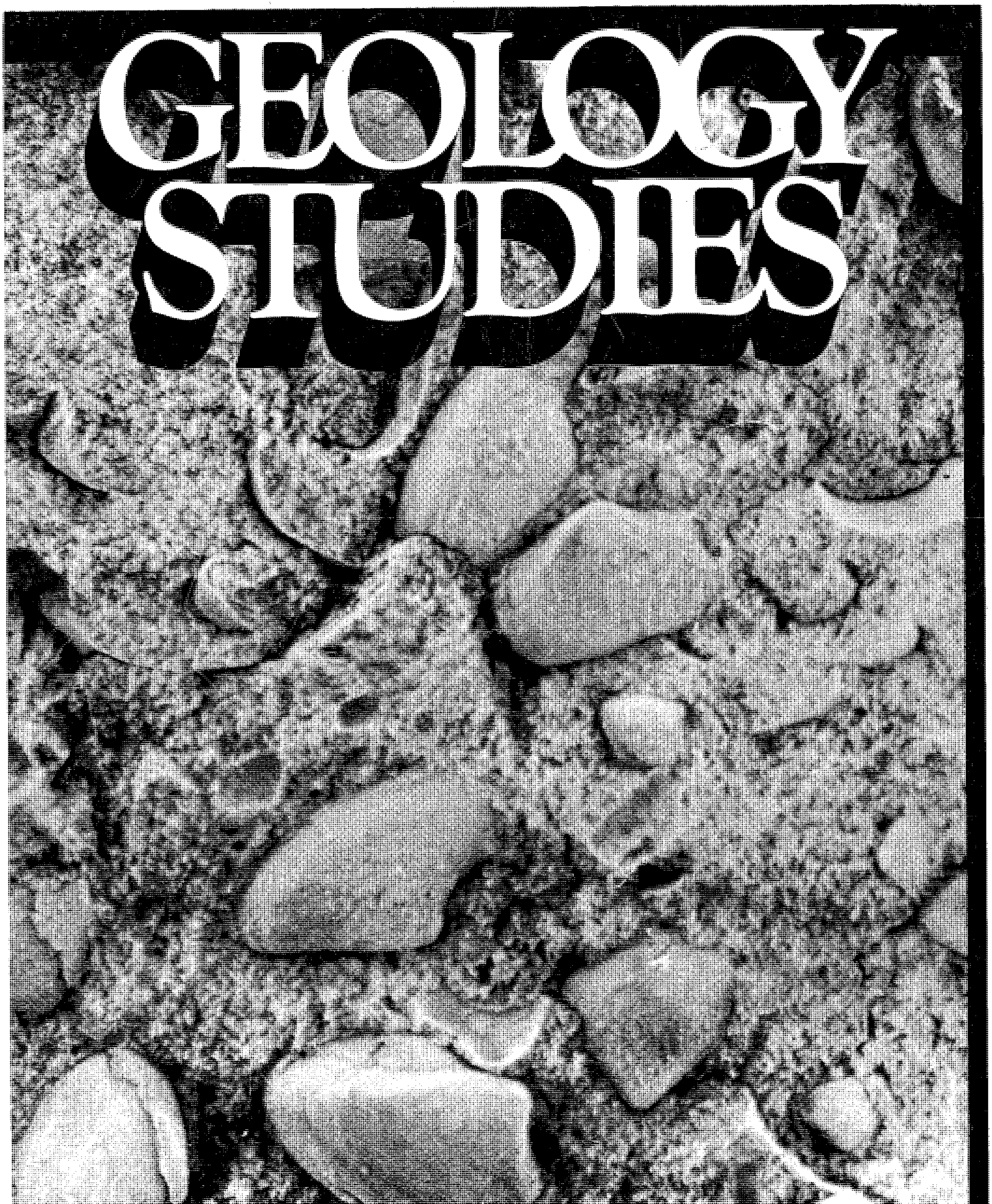
BRIGHAM YOUNG UNIVERSITY

GEOLOGY STUDIES



VOLUME 28, PART 3 DECEMBER 1981

Brigham Young University Geology Studies

Volume 28, Part 3

CONTENTS

Cover: Slab of bivalves showing Myalina-Pleuroma *suite, from Torrey section, Sinbad Limestone Member, Moenkopi Formation in the Teasdale Dome Area, Wayne County, Utah. Photo courtesy James Scott Dean.*

A publication of the
Department of Geology
Brigham Young University
Provo, Utah 84602

Brigham Young University Geology Studies is published by the Department of Geology. This publication consists of graduate student and faculty research within the department as well as papers submitted by outside contributors. Each article submitted by BYU faculty and outside contributors is externally reviewed by at least two qualified persons.

ISSN 0068-1016
Distributed December 1981
12-81 600 52593

CONTENTS

Three Creeks Caldera, Southern Pavant Range, Utah

Thomas A. Steven
U.S. Geological Survey
Denver, Colorado 80225

Abstract.—The Three Creeks Tuff Member of the Bullion Canyon Volcanics had its source in an obscure subsidence structure (caldera) in the southern Pavant Range, Utah. Subsidence apparently began after the lower part of the member had been deposited and proceeded concurrently with eruption of the middle part of the member. A shallow sag, 5–8 km across and faulted along the southeastern side, was produced; ash flows deposited within the subsiding block are at least twice as thick as those deposited concurrently outside the block. The fault scarp on the southeastern side of the caldera was extensively modified by landsliding and erosion before renewed eruptions filled the depression to overflowing with ash flows identical in lithology with those deposited during earlier Three Creeks eruptions. Minor subsidence along earlier structural trends accompanied the late Three Creeks eruptions.

Minor late resurgence reelevated the subsided block so that units within the caldera are now at approximately the same stratigraphic and structural levels as equivalent rocks outside the caldera. Deformation accompanying the resurgence was limited to caldera-fill tuffs along the trend of the fault zone bounding the southeastern side of the caldera where the upper part of the Three Creeks Member dips as much as 30° southeastward into the topographic wall of the caldera. The resurgence may have taken place while some of the caldera-filling tuffs were still hot and plastic.

The broad, relatively diffuse subsidence that formed the Three Creeks caldera may have resulted from episodic eruptions from a relatively deep magma chamber, so that roof support was lost gradually, rather than catastrophically, as in the case of many well-formed calderas. The size and shape of the magma chamber may also have been factors contributing to the mode of subsidence.

Introduction

An obscure subsidence structure related to eruptions of the Three Creeks Tuff Member of the Bullion Canyon Volcanics has been identified in the southern Pavant Range, Utah, along the northern flank of the Marysvale volcanic field (fig. 1). The Three Creeks Tuff Member is a single ash-flow tuff sheet whose original volume probably was on the order of 100–200 km³, sufficiently large to suggest that subsidence related to eruption probably took place at its source (Smith 1960, p. 819). Thickness and welding relations suggested, early in the course of

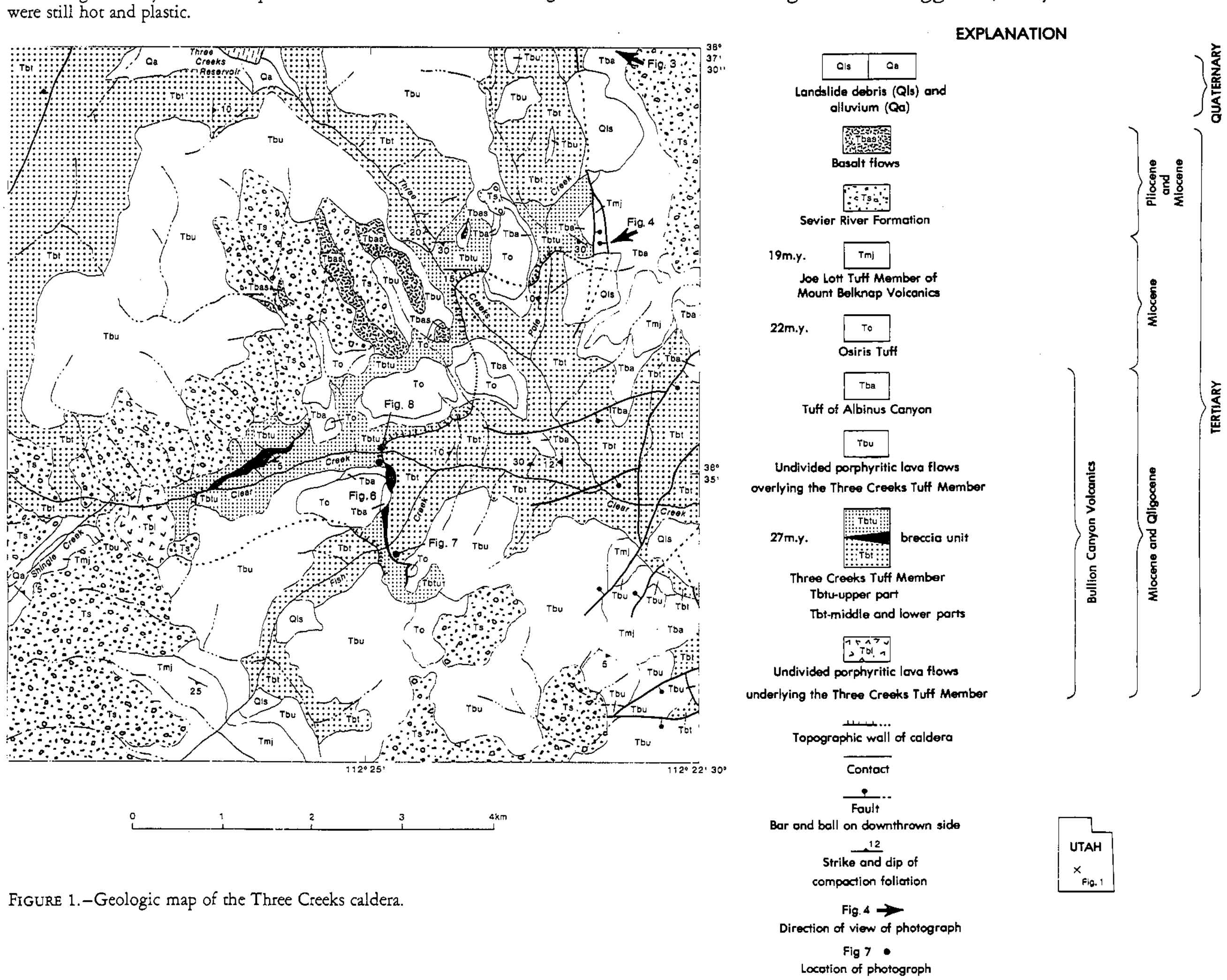


FIGURE 1.—Geologic map of the Three Creeks caldera.

field studies in the Marysvale area (Steven and others 1979), that the sheet probably originated in the Clear Creek drainage between the Tushar Mountains and the Pavant Range.

Geologic mapping by Callaghan and Parker (1962) and by Caskey and Shuey (1975) did not indicate any subsidence feature in the Clear Creek area, but subsequent careful mapping has disclosed evidence of a largely buried caldera. The very obscurity of this feature and the many bits of subtle evidence for its existence are the main subjects discussed in this paper. Many other seemingly homeless ash-flow tuff sheets may have been derived from similarly obscure sources.

Regional Setting

The Three Creeks Tuff Member of the Bullion Canyon Volcanics was erupted about 27 m.y. ago (Steven and others 1979) from a source along the northern flank of the Marysvale volcanic field. At this time, a large stratovolcano centered in the northern Tushar Mountains dominated the Marysvale field (fig. 2); this volcano formed primarily before 30 m.y. ago, and influenced the distribution of most later volcanic units. A large volcanic dome of porphyritic quartz latite, in the southern Pavant Range east of the Three Creeks source (fig. 2), formed a barrier that blocked the spread of Three Creeks ash flows eastward along the northern flank of the Marysvale volcanic field. Smaller flank volcanoes near present-day Cove Fort (fig. 2) were largely covered by younger lava flows and ash-flow tuffs beneath the Three Creeks Member (fig. 1) by the time the Three Creeks was erupted.

The Three Creeks Tuff Member thus was erupted onto an irregular volcanic plain flanking the northern side of a major stratovolcano. Incandescent ash was erupted episodically to form many successive ash flows that spread widely except where constrained by preexisting volcanoes. Figure 2 shows the presently known distribution of the Three Creeks Tuff Member. The unit is thick and densely welded all around the eroded northern and northwestern peripheries shown, and the unit clearly was emplaced well beyond the present area of distribution in these directions. The approximately 1,100 km^2 of Three Creeks Tuff Member shown on figure 2 is probably only about half the original extent of the unit. Assuming an average thickness of 100 m (an order of magnitude figure only), about 100 km^3 of the Three Creeks Member still exists; the original volume may have been as much as twice this. This volume is sufficient to support an assumption that subsidence at the source probably took place as a consequence of eruption (Smith 1960, p. 819; Steven and Lipman 1976, p. 31), but that a large, well-formed caldera need not have formed.

The Three Creeks Tuff Member was covered by a sequence of lava flows and ash-flow tuffs, no more than 500 m thick, erupted over an 8 m.y. span of time (fig. 1). Locally derived lava flows of porphyritic quartz latite (fig. 1) formed a discontinuous cover over the Three Creeks; these flows range from a single viscous domal flow in the northwestern part of figure 1, to several thinner flows in the southern part of the map area. The low area between these lava accumulations was widened and deepened by stream erosion before ash flows from distant sources deposited tongues of both the tuff of Albinus Canyon and the 22-m.y.-old Osiris Tuff (Fleck and others 1975) in the valleys. Still younger deposits consist of the Joe Lott Tuff Member of the Mount Belknap Volcanics, deposited 19 m.y. ago (Steven and others 1979, p. 25), and overlying fluviatile sediments of the Sevier River Formation with local interlayered basalt lava flows. The Joe Lott shows no thickening along the Three Creeks caldera margin, and the Sevier River Formation appears to have filled a stream valley.

The modern drainage, superimposed through a cover of soft Sevier River Formation, shows no influence by the older structures that it exhumes.

Three Creeks Tuff Member

As detailed by Steven and others (1979, p. 13–17), the Three Creeks Tuff Member is a crystal-rich quartz-latite ash-flow tuff consisting of about 50 percent phenocrysts in a variably welded matrix of devitrified glass shards and collapsed pumice fragments. The phenocrysts consist typically of andesine (35 percent), amphibole (9 percent), biotite (3 percent), quartz (2 percent), and a percent or less each of sanidine and Fe-Ti oxides. Apatite, sphene, and zircon comprise minor accessory minerals. These percentages vary both laterally and vertically, but not in any seemingly systematic manner.

The Three Creeks Tuff Member is a multiple-flow compound-cooling unit. Near its source in Clear Creek, cooling and welding variations define a rude stratigraphy that, although not recognized in the outflow sheet remote from the source area, is critical in establishing the history of subsidence at the source.

The lower part of the Three Creeks Tuff Member is generally densely welded, with minor less-welded partings. A thickness of about 200 m of this densely welded rock is exposed in the canyon of Clear Creek near the eastern border of figure 1, and a somewhat thinner section is widely exposed in the headwaters of Clear Creek, Three Creeks, and Pole Creek, west and north of figure 1. The base is widely exposed along the western and northern flanks of the Pavant Range (fig. 2), but nowhere within the area of fig. 1. The lower densely welded rock grades upward into a ledgy sequence of soft, slightly to moderately

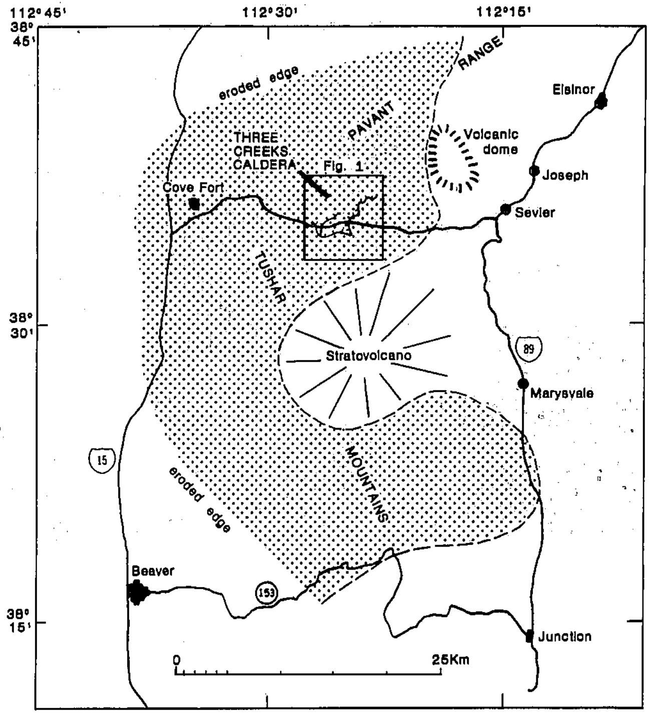


FIGURE 2.–Distribution of the Three Creeks Tuff Member of the Bullion Canyon Volcanics (stippled pattern).

welded tuff containing some layers of more densely welded tuff. Except for differences in welding, the lithology and phenocryst content remain similar across the transition. The middle sequence is 200 to 250 m thick in Clear Creek Canyon, outside the subsided area, but is more than 500 m thick along Three Creeks and Pole Creek within the caldera (fig. 3).

The upper part of the Three Creeks Tuff Member consists of densely welded ash-flow tuff similar to that in the lower part. It caps hills near the outer perimeter of the Clear Creek drainage basin north and west of the area of figure 1, and forms a band of densely welded tuff that extends diagonally across the center of figure 1 adjacent to the topographic wall on the Three Creeks caldera. To the north and west, the upper part of the member appears to parallel layering in the lower and middle parts, but near the center of figure 1 it abuts and wedges out in depositional contact against these units on the topographic wall of the caldera (fig. 4).

The topographic wall of the Three Creeks caldera is marked locally by discontinuous zones of breccia, largely of talus and landslide debris with predominant Three Creeks fragments and minor mudflow breccia with fragments from mixed sources. A subsidiary topographic wall about a kilometer inside the main wall is exposed north of Clear Creek in the west central part of figure 1, perhaps over the buried structural margin. This subsidiary wall is marked by a prominent zone of breccia consisting of locally derived talus and landslide debris in its lower part, overlain in turn by rudely bedded mudflow deposits and by typical ash-flow tuff deposits of the Three Creeks Tuff Member.

The differentially welded layers of Three Creeks form a broad downwarp whose ill-defined axis plunges gently southeastward across the north central part of figure 1. North of the confluence of Pole and Three Creeks, the dips of compaction foliation in the upper part of the Three Creeks Tuff Member increase sharply to 30° south. The underlying layers in the middle part of the member appear to dip about as steeply, whereas the same layers forming the topographic wall of the caldera just to the south are relatively flat lying (fig. 4). Figure 5 is a sketch cross section showing the interpreted relations in this area.

The topographic wall of the Three Creeks caldera cuts sharply across the middle part of the member (figs. 4, 6, 7A) and is sinuous in plan (fig. 1). The talus and landslide breccia form rude layers that tend to parallel the immediately underlying wall (figs. 6, 7A, 7B), requiring subaerial accumulation between episodes of pyroclastic eruption. In one place where the actual wall was exposed (fig. 8), the wall is strikingly grooved, probably because of grinding along the sole of a landslide. The breccias are especially well displayed along the topographic wall west and south of the confluence of Fish and Clear Creeks where they abruptly truncate the flat-lying ledges of the middle part of the Three Creeks Member. In the area illustrated by figure 7, a spoon-shaped mass of the upper part of the member is plastered against the middle part of the member east of Fish Creek, and the intervening talus breccias stand in cliff exposures.

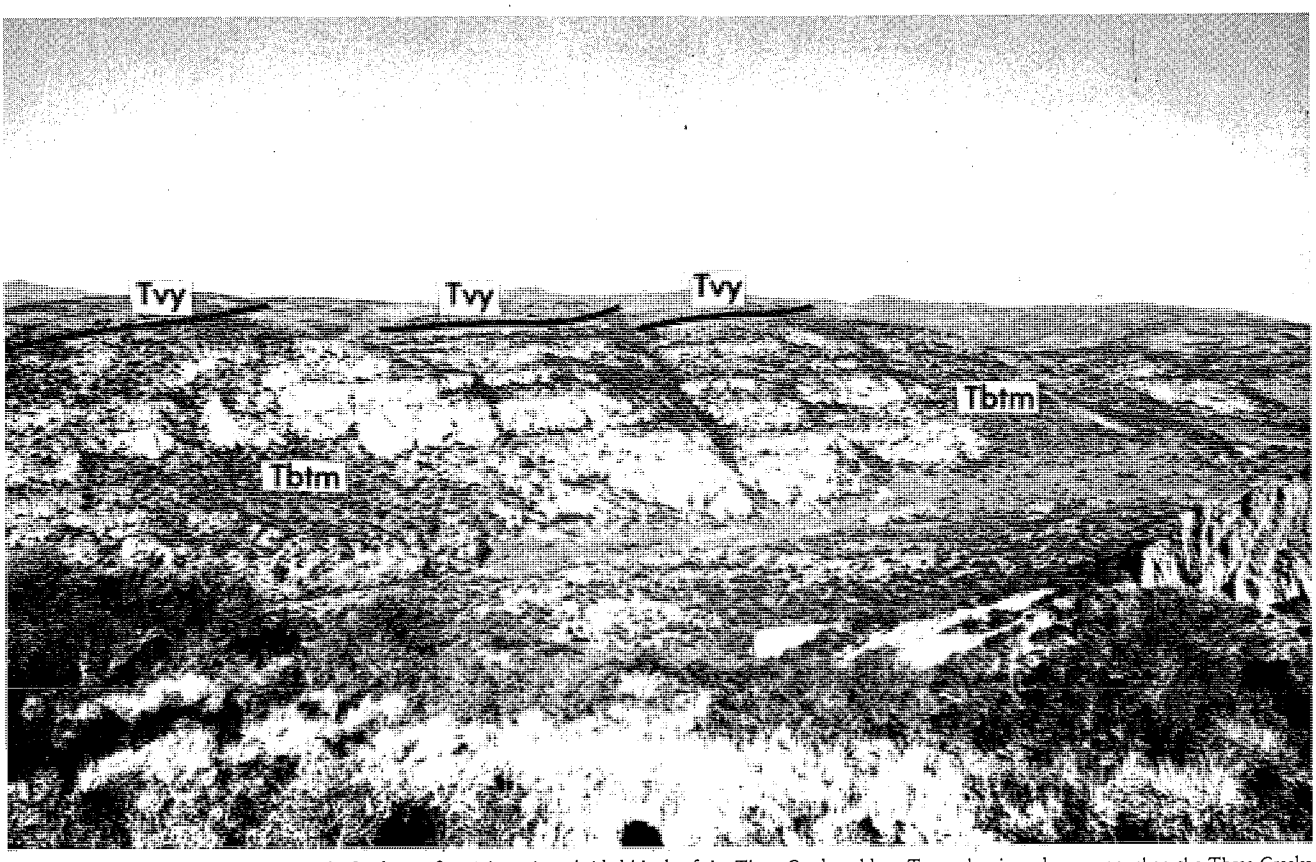


FIGURE 3.—View looking west across Pole Creek (see fig. 1) into the subsided block of the Three Creeks caldera. Tvy, volcanic rocks younger than the Three Creeks Tuff Member; Tbtm, middle part of the Three Creeks Tuff Member.

Evolution of the Three Creeks Caldera

Stratigraphic and structural relations in the Clear Creek drainage basin indicate an extended sequence of events that took place in the source area during and shortly after eruption of the Three Creeks Tuff Member. Early eruptions spread hot ash in a rapid sequence of ash flows that welded into a dense sheet showing only local evidence of compound cooling. With time, the eruptions became more episodic, and perhaps the erupted ash was somewhat cooler so that the middle part of the member accumulated as a sequence of distinct layers with well-defined partial to complete cooling breaks between them (figs. 3, 4).

Broad subsidence may have begun in the source area during the earlier and hotter eruptions, but the actual beginning has not been documented. Subsidence was clearly under way during accumulation of the softer and more-layered middle part of the member, which is more than twice as thick within as it is outside the subsided area. Subsidence formed a broad downwarp, faulted along the southeastern side, in the Three Creeks-Pole Creek area. The fault scarp exposed chiefly the softer tuffs in the middle part of the Three Creeks Tuff Member, and landsliding and erosion of these weak rocks resulted in a sinuous topographic wall that flared southeastward from the faulted margin of the subsided block. This topographic wall was partly veneered by talus and landslide debris and local mudflow deposits (figs. 6, 7A, 7B), whose rude layering generally parallels the underlying wall. These steeply dipping fragmental units have little or no interlayered primary pyroclastic material, and apparently were deposited during an extended period of volcanic quiescence during which the caldera scarp was extensively modified by slumping and erosion.

Renewed eruptions from the Three Creeks magma chamber again spread hot ash flows across the source area, where they were trapped against the older topographic wall on the south,

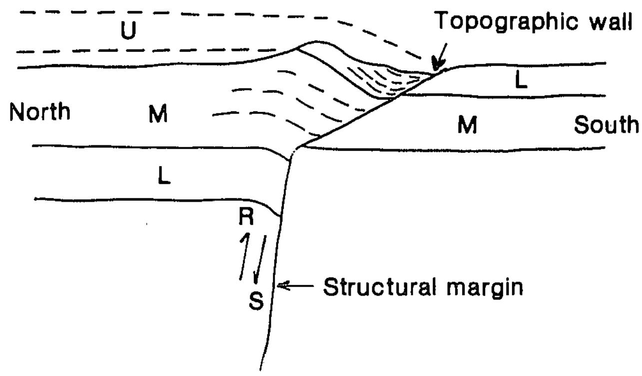


FIGURE 5.—Interpreted relations along the topographic wall of the Three Creeks caldera. L, M, and U represent lower, middle, and upper parts of the Three Creeks Tuff Member of the Bullion Canyon Volcanics. Arrows indicate direction and relative amount of subsidence (S) followed by resurgence (R).

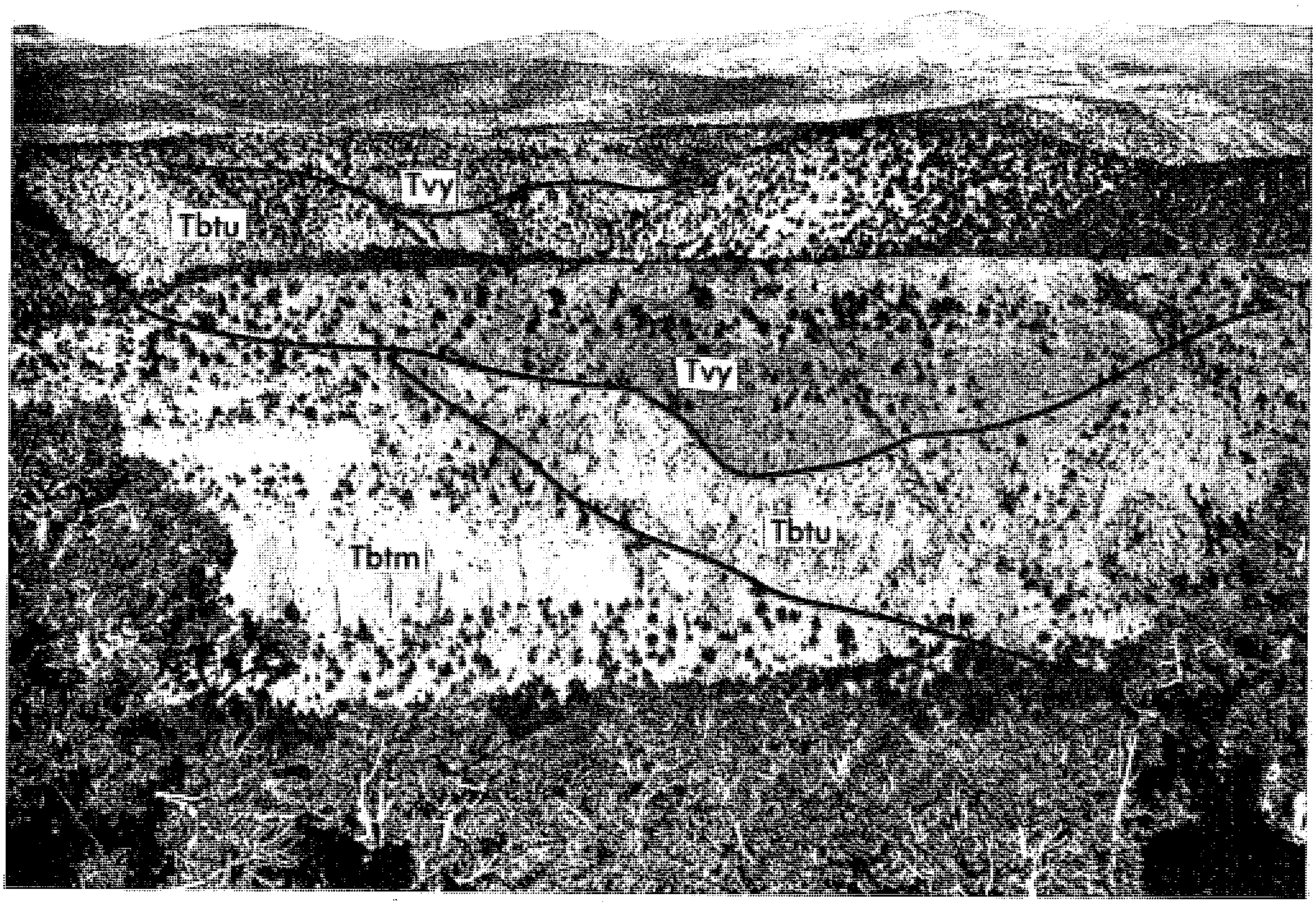


FIGURE 4.—View looking west across Pole Creek (see fig. 1) at the topographic wall of the Three Creeks caldera. Tvy, volcanic rocks younger than the Three Creeks Tuff Member; Tbtu, upper part, and Tbtm, middle part of the Three Creeks Tuff Member.

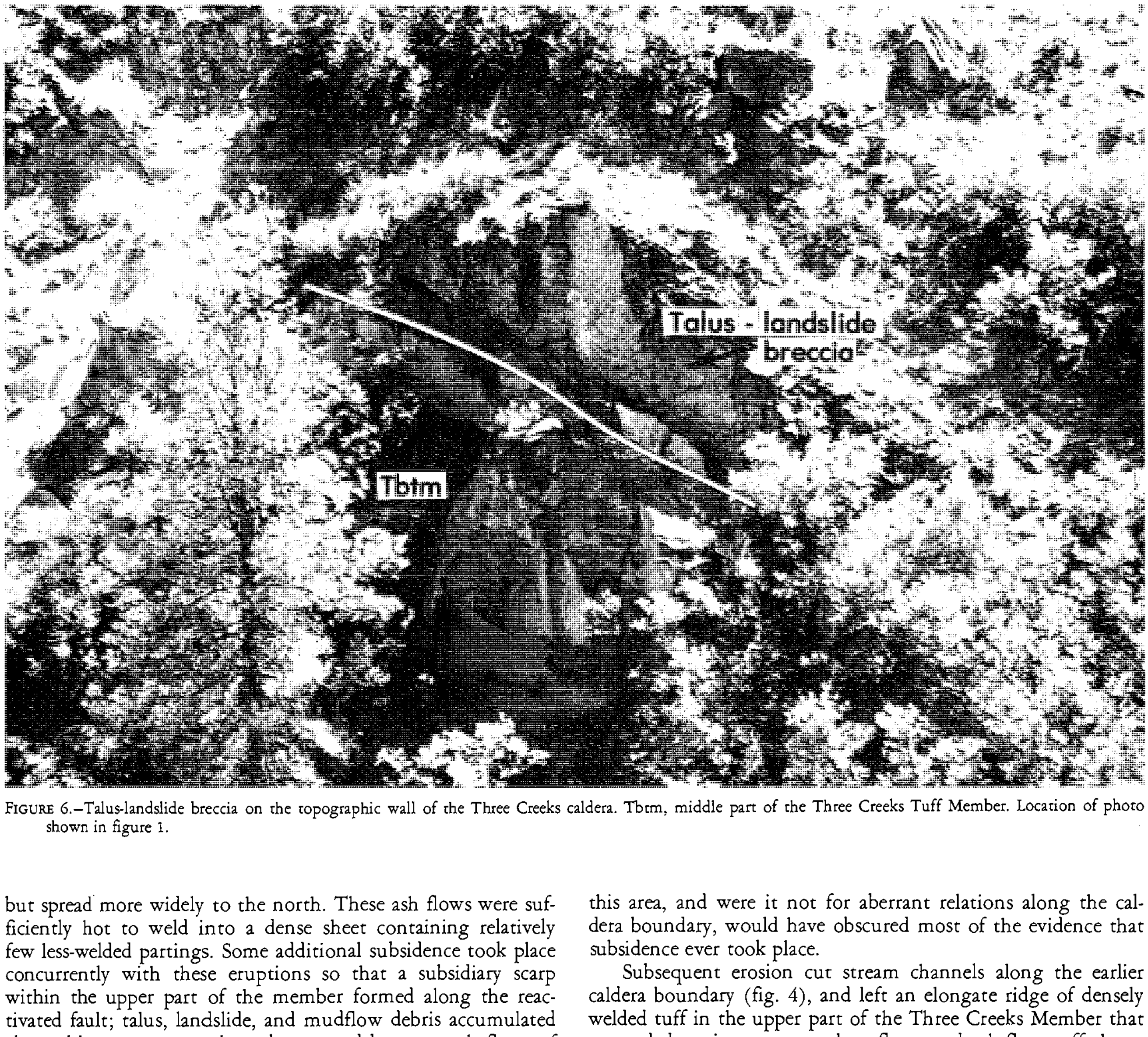


FIGURE 6.–Talus-landslide breccia on the topographic wall of the Three Creeks caldera. Tbtm, middle part of the Three Creeks Tuff Member. Location of photo shown in figure 1.

but spread more widely to the north. These ash flows were sufficiently hot to weld into a dense sheet containing relatively few less-welded partings. Some additional subsidence took place concurrently with these eruptions so that a subsidiary scarp within the upper part of the member formed along the reactivated fault; talus, landslide, and mudflow debris accumulated along this new scarp, only to be covered by more ash flows of the same type.

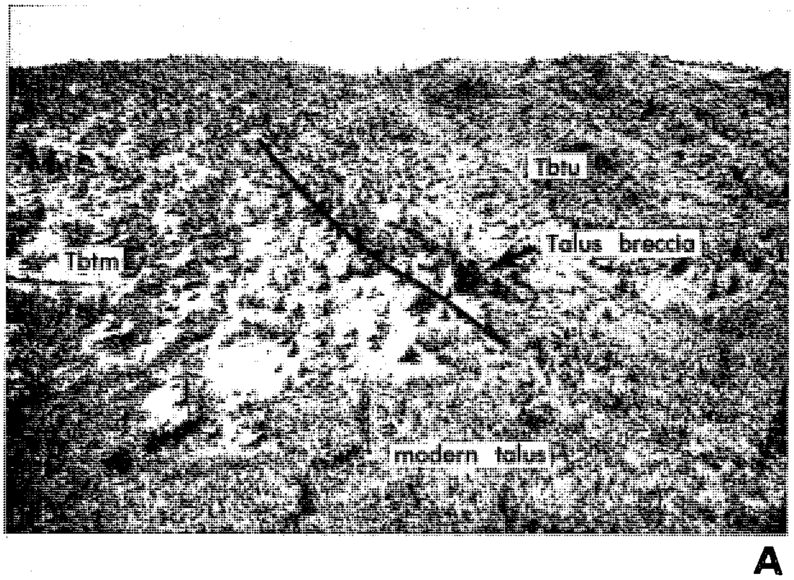
Shortly after the final Three Creeks eruptions ceased, and possibly while some of the upper part of the member was still hot and plastic, part of the subsided block was resurgently uplifted by reversed movement on the buried fault (fig. 5). Uplift was largely in the Pole Creek-Three Creeks area, where the densely welded rocks in the upper part of the member dip steeply against flat-lying rocks of the topographic wall of the caldera (fig. 4). The tilting was confined to caldera-fill rocks, which virtually requires that they were still plastic so that the soft but cool layers in the outer wall were not deformed in any way.

Resurgence was only sufficient to lift the soft middle part of the member within the caldera to a structural position approximately equivalent to that of the same rocks outside the caldera. Subsequent erosion has removed most of the hard upper part of the member, leaving only an elongate mass with triangular cross section along the caldera margin. Thus, resurgence almost exactly erased the effects of earlier subsidence in this area, and were it not for aberrant relations along the caldera boundary, would have obscured most of the evidence that subsidence ever took place.

Subsequent erosion cut stream channels along the earlier caldera boundary (fig. 4), and left an elongate ridge of densely welded tuff in the upper part of the Three Creeks Member that protruded up into younger lava flows and ash-flow tuff sheets (fig. 1). For the most part, however, the flat-lying younger rocks show virtually no evidence that they cover a caldera marking the source area of an important ash-flow tuff unit.

Comparisons

Why do some ash-flow eruptions of moderate volume result in well-formed calderas with complex histories of subsidence and filling, whereas others result only in obscure faulted downwarps like the Three Creeks caldera? This question is especially pertinent in the Marysvale volcanic field, where the large well-formed Mount Belknap caldera (Cunningham and Steven 1979) subsided in response to eruption of the Joe Lott Tuff Member of the Mount Belknap Volcanics—a somewhat less-voluminous but still comparable unit to the Three Creeks Tuff Member. Noting that the composition of the Joe Lott rocks closely approaches the Q-Or-Ab-H_2O system of Tuttle and Bowen (1958), Cunningham and Steven (1979, p. 32) calculated a water pressure of 800 ± 200 bars, which corresponds to a lithostatic load generated by 3–4 km of cover over the



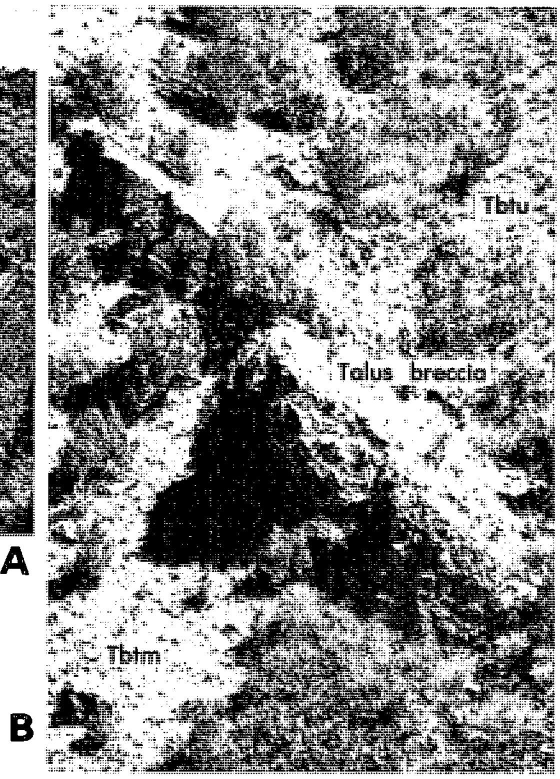


FIGURE 7.–Broad view (A) and detail (B) of talus breccia along the topographic wall of the Three Creeks caldera near Fish Creek (see fig. 1), Tbtu, upper part, and Tbtm, middle part of the Three Creeks Tuff Member.

FIGURE 8.–Grooves (see arrows) on the topographic wall of the Three Creeks caldera. Tbtm, middle part of the Three Creeks Tuff Member. Location of photo shown in figure 1.

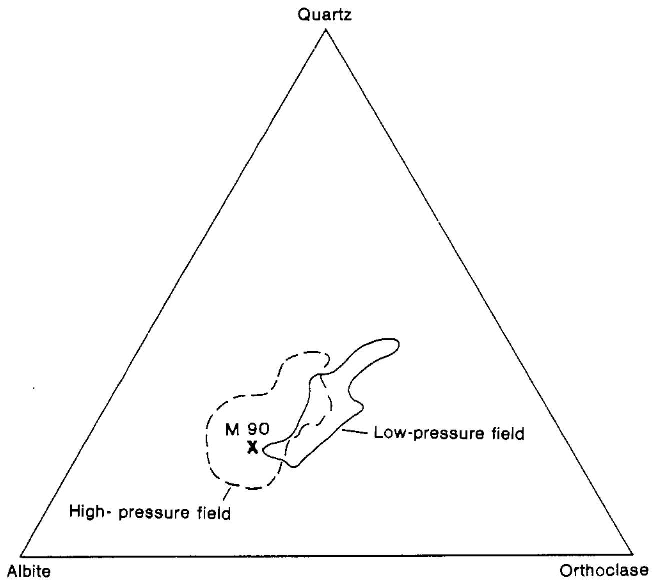


FIGURE 9.–Ternary diagram showing high-pressure and low-pressure fields for Oligocene ash-flow tuffs and postcollapse lavas in the San Juan Mountains, Colorado (modified from Lipman and others 1978, fig. 4). Position of sample M 90 (x) of the Three Creeks Tuff Member of the Bullion Canyon Volcanics shown with respect to these fields.

magma chamber. The intricate response of the Mount Belknap caldera to eruption of the Joe Lott Tuff Member seems a natural result of this shallow depth of cover.

The magma chamber beneath the Three Creeks caldera probably was much deeper than that under the Mount Belknap caldera, so that only broad subsidence of a relatively stronger cover could take place. This suggestion has some support in the lithology and phenocryst mineralogy of the Three Creeks Tuff Member, which closely resembles the Fish Canyon Tuff in the San Juan Mountains of Colorado (Steven and Ratté 1965, p. 18). Lipman and others (1978, p. 63–66) interpret the Fish Canyon as belonging to an assemblage of crystal-rich quartz latitic ash-flow tuffs whose phenocrysts crystallized in high-pressure environments considerably below shallow subcaldera levels. As shown on an Ab-Or-Q ternary diagram (fig. 9), a sample (M90) of the Three Creeks Tuff Member plots well within the high-pressure field defined by San Juan rocks. If these phenocrysts were near equilibrium with the enclosing melt at the time of eruption, they presumably should have come from a relatively deep magma chamber. Present data are too incomplete, however, to determine the extent to which equilibrium had been maintained until the time of eruption.

The time span of eruptions also may have had significant influence on the amount and character of subsidence. The layered, compound-cooling characteristics of the middle part of the Three Creeks Tuff Member suggest that intermittent eruptions extended over a significant period of time so that related subsidence probably was gradual rather than catastrophic. In addition, the size and shape of the magma chamber could have been important factors (Cunningham and Steven 1979), but the significance of these factors is difficult to evaluate.

In broad perspective, the Mount Belknap and Three Creeks calderas seem to mark widely separated points on what is probably a continuum of subsidence types, in which depth of magma chamber is only one of many interactive factors. As obscure as the Three Creeks caldera is, it is unlikely to represent an end member in this series. Subsidence so broad and diffuse as to be virtually undetectable in all but the most ideal circumstances seems a logical projection. Recognition of such obscure features in poorly exposed or structurally complex areas would be especially difficult. Had not the southern side of the subsided block broken to form a topographic scarp, it is possible that the Three Creeks caldera would not have been recognized, even in an area as well exposed as the Clear Creek drainage basin.

REFERENCES

Callaghan, Eugene, and Parker, R. L., 1962, Geology of the Sevier Quadrangle, Utah: U.S. Geological Survey Geologic Quadrangle Map GQ-156.

Caskey, C. F., and Shuey, R. T., 1975, Mid-Tertiary volcanic stratigraphy, Sevier-Cove Fort area, central Utah: Utah Geology, v. 2, no. 1, p. 17–25.

Cunningham, C. G., and Steven, T. A., 1979, Mount Belknap and Red Hills calderas and associated rocks, Marysvale volcanic field, west-central Utah: U.S. Geological Survey Bulletin 1468, 34p.

Fleck, R. J., Anderson, J. J., and Rowley, P. D., 1975, chronology of mid-Tertiary volcanism in High Plateaus region of Utah: Geological Society of America Special Paper 160, p. 53–61.

Lipman, P. W., Doe, B. R., Hedge, C. E., and Steven, T. A., 1978, Petrologic evolution of the San Juan volcanic field, southwestern Colorado: Pb and Sr isotope evidence: Geological Society of America Bulletin, v. 89, p. 59–82.

Smith, R. L., 1960, Ash flows: Geological Society of America Bulletin, v. 71, no. 6, p. 795–842.

Steven, T. A., Cunningham, C. G., Naeser, C. W., and Mehnert, H. H., 1979, Revised stratigraphy and radiometric ages of volcanic rocks and mineral deposits in the Marysvale area, west-central Utah: U.S. Geological Survey Bulletin 1469, 40p.

Steven, T. A., and Lipman, P. W., 1976, Calderas of the San Juan volcanic field, southwestern Colorado: U.S. Geological Survey Professional Paper 958, 35p.

Steven, T. A., and Ratté, J. C., 1965, Geology and structural control of ore deposition in the Creede district, San Juan Mountains, Colorado: U.S. Geological Survey Professional Paper 487, 87 p.

Tuttle, O. F., and Bowen, N. L., 1958, Origin of granite in the light of experimental studies in the system $NaAlSi_3O_8$-$KAlSi_3O_8$-SiO_2-H_2O: Geological Society of America Memoir 74, 153p.