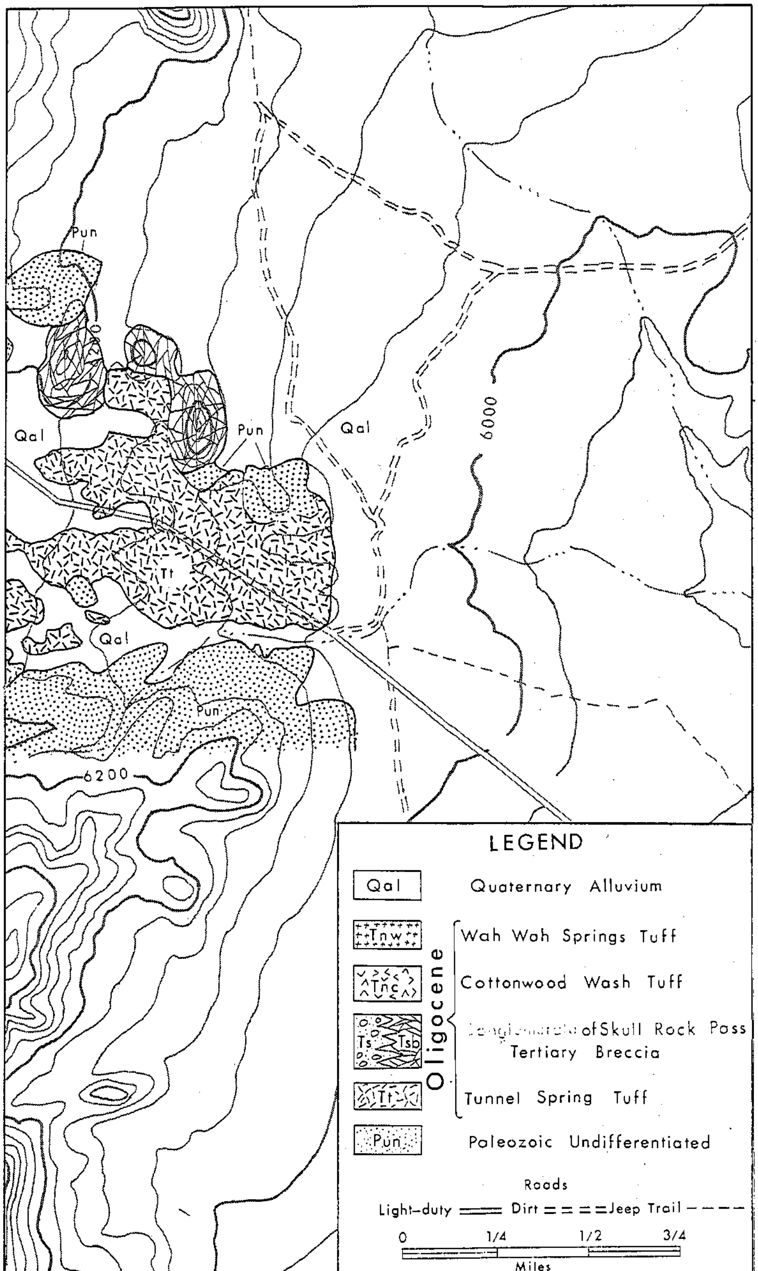


TEXT-FIGURE 5.—Geologic map of Crystal Peak area, Millard County, Utah. *A.* West half (Geology from Hintze, 1973a: modified by A. V. Bushman, 1973).
B. East half (Geology from Hintze, 1973a; modified by A. V. Bushman, 1973).

in 48 percent hydrofluoric acid, rinsed, blotted immediately on absorbent paper, and allowed to dry. Next the slab was immersed in a sodium cobaltinitrate solution for one and one-half minutes. It was then washed immediately in cold water (to remove excess solution) and allowed to dry face up.

Quartz phenocryst appears as glassy, unstained, and virtually unetched, smoky gray crystals. In hydrofluoric acid, plagioclase phenocrysts etch and develop a white coating but do not stain. The potassium in the biotite phenocrysts causes a yellowish green stain. Sanidine phenocrysts stain yellow.

Percentages of each type of phenocryst were visually estimated utilizing a grid containing 100 squares placed directly over the stained slab. The percentages listed for the Crystal Peak area are the average of 12 specimens (Text-fig. 3). In 8 of the 12 specimens were found small traces of hematite, generally less than 0.01 percent of the total phenocrysts.

Many quartz crystals display embayments filled with the glassy matrix. Sanidine commonly shows inclusions of plagioclase, some of which are quite large. Pumice fragments are nearly equidimensional spherical bodies that have sharp, clear boundaries and display no devitrification or deformation. The matrix of the Tunnel Spring Tuff is composed of fine shards of glass the boundaries of which have been obscured by minor devitrification (Pl. 1, fig. 1).

Depositional and Structural Features

Bedding within the Tunnel Spring Tuff is found in three locations in the Crystal Peak area and is shown by strike and dip symbols in Text-figure 5A. Bedding in a wash on the steep west side of the peak is typical of all bedded exposures. The first layer below the massive tuff is 0.3 meters thick and is composed of fine shards of angular glass and biotite flakes. The bedded layer is light gray in color and well sorted. A sharp contact separates the light gray layer from an underlying bedded tan layer. The base of the tan layer is not exposed. The second bedded layer is composed mostly of fine angular shards of glass but also has minor amounts of slightly larger quartz and biotite crystals. The sorting is not as well developed as in the first layer. The second layer is characterized by white pumice fragments 1-2 mm in size that are easily identified in the light tan bedded layer. All bedded layers in the Crystal Peak area dip beneath Crystal Peak (Text-fig. 5A).

Crystal Peak displays some apparently large-scale bedding. These "beds" are caused by a variation in color not obvious upon closer examination (Pl. 1, fig. 2).

Within the Peak itself, four prominent sets of joints are recognized. Several large gullies as much as 15 meters deep are largely controlled by jointing and serve as erosional avenues. In tuff exposures in areas other than the Peak, jointing is identifiable in all four sets.

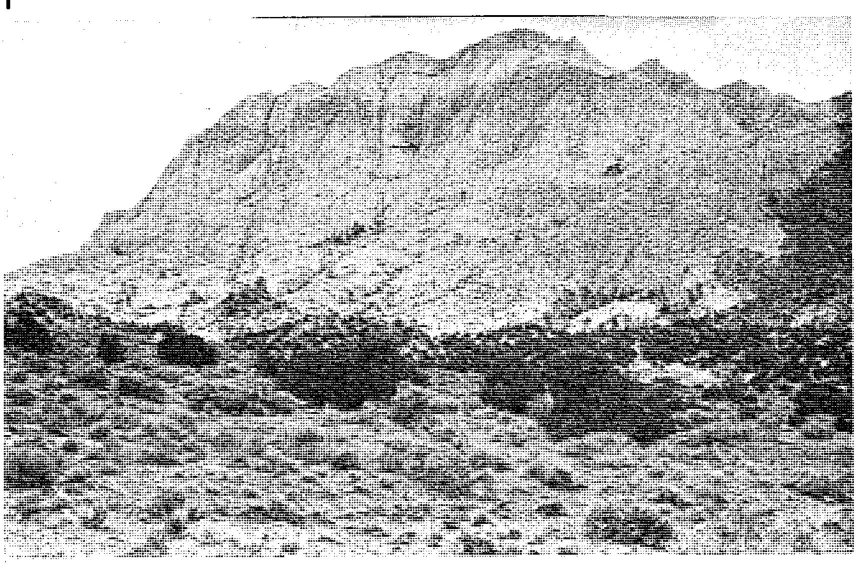
Several large exposures of Paleozoic rocks around Crystal Peak appear to be in place, but upon closer examination they are found to be highly brecciated and resting on the Tunnel Spring Tuff.

COWBOY PASS AREA

Field Relations

The Cowboy Pass area is located just west of the Tunnel Spring Mountains (Text-fig. 6A and B). Stratigraphic relations are the same as in the Crystal

1

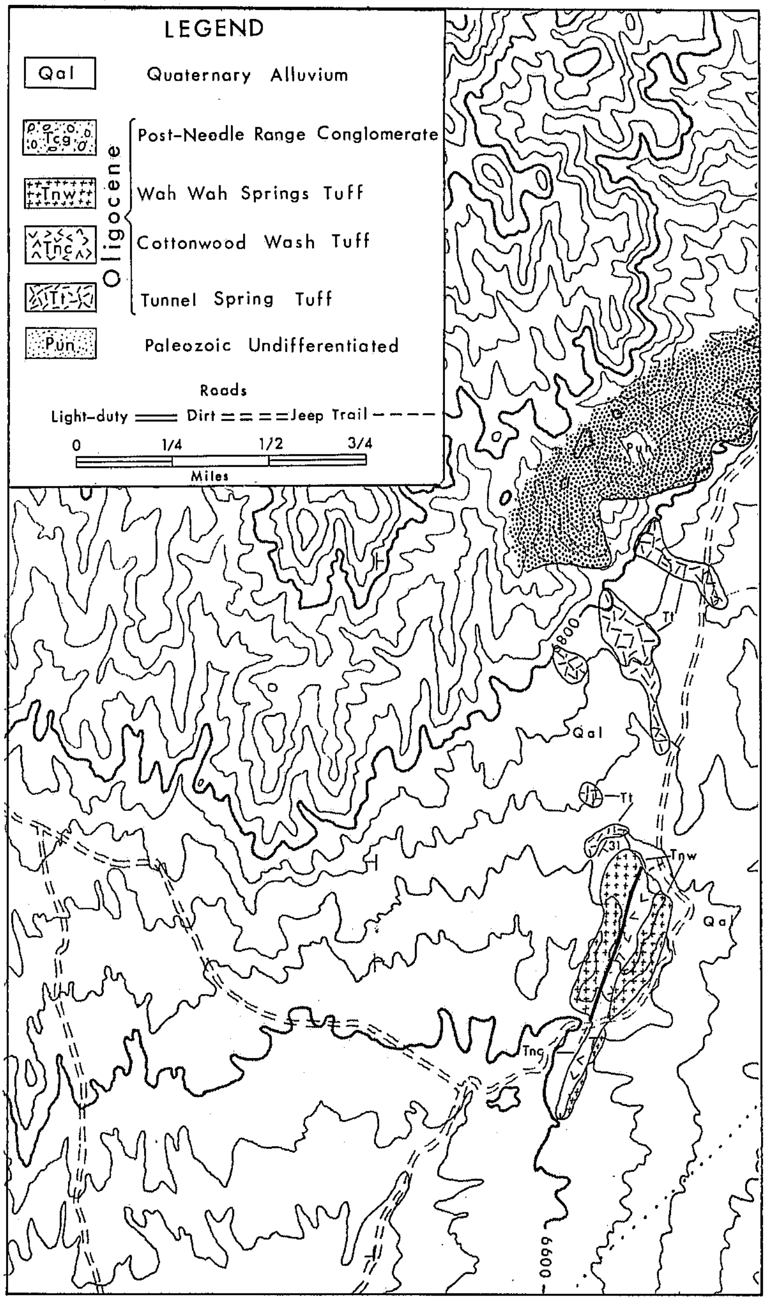


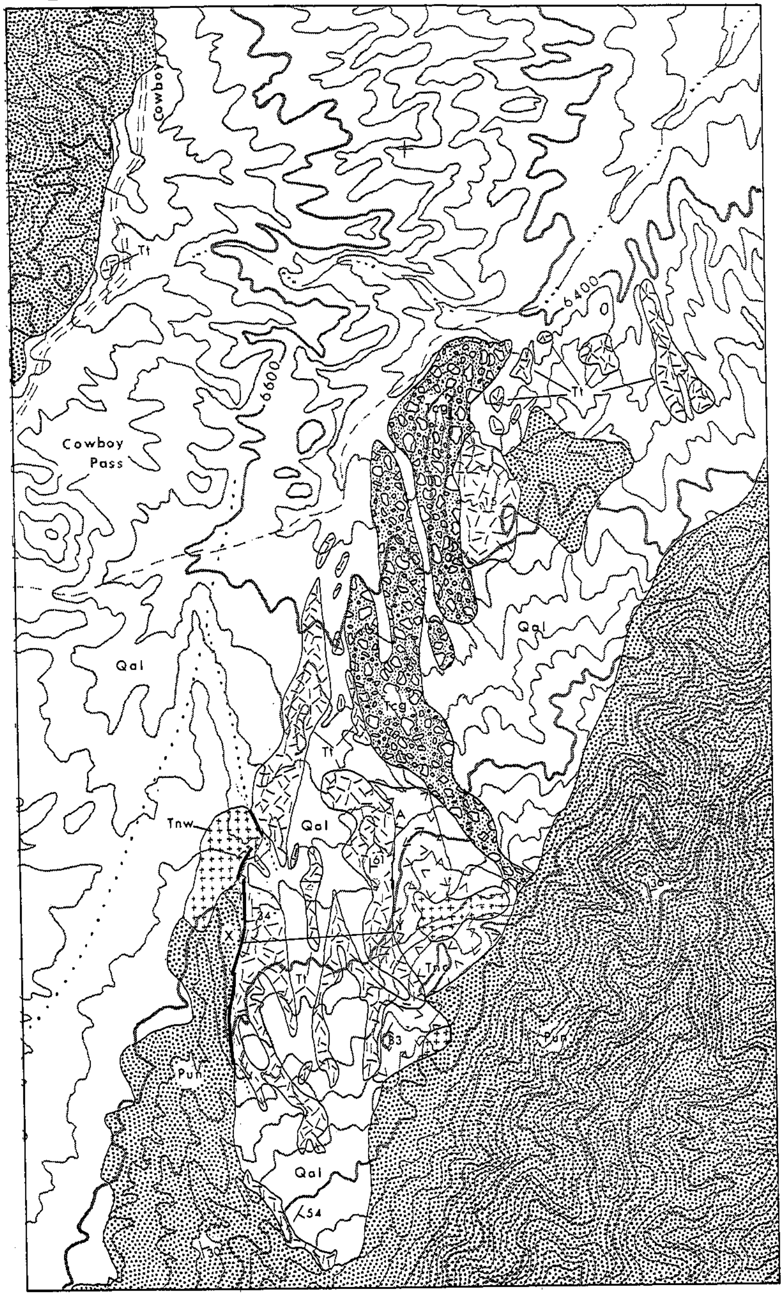
2

EXPLANATION OF PLATE 1

SHARD DEVITRIFICATION AND APPARENT BEDDING

FIG. 1.—Photomicrograph of Tunnel Spring Tuff, showing shard devitrification.
FIG. 2.—View of Crystal Peak, showing apparent bedding.


LEGEND
Qal Quaternary Alluvium
Tcg Post-Needle Range Conglomerate
Tnw Wah Wah Springs Tuff
Tnc Cottonwood Wash Tuff
Tt Tunnel Spring Tuff
Oligocene
Pun Paleozoic Undifferentiated
Roads
Light-duty Dirt Jeep Trail
0 1/4 1/2 3/4
Miles
Pun
Tt
6800
Qal
Tt
31
Tnw
Qal
Tnc
6600



TEXT-FIGURE 6.—Geologic map of Cowboy Pass area, Millard County, Utah.
A. West half (Geology from Hintze, 1973b; modified by A. V. Bushman, 1973).
B. East half (Geology from Hintze, 1973b; modified by A. V. Bushman, 1973).

Peak area, except where the Tunnel Spring Tuff is locally faulted against the Wah Wah Spring Member of the Needles Range Formation.

The maximum thickness of this section of Tunnel Spring Tuff is 570 meters, which is easily measured because the tilted and bedded tuff is exposed in a small valley. Exposures in the area seldom exceed 6 to 9 meters in relief. At the eastern contact of the Cottonwood Wash Tuff and the Tunnel Spring Tuff, at point A (Text-fig. 6B), a series of interbedded conglomerates and sandy tuffaceous units too small to be mapped separate the two units.

Petrography

The Tunnel Spring Tuff displays "Swiss-cheese" erosional cavities and alternates from white to reddish pink several times through the section. The color change is not related to the bedding. Except for a few minor differences, the tuff in this locality is the same as at Crystal Peak. Xenoliths average 1 to 2.5 cm, and few exceed 5 cm. The listed percentages for the Cowboy Pass area phenocrysts are the average of 12 specimens (Text-fig. 3). A major change from the percentages obtained at Crystal Peak is immediately observed, the plagioclase percentage being higher than that of the sanidine. Traces of hematite were found in 9 of the 12 samples. Pumice fragments are less numerous and smaller than at Crystal Peak, and devitrification of the shards is slightly more advanced.

Depositional and Structural Features

The most complete section of the Tunnel Spring Tuff is found in the Cowboy Pass area. Line XY of Text-figure 6B indicates a measured section 570 meters in thickness. Surfical deposits cover some areas of the section with a thin layer of tuffaceous sand from the weathered tuff. Bedding is present in at least three different locations along the measured section, varying in thickness from 1 to 2 meters and identified by biotite-rich zones with the flakes parallel to the bedding. Faulting at the western contact of the Tunnel Spring Tuff (Text-fig. 6B) may have altered the true thickness of the tuff along the measured section, but the alluvial cover makes exact relations uncertain.

No large blocks of Tertiary breccia are found in the Cowboy Pass area, but boulders of Eureka Quartzite 0.1 to 0.3 meters in size are present. The tuff exposed in small patches in the northern part of the map is highly faulted, the faults being too small to map.

CEDAR PASS AREA

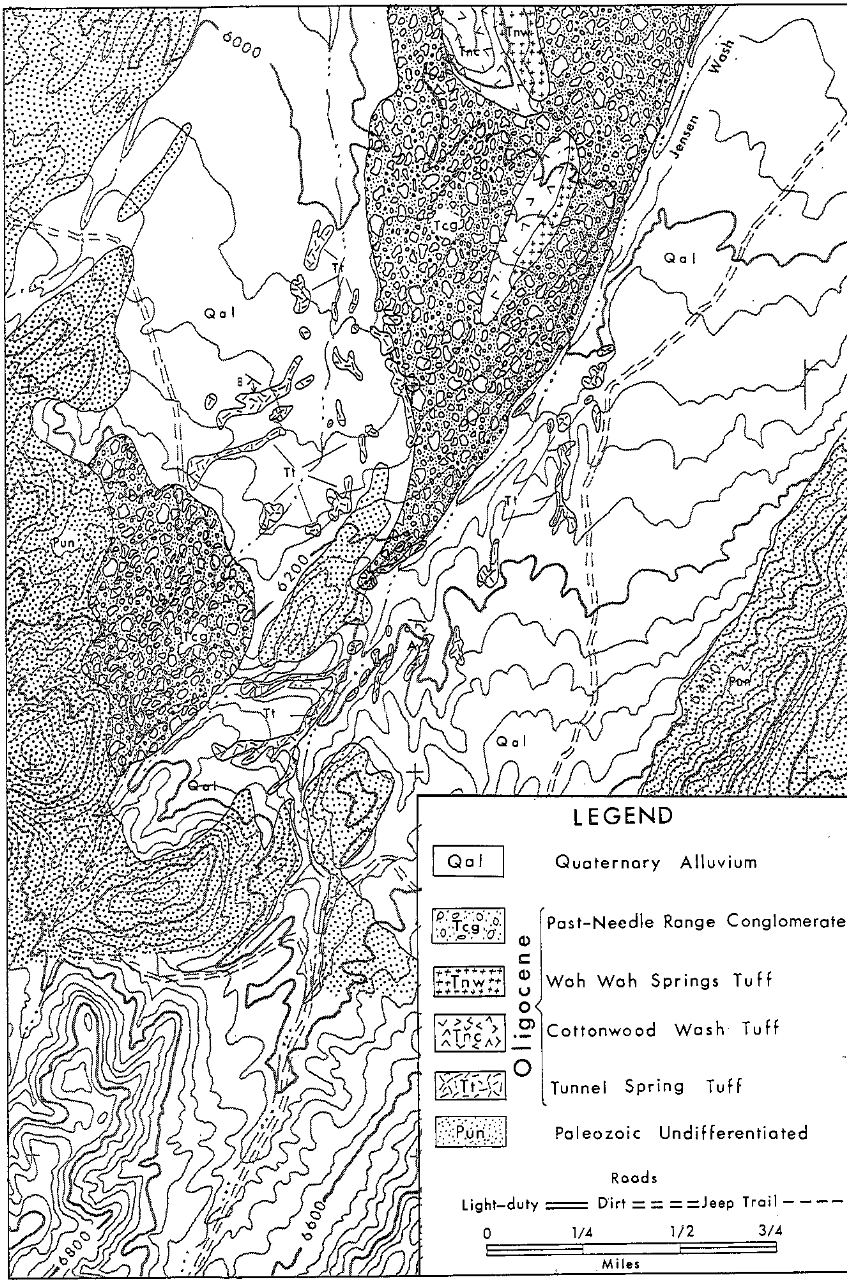
Field Relations

Cedar Pass is six kilometers south of U. S. Highway 50-6 in Millard County (Text-fig. 7). In this area, exposures of the Tunnel Spring Tuff protrude through the post-Needles Range conglomerate and the more recent alluvium in small washes. Relief of the tuff is restricted to the depth of erosion, generally 1 to 2 meters, except in Jensen Wash (Text-fig. 7), where relief may reach 15 meters.

Large blocks of the Tunnel Spring Tuff in Jensen Wash have eroded loose and have slumped into the wash. Since the base of the tuff is not exposed, a thickness could not be determined.

Petrography

The Tunnel Spring Tuff displays a color change from grayish pink at the top to white at the bottom in Jensen Wash. "Swiss-cheese" cavities are present



TEXT-FIGURE 7.—Geologic map of Cedar Pass area, Millard County, Utah. (Geology from Hintze, 1973b; modified by A. V. Bushman, 1973.)

in both units but are better developed in the grayish pink unit. Pumice fragments are quite large and do not appear deformed in hand sample. Carbonate xenoliths exhibit slight thermal metamorphism, and most are unaltered. The average size of the xenoliths is 1 to 2.5 cm, with larger ones locally present. The fabric of the tuff is essentially the same as that of the Crystal Peak area. Large round concretions, some as much as 0.3 meters in diameter (composed of tuff material crystallized around carbonate xenoliths) and a great deal of yellow staining characterize the Tunnel Spring Tuff in this area.

The yellow staining is the result of the weathering of what appear to be tree branches trapped in the tuff. The listed phenocryst percentages for the Cedar Pass area are shown in Text-figure 3.

Depositional and Structural Features

Bedding is exposed in several different locations in Jensen Wash, with only one other area of bedding found in the area. At point A (Text-fig. 7) a bedded sequence 13.1 meters thick and dipping below the massive Tunnel Spring Tuff is exposed. The bedded unit is composed of fine well-sorted glassy material.

Jointing is present in all exposed areas of the Tunnel Spring Tuff. Eureka Quartzite boulders lie on the tuff throughout the area. Faulting of the nearly horizontal Tunnel Spring Tuff is restricted to slump blocks in Jensen Wash caused by stream erosion undercutting the tuff.

DESERT RANGE AREA

Field Relations

The Desert Range area is 10.3 kilometers directly north of the headquarters of the Desert Range Experimental Station (Text-fig. 8). The stratigraphy in this area is the same as at Crystal Peak, with both the Cottonwood Wash and Wah Wah Spring Members of the Needles Range Formation overlying the Tunnel Spring Tuff.

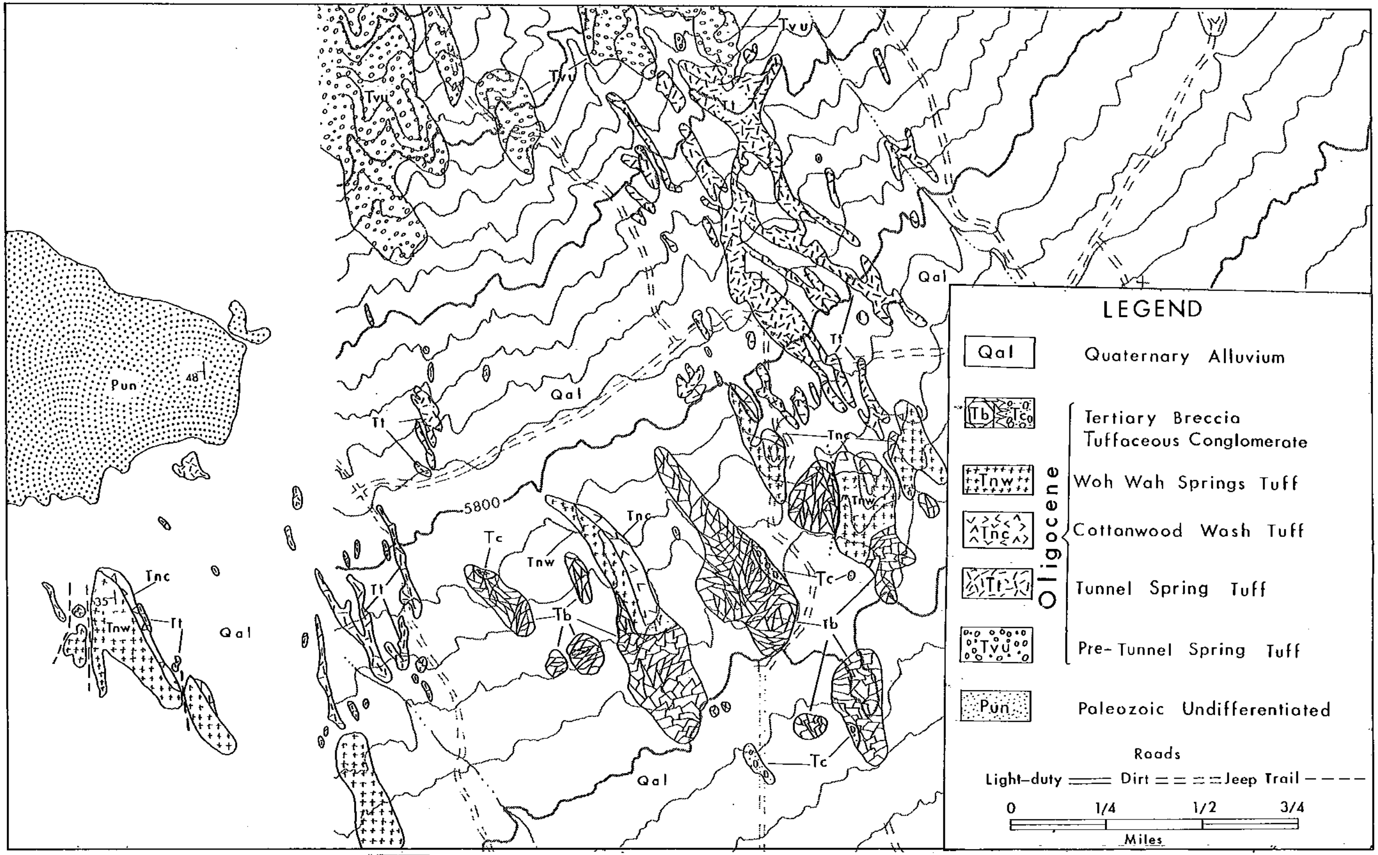
Exposures in this area are found in numerous small gullies on the southern slopes of the Tunnel Spring Mountains. The most relief is 3 meters, with most exposures barely visible in the gullies.

The Tunnel Spring Tuff is in contact only with the Cottonwood Wash Tuff Member and recent alluvium in this area. Landslide masses of Tertiary breccia, which overlie the Cottonwood Wash and Wah Wah Springs Members of the Needles Range Formation in this area, appear to be the result of the younger landslide breccia's settling downward as erosion removed material.

Northwest of the Tunnel Spring Tuff shown in Text-figure 8 a series of volcanic rocks underlie the Tunnel Spring Tuff. Composition of these pre-Tunnel Spring Tuff volcanic rocks often changes every 30 to 50 meters, and exposures form large, rounded, resistant mounds. The pre-Tunnel Spring Tuff volcanic rocks appear to be the result of a very viscous magma which formed small domes as it was extruded.

Petrography

The Tunnel Spring Tuff is white, and where relief exceeds a few meters it has weathered in the characteristic "Swiss-cheese" fashion. The petrographic description of the Crystal Peak area serves equally well in describing the tuff here. One major difference is the size of the xenoliths, here never exceeding 5 cm in size.



TEXT-FIGURE 8.—Geologic map of Desert Range area, Millard County, Utah. (Geology from Hintze, 1973a; modified by A. V. Bushman, 1973).

A histogram showing the percentage of phenocrysts for the Desert Range area is found in Text-figure 3. No trace of hematite was found in the 12 samples used. Phenocrysts are smaller and highly fractured. Devitrification has only slightly affected the shards, leaving the pumice fragments unaltered.

Depositional and Structural Features

Bedding in the Tunnel Spring Tuff is virtually nonexistent in this area. The most significant structural feature of the area is the large blocks of Fish Haven Dolomite and Eureka Quartzite that are highly brecciated. These blocks compare in size to those found in the Crystal Peak area. Evidence of faulting of the tuff is not directly observed, but faulting of adjacent younger units indicates postemplacement faulting.

SNAKE PASS AREA

Field Relations

Snake Pass is located at the southern end of the Confusion Range (Text-fig. 9). Stratigraphic relations are the same as in the Crystal Peak area. Total relief reaches only 0.3 to 0.6 meter in small gullies.

The Tunnel Spring Tuff is exposed on the eastern side of a small cuesta capped by both members of the Needles Range Formation, which strike N 30 W and dip 20 degrees to the southwest. A small layer of sandstone 10 cm thick, composed of quartz grains and rounded glass fragments, and cemented with calcium carbonate separates the Cottonwood Wash Tuff Member and the Tunnel Spring Tuff.

Petrography

The petrographic description of the Tunnel Spring Tuff in the Crystal Peak area serves equally well in this area, with some minor exceptions. Average size of the xenoliths is between 6 and 12 mm, larger ones being rarely found. Size of the phenocrysts is definitely smaller than at Crystal Peak because fracturing has decreased their size.

In weathered exposures the tuff has a very pronounced sugary texture not observed in other areas. The sugary texture is the result of the fine-grained matrix weathering quickly and leaving the phenocrysts in relief. The phenocryst correlation (Text-fig. 3) of 12 specimens conforms well with the Crystal Peak area, except that hematite traces are not found.

Pumice fragments are smaller and more numerous than at Crystal Peak. The matrix is composed of shards of glass that tightly outline the unaltered pumice fragments and phenocrysts.

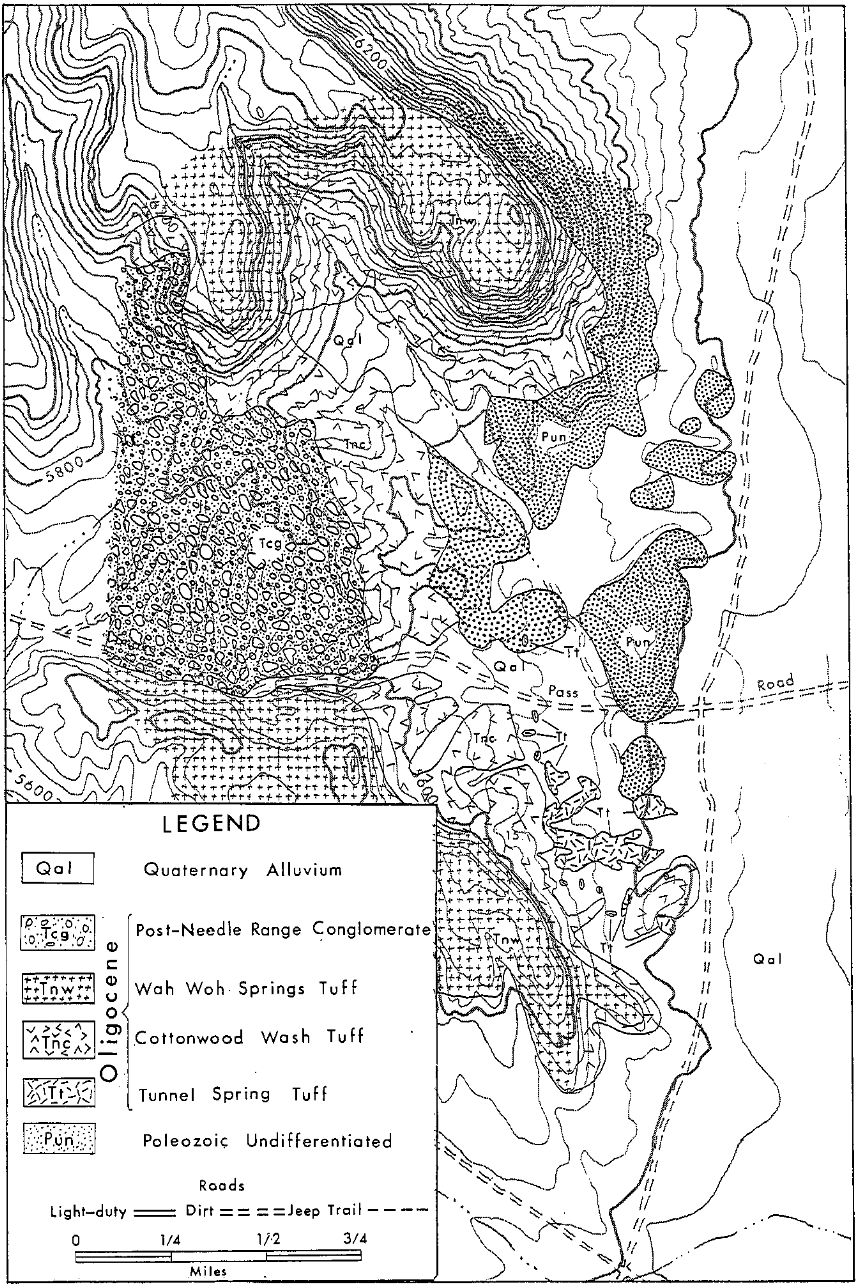
Depositional and Structural Features

The Tunnel Spring Tuff is massive, unsorted, and unbedded in this area. Boulders of Eureka Quartzite litter the area of tuff exposures. Evidence of major faulting is not observed, but some small patches of the tuff are faulted.

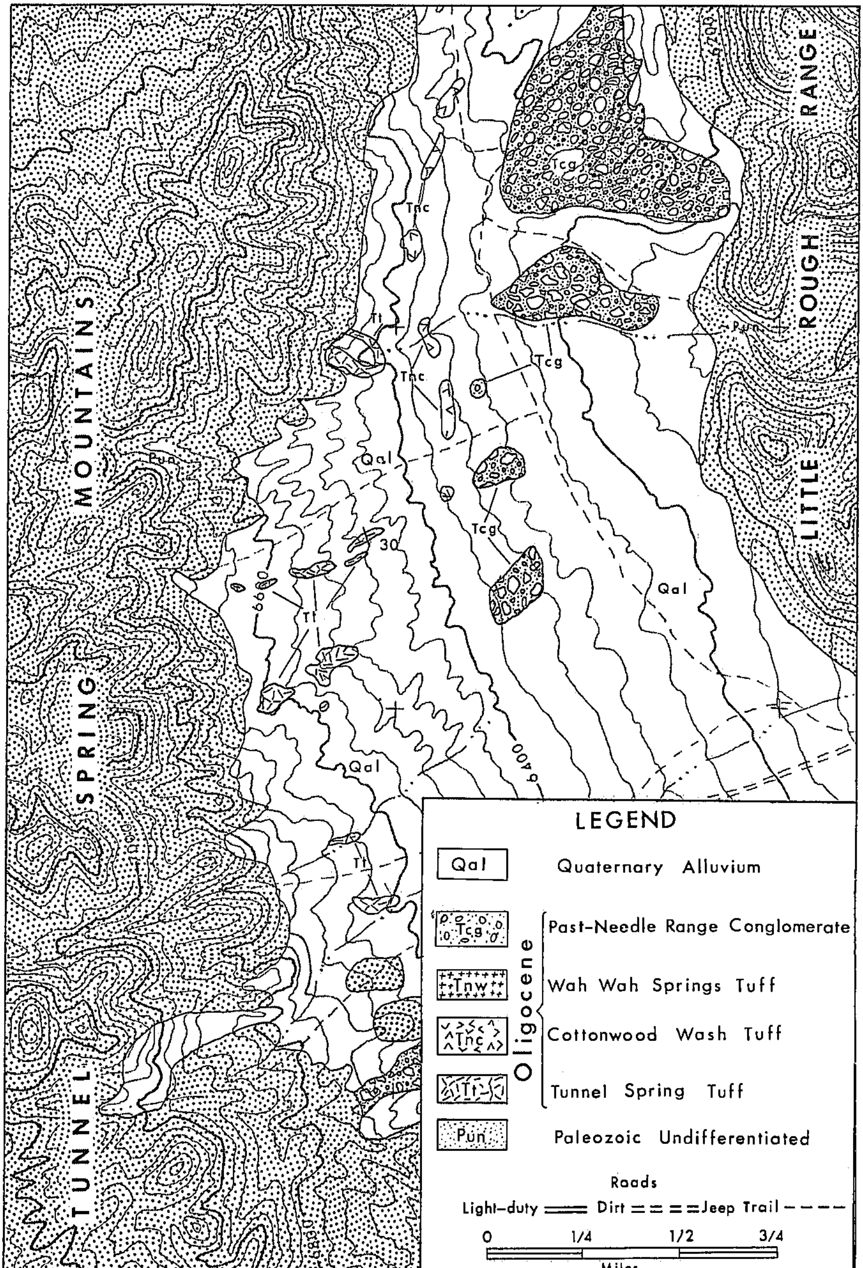
TUNNEL SPRING MOUNTAIN AREA

Field Relations

The Tunnel Spring Mountain area is located on the eastern slopes of the Tunnel Spring Mountains (Text-fig. 10). Stratigraphic relations apparently



TEXT-FIGURE 9.—Geologic map of Snake Pass area, Millard County, Utah. (Geology from Hintze, 1973c; modified by A. V. Bushman, 1973.)



TEXT-FIGURE 10.—Geologic map of Tunnel Spring Mountain area, Millard County, Utah. Geology from Hintze, 1973a; modified by A. V. Bushman, 1973.)

are the same as in the Crystal Peak area, but alluvial cover obscures most contact relations.

The Tunnel Spring Tuff is exposed in small washes that cut the alluvium on the eastern slopes of the range. Relief in the tuff is limited to the depth of the gullies and seldom exceeds 7 meters. The base of the tuff is not exposed.

Petrography

The color of the Tunnel Spring Tuff varies from white to a reddish pink, with "Swiss-cheese" erosional cavities present. Except for the 8 to 10 mm xenoliths and the numerous pumice fragments, the petrography of this area is characteristic of the Crystal Peak area. The percentage of phenocrysts for this area is the highest of all areas, but the proportions of phenocryst varieties compare well with those of the Crystal Peak area (Text-fig. 3). Traces of hematite were found in 2 of the 12 samples.

Depositional and Structural Features

Bedding shown by a strike-and-dip symbol is found in one of the larger exposures of the Tunnel Spring Tuff (Text-fig. 10). Three bedded layers are separated by massive unbedded tuff. Total thickness of the sequence is 4.5 meters. Bedding is due mainly to sorting of the phenocrysts and is highlighted by a slight reddish pink color change. The only evidence of postemplacement faulting in this area, is tilting of the tuff.

NORTH CANYON AREA

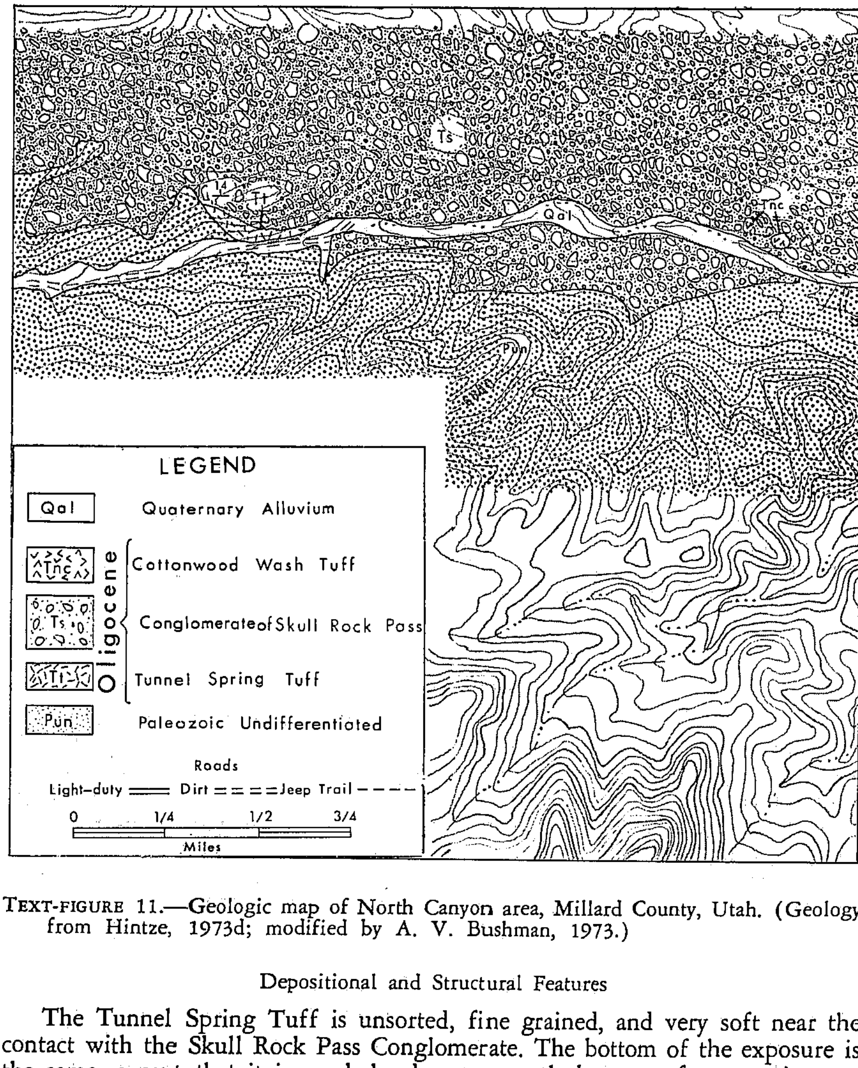
Field Relations

A very small exposure of the Tunnel Spring Tuff is found 10 kilometers northeast of Notch Peak on the north side of North Canyon (Text-fig. 11). It is overlain by the Skull Rock Pass conglomerate. The western edge of the tuff is in contact with Paleozoic shale, and the eastern edge dips under the Skull Rock Pass conglomerate. Most of the exposure is covered with talus from the overlying conglomerate.

McKee dated the Tunnel Spring Tuff at North Canyon at 30.9 ± 1.2 million years (personal communication to L. F. Hintze, 1971). This age is not within the range of dates obtained by Armstrong, 33.7 ± 0.7 million years, (personal communication to L. F. Hintze, 1970) and McKee, 32.7 ± 1.3 million years (personal communication to L. F. Hintze, 1971) at Crystal Peak for the Tunnel Spring Tuff. Degradation of the biotite by devitrification used in dating the tuff could cause discrepancy in ages. The exposure at North Canyon designated as Tunnel Spring Tuff may be, as suggested by total phenocryst percentage, an earlier ash-flow tuff similar in composition to the Tunnel Spring Tuff.

Petrography

The Tunnel Spring Tuff is white and very fine grained. Where the tuff is weathered it is a fine white ash that feels very smooth between the fingers. Eighty to eighty-five percent of the tuff is composed of slightly devitrified shard fragments. The total phenocryst percentage is low as compared with other areas, but relative percentages of each mineral variety is similiar (Text-fig. 3). Traces of hematite were found in two of the samples. The size of phenocrysts and pumice is smaller than at Crystal Peak, and the phenocrysts are highly fractured.



TEXT-FIGURE 11.—Geologic map of North Canyon area, Millard County, Utah. (Geology from Hintze, 1973d; modified by A. V. Bushman, 1973.)

Depositional and Structural Features

The Tunnel Spring Tuff is unsorted, fine grained, and very soft near the contact with the Skull Rock Pass Conglomerate. The bottom of the exposure is the same, except that it is much harder, apparently because of compaction.

No jointing or brecciation is found associated with this exposure of the Tunnel Spring Tuff. Postemplacement faulting has displaced the tuff from its original position. A barely exposed tuffaceous conglomerate layer is found just below the Cottonwood Wash Tuff Member.

CONCLUSIONS

1. The rhyolitic Tunnel Spring Tuff has been dated at 33.7 ± 0.7, 32.7 ± 1.3, and 30.9 ± 1.2 million years by the K-Ar method. The discrepancy in age of the Tunnel Spring Tuff may be the result of degradation by ground water (during devitrification) of the biotite used in dating. The phenocryst percent-

age at North Canyon is much lower than at the remaining areas, and the date of 30.9 ± 1.2 million years obtained may indicate an earlier tuff unit very similar in composition and age. Any type of alteration of the biotite could cause discrepancy in dating the Tunnel Spring Tuff.

2. The stratigraphic position of the Tunnel Spring Tuff is well defined. It rests unconformably on eroded surfaces of Paleozoic sedimentary rocks and lies below the Needles Range Formation and the Skull Rock Pass conglomerate.

3. Depositional and structural features of the Tunnel Spring Tuff indicate a massive unsorted and nonwelded tuff that filled topographic lows.

4. The mode of emplacement of the Tunnel Spring Tuff as defined by its field, depositional, and microscopic characteristics is an ash-flow tuff.

5. Pre-Tunnel Spring Tuff paleogeography consisted of a landscape with at least 350 meters of relief. Western Utah was a probable source for Claron fluvial and lacustrine sediments. The paleoenvironment was capable of producing large scale conglomeratic, fluvial, and lacustrine deposits.

6. Faults within the Tunnel Spring Tuff confirm north-south trending regional normal faulting characteristic of the Basin and Range Structure.

7. The Tunnel Spring Tuff is similar in composition and age to other pre-Needles Range volcanic units in eastern Nevada and southwestern Utah.

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