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SUBSURFACE GEOLOGY OF THE SILENT CANYON CALDERA
NEVADA TEST SITE, NEVADA

by

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3. Timber Mountain Tuff, southern Nevada, and its relation to cauldron subsidence, by F. M. Byers, Jr., Paul P. Orkild, W. J. Carr, and W. D. Quinlivan. 23 p., 11 figs.

4. Silent Canyon volcanic center, Nye County, Nevada, by Donald C. Noble, K. A. Sargent, H. H. Mehnert, E. B. Ekren, and F. M. Byers, Jr. 20 p., 4 figs., 2 tables.

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Abstract

Deep drilling in the vicinity of Silent Canyon on eastern Pahute Mesa, Nevada, has revealed a Tertiary volcanic section locally thicker than 14,000 feet. The area drilled covers most of the Silent Canyon caldera and some of the surrounding area. The caldera is rudely elliptical in plan and measures 10 by 14 miles.

Except on its east edge, the caldera is completely obscured by younger volcanic rocks, including ash-flow sheets from several other centers. The structure, originally inferred from surface mapping and a 20-mgal gravity low, has been confirmed by drilling at 21 sites.

Petrographic, chemical, and magnetic studies of more than 4,000 feet of drill core have revealed a complex sequence of volcanic rocks. Pre-caldera rocks include thick calc-alkalic lavas and tuffs. Peralkaline lavas and tuffs of the Silent Canyon center include the Belted Range Tuff (13-14 m.y.), eruption of which resulted in caldera collapse. The Belted Range Tuff has been downdropped 5,000-7,000 feet in the caldera. Subsequently, the depression was partially filled in the eastern part by genetically related peralkaline lavas and tuffs and in the western part by later calc-alkaline lavas and tuffs apparently genetically unrelated to the peralkaline rocks of the Silent Canyon center. Renewed subsidence probably occurred during their eruption.

Isopach maps of younger tuffs show that the caldera was topographically low during deposition of later (12.5-7 m.y.) ash-flow sheets from other volcanic centers.

Introduction

The Silent Canyon caldera of late Tertiary age is a major geologic feature in southern Nye County, Nev. (fig. 1). The caldera is about 25 miles northeast of Beatty, lying within the Nevada Test Site.

The geology of the caldera has been mapped as part of a program of geologic studies conducted by the U.S. Geological Survey on behalf of the Atomic Energy Commission. The program began in the fall of 1962 when the U.S. Geological Survey was asked to select an area suitable for deep underground nuclear testing within the conterminous United States. The Pahute Mesa area, which includes about 200 square miles, subsequently was selected because of favorable geology and topography, and a large gravity low centered in the area. Surface geology indicated that Pahute Mesa was underlain by relatively undeformed and probably also by relatively impermeable volcanic rocks with faults widely enough spaced that safety and construction problems were not serious. The topography is characterized by a series of flat-topped hills and mesas locally separated by deep canyons and commonly bounded by fault scarps. The magnitude and configuration of the gravity low indicated that Pahute Mesa was underlain by a 5,000- to >10,000-foot thickness of volcanic rocks that probably consisted of large amounts of low-density rocks, such as zeolitized tuff, suitable for nuclear tests. Three years of subsurface exploration has provided the information necessary for the evaluation and development of Pahute Mesa as a nuclear testing area.

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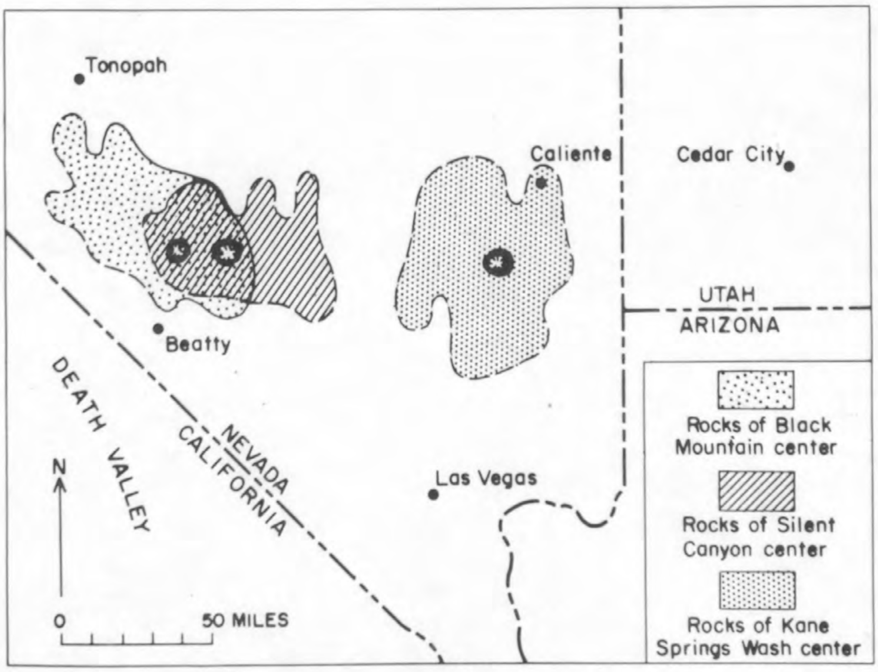

Figure 1.--Sketch map showing source areas, represented by the main collapse calderas, and approximate original distribution of rocks of the Black Mountain, Silent Canyon, and Kane Springs Wash volcanic centers.

A closely coordinated team of more than 30 geologists, geophysicists, and hydrologists has integrated data from exploratory drilling, gravity and aeromagnetic studies, and surface mapping.

A 7,500-foot exploratory hole (X on figs. 2, 3, and 6) in center of the gravity low was completed in volcanic rocks in May 1963. Since then, 20 other exploratory holes (fig. 6), totaling more than 128,000 feet, have been drilled. One hole in the vicinity of Silent Canyon on eastern Pahute Mesa (Y on figs. 2, 3, and 6) has revealed a Tertiary volcanic section locally more than 14,000 feet thick. The area drilled covers most of the Silent Canyon caldera and some of the surrounding area.

Rock units

The distribution of the major geologic units related to the Silent Canyon center and of the pre- and post-Silent Canyon rocks is shown in figure 2. The pre-Silent Canyon rocks, referred to as basement rocks on the map, include not only pre-Tertiary rocks, but older calc-alkalic tuffs and lavas that underlie the earlier lavas and tuffs of the Silent Canyon center. Paleozoic sedimentary rocks crop out about 10 miles north of the Silent Canyon caldera (section A-A', fig. 3) and 8 miles east-southeast of the caldera. A small stock of Mesozoic plutonic rock is exposed 5 miles east of the caldera, but no pre-Tertiary rocks were penetrated in any of the drill holes within or just outside the caldera (fig. 3).

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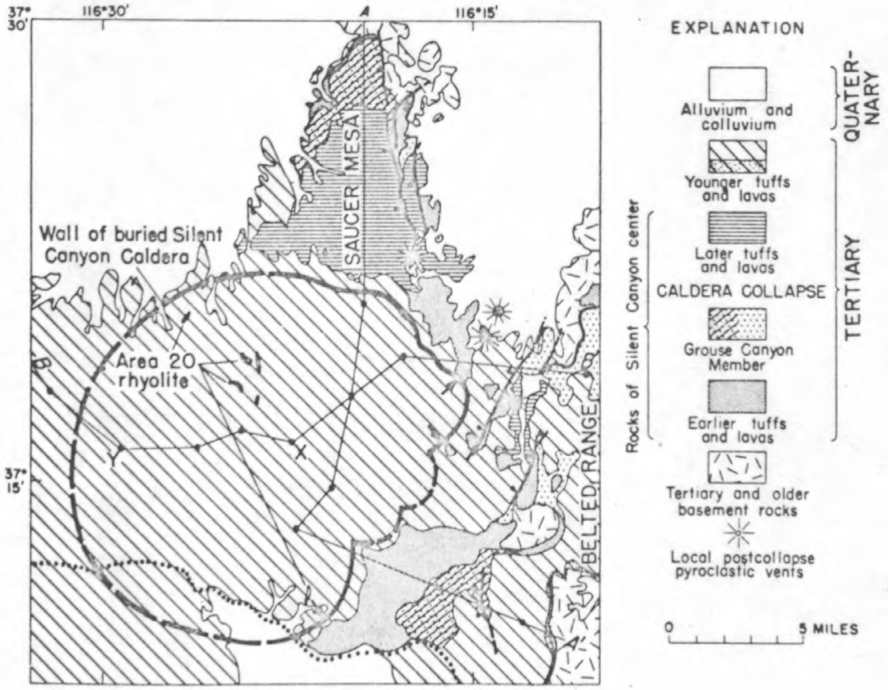

Figure 2.--Generalized geologic map of the caldera area of the Silent Canyon volcanic center. Arrows show localities where wall of Silent Canyon is exposed. Ash-fall tuff underlying Grouse Canyon Member of Belted Range Tuff is mapped with the Grouse Canyon Member. Dotted line is northeastern limit of Timber Mountain caldera. Lines A-A' and B-B' are cross sections shown in figure 3.

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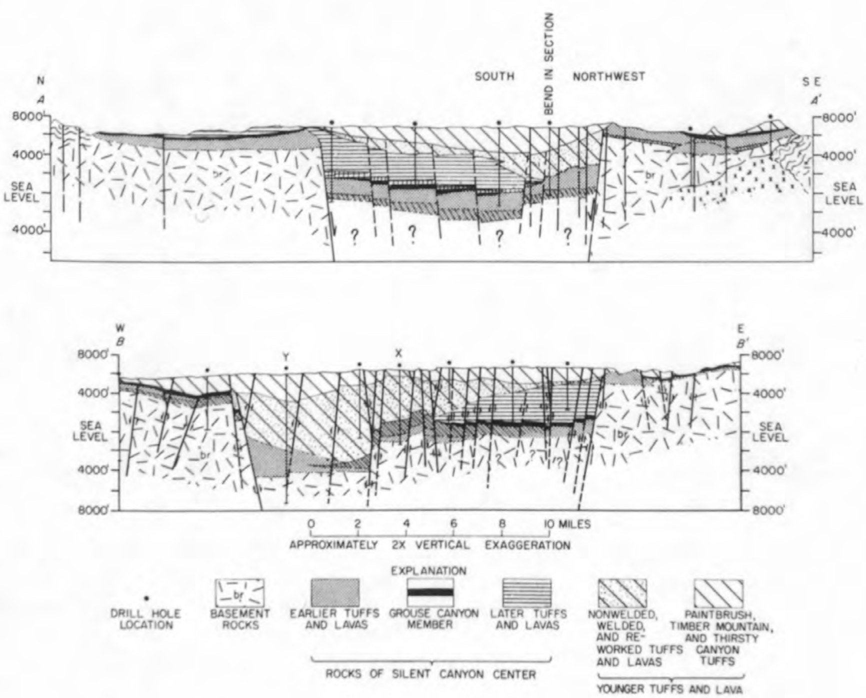

Figure 3.--Generalized north-south (A-A') and east-west (B-B') cross sections of Pahute Mesa showing Silent Canyon caldera and major rock types. Wavy line pattern shows basement rocks consisting of Paleozoic sedimentary rocks; X's indicate Mesozoic plutonic rocks; cross-hatch shows Tub Spring Member of Belted Range Tuff. Vertical exaggeration approximately 2X. Lines of sections shown on figure 2.

Pre-Silent Canyon Tertiary rocks of the basement are mainly calc-alkalic lavas and tuffs; the contact between the earlier tuffs and lavas of the Silent Canyon center and the basement rocks has arbitrarily been placed in the cross sections (fig. 3) at the top of thick, extensive calc-alkalic units, including a regional welded tuff unit. In the deepest drill hole (13,686 feet), however, two altered (pyritized, partially silicified) peralkaline lava flows were penetrated below 12,150 feet and underlie calc-alkalic tuffs whose upper contact is 10,860 feet (fig. 3). These altered peralkaline flows are probably among the earliest extrusions of the Silent Canyon center and possibly may be approximately contemporaneous with the earliest peralkaline lavas in the Belted Range, dated at 14.8 m.y. (Noble and others, 1968).

The Tub Spring and Grouse Canyon Members of the Belted Range Tuff are described by Noble and others (1968). In the present paper, the earlier tuffs and lavas of the Silent Canyon center (figs. 2 and 3) include the Tub Spring Member, peralkaline quartz-rich lava and bedded tuff similar to and underlying the Tub Spring, peralkaline and minor calc-alkalic tuffs and lavas between the Tub Spring Member and the overlying Grouse Canyon Member. It should be emphasized here that around and within the Silent Canyon caldera these two members are locally separated by as much as 2,000 feet of peralkaline lavas and tuffs, locally including calc-alkalic lavas and tuffs, whereas at greater distances from the center the two members are separated by less than 300 feet of bedded tuff. In a few drill holes the Grouse Canyon is missing and the stratigraphic interval at which the Grouse

Canyon would occur is occupied by thick peralkaline rhyolite above the Tub Spring Member. Other holes that penetrated the Grouse Canyon Member were bottomed short of the Tub Spring. In the deepest drill hole, 13,686 feet (fig. 3), neither member was found--mostly peralkaline rhyolite in the interval 8,250-10,860 feet. Finally, in each of two drill holes within the caldera the Tub Spring (fig. 3) and Grouse Canyon Members attain thicknesses of 1,400 and 1,700 feet, respectively, which are several times greater than the greatest thicknesses measured outside the caldera.

The later peralkaline lavas and tuffs of the Silent Canyon center (figs. 2 and 3) postdate the principal caldera collapse, accompanying the eruption of the Grouse Canyon Member. The lavas and tuffs occur mainly in the eastern part of the Silent Canyon center.

The younger tuffs and lavas are all calc-alkalic and later than the peralkaline effusions of the Silent Canyon center. They are subdivided on sections A-A' and B-B' (figs. 2, 3, and 6).

The older subunit (stippled pattern, figs. 2, 3, and 6) of the younger tuffs and lavas consists of zeolitized ash-fall and nonwelded ash-flow tuffs, minor reworked tuffs, and rhyolite flows. These rocks accumulated to as much as 6,000 feet in the deepest part of the caldera (fig. 3) and are confined within it. They form narrow outcrops in only two places: inside the southeast exposure of the caldera wall and in the bottom of a deep canyon that cuts just north of the line of section B-B' (figs. 2, 3, and 6).

The younger subunit of the younger tuffs and lavas includes the Paintbrush, Timber Mountain, and Thirsty Canyon Tuffs (Orkild, 1965; Byers and others, 1968; Noble and others, 1964). These tuffs were erupted from centers south, southwest, and west of the Silent Canyon caldera and, except for the Thirsty Canyon, generally are thicker within the Silent Canyon caldera (figs. 4 and 5) than around its margins.

Structure

The main structural features (fig. 3) of the eastern Pahute Mesa area are the Silent Canyon caldera, the basin-range faults, and the horst-like buried structural high within the caldera. The wall of the Silent Canyon caldera is exposed at three places (shown by arrows on fig. 2), but elsewhere the caldera wall is approximately located by a steepening of gravity contours into a 20-milligal residual gravity low (fig. 6) and by initial dips in overlying tuffs. The indicated location of the west boundary of the caldera collapse zone is based entirely on gravity and subsurface data. The steepest gradients on the gravity map (fig. 6) outline the outermost ring faults of the caldera and coincide approximately on the east side with scallops discussed by Noble and others (1968). Within the caldera, drilling and gravity data indicate two basins: a shallow broad basin in the eastern part and a deep basin elongated along a N. 20° E. trend in the western part. These two basins are separated along the west edge of a central gravity high by a major north-south fault, which increases

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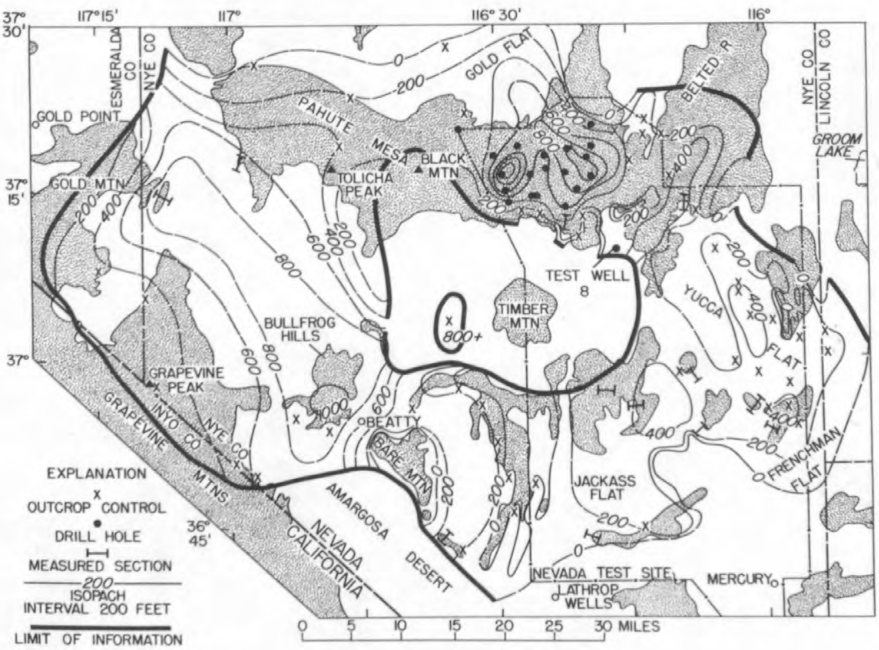

Figure 4.--Isopach map of Rainier Mesa Member of Timber Mountain Tuff. Contours are dashed where thicknesses are inferred.

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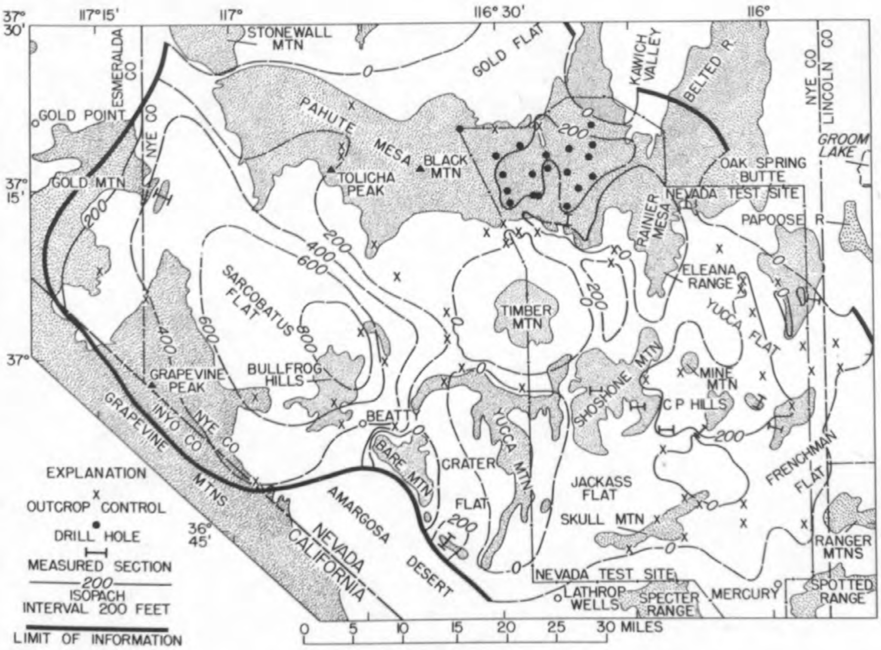

Figure 5.--Isopach map of Ammonia Tanks Member of Timber Mountain Tuff. Contours are dashed where thicknesses are inferred.

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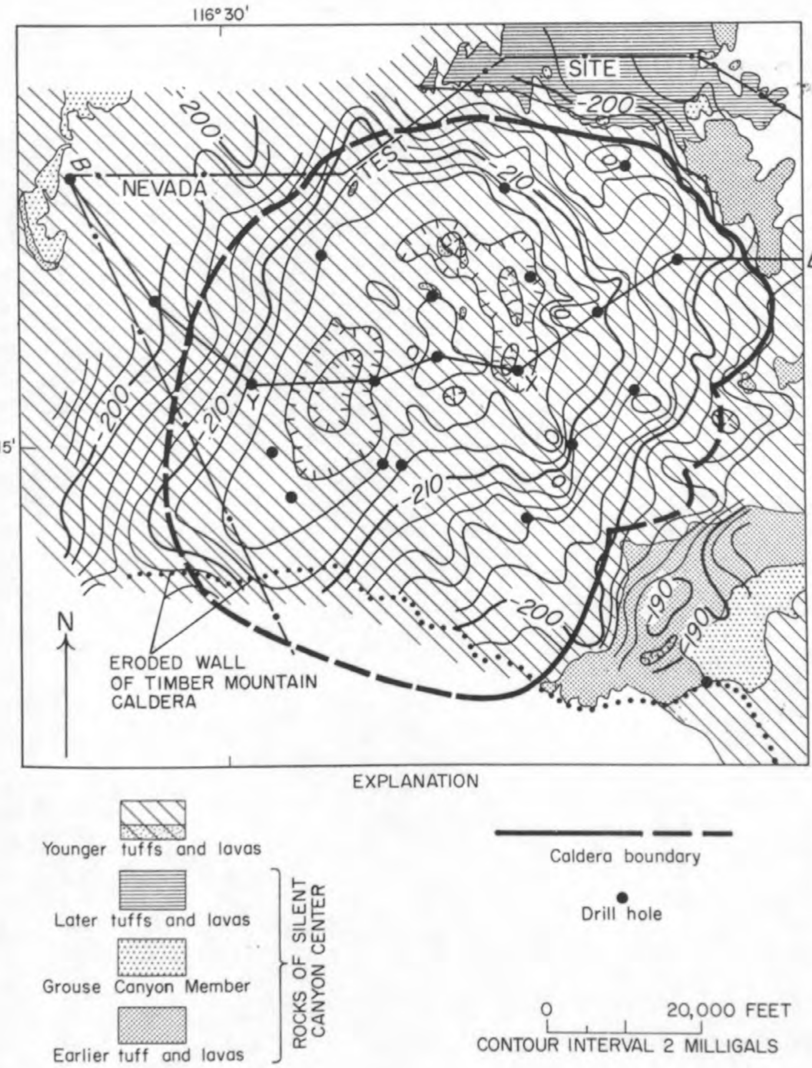

Figure 6.--Residual gravity map of Silent Canyon caldera, showing outline of caldera, locations of drill holes, and major geologic units. X and Y on cross section B-B' indicate exploratory holes mentioned in text. Gravity contours adjusted for regional gradient. Gravity data by D. L. Healey and C. H. Miller.

its displacement in the older rocks. Drill-hole information and surface mapping show that within the gravity low local highs are produced by near-surface high-density rhyolite flows. The southern part of the Silent Canyon caldera is overlapped slightly by the Timber Mountain caldera (dotted line figs. 2 and 6).

Basin-range faulting was active during deposition of the intracaldera and postcaldera rocks and probably during deposition of the precaldera rocks (fig. 3). Faulting in the postcaldera rocks dies out northward at the hinge line of an early broad dome related to the Timber Mountain caldera (Christiansen and others, 1965). The basin-range faults change strike southerly from about north-south to N. 20° E. at this hinge line. Displacement on nearly all the basin-range faults is down on the west as much as 800 feet. Most faults, except the ring faults of the Silent Canyon caldera, are expressed at the surface; in the western part of the area underlain by the caldera, some basin-range faults are concealed beneath the Thirsty Canyon Tuff, the youngest postcaldera formation. Locally, faults near the eastern part of the ring fracture zone have served as fissure vents for peralkaline lava flows.

Cross section A-A' (fig. 3) is roughly north-south through the eastern part of the caldera. The precaldera rocks have been faulted downward within the caldera at least 7,000 feet on the north side to about 5,000 feet on the southeast side. Maximum structural relief is about 7,000 feet in the central part of the section. The major subsidence occurred during the eruption and emplacement of volcanic rocks of the Silent Canyon center, but probably was renewed during emplacement of the nonwelded and reworked tuff (stippled on fig. 3), for the base of this subunit is now 8,250 feet below the surface in the deepest drill hole (fig. 3).

Cross section B-B' (fig. 3) is approximately east-west through the center of the caldera. The amount of collapse at the caldera wall varies from about 7,000 feet on the west side to about 5,000 feet on the northeast side. The structural and gravity high in the center of the caldera was penetrated by two drill holes, one of which is in section B-B'. This high is partly a horst formed between northerly basin-range faults; however, it may be partly the effect of either broad doming or mild resurgence shortly after extrusion of the Tub Spring Member and caldera collpase, for not only are rocks of the Silent Canyon center structurally higher, but also pyritized peralkaline rocks are 2,000-4,000 feet higher in the horst than in similar rocks of the adjacent basins within the caldera.

History of the Silent Canyon caldera

Drill-hole, gravity, and field studies have been combined to reconstruct the evolution of the Silent Canyon caldera and subsequent events. Figure 7 shows a series of diagrammatic east-west cross sections illustrating the sequence of events related to the Silent Canyon center.

In late Miocene time, lavas and tuffs of early Silent Canyon age were extruded on a basement of older Tertiary volcanic and Paleozoic sedimentary rocks (fig. 7A). A potassium-argon age of 14.8 m.y. was obtained on the oldest known rock of the Silent Canyon center (Noble and others, 1967).

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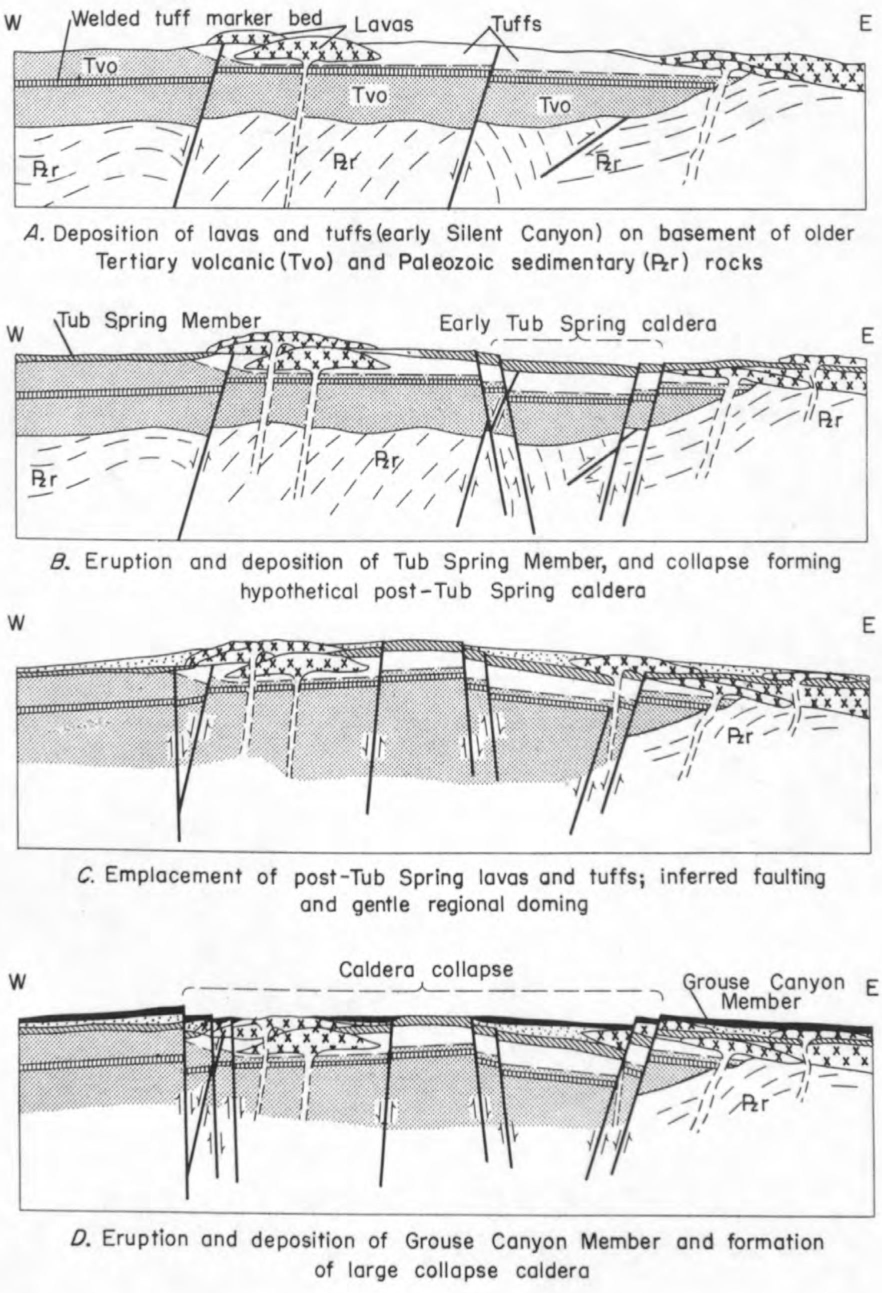

A. Deposition of lavas and tuffs (early Silent Canyon) on basement of older Tertiary volcanic (Tvo) and Paleozoic sedimentary (Pzr) rocks

B. Eruption and deposition of Tub Spring Member, and collapse forming hypothetical post-Tub Spring caldera

C. Emplacement of post-Tub Spring lavas and tuffs; inferred faulting and gentle regional doming

D. Eruption and deposition of Grouse Canyon Member and formation of large collapse caldera

Figure 7.--Diagrammatic cross section of Pahute Mesa, showing major rock types and evolution of the Silent Canyon Center.

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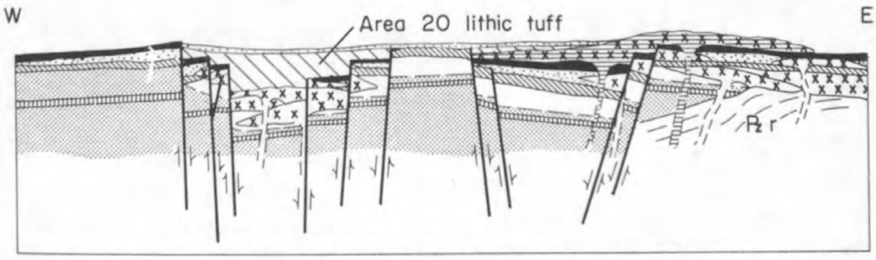
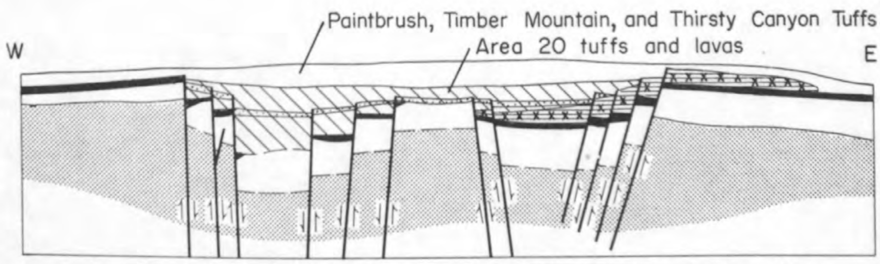


E. Eruption of peralkalic lavas and tuff outside and within eastern part of caldera, followed by eruption of calc-alkalic tuffs and lavas on western side, coupled with renewed subsidence



F. Eruption of calc-alkalic tuffs and lavas of Area 20 within caldera; continued filling over 6 m.y. of partially filled depression by unrelated tuffs from 3 other centers

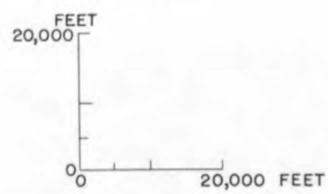


Figure 7.--Diagrammatic cross section of Pahute Mesa, showing major rock types and evolution of the Silent Canyon Center.

Subsequent eruption of the Tub Spring Member of the Belted Range Tuff (fig. 7B) is inferred to have been followed by an initial collapse forming a post-Tub Spring caldera. The Tub Spring is thicker within this hypothetical depression and thins away from it. This greater thickness within the caldera may be due to continued eruption during subsidence. Collapse accompanying eruption of the Tub Spring was a minimum of 1,000 feet, and the member had an original volume of at least 15 cubic miles.

Emplacement of post-Tub Spring lavas and tuffs occurred in the vicinity of the Silent Canyon caldera and was followed by gentle regional doming accompanied by tension faulting (fig. 7C). Eruption of peralkaline rhyolitic flows and tuffs (stippled pattern, fig. 7C-E) continued through these tension fissures.

The Grouse Canyon Member of the Belted Range Tuff was erupted onto probable topographic highs near the caldera formed by the Tub Spring and post-Tub Spring lavas and tuffs. These constructional highs, combined with possible doming of the source area before eruption, account for the thin or absent Grouse Canyon near its source around and within the western part of the Silent Canyon caldera (fig. 7C). Eruption of the Grouse Canyon Member was accompanied by caldera collapse (fig. 7D). A third to a half mile of collapse is required to account for the member's minimum original volume of 50 cubic miles. Either removal of the fine ash to great distances giving a larger volume of erupted material, as at Krakatoa, or rapid magma withdrawal after eruption could permit greater collapse than that inferred from the known volume of ash-fall and ash-flow tuffs. Whether the total subsidence of 5,000-7,000 feet occurred during or shortly after eruption of the Grouse Canyon Member is not known. Minor subsidence of the western basin inside the caldera can be related to renewed basin-range faulting.

Post-Grouse Canyon rocks of peralkaline composition and genetically related to the Silent Canyon center were extruded mainly north and east of the caldera (fig. 7E). These peralkaline lavas and tuffs were emplaced both outside the caldera and within its eastern part. A potassium-argon age of 13.1 m.y. was obtained on one of the younger post-Grouse Canyon peralkaline rock units (Noble and others, 1968).

Subsequent eruption of calc-alkalic tuffs and lavas in the western part of the caldera was coupled with renewed subsidence (fig. 7E). These tuffs and lavas are probably from a different magma source than the peralkaline rocks.

The younger calc-alkalic tuff sheets from other centers are the Paintbrush, Timber Mountain, and Thirsty Canyon Tuffs, which poured into a still-existing depression above the Silent Canyon caldera, as shown by thickening of these sheets within the caldera (fig. 7F). Their period of emplacement covered the period 12.5-7 m.y. ago (R. W. Kistler, written commun., 1964). Isopachs on these younger tuff sheets also reflect west-facing scarps of basin-range faults, which were most active during this period.

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