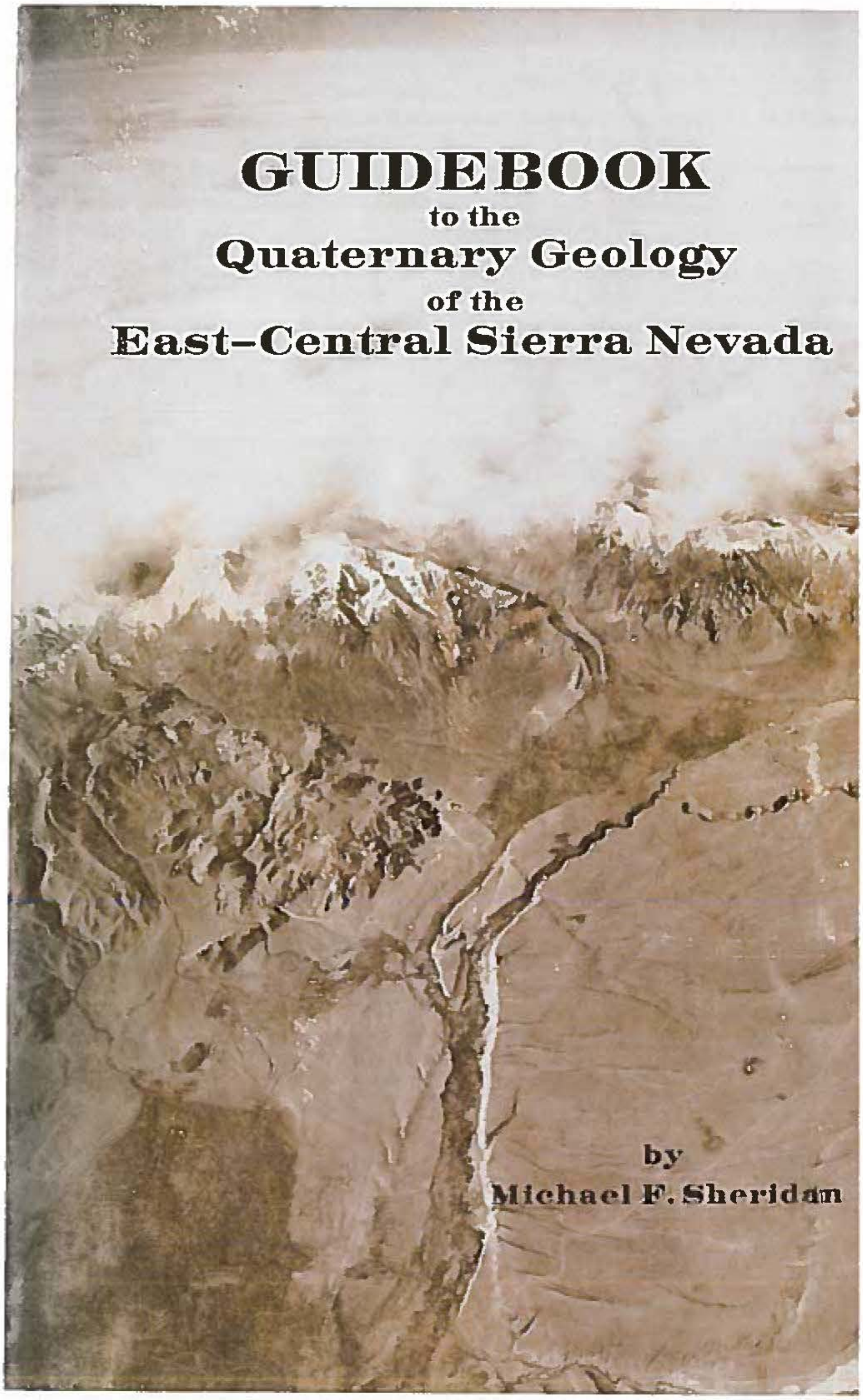

GUIDEBOOK
to the
Quaternary Geology
of the
East-Central Sierra Nevada

by
Michael F. Sheridan

PRICE $5.00
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COVER—Oblique aerial view of Bishop, California. U. S. Geological Survey high altitude photo, series 744 R, number 208. Approximate scale of 1:121,000.

GUIDEBOOK
to the
Quaternary Geology
of the
East-Central Sierra Nevada

This guidebook was prepared for the XVI Field Conference of the Rocky Mountain Section of the Friends of the Pleistocene, October 9-10, 1971.

To Curt Phillips
with compliments of the author
Mike Sheridan
9-Oct 71

by
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This guidebook is the outgrowth of several guides compiled by R. D. Reger and R. K. Merrill for field trips in Glacial Geology and Volcanology classes in the Department of Geology, Arizona State University. These trips conducted by Dr. Troy L. Péwé have led to an integrated picture of the dramatic glacial and volcanic history of this region. I would like to thank Troy L. Péwé and Jan Sheridan for reading early versions of the manuscript and providing useful comments. Appreciation is extended to the Geological Society of America and Robert P. Sharp for permission to use previously published materials.

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INTRODUCTION

The eastern Sierra Nevada from Bishop to Mono Lake is noted for the spectacular beauty of its rugged mountains and deep valleys. This region is a favorite outdoor recreation area in both the summer and winter. It is also of critical scientific importance for Quaternary geologic studies. The standard Sierra glacial stratigraphy was developed here (Table 1).

TABLE 1 – Glacial Stratigraphy*

Correlative	Sierra Glaciation
Neoglacial –	Matthes[3] – 700 years to present.**
	Recess Peak[3] – 2000 to 2600 years.**
	Hilgard[3] – 9000 to 10,500 years?**
Wisconsinan –	Tioga[1] – about 20,000.**
	Tenaya[2] – about 45,000.**
	Tahoe[1] – 60,000 to 75,000.**
Illinoian –	Mono Basin[2] – about 130,000.**
	Casa Diablo[4] – about 400,000.**
Kansan –	Sherwin[1] – older than 710,000 years (Dalrymple, 1965).
Nebraskan –	McGee[1] – older than 2.6 m.y. (Dalrymple, 1963).
	Deadman Pass[4] – between 2.7 m.y. and 3.1 m.y. (Curry, 1966).

1. Names of Blackwelder (1931)
2. Names of Sharp and Birman (1963)
3. Names of Birman (1964)
4. Names of Curry (1966, 1971)

*This table does not include some glaciations indicated by Curry (1971, Table 1).

**Absolute age follows Curry (1971, Table 1)

Because volcanism, tectonism, and glaciation are intimately related process in the Quaternary history of the east-central Sierra Nevada, radiometric dating of the volcanic rocks has established an unequalled corroboration of detailed Pleistocene chronology (Table 2). It was here that the "ice age" was dated at more than 1 million years; then shown to be at least 3 million years (Curry, 1966). Throughout this period of active volcanism and glaciation the eastern Sierra escarpment attained as much as 4,000 feet of its present majestic relief by warping and normal faulting (Christiansen, 1966). This tectonism has diversified the glacial and volcanic patterns to an extent that has only recently been imagined.

The purpose of this text is to present a general view of the geology through an appreciation of the excellent exposures of typical units in the classical sequence. Because many aspects of the Quaternary geology of this region are well known, heavy reliance is placed on the abundant geologic literature. Some classic as well as controversial stops recorded here are familiar to geologists who have worked this area. Several stops included in the 1965 INQUA VII Field Congress trip I will be familiar.

The geology of this area is contained in the 1:250,000 Mariposa Sheet sold by the California Division of Mines and Geology. The U. S. Geological Survey topographic maps covering the route are: Bishop, Mt. Tom, Casa Diablo Mountain, Mt. Morrison, and Mono Craters. Geologic maps at the scale of 1:62,500 are available for all of these quadrangles from the U. S. Geological Survey.

TABLE 2 – Dated Volcanic Units

Unit	Date	Reference
Mono Lake sublacustrine eruption	81 years	Christiansen and Gilbert, 1964
Inyo Lakes explosion craters	650 ±200 years	Rinehart and Huber, 1965
Panum Crater	1300 years	Friedman, 1968
Mammoth ash	1440 ±150 years	Rubin and Alexander, 1960
Northern Coulee	1800 years	Friedman, 1968
Southern Coulee	2500 years	Friedman, 1968
Caldera north of Punchbowl	5800 years	Friedman, 1968
Mono and Inyo domes	6,400 to 10,200 years	Dalrymple, 1967
Mammoth Mountain upper coulee	0.15 ±.05 m.y.	Curry, 1971
Mammoth Mountain quartz latite	0.18 ±.09 m.y.	Huber and Rinehart, 1967
Basalt of Mammoth Creek (upper unit)	0.19 ±.04 m.y.	Curry, 1971
Basalt of Mammoth Creek (middle unit)	0.28 ±.07 m.y.	Curry, 1971
Rhyolite at Whitmore Hot Springs	0.28 ±.03 m.y.	Doell and others, 1966
Mammoth Mountain quartz latite	0.37 ±.04 m.y.	Dalrymple, 1964a
Basalt of Mammoth Creek (lower unit)	0.44 ±.04 m.y.	Curry, 1971
Andesite of Devils Postpile	0.63 ±.35 m.y.	Huber and Rinehart, 1967
Tuff of Reds Meadow (Bishop Tuff?)	0.66 ±.02 m.y.	Huber and Rinehart, 1967
Bishop Tuff (average of 6 dates)	0.71 ±.04 m.y.	Dalrymple and others, 1965
Obsidian of Glass Mountain	0.90 ±.10 m.y.	Gilbert and others, 1968
Andesite of Devils Postpile	0.94 ±.16 m.y.	Dalrymple, 1964b
McGee Mountain basalt	2.6 ±.1 m.y.	Dalrymple, 1963
Two Teats quartz latite	2.7 ±.1 m.y.	Curry, 1966
Two Teats quartz latite	2.74 ±.1 m.y.	Curry, 1966
Two Teats quartz latite	3.0 ±.1 m.y.	Dalrymple, 1964a
San Joaquin Mountain basalt	3.1 ±.1 m.y.	Dalrymple, 1964a
Mammoth Mine basalt	3.1 ±.1 m.y.	Dalrymple, 1964a
Owens Gorge basalt	3.2 ±.1 m.y.	Dalrymple, 1963
Benton Range basalt	3.2 ±.1 m.y.	Dalrymple, 1964a

GLACIAL GEOLOGY

The Pleistocene glacial history of this area was initially studied by I. C. Russell (1885) and later by Eliot Blackwelder (1931), W. C. Putnam (1949, 1950) and J. H. Birman (1964). The oldest glacial deposits of this area are found near Deadman Pass in the Devils Postpile quadrangle. Radiometric ages of volcanic units above and below till of this glaciation indicate that it occurred very close to 3 million years ago (Curry, 1966, 1971). This location is not easily accessible and will not be visited on this trip.

The McGee glaciation (Blackwelder, 1931) is represented by deeply weathered till and boulders found scattered high on mountain summits and ridges. The type locality is on the smooth summit of McGee Mountain which we will drive past. We will not however, have a chance to examine the McGee till first hand. The great height at which the McGee till is now found is interpreted by most to be the result of faulting in post-McGee time.

The next oldest glaciation is the Sherwin (Blackwelder, 1931). Till of this advance or series of advances is deeply weathered with constituent boulders of granitic composition easily cut or crumbled. This till has no definitely morainal surface form but occurs as a rubble surface near the west side of Wheeler Crest. The type locality of the Sherwin till as defined by Blackwelder (1931, p. 895) is at Sherwin Summit. Blackwelder (1931) erroneously concluded that the Sherwin till overlies the Bishop Tuff.

Although Sherwin till crops out in some valleys and high on some hillsides, it is obviously buried by Bishop Tuff in Owens Gorge and in the roadcut south of Toms Place (Sharp, 1968). The Sherwin till is hence older than the Bishop Tuff dated at 0.71 m.y. (Dalrymple and others, 1965). The Sherwin glaciation was correlated by Blackwelder (1931) with the Kansas glaciation of the Midwest sequence.

Although Blackwelder believed that there might have been an Illinoian glaciation in this area, he did not specify which moraines exemplified this glaciation. It is now generally agreed that the Mono Basin glaciation probably correlates with the Illinoian of the Midwest sequence (Sharp and Birman, 1963). Mono basin moraines are well exposed in Sawmill canyon of the Mono Craters quadrangle.

Recently an additional glaciation has been named the Casa Diablo for the type location near Casa Diablo Hot Spring (Curry, 1971). Radiometric ages date this glaciation at about 400,000 years ago.

Three major Wisconsinan age glaciations of the Sierra Nevada are dramatically represented in this area. Blackwelder initially concluded that the Wisconsinan sequence here could be reasonably subdivided into two stages on the basis of differences of extent, form, and boulder-weathering ratios. The oldest advance he designated the Tahoe and the youngest he called the Tioga. More recent work by Sharp and Birman (1963) and Birman (1964) add a third stage called the Tenaya between the Tahoe and Tioga. The Tioga moraines are generally found up-valley from and nested within the Tahoe moraines. Tioga till is very fresh and the moraines are quite small as compared with the associated Tahoe deposits.

Three neoglacial advances are recognized by Birman (1964) in the central Sierra Nevada. The neoglacial deposits from oldest to youngest are Hilgard, Recess Peak, and Matthes.

VOLCANIC GEOLOGY

The first comprehensive geologic mapping of this area was done by Gilbert (1938, 1941). The major late Tertiary and Quaternary units were identified at that time and the Long Valley-Mammoth embayment was recognized as a major volcanic center. Through continued work east of Mono Lake the Berkeley group has concluded that the Mono Basin developed during the last 3 million years primarily through downwarping and faulting (Gilbert and others, 1968). Most of this area has subsequently been mapped on a scale of 1:62,500 by the U. S. Geological Survey as part of the central Sierra project under Paul Bateman (Bateman, 1965; Crowder and Sheridan, 1971; Huber and Rinehart, 1965, 1967; Kistler, 1966; Rinehart and Ross, 1957, 1964).

Because of the continuous volcanism for the last several million years, rocks in this area have been dated to establish a Quaternary chronology (Dalrymple, 1963, 1964a, 1964b, 1967; Evernden and others, 1964) and to refine the paleomagnetic chronology (Dalrymple and others, 1965; Doell and others, 1966). The dated rocks in the area covered by this field trip are listed in Table 2. The Quaternary volcanism of this area may be grouped into three stages centered around the eruption of Bishop Tuff from Long Valley caldera. First is the development of a basalt to andesitic-basalt lava plateau over an area of moderate topography during the period of 3.2 to 2.7 million years ago.

The second stage involves the caldera cycle that corresponds closely with the patterns of resurgent cauldrons outlined by Smith and Bailey, (1968). The pre-caldera domes are represented by Glass Mountain (0.9 m.y.), Glass Mountain Ridge, Bald Mountain and a few other rhyolite to hornblende andesite domes. The caldera eruption of Bishop Tuff at 0.71 m.y. brought about the collapse of the Mammoth embayment area and spread a thick sheet of Bishop Tuff in all directions (see Figure 11). Next came the intrusion of post-collapse domes such as the one north of Whitmore Hot Springs (0.28 m.y.) and Mammoth Mt. (0.15-0.37 m.y.), the formation of other rhyolite to andesite domes in the resurgent cauldron core, and the filling of the northern and southern moat by basalts. This was followed by hydrothermal activity that persists to the present.

The third stage is represented by the Inyo Crater-Mono Crater belt that may or may not be related to the caldera cycle. This chain of active volcanoes conforms to the fundamental structural motif of the eastern Sierra escarpment.

ROADLOG

The following roadlog is divided into two field trips. The first day covers Bishop to Mammoth Lakes, and the second day considers Mammoth Lakes to Conway summit. Mileage is recorded in three columns. The first column is the cumulative daily mileage along the route. The second column is the interval between entries in the log. The third column is the total mileage north of Bishop along Highway 395. An index map showing the location of the field trip route is given in Figure 1. The stops numbered 1 through 21 are shown on Figure 2.

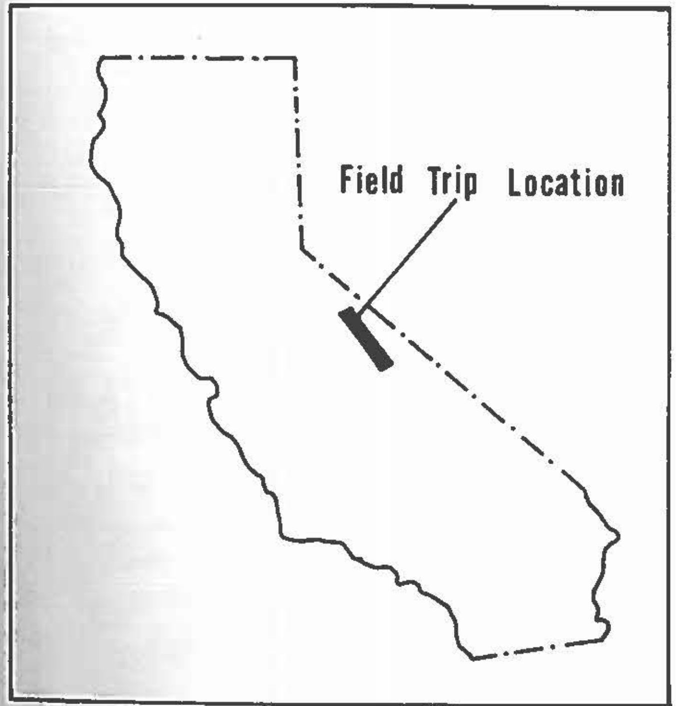


Figure 1—Index map.

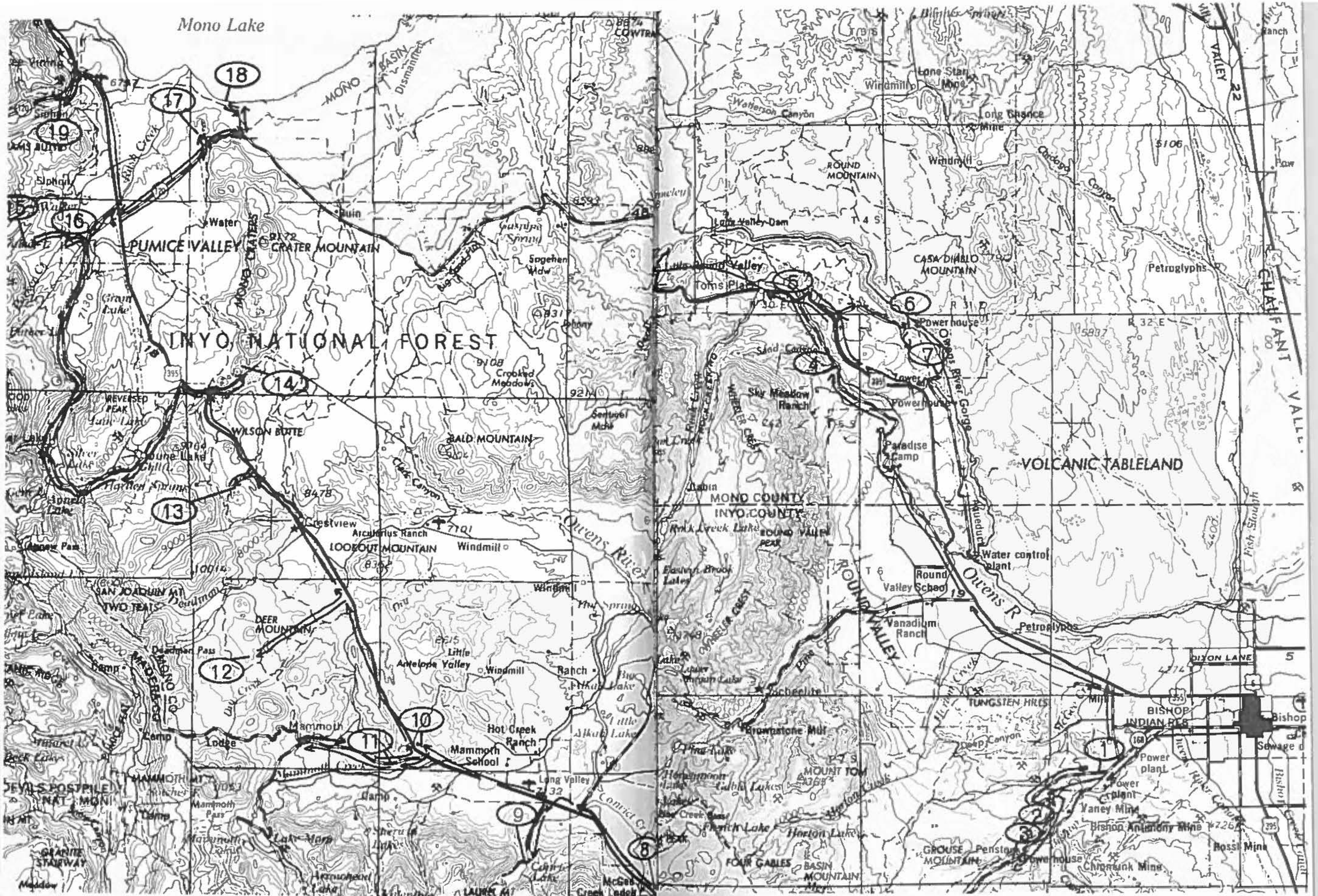


Figure 2—Field Stops, Bishop to Mono Lake. Bold numerals refer to stop numbers. Base from Mariposa Sheet (1:250,000).

Cumulative Miles	Interval	Miles North from Bishop on 395
0.0	Turn onto West Line Street from Highway 395.	0.0

The towns of Lone Pine, Big Pine and Bishop, California are located within a great graben which is bounded on the west by the Sierraa Nevada and on the east by the Inyo Mountains. The White Mountain-Inyo Mountain escarpment is a nearly linear feature whereas the Sierra Nevada front north of Bishop is a complex series of *en echelon* N-S trending normal faults which are periodically offset by north-dipping ramps. In front of each ramp is a deep embayment in the Sierra front such as Round Valley west of Bishop and the Mammoth embayment.

0.7

0.7 Northern Inyo Hospital. Field trip group meets west of the hospital on Line Street.

Proceeding from Bishop to STOP 1 on our left is the Coyote Flat ramp (Figure 3). The Tungsten Hills in the foreground were named for the several tungsten prospects (generally of scheelite) found along the contact of the calc-silicate pendants and Mesozoic quartz monzonite (Bateman, 1965). Remnants of initially flat-lying basalts dated at 9.6 m.y. (Dalrymple, 1963) are now tilted parallel to the dip slope of this ramp. Toward the mountains three stages of alluvial terraces extend outward from the Tahoe-aged moraine to our front. To our right is the prominent Owens River scarp cut into the Bishop Tuff.

2.9

3.6 A Basalt cinder cone that lies north of the road is partially covered by outwash gravels of Wisconsinan glaciations. The Tungsten Hills form the knobby granite exposures in the middle ground to the west. The road climbs up along the dip of the Wisconsinan outwash.

1.0

4.6 Ed Powers road to the north.

0.2

4.8 STOP 1 – Quartz monzonite melted by basalt dike.

Melting and assimilation of quartz monzonite by basalt is illustrated in this outcrop. The granitic rock is vesicular,

Figure 3—Coyote Flat warp (opposite); oblique aerial view. U. S. Geological Survey high altitude photo, series 744 R, number 209. Bold numerals refer to stop numbers.

indicating that it was melted near the surface so that gases could expand at low pressure conditions. The quartz monzonite is glassy and has columnar-joints perpendicular to the contact with the basalt. These columnar joints in the quartz monzonite indicate near surface cooling. Quartz crystals and postassium feldspar xenocrysts in the basalt are deeply corroded and surrounded with brown glass, wedge-shaped tridymite crystals or prismatic orthopyroxene. The potassium feldspars anomalously found in the basalt are thought to be a result of assimilation. The petrography of this outcrop was first described by Knopf (1918, p. 74-75; 1938, p. 373-376) and later by Bateman (1965, p. 151).

A remarkable panorama is seen from this vantage point. The White Mountains to the east present a nearly straight fault-scarp face. Youthful alluvial fans at the base are cut by recent antithetic faults. White Mountain Peak is the highest point on the range at 14,252 feet. The flat upper surface of the Bishop Tuff forms the middleground to the northeast and north. The granite peak of Casa Diablo Mountain (7,982) is a notable mountain to the north with the rhyolite dome of Glass Mountain (11,123) to its west. The upper plateau surface of the Bishop Tuff extends westward to Wheeler Crest (12,966). This granite ridge is followed south along a main Sierra scarp past the triangular face of Mt. Tom (13,652) and up into Buttermilk Country to our west. The Tungsten Hills make up the dark rounded granite exposures in the foreground to the west. The peaks noted on the skyline forming the Sierra crest south from Mt. Tom are Four Gables (12,825), Basin Mountain (13,225), and Piute Crags. To the west is the Coyote Flat warp.

To the north the surface of the Volcanic Tableland almost everywhere parallels internal layering in the Bishop Tuff. The central and eastern parts of the ash flow sheet have undergone relatively little erosion (50-200 feet) and the surface provides a reference plane that is sensitive to subsequent deformation. Fault scarps and broad warps are remarkably preserved. The western part of the sheet have been more deeply eroded, and all but the largest features of the original surface were destroyed by streams that headed in the Sierra Nevada. The most conspicuous features of the landscape are resistant fumarolic mounds and ridges (Sheridan, 1970) that have been indurated by gas action.

2.3

7.1 Buttermilk Road. View of the Sierra crest to the west.

1.1

8.2 STOP 2 – Dissected lateral moraine of Tahoe stage. Road winds through fresh roadcuts in Tahoe till. This stop is at a view-point on top of moraine. This is a fairly fresh, typically sand-granular mountain till. Constituent boulders are still fairly well preserved with about 30% being fresh and about 70% showing weathering features. The quantitative age determination of this Tahoe moraine is based primarily on boulder counts and weathering phenomena, i.e., (1) weathered vs. unweathered ratios, (2) number of boulders over 1 foot diameter in a given area, and (3) the ratio of granitic boulders/resistant metamorphic boulders (Blackwelder, 1931; Birman, 1964; Sharp, 1968). Boulders on the surface of this moraine exhibit polishing, cutting, notching, grooving and pitting by wind-blown sand. Crudely-developed ventifacts on the surface demonstrate an uneven resistance to the effects of sand blasting and polishing. Feldspar is less resistant to these agents than quartz and so is more easily eroded or pitted, whereas quartz under the same conditions will be polished. Some granitic boulders are split by frost action working along incipient joints and other boulders are spalling. A few of the granitic boulders have been reduced to grus. Xenoliths within granitic boulders commonly form weathering pits 6 inches wide to 8 inches deep. Artifacts of brownish-yellow chert are found on the moraine. The soil horizons are about 24 inches thick here.

The glacial outwash extending from this left lateral moraine abutts against the tungsten Hills and grades toward Bishop. Several terraces are cut into this deposit.

From this viewpoint the Tungsten Hills form the low knobs of granitic material protruding through the glacial outwash alluvium to the northwest. The major Sierra scarp is visible in the abrupt rise of Wheeler Crest 7,000 feet above the valley floor. The Bishop Tuff forms an even-surfaced veneer covering the valley from the Sierra Nevada on the west to the White Mountains on the east. Upper Precambrian and Cambrian sedimentary rocks form distinctive bands in the White Mountains to the east. The dark rock exposed on the top of the range to the southeast is the Campito Formation in which Olenellid trilobites have been found. The banded rock directly beneath the Campito Formation is the Precambrian Deep Springs dolomite and sandstone. Directly under the Deep Springs Formation is the massive, light-colored Reed Dolomite.

As we proceed up-valley parallel to Bishop Creek we are driving up an intermoraine valley of Tahoe age (equivalent to the Early Wisconsinan of the Midwest sequence). To our left we can see where Bishop Creek is diverted against bedrock by the south lateral Tahoe moraine. Most of the Tahoe moraine has subsequently been removed by erosion from the south wall of the canyon.

2.6

10.8 STOP 3. – Recessional moraine of Tioga glaciation. The soil profile is less well-developed than on older moraines, and there is less cementation of the fine fraction of the till. The boulder count is higher on the Tioga than on the Tahoe moraine at STOP 2. Boulders are much fresher and less weathered. Wind polish and spalling of the granite boulders is much less developed than on the Tahoe moraine. To the east a nest of Tioga recessional moraines is situated within the Tahoe laterals. To the southeast skyline lies the Palisades Glacier – the southernmost active glacier in the United States.

Return toward Bishop down Highway 168.

1.5

12.3 View of the White Mountains and Bishop Tuff to the northeast (Figure 4). Recent tectonism is obvious from fault scarps and youthful alluvial fans.

0.5

12.8 6000 foot mark.

0.6

13.4 Pass STOP 2.

0.4

13.8 Side glacial channel of Tahoe left lateral moraine.

0.7

14.5 Buttermilk Road. View of the White Mountains to the east. Upon leaving the Tahoe moraines on our way down slope the road follows the steep outwash fan grading from the Tahoe moraines toward Bishop. Numerous boulders up to 4 feet in diameter were carried here by the proglacial streams during the building of the outwash fans.

1.5

16.0 Terraces are seen cut into the outwash surface to the south.

0.8

16.8 Pass STOP 1.

Figure 4—Bishop Tuff southern lobe (opposite). The tuff surface is dotted with fumarolic mounds and ridges (Sheridan, 1970) and cut by numerous faults. Youthful alluvial fans apron the White Mountain escarpment. U. S. Geological Survey oblique high altitude photo, series 374L.

0.2

17.0 Ed Powers Road. Bear left to connect with Highway 395.

1.0

18.0 Red Hill Road. The basalt cindercone to the south is overlain by Wisconsinan age outwash. The erosional scarp of the Bishop Tuff is straight ahead. Casa Diablo Mountain and Glass Mountain are prominent peaks on the skyline to the north.

1.3

19.3 Junction of Ed Powers road and Highway 395. A thin deposit of wind-blown sand directly overlies the nonwelded upper surface of the Bishop Tuff here.

After turning onto 395, Wheeler Crest lies straight ahead with Mount Tom to the west. The gentle warp of Coyote Flat and Tungsten Hills to the north is easily seen (Figure 3).

0.6

19.9 The basalt cone to the north of the road is surrounded 5.8
by the overlying Bishop Tuff.

0.8

20.7 Pleasant Valley Dam Road. Low gravel-capped terraces 6.6
cut into the Bishop Tuff on both sides of the highway.

2.8

23.5 Wisconsinan moraines extend from the U-shaped Pine 9.4
Creek Valley at the south end of Wheeler Crest. The town of Rovana is nested between the Wisconsinan moraine crests that extend to the east and a set of somewhat older moraine ridges that trend to the southeast.

0.8

24.3 Pine Creek Road turnoff. Fumarolic mounds and ridges 10.2
on the Bishop Tuff are prominent to the north and east of the road. The Bishop Tuff surface dips under the valley fill along the highway and this unit probably extends in the subsurface to the Sierra front.

1.2

25.5 Pine Creek. 11.4

0.4

25.9 Old Sherwin Grade Road. Bear left off Highway 395. 11.8
This road follows the southwest scarp of the Bishop Tuff surface.

1.9

27.8 The bouldery deposit on the valley floor in this region is the outwash fan of Rock Creek on the floor of Round Valley. The deformed stripped surface of the Bishop Tuff rises to the east. Conical hills from 50 to 100 feet high on the surface mark fumarolic mounds (Sheridan, 1970). The white

alteration material comprising the vapor-phase zone of the mounds is cristobolite, tridymite and alkali feldspar. These fumarole sites are concentrated along early joints in the Bishop Tuff, indicating that jointing occurred after compaction of the tuff and prior to complete cooling.

1.2

29.0 Paradise Camp. Bouldery well-cemented gravel is plastered on the side of the canyon wall. A similar gravel occurs as a thin veneer on the Bishop Tuff surface in many places (Sharp, 1968). The distribution of these gravels is shown in Figure 5. The boulders are strongly decomposed indicating a fairly old age.

0.2

29.2 Exposure of the old gravel deposits resting on Bishop Tuff.

0.2

29.4 5000 foot marker. Road progresses up over the warped Bishop Tuff surface. West across Round Valley is the 6,000 foot scarp of Wheeler Crest. To the southwest is the U-shaped glaciated gorge of Pine Creek with faulted lateral moraines extending from the canyon mouth into Round Valley. Recent faulting along the eastern scarp of the Sierra Nevada is illustrated by fault scarps approximately 10 to 20 feet high cutting alluvial fans developed along the Sierra scarp.

0.9

30.3 Bouldery glacial outwash deposit over the Bishop Tuff. The soil formation on this gravel is much deeper than that on the Mono Basin moraines at Sawmill Canyon (STOP 15); yet it rests on the Bishop Tuff and is therefore younger than the Sherwin till. Perhaps these gravels are related to the Casa Diablo glaciation of Curry (1971).

1.0

31.3 Rock Creek gorge to the east.

1.0

32.3 6,000 foot marker. The road here traverses the pinyon-juniper forest in which a few scattered Jeffery pine grow. To the north of the road in Rock Creek Gorge is one of the few places where a basal welded vitrophyre of the Bishop Tuff is exposed. In most places the welded zone is devitrified. The vitrophyre occurs about 150 feet above the base of the sheet; the intermediate material is nonwelded to partially-welded vitric tuff. The tuff here overlies the quartz monzonite of Wheeler Crest (Rinehart and Ross, 1957). This vitrophyre is thought to be formed by such rapid cooling of the hot tuffaceous body, that the typical devitrification of the matrix did not occur. Above the columnar-jointed vitrophyre are the densely-welded devitrified zone, the partially-welded vapor-phase zone, and the partially-welded vitric zone which occurs at the top of the section.

0.9

33.2 Top of Sherwin rise. Nonwelded Bishop Tuff is exposed in the road cuts as we begin to descend into Rock Creek.

0.2

33.4 Wheeler Crest quartz monzonite underlies Bishop Tuff.

0.6

34.0 Rock Creek Bridge.

0.3

34.3 Northeast trending fault displaces Sherwin till to the north in contact with the Wheeler Crest quartz monzonite.

0.3

34.6 STOP 4. Soil horizon in Sherwin till sequence. Lower till is supposedly more deeply weathered than the upper that is typical Sherwin. Sharp (1968) suggests that this might be the Sherwin-McGee till contact. The lower till should be considered in light of widespread pre-Sherwin tills in this area noted by Curry (1966, 1971).

1.3

35.9 Exposures of Sherwin till in road cuts.

0.8

36.7 STOP 5. Juncture with Highway 395. Bear left and park in Forest Service parking area 0.1 mile to the north. Walk 0.2 miles south to stop 5 along Highway 395.

This roadcut, first described by Putnam (1960a), exposes Bishop Tuff overlying Sherwin till. Four units are exposed in the road cut (Figure 6). At the base is Sherwin till, consisting of thoroughly decomposed boulders of granitic and metamorphic rocks from the headwaters of Rock Creek. Some of the boulders are striated. Overlying the till is a 15 foot section of bedded Bishop Tuff air fall ash and lapilli. The layering of the air fall unit is parallel to the south-sloping till surface. Overlying the air fall deposit is nonwelded Bishop Tuff ash flow with a faint suggestion of horizontal bedding. This nonwelded ash flow unit lacks the induration of the Bishop Tuff in the bluffs to the north. It is not welded because it was close to the edge of the ash-flow sheet and cooled quickly. A potassium-argon date on the basal pumice unit yields an age of 0.71 m.y. (Dalrymple and others, 1965). The fourth unit is boulder gravel deposited by Rock Creek, resting on the pumice at the top of the cut. This gravel may be

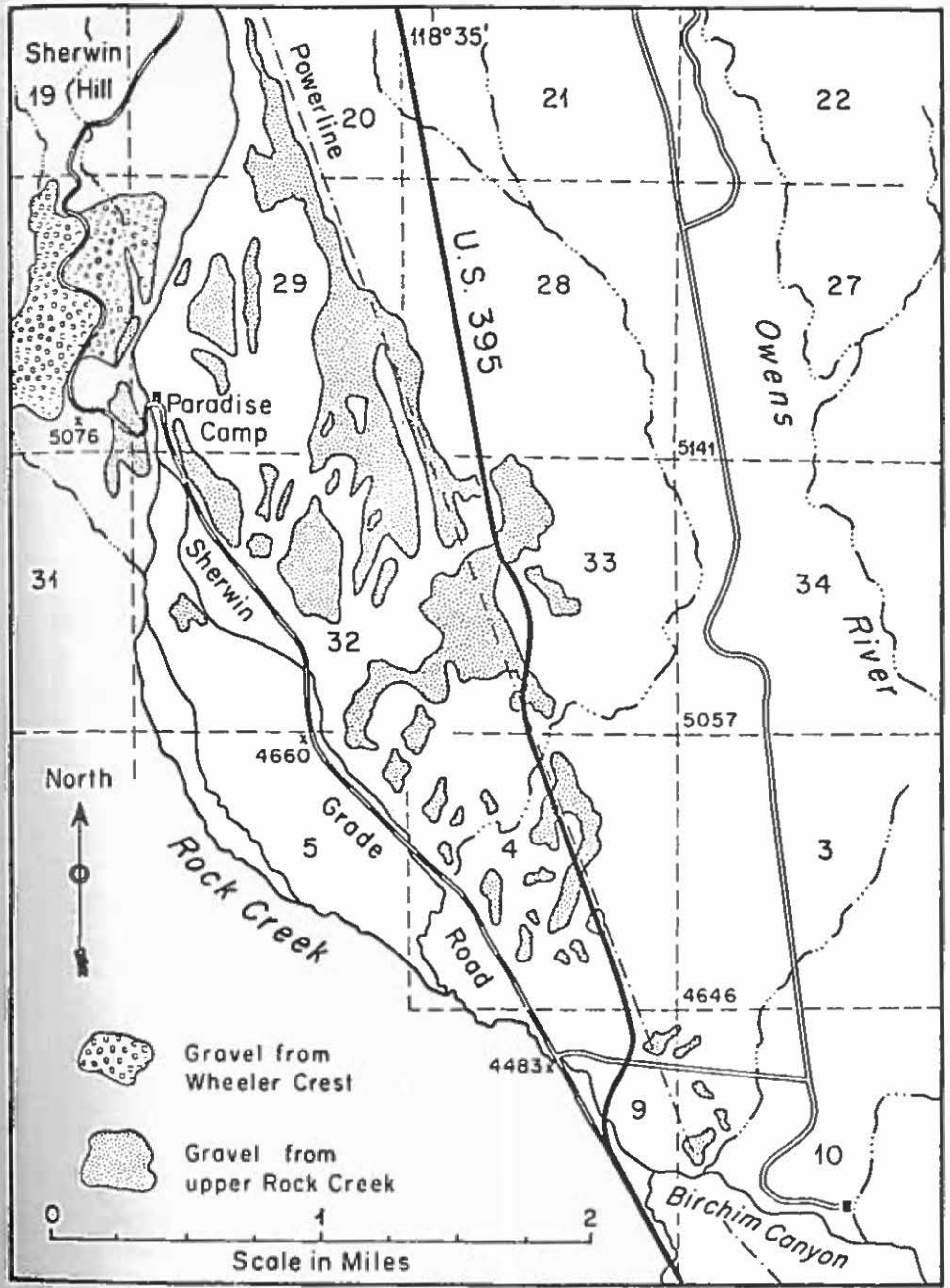


Figure 5—Post-tuff gravels on Sherwin Grade. Figure is from Sharp (1968, p. 360) with permission.

outwash of the Tahoe or older glaciation. After its deposition, it slumped into fissures in the underlying pumice, possibly opened during earthquakes, and formed clastic dikes that narrow and grow fine-grained downward into the Sherwin till below.

Return to Highway 395 and head south.

0.7

37.4 Exposures of Sherwin till in road cuts. Where the road forms double lanes, stay in left lane. Be prepared to turn left onto an unmarked dirt road. 21.5

0.6

38.0 Turnoff for Owens Gorge overlook. Sherwin till composes the round knob to the south with the microwave relay station at the crest. Bishop Tuff forms the cliff exposures to the north of the road which follows the contact between Sherwin till and Bishop Tuff (Figure 7). 20.9

0.8

38.8 Granite knobs protrude on the left side of the road. Tuff crops out on right side. Bear to the right between two granite hills. The road then traverses the Bishop Tuff surface.

0.5

39.8 STOP 6. Owens Gorge overlook. Four units are visible within the gorge. Mesozoic quartz monzonite at the base of the section is overlain by a series of basalt flows dated at 3.2 m.y. (Dalrymple, 1963). A thin till or glacial outwash deposit lies between the basalt and the overlying Bishop Tuff. Because till was encountered at this position in the water tunnel excavation from here to the head of Owens Gorge, it is assumed to be the same as the type Sherwin till in the hills to the west (Putnam, 1960; Sharp, 1968).

The zonation of the Bishop Tuff is similar to that found in many moderate temperature ash-flow sheets of magnitude 4 to 6 as defined by Smith (1960a, p. 819). In sections thicker than 400 feet, as seen in the gorge to the south, the central part of the sheet is comprised of a densely-welded zone which in Owens George reaches a maximum thickness of 300 feet. Toward the top and base, as well as northward over the basement high, the degree of welding decreases. Most thick sections with a zone of dense welding display devitrification in the densely-welded zone. Vapor-phase crystallization develops in the overlying partly-welded to nonwelded ash. Although in lower Owens Gorge the sheet contains two cooling units with densely-welded zones (Sheridan, 1968, p. 351), the general zonal pattern of the sheet here is that simple cooling.

Figure 6—Big pumice cut. The four units exposed from the base are: Sherwin till, Bishop Tuff air fall, Bishop Tuff ash flow, and outwash gravels.

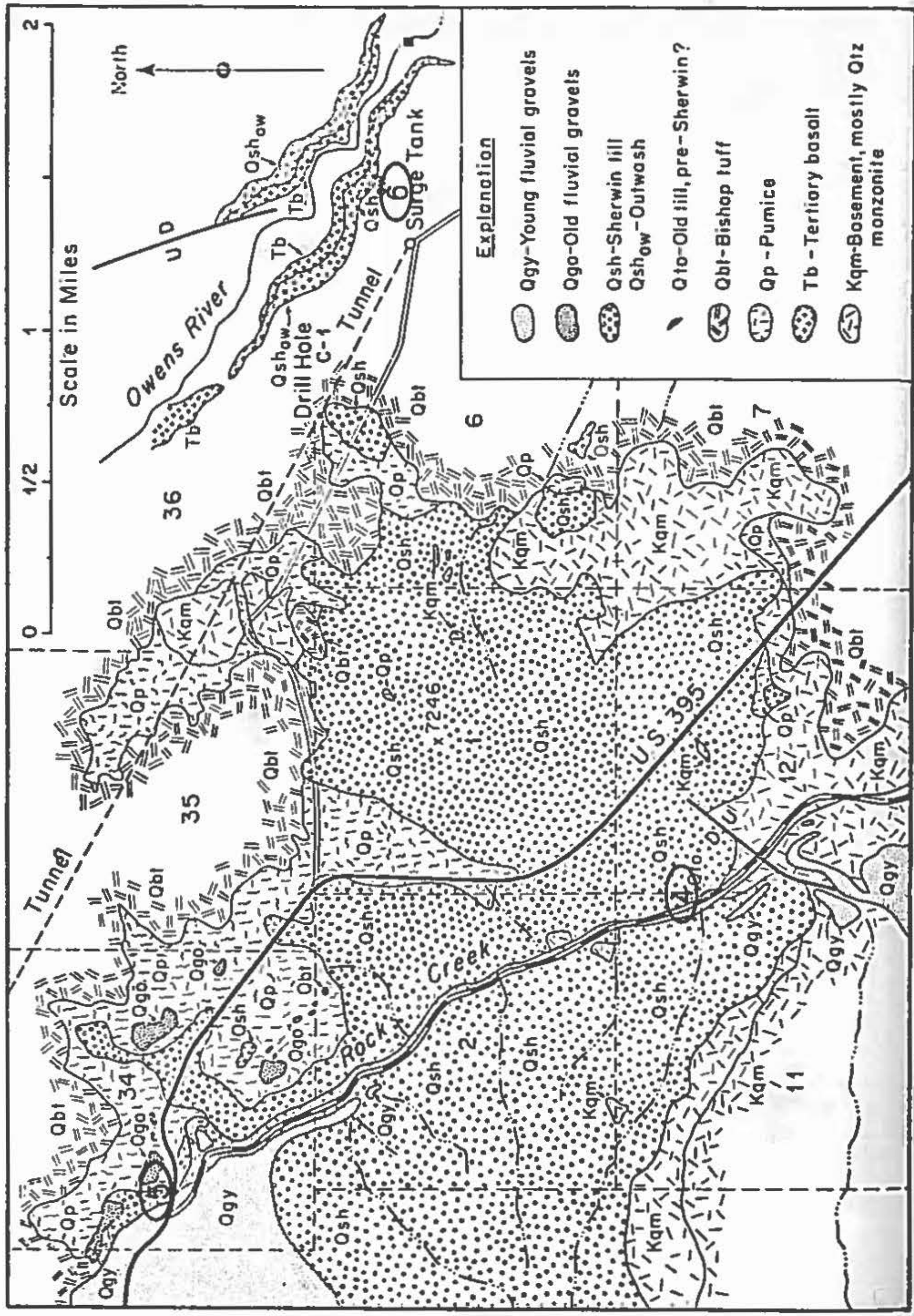


Figure 7—Geologic map of Sherwin Grade area. Figure is from Sharp (1968, p. 354) with permission. The unit Qp is nonwelded ash flow of Bishop Tuff.

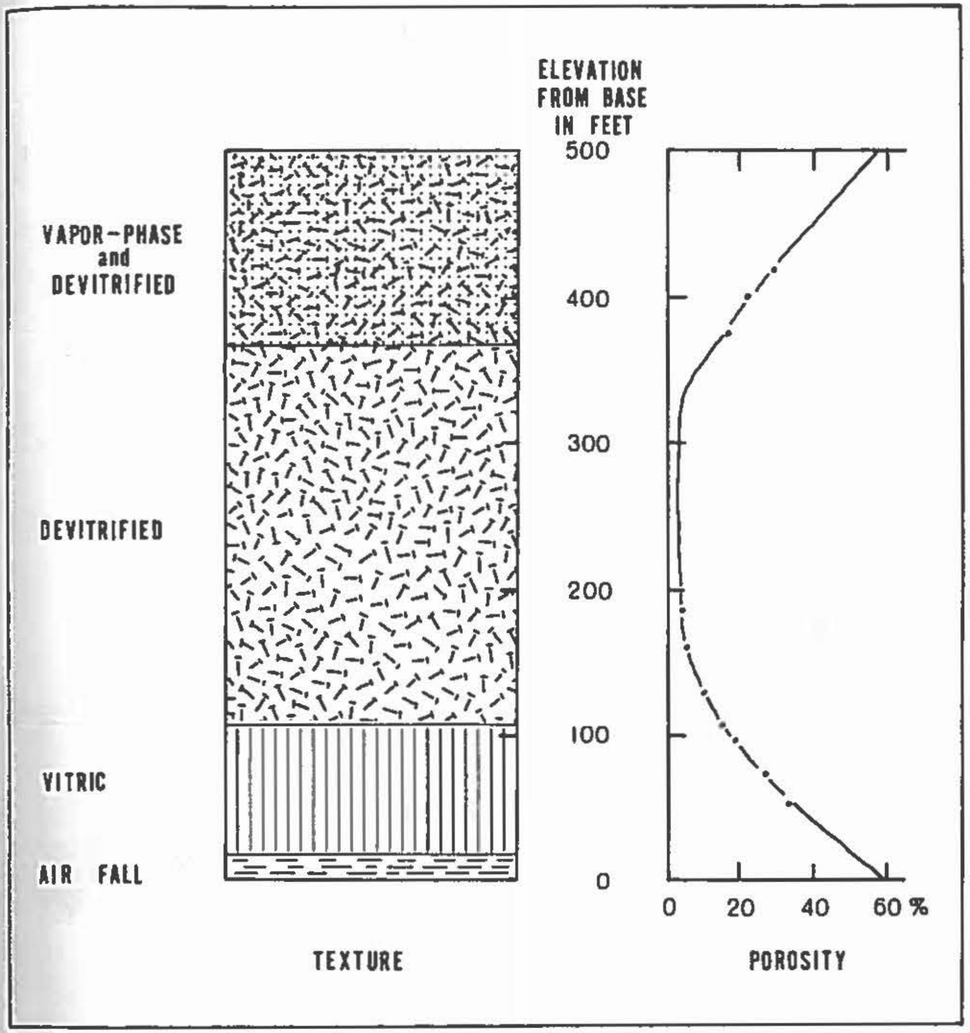


Figure 8—Bishop Tuff density profile from a section in Owens Gorge one mile south of the surge tank. Figure is from Sheridan (1970, p. 856).

Figure 8 demonstrates the ash-flow zonation in a section 1 mile south of the overlook. Nonwelded vitric ash at the base of the sheet overlies a white well-bedded air fall unit. Above the nonwelded ash is partially-welded (porosity 10 to 45%) vitric tuff which grades upward to densely-welded devitrified tuff (porosity less than 10%). The partially-welded to nonwelded upper part of the sheet (porosity less than 10%) shows a gradual upward superposition of vapor-phase crystallization on devritification. Although vapor-phase crystallization has little effect on the appearance of rock with porosity between 10 and 20%, the cliff-forming topography of the densely-welded devitrified zone gives way to a slope-forming unit at this point. Widely-spaced (20 to 40 feet) joints in the densely-welded devitrified zone, which are incrusted with tridymite and fayalite toward the top, abruptly yield to closely-spaced (1 to 2 feet) columnar joints at the 10% porosity level (Sheridan, 1970).

The densely-welded zone and the zone of the vapor-phase alteration pinch out northward in the gorge as the tuff sheet thins over the bedrock.

0.6

40.4 Bear left on paved road heading west after proceeding around loop.

0.3

40.7 Bear left onto main power road.

1.7

42.4 Turnoff for Upper Gorge power plant. Bear sharp left.

0.3

42.7 STOP 7. Department of Water and Power, City of Los Angeles gate.

This canyon section illustrates typical ash-flow zonation in the upper part of the Bishop Tuff sheet and also demonstrates the cooling history of the sheet during the stage of fumarole development.

Zone contacts provide a first-order key to interpreting the thermal configuration within the cooling ash-flow sheet. Devitrification is the main type of secondary crystallization in samples with bulk rock porosity of 0 to 20%. Vapor-phase crystallization, which requires pore space to develop, is not evident in rocks with less than 10% porosity and is best developed in rocks with greater than 20% pore space. The zones of vapor-phase crystallization and devitrification overlap in the upper crystalline part of the sheet which is partially-welded to nonwelded. It is apparent that the lower limit of the vapor-phase crystallization is an even surface which is controlled by the welding character of the sheet.

The densely-welded devitrified zone (0 to 10% porosity) of the Bishop Tuff is a cliff-forming unit, whereas the overlying partially-welded devitrified zone (10 to 20% porosity) is a slope former. Hence the 10% porosity level of Bishop Tuff

in deep gorges is easily recognized as the top of the vertical cliff in the lower parts of the canyons. This surface is always a smooth, gently sloping horizon except where broken by faults. If this welding-zone contact does indeed represent an isothermal surface, it must be assumed that the temperature configuration within the sheet during welding was more or less regular, and the isothermal surfaces were smooth, gently dipping planes.

The upper surface of the vapor-phase zone is controlled in large part by the rate of gas flow upward through the sheet. If rock porosity were the only factor controlling gas flow, the upper surface of the vapor-phase zone should be a smooth, gently sloping plane parallel to surfaces of equal welding. To a first approximation, the upper vapor-phase contact does have this configuration. However, there are notable irregularities in the vapor-phase surface near fumarolic mounds. Local thickening of the vapor-phase zone by as much as 50% at fumarolic centers resulted from a much greater gas flow, which raised the temperature enough to promote vapor-phase crystallization.

A qualitative picture of the thermal regime between two fumarolic fractures at the time of initial fumarolic activity is presented in Figure 9. The position and spacing of isothermal surfaces and heat flow lines obviously changed as the sheet cooled. Therefore estimates of temperatures and heat flow at the start of the fumarolic stage are based on approximations outlined by Sheridan (1970).

Because heat is transported upward much more rapidly by escaping vapors than by conduction, fumarolic fratures are areas of abnormally high heat flow. The direction of heat flow near fumarolic cracks at depth within the sheet must have a vector component away from the fracture as well as a upward component. The thermal regime during fumarolic stages of cooling must therefore be quite irregular as compared with the early thermal regime of the sheet during welding.

The jointing pattern of Bishop Tuff in central Owens Gorge also has direct implications regarding relative temperature distribution and heat flow near fumaroles during cooling of the ash-flow sheet. If we assume that jointing occurs normal to isothermal surfaces, then the isothermal configuration in this section of Owens Gorge must have been exceedingly complex. Although these joints are often vertical, inclined and radial joint patterns are not uncommon. Some

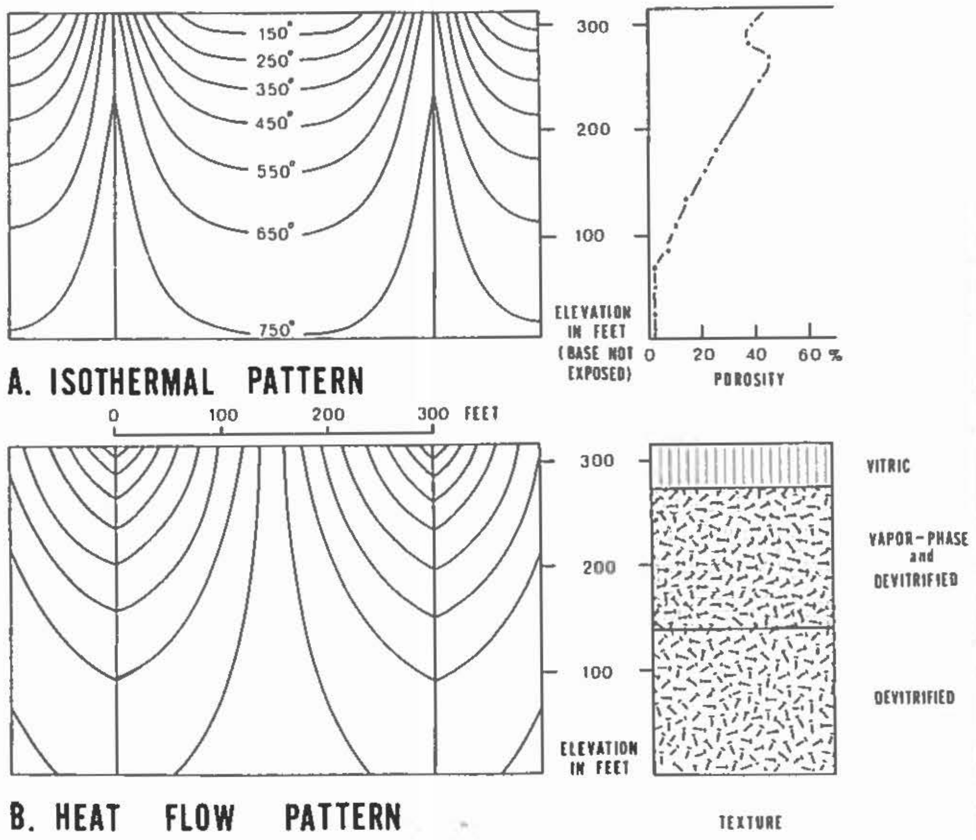


Figure 9—Bishop Tuff cooling patten between two fumarolic fractures in Owens Gorge along the power line road. Figure is from Sheridan (1970, p. 862).

fumarolic mounds are found above the center of columnar joint roses in the partially-welded zone effected by vapor-phase crystallization. Along this power road, such columnar joint roses in the central section of Owens Gorge are spaced at 300 to 500 feet (Figure 10).

From the gate proceed on foot down the power plant road. Orange partially-welded vitric tuff is the cap rock of

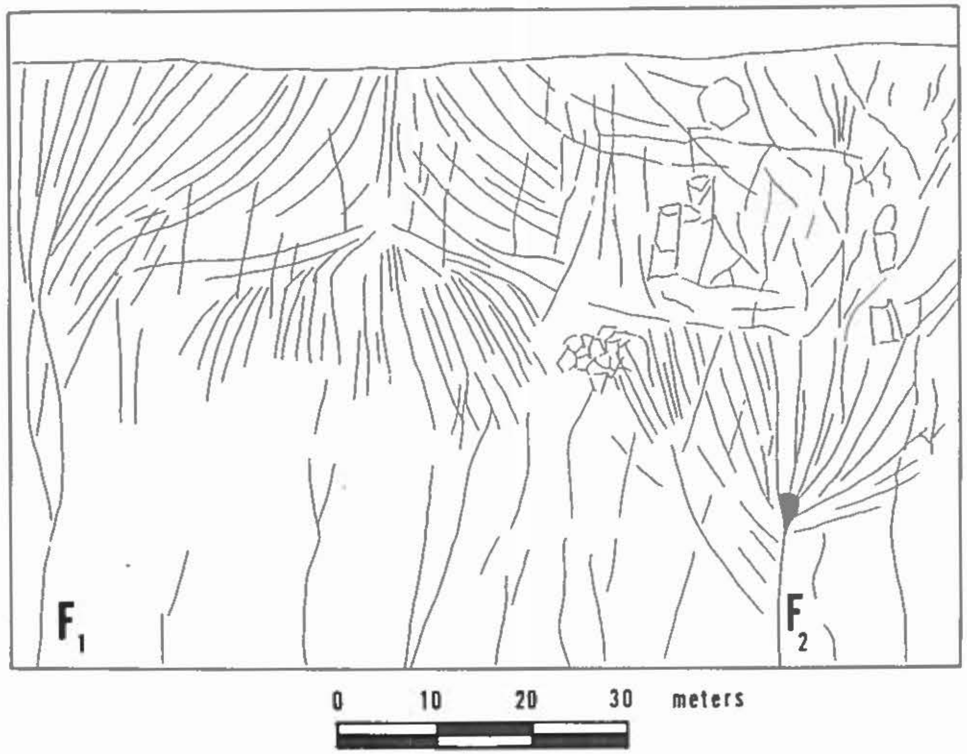


Figure 10—Joint pattern below fumarolic ridges corresponding to the cooling pattern of Figure 9. Figure is from Sheridan (1970, p. 862).

the gorge section here. An irregular development of vapor-phase crystallization along fumarolic fractures can be seen near the gate. Down section the tuff porosity decreases and the typical columnar joints of the vapor-phase zone are noted. Across the gorge, fumarolic centers of Figure 10 are seen with their rosette joint patterns. Below the vapor-phase zone is the densely-welded devitrified tuff that forms the vertical walls of Owens Gorge.

Chemical analyses of tuff from this section are given in Table 3.

TABLE 3 – Chemical Analyses of Bishop Tuff*

	1	2
SiO_2	75.6	76.7
Al_2O_3	13.1	13.0
Fe_2O_3	.8	.5
FeO	.13	.26
MgO	.18	.13
CaO	.56	.52
Na_2O	3.8	3.7
K_2O	4.8	4.5
TiO_2	.11	.06
P_2O_5	.01	.00
MnO	.04	.03
H_2O	.35	.34
CO_2	.16	.08
Total	99.64	99.82

*From Bateman, 1965.

0.2

42.9 Bear left onto power service road.

0.7

43.6 Cutoff road to Highway 395. Upper surface of Bishop Tuff in this area is partially-welded to nonwelded. Fumarolic mounds project through this nonwelded tuff.

0.3

43.9 Highway 395. Bear right. Good exposures of nonwelded Bishop Tuff here exhibit some banding of pumice. Development of white vapor-phase alteration of pink nonwelded ash is well exposed just to the north of this junction. 16.7

0.1

44.0 6,000 foot mark. 16.8

2.1

46.1 Bishop Tuff pinches out against a bedrock high. Quartz monzonite exposed in this roadcut is directly overlain by Sherwin till on the north side of the exposure. Exposures of Sherwin till continue up onto Sherwin Hill. 18.9

1.4

47.5 Exposures of Sherwin till in the road cut. 20.3

0.6

49.2 Big pumice cut. 22.0

1.1

50.3 Toms Place turnout. Rock Creek canyon is the prominent U-shaped valley in the Sierra front to the west. To the east the low bluffs are composed of Bishop Tuff. The various benches in the tuff mark original ash-flow contacts. 23.1

1.0

51.3 Three ash flows of the Bishop Tuff are present in the cliffs to the north. The dip of these units is to the northeast, back toward the caldera. This suggests post-eruption slumping of the southern caldera wall. 24.1

1.3

52.6 Pleistocene lake terraces cut into the Bishop Tuff are seen to the east. New road cuts expose fresh nonwelded to partially-welded tuff. 25.4

0.4

53.0 McGee Mountain rises straight ahead. Wisconsinan moraines that extend into the valley from Hilton Creek and McGee Creek to the west are offset by faults. 25.8

0.7

53.7 Crowley Lake exit. 26.5

0.7

54.4 STOP 8. Scenic turnout. 27.2

This stop is located about 4 miles southeast of the southern margin of Long Valley caldera, a 9 x 19 mile east-west depression that forms a large embayment in the Sierra front (Figure 11). The prominent mountain due north is Glass Mountain, a 11,100 foot ridge of rhyolite flows and ash which rises about 4,000 feet above the valley floor. Glass Mountain has been dated at 0.9 m.y. (Gilbert and others, 1968, p. 296) and is a precaldera range. The northeast rim of the caldera is visible from this point and can be traced from the round treeless slopes of Bald Mountain eastward along Glass Mountain ridge in a curbing arc down to the north shore of Crowley Lake.

Lookout Mountain to the north is one of several rhyolite domes which have intruded the collapsed caldera. Smith and Bailey (1968, p. 629) cite Long Valley as the "youngest large epicontinental caldera in the United States." It shows incipient resurgence associated with hydrothermal activity in the southern ring-fracture zone.

The south-sloping plateau of Bishop Tuff can be seen to the southeast across Lake Crowley reservoir. At least three ashflow units dip towards the caldera. This dip is due to post-collapse slumping of the caldera rim and to welding compaction of the tuff in the thicker central part.

Pleistocene Long Valley Lake occupied much of the down faulted block on the eastern end of the caldera. Lake shore terraces and lake beds are present through much of this area

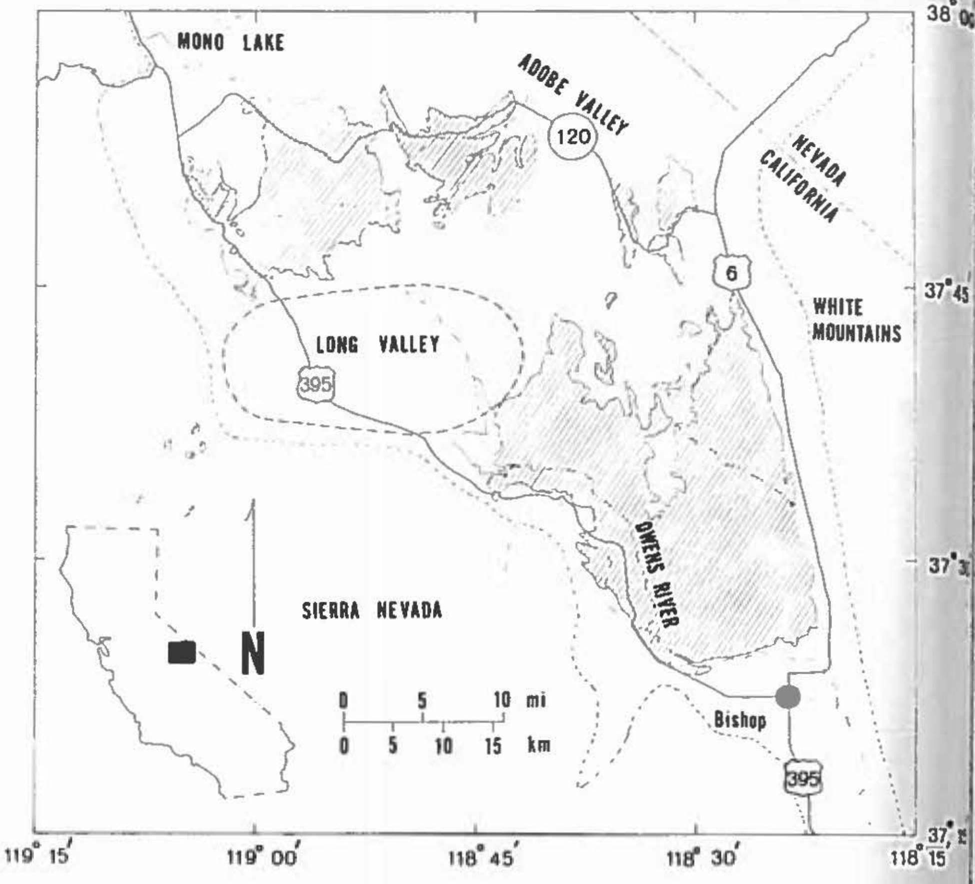


Figure 11—Location of Long Valley caldera. Bishop Tuff, shown by diagonal pattern, has a radial distribution about the caldera. Figure is from Sheridan (1970, p. 851).

and can be easily detected across Crowley Lake marina to the east. Incipient resurgence of magma into the caldera is noted by tilting of the lake terraces from a level of 7,100 feet at Long Valley Dam to an elevation of 7,800 feet along the north side of the caldera. Post-caldera rhyolites intrude and overlie the lake beds at several places.

To the west, Pleistocene lake terraces cut the moraines in Hilton Creek and McGee Creek. The shoreline can be traced to the north where the road rises over it east of McGee Mountain.

1.8

56.2 McGee Creek. 29.0

1.4

57.6 Crowley Lake Drive exit. 30.4

1.6

59.2 Whitmore Hot Springs exit. Mammoth Mountain, dated at 370,000 years (Dalrymple, 1964a), is a quartz latite dome at the western margin of Long Valley caldera. The Minarets are the sawtooth Sierra peaks to the northwest with Banner and Ritter to their north. In the middle ground the flat-topped domical mountain is Lookout Mountain, a post-collapse rhyolite dome. The rhyolite domes and lavas north of Whitmore Hot Springs are post-caldera dated at 280,000 years (Doell, and others, 1966). 32.0

0.9

60.1 Convict Lake turnoff. Turn left from Highway 395. The older east-trending moraine to the south of this road is interpreted by Curry (1971, plate 1) to be Casa Diablo till with a core of Sherwin till. This explanation differs from that of Sharp for STOP 9 given below. 32.9

2.1

62.2 STOP 9. Tioga recessional moraines at Convict Lake (Figure 12). The following discussion of this morainal assemblage is by R. P. Sharp in the INQUA field guide (Wahraftig and others, 1965).

"The geometry of the [moraines] at Convict Lake is one of the most complicated along the east side of the Sierra Nevada. The terminal moraines of the Convict Lake glacier are clearly visible from Highway 395 west of the turnoff [(Shelton, 1966(fig. 208)]. East of these a prominent morainal ridge 1,000 feet high trends eastward toward Lake Crowley. The high flat-topped mountain behind the ridge is McGee Mountain, and the . . . bouldery patches near its top are the [type of locality of] McGee Till."

"The McGee Till rests in part on a surface of low relief carved across metamorphic rocks and in part on patches of basaltic andesite (Rinehart and Ross, 1964). The andesite has been dated by the potassium-argon method at 2.6 m.y. (Dalrymple, 1963). According to Putnam (1962) at least 3,500 feet of displacement on the faults along the north and east bases of McGee Mountain took place after the deposition of the McGee Till, but his interpretation is questioned by Lovejoy (1965) who postulates no major Pleistocene faulting at this site. The till consists largely of granitic blocks (many more than 20 feet long) derived from the head of McGee Creek Canyon, a few miles to the south, and of metamorphic rocks from cirques tributary to McGee Creek (Blackwelder, 1931; Putnam, 1962). Although the upper surfaces of the blocks are deeply etched by weathering so that mafic inclusions stand a foot or more in relief, protected undersides of boulders buried only a few inches in till preserve glacial polish and striations."

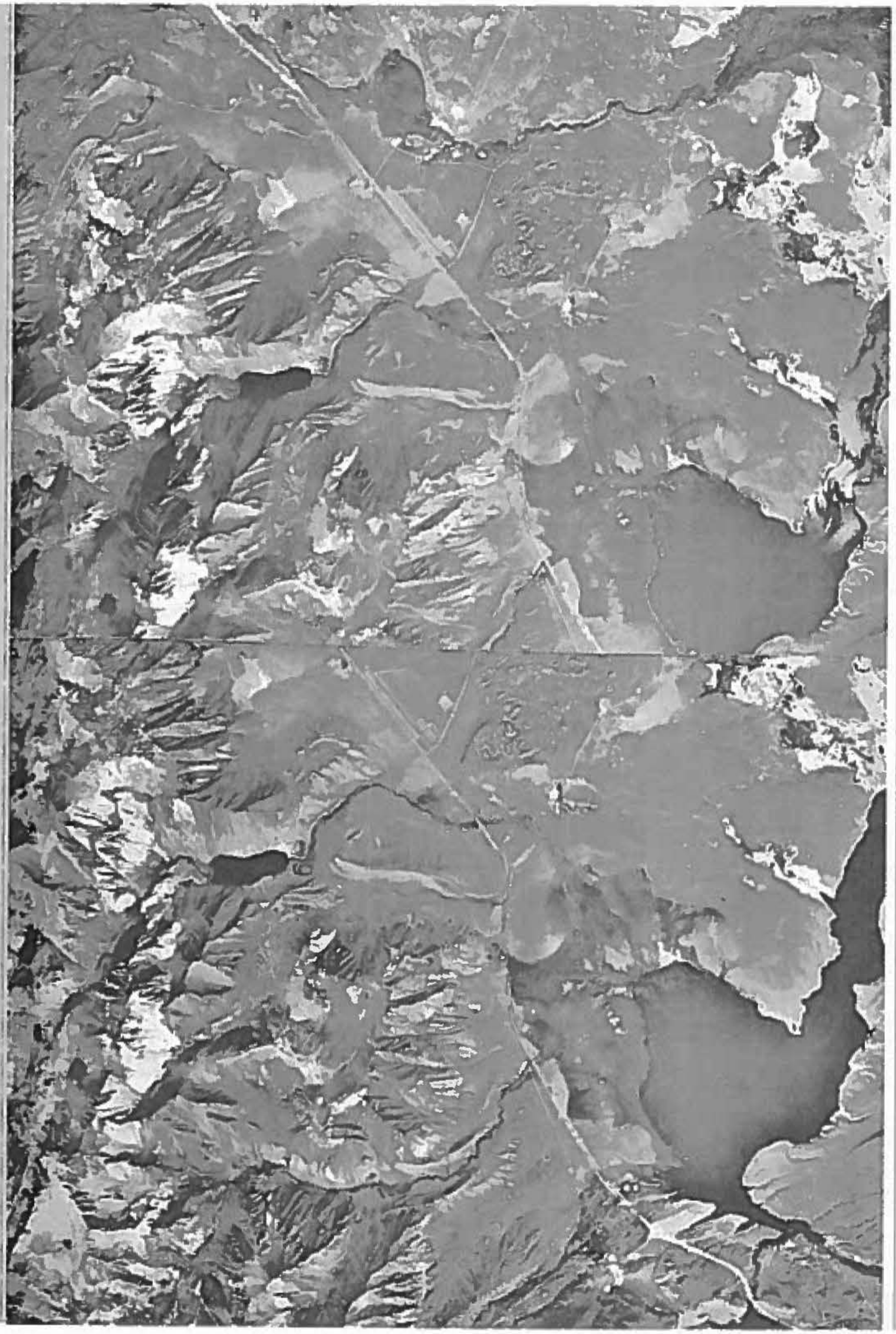
"The canyon of McGee Creek, south of McGee Mountain, is 2,000 feet below the level of the till, and debouches directly onto the floor of Long Valley on the east side of the mountain. A glacier thick enough to fill the present canyon and deposit the McGee Till would also have built a piedmont lobe several miles across the floor of Long Valley. There is no evidence for such a lobe, and it is concluded therefore that the McGee Till was deposited when the canyon of McGee Creek was much shallower than now, and probably when the frontal escarpment was much lower."

"The thousand-foot-high ridge east of Convict Lake is the north lateral moraine of an ancient glacier that followed an easterly course from the mouth of Convict Creek canyon, rather than the northerly course of the present creek. Till plastered against the base of McGee Mountain to the same height as the north lateral moraine was the south lateral moraine of this glacier, and Tobacco Flat, between the ridge and McGee Mountain was the glacier bed. The north lateral moraine was breached at its west end by Convict Creek, and the more recent glaciers took a northerly course through this breach, and deposited the massive morainal loops north of Convict Lake as well as the lateral moraines blocking the west end of Tobacco Flat."

"The moraines at Convict Lake have been subject to various interpretations. Blackwelder (1931) made no map of them, but in a photograph (fig. 25, p. 901) he labelled the outer moraine of the north loop as Tahoe. Kesseli (1941a) from a topographic study suggested that Convict Creek and its glacier had changed from an easterly course through Tobacco Flat to a northerly course as at the present, and that this change probably required a period of ice-retreat between two glaciations."

"Putnam (1960b, 1962) mapped the massive east-trending

Figure 12—Stereopair of Convict Lake area (opposite). U. S. Geological Survey high altitude photos, series 374. Approximate scale 1:121,000.



1,000 foot lateral moraine as Sherwin, the moraines within it at Tobacco Flat and the outer moraines of the northern complex as Tahoe, and the inner moraines within a mile of Convict Lake as Tioga. Rinehart and Ross (1964) distinguish older and younger morainal deposits, but do not name them. By their definition the older deposits are the east-trending moraines that enclose Tobacco Flat and the younger are the moraines of the north-trending course of the glacier. They see evidence of possible two separate glacial advances in the older deposits, and possibly as many as three advances in the moraines north of Convict Lake. They point out the possibility that the east-trending and north-trending moraines may be contemporaneous deposits of a bifurcating glacier."

Return to Highway 395

2.1

64.3 Junction Highway 395. Turn to the north. 32.9

Post-caldera rhyolite domes crop out to the east of the road. A large kaolin pit is developed in the hydrothermally altered rhyolite. To the southwest are the moraines of Laurel Creek and Sherwin Canyons. Two or three ages of moraines are present in Laurel Canyon. The youngest moraines present a high terminal ridge breached by the zig-zag bed of Laurel Creek. The older lateral moraines extend north and northeast from the base of the younger terminal moraine. Curry, (1971, plate 1) identifies the older moraine to the east of Laural Creek as Casa Diablo till and the older moraines to the west of the Creek as Sherwin.

Sherwin Canyon has a broad bench of blocks at its mouth. Kesseli (1941b) interpreted this deposit as a possible Pleistocene rock glacier complex. Several post-Wisconsinan rock glaciers head in this canyon. The difference in grain-size of the moraines in Laurel and Sherwin Canyon may be due to bedrock. Laurel Canyon beds in tough fine-grained metamorphic rock whereas Sherwin Canyon beds in jointed granodiorite.

1.3

65.6 State Fish Hatchery road. 34.2

0.9

66.5 Road traverses basalt flow in caldera moat zone. 36.8

1.7

68.2 Mammoth Lakes turnoff. Bear onto turnoff and take the east turn on reaching Highway 168. 35.1

0.6

68.8 Old Highway 395. Bear to the north.

0.3

69.1 STOP 10. Casa Diablo Hot Springs.

This area of hot springs and fumaroles has exhibited geyser-like activity in the historic past. Vents at this location read 92° C, the boiling point for this altitude. This area is part of the geothermal system associated with Long Valley caldera that is now being prospected for geothermal power. Test wells have produced as much as 69,000 lbs./hr. of steam at temperatures of 132° C to 181° C (McNitt, 1963). Large areas of kaolin, travertine and opal are associated with present and past hot spring activity. Cinabar was collected from this area in 1957 (Rinehart and Ross, 1964).

On the hill east of the road behind the hot springs area are outcrops of obsidian and lithoidal rhyolite flows. The matrix of these flows is partially devitrified along flow bands. The dark bands are the non-devitrified obsidian glass. The rhyolite exhibits interesting examples of folding and shearing structures. Basalt inclusions can be found in the rhyolite.

0.9

70.0 Mammoth turnoff underpass.

0.5

70.5 STOP 11. Casa Diablo till.

Extending for about 2 miles toward Mammoth is a series of Quaternary basalt flows that originated to the northwest. Presently a thin veneer of alluvium and glacial outwash covers the ropy and locally scoriaceous surface.

In a stream gully to the north of the road is the type locality of Curry's Casa Diablo glaciation. There Casa Diablo till overlies a basalt dated at 0.44 m.y. and is overlain by basalt flows dated 0.28 m.y. and 0.19 m.y. (Curry, 1971). Because till of this glaciation is elsewhere overlain by quartz latite with an age of 0.37 m.y., Curry (1971) assigns this glaciation an age of about 400,000 years.

1.9

72.4 Wisconsinan age moraine on top of basalt dated at 0.19 m.y. .

0.2

72.6 Mammoth Ranger Station.

END OF DAY 1

0.0 Mammoth Visitors Center, Ranger Station, is the grouping point for start of day two. Proceeding east on the Mammoth Lake Road the moraines of Laural Canyon and Convict Lake drape from the Sierra escarpment to the south. Glacial erratics and ground moraine (Wisconsinan).rest on a basalt flow dated at 192,000 years (Curry, 1971).

2.6

2.6 Turn north on Highway 395. 36.8

1.5

4.1 Road begins its climb up through the resurgent core of 38.3 the Long Valley caldera. These rocks are a series of rhyolite domes and lavas that vary in texture from lithoidal to glassy. The highway passes through the central graben of the uplifted dome. Jeffery pine forest lines the road.

3.2

7.3 The thick white rhyolitic ash layer that mantles the 41.5 ground through most of this region is dated at 1440 ± 150 years (Rubin and Alexander, 1960). The eruptive center for this is within Long Valley caldera somewhere in this area.

0.4

7.7 Turnoff to the west for Inyo Craters. 41.9

4.3

12.0 STOP 12 – Inyo Craters parking area. A 15-minute walk along a nature trail brings you to the rim of the craters. Inyo craters are relatively young features. Ejecta from these two vents rest upon the rhyolitic ash blanket that covers most of this region. The 30-40 foot gently-dipping carapace containing andesite boulders has been dated at 650 ±200 years (Rinehart and Huber, 1965). Andesite flows form the vertical crater walls. Both oblong craters have small lakes.

Two large post-collapse domes are seen to the south of the road as you drive back toward Highway 395.

4.3

16.3 Return to Highway 395. Turn north. 41.9

0.9

17.2 Andesites in the ring fracture zone are overlain by the 42.8 white rhyolite ash.

0.9

18.1 The road drops into the ring fracture zone on the north 43.7 side of the caldera. A thin basalt flow that originates to the west fills the ring fracture zone here. This flow is overlain by the white rhyolite pumice. A spiney rhyolite dome has extruded along the caldera rim to the west. From here we can see the caldera rim swing north from Mammoth Mountain along Deadman Ridge, the type location of a 3 m.y. till (Curry, 1966). From there the rim turns eastward along the low ridge in the foreground.

1.5

19.6 Crestview. The road rises up over the topographic rim 45.2 of the caldera. The units exposed along the road are 3 million year andesite flows overlain by glacial outwash deposits in turn overlain by Bishop Tuff.

0.8

20.4 The bouldery glacial deposit is here sandwiched between 46.0 the 3 m.y. andesites and the Bishop Tuff.

0.5

20.9 Outcrops of Bishop Tuff in road cuts. To the west is 46.5 obsidian dome, a recent rhyolite protrusion. A central dome can be seen with completely surrounding lava coulees.

0.2

21.1 8000 foot marker. 46.7

0.3

21.4 Deadman Summit. Elevation 8041 feet. 47.0

0.4

21.8 Obsidian dome turnoff. Bear left onto dirt road. 47.4

1.3

23.1 STOP 13 – Obsidian dome. The relatively fresh edge of the flow here shows the typical blocks of flow-banded rhyolite that form a steep talus front. The brecciated top and bottom of the flow encase the dense glassy flow interior.

The unexpanded rhyolite is black and glassy whereas the vesiculated blocks are gray. Contorted flow bands with tension cracks are present on most blocks (Figure 13). Ropy textures with iron staining may also be seen.

The upper surface of the glass flow is typical of fresh domal protrusions with vague flow sheets or pressure ridges in the blocky surface. Numerous spines and protrusions project from cracks. This dome is one of a series that extends southward from Mono Craters into the Long Valley Caldera.

1.2

24.3 Return to Highway 395. Turn north. Straight ahead is 47.4 Wilson Butte, a rhyolite dome in the Inyo Crater-Mono Crater chain.

2.5

26.8 An explosion crater on the south end of the Mono Crater 49.9 chain is visible to the east. Bishop Tuff forms the vertical

Figure 13—Flow banding on obsidian dome. Near vertical foliation and brecciated upper surface of flow. Photo by D. M. Ragan.

crater walls that are overlain by a bedded tuff rampart. Outcrops on the west side of the road ahead are also Bishop Tuff indicating a north-south trending fault with displacement of about 500 feet. Dalrymple (1966) has dated several domes in the Mono chain as between 6,400 and 10,200 years. Younger hydration dates were obtained on Southern Coulee and Panum Crater (Friedman, 1968).

0.4

27.2 Punchbowl road. Turn right onto the dirt road. 50.3

0.7

27.9 As the road turns south there is a good view of Wilson Butte. The explosion crater will be seen to the south of the road as we cross the axis of the domes.

0.7

28.6 STOP 14 – Devils Punchbowl. This explosion crater has a small rhyolite protrusion in the bottom. To the north is a later rhyolite dome that has nearly filled its crater with only a small moat separating the dome from its carapace (Figure 14).

1.6

30.2 Return to Highway 395. Turn north. Heading north the road crosses a Tahoe-aged right lateral moraine of the June Lake lobe of the Reversed Creek glacier (Putnam, 1949). At a distance of 0.4 miles the road crosses the lower crests of the Tioga-aged right lateral moraines. All moraines are here covered by a thick mantle of rhyolitic air fall ash. 50.3

0.8

31.0 June Lake turnoff. Bear left to follow the June Lake Loop. Crests of Wisconsinan lateral moraines form the ridges to the south of the road. Low recessional moraine ridges are noted traversing the road (Figure 14). 51.1

To the north, Highway 395 crosses the former bed of the Tioga-age glacier. Tioga till mantles a basalt cinder cone and lava. Basaltic boulders and bombs embedded in Tioga till are exposed in roadcuts. Beyond the Tioga terminal moraine 1 mile north of the June Lake cutoff the flow, resting on Tahoe till, crops out at the surface.

Farther to the north the road descends a dry gorge cut by glacial meltwater (Tioga age) of the June Lake Lobe through the Bishop Tuff. Here the Tahoe moraine and till has been stripped from the Bishop Tuff. The Aeolian Buttes composed of Bishop Tuff are on the east. Putnam (1949) named till exposed here beneath the Bishop Tuff the Aeolian Buttes till, but later (Putnam, 1962) correlated this deposit with the Sherwin till.

1.0

32.0 June Lake. The first in a series of glacial lakes strung along this U-shaped valley.

0.3

32.3 Outcrops of Bishop Tuff at road level.

1.6

33.9 Overlook into Gull Lake.

0.6

34.5 Outcrops of silty laminated lake beds that resemble varved clays.

2.2

36.7 Hanging Valley of Rush Creek.

0.5

37.2 Silver Lake.

2.9

40.1 Grant Lake. Several lateral moraine crests are seen in the ridges to the west of the road. Here is an excellent exposure of glacially polished, striated, and chatter-marked granite bedrock. Striations are deep and crossed by crescentic gouges. The gouges point into the direction of flow as well as away from the flow and would qualify as chatter marks or crescentic cracks (Harris, 1942).

1.1

41.2 Tioga recessional moraine cuts across Grant Lake.

1.6

42.8 Another Tioga recessional moraine extends into Grant Lake. On the far side of the lake an outcrop of Bishop Tuff is overlain by the Tioga moraines.

0.9

43.7 End moraines of Tioga glaciation. Mono Craters are seen to the east.

1.1

44.8 High Lake Russell shore line. This shoreline can be projected to the north across the moraines of Sawmill and Bloody Canyon and on to the Tioga moraines near Lee Vining, roughly following the 7200 foot contour (Figure 15). To the east this shoreline disappears at the base of Mono Craters, which are apparently younger features. Turnout for Bloody Canyon and Sawmill Canyon moraines.

0.5

45.3 Take a sharp right and proceed along the aqueduct road.

0.5

45.8 Bridge over Parker Creek.

0.3

46.1 Take a sharp left up Sawmill Canyon.

1.8

47.9 STOP 15 – Mono Basin moraine crest of Sawmill Canyon (Figures 15 and 16). The following site description is by R. P. Sharp (Wahrhaftig, and others, 1965). "The moraines that enclose Sawmill and Bloody Canyons are the most convincing evidence for the four late Pleistocene ice advances in the Sierra Nevada. The earliest advance, the Mono Basin (Sharp and Birman, 1963), is represented by the subdued ridges that enclose Sawmill Canyon; these are lateral moraines of an

Figure 14–Stereopair of the Mono Craters-June Lake area. U. S. Geological Survey high altitude photos, series 374. Approximate scale 1:121,000.

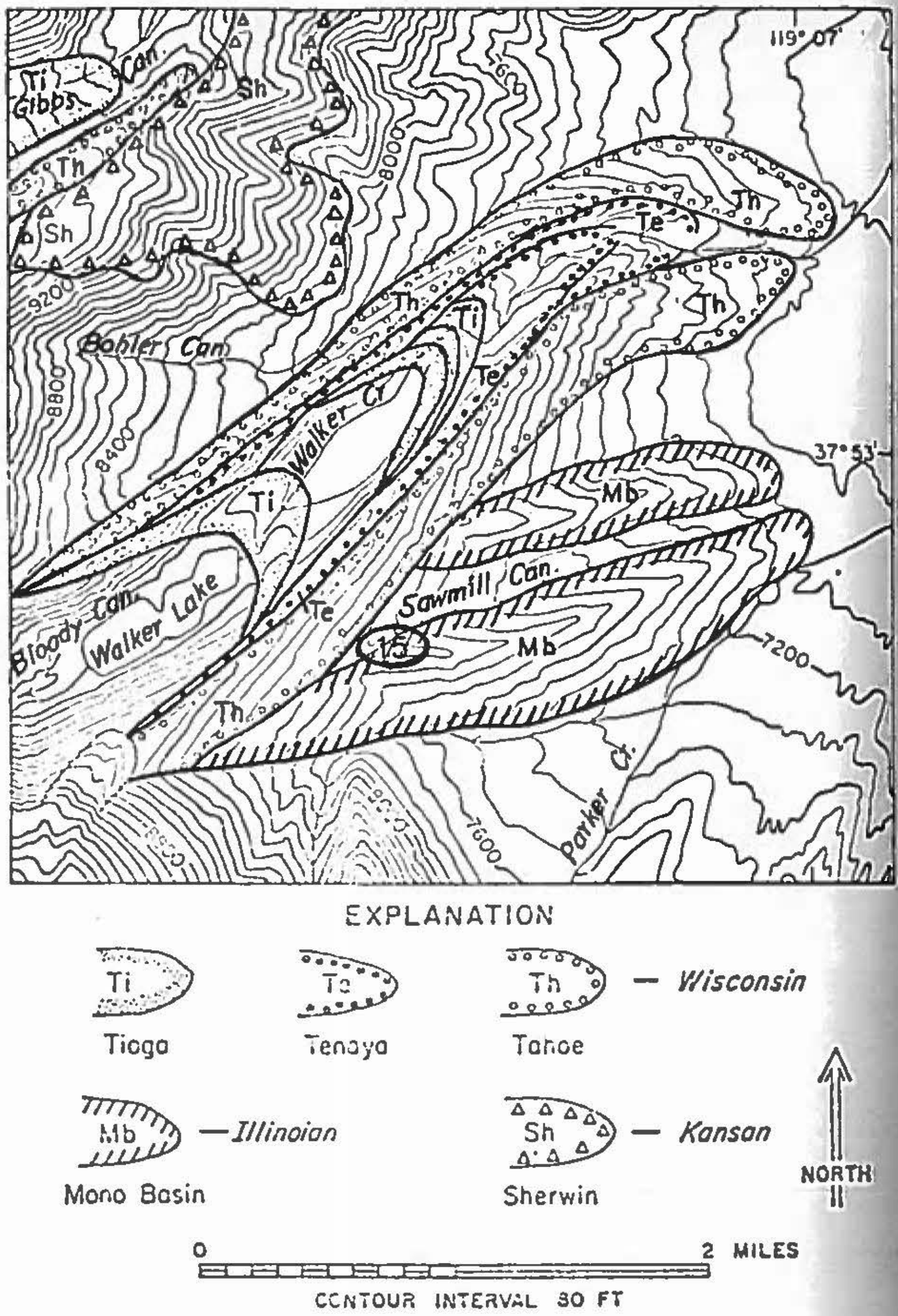


Figure 15—Morainal assemblage of Sawmill Canyon and Bloody Canyon. Figure is from Sharp and Birman (1963) with permission.

Figure 16—Stereopair of the Sawmill Canyon Bloody Canyon area. U. S. Geological Survey high altitude photos, series 374. Approximate scale 1:121,000.

ancient glacier that descended Bloody Canyon from cirques and an icefield around Mono Pass."

"The immense lateral moraines of the Tahoe advance rise 250-300 feet above the upper ends of the Mono Basin lateral moraines, where they bury the latter, and extend northeastward at least as far as the Mono Basin moraines. Had the Tahoe age glacier followed the course of the earlier glacier, the Mono Basin moraines would have been completely buried by Tahoe till and we would have no visible record of that ice advance. It is only because of the change in the course of the creek that we are here able to see the Mono Basin till, which elsewhere is buried in the cores of . . ." the Tahoe lateral moraines (except possibly at Pine Creek).

"The moraines at Sawmill Canyon have been known since W. D. Johnson mapped this area for I. C. Russell in 1883. Blackwelder (1931) pointed out the anomalous moraines of Sawmill Canyon as possible evidence for a glaciation between his Tahoe and Sherwin glaciations; Kesseli (1941a) used the topographic relations here as well as similar relations at Parker Creek immediately to the south, Convict Lake, and a few other places, as evidence for a pre-Tahoe glaciation. Putnam (1949) regarded them as an early phase of the Tahoe."

"The breaching of the north lateral moraine, cutting a canyon large and deep enough to re-direct the ice, and the building of new moraines that completely bury the heads of the older ones, require considerable time. For this reason the Sawmill Canyon moraines have been regarded informally by many geologists as evidence for an additional glacial advance."

"The Tenaya and Tioga moraines lie on the walls of Walker Creek valley inside the massive Tahoe moraines, where they form parallel sharp ridges separated by moats. Each moraine is significantly sharper, fresher, and more bouldery than the moraine that encloses it."

"Sharp and Birman (1963) have attempted to devise criteria to determine the relative time elapsed since the formation of the various moraines, and on the basis of these criteria conclude that the Mono Basin is significantly older than the Tahoe and separated from it by a comparatively long interglacial . . . . These lithologic criteria . . . show consistent differences between moraines of different age in a single canyon, provided moraines on the same side of the glaciated canyon are compared with each other. They cannot in general be used to correlate moraines from canyon to canyon."

Return to June Lake Road.

3.1

51.0 Turn north on June Lake Road.

0.3

51.3 STOP 16 — Mono Craters view point. From this location we can see evidence of the existence of Pleistocene pluvial Lake Mono (called Lake Russell in honor of I. C. Russell who did so much of the early geologic mapping in this area). This evidence is the break in slope, probably representing a former beachline, just below the road as we look toward Williams Butte (to our northwest). This beachline can be traced around to where it notches the Tahoe moraines of Bloody Canyon and the Mono Basin moraines of Sawmill Canyon. Putnam (1949) correlated this prominent shoreline with the Tahoe glaciation. When Lake Russell reached this high level (7180 feet) its waters spilled over a low divide and into Adobe Valley to the east beyond the Mono Craters. The presence of this distinct high water level indicates that the lake was able to maintain its level for a substantial length of time. Other lower and younger shorelines of Lake Russell are much less distinctive and are indicated by minor terraces.

The Mono Craters, a range of rhyolitic tuff rings, cinder cones, endogenous domes, and stubby flows, rising to 2500 feet above the level of Mono Lake, extends in a broad arc nearly due south from the south shore of the lake in line with the two islands. Farther south, on the extension of the same line, are the Inyo Craters. Potassium-argon ages on the Mono Craters ranges from 6,400 to 10,200 years (Dalrymple, 1967). The older ages by Evernden and Curtis (1965) should be reconsidered. Many of the eruptions are post-glacial, for unreworked pumice covers large areas of the lake plain, and the northern craters, well below the level of the Tioga-age lake, have no shorelines. A lack of ash layers in the uppermost 0.5 m of lake beds dated at 2,200 years (Dalrymple, 1967) is interpreted as a quiet period for Mono Craters.

Preliminary hydration dating by Friedman (1968) indicates that Panum Dome is 1,300 years, North Coulee is 1,800 years, South Coulee 2,500 years, the explosion Crater north of Devil's Paint Pot is 6,000 years, and Devil's Paint Pot is 30,000 years. Only the Devil's Paint Pot age is in gross disagreement with the dates of Dalrymple (1967).

The localization of the Mono Craters-Inyo Craters chain is a subject of considerable debate. Russell (1889) concluded that the Mono Craters volcanoes were probably localized along faults related to the east scarp of the Sierra Nevada. Mayo and others (1936) described the structures in the rhyolite domes south of the Mono Craters and concluded that embayments in the Sierra Nevada scarp in this region are determined by faults in turn controlled by northwest-striking joint sets in the bedrock. They also concluded that north-striking joint sets mark local zones of structural weakness along the east front of the Sierra Nevada, and that one of these zones controls the general trend of the Mono Craters. Kistler (1966a) has proposed that the location of the rhyolite vents is controlled by a nearly circular mylonite shear zone in the Mesozoic basement rocks.

1.1

52.4 Junction of Highway 395. Turn south. 57.0

0.4

52.8 Junction with Highway 120. Turn left and proceed 56.6
toward Panum Crater, the small rhyolite dome north of the highway with its ash rampart (Figure 16). As we drive across the former bed of Lake Russell, notice the thick deposit of Mono Crater pumice. To our left we see the Tahoe shoreline of Lake Russell notching the moraines near Lee Vining. The structure of Southern Coulee to our right is described by Loney (1968). This flow is typical of several rhyolite and obsidian extrusions south of the road which overwhelmed their tuff rings and poured out as short stubby flows. Flow tops and bottoms are vesiculated and brecciated whereas the central parts are dense, glassy, and flow-banded. This rhyolite flow, dated at 2,500 years (Friedman, 1968), overlies the Tahoe lateral moraine of the June Lake lobe.

2.9

55.7 Dirt road to Panum Crater to the north.

0.8

56.5 STOP 17 – Panum Crater. Panum Crater or North Crater is a well-preserved tuff ring enclosing an endogenous rhyolite dome. This dome is composed of pumice blocks and obsidian flows. Numerous spines and pressure ridges accent the upper surface (Figure 17). Bombs are found on the slopes of the dome as well as on the surrounding tuff ring. Older tuff rings surround an explosion crater on its southeast side. Quarries in this explosion crater provide good exposures of primary bedding features that are considered characteristic of base-surge deposits.

Scattered on the former lake bed between the road and crater are numerous obsidian pebbles. The local Paiute Indians used obsidian from these domes and Glass Mountain to make artifacts.

Figure 17–Spine on Panum Crater dome.

From the southeast side of Panum Crater is an excellent view of the morainal complex of Sawmill and Bloody Canyons to our southwest. Also seen is the high Lake Russell shoreline cutting the Tahoe moraine at Lee Vining.

Return to Highway 120.

0.8

57.3 Junction Highway 120. Head east. To the north is Mono Lake with its numerous tufa columns. Lake Russell shore lines are noted from road level down to the present shore.

1.6

58.9 Turn north onto dirt road.

1.1

60.0 Turn west along beach line road. Well developed beach terraces are preserved along this part of the road.

0.4

60.4 STOP 18 – Mono Lake. Mono Lake is 13 miles long, 9 miles wide, and approximately 170 feet deep. The lake has no outlet, and its present level is about 700 feet below the

Tahoe stage drainage into Adobe Valley. Mono Lake water has about 6% dissolved solids with the composition given in Table 4.

TABLE 4 – Composition of Mono Lake Water in mg per liter*

SiO_2	14	HCO_3	5,230
Fe	0.60	CO_3	11,200
Ca	4.3	SO_4	7,870
Mg	37	Cl	14,500
Na	21,700	F	44
K	1,150	Br	35
NH_4	0.9	I	6
		NO_2	0.04
		NO_3	16
pH = 9.7		B	350

*From Whitehead and Feth, 1961.

The tufa columns of Mono Lake are porous limestone pinacles located at present and former lake levels. The tufa forms about the orifice of sublacustrine springs. Dunn (1951; 1953) asserts that the dominant mechanism for tufa formation is the chemical difference between the spring and lake waters. However, a later study by Scholl and Taft (1964) shows that algae play dominant role in the precipitation of the tufa. Photosynthetic withdrawal of carbon dioxide lowers the solubility of calcium carbonate close to the plants.

The bathymetry of Mono Lake has recently been investigated by Scholl and others (1965) who find that its eastern half is a smooth lake plain and the western part has two deep basins with much irregular topography, due in part to faulting, volcanism, glaciation, and submarine slumping. They assert that most of the lake floor relief, including the islands, was formed in Holocene times.

Return to Highway 120 via the dirt roads.

0.4

60.8 Turn south on dirt road to Highway 120. Excellent view of Northern Coulee straight ahead (Figure 18).

1.1

61.9 Return to Highway 120. Turn west.

1.6

63.5 Dirt road to Panum Crater.

2.9

66.4 Junction with Highway 395. Turn north. 56.6

Approaching Lee Vining the road ascends the Pleistocene (Tahoe) proglacial delta of the Lee Vining Creek. Shoreline terraces mark the mountainside to the west, up to an elevation of 7180 feet. Proceeding toward the Lake Russell notch in the Tahoe moraines, the road follows a beach level.

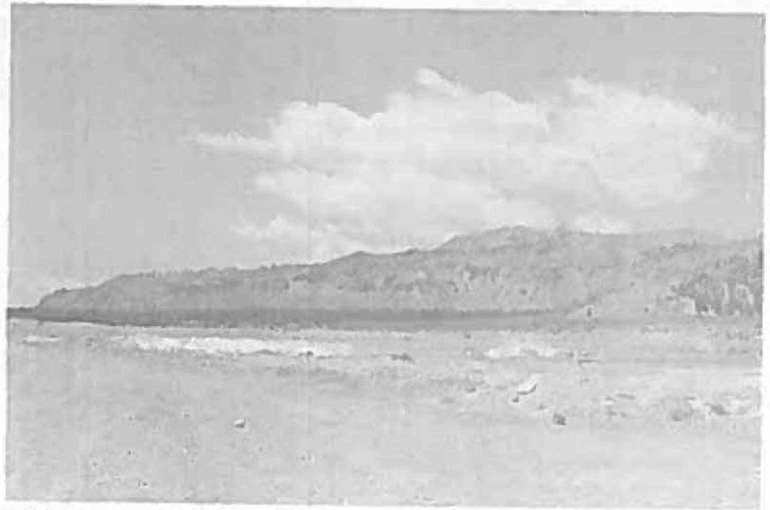


Figure 18—Northern Coulee of Mono Craters. Tufa of Lake Russell shorelines in the foreground.

4.1

70.5 Junction Highway 120. Bear left and proceed up Tioga Pass road to the Ranger Station. 60.6

0.4

70.9 Tahoe stage terraces of pluvial Lake Russell.

0.6

71.5 STOP 19 – Terminal moraine of Tioga glaciation. For miles beyond the Ranger Station, several recessional moraines of Tioga age cross the flat valley floor (Putnam, 1950). The south wall of the valley is the compound lateral moraine of Tahoe, Tenaya, and Tioga age (Birman, 1964). Beyond, the south lateral moraines form a discontinuous plaster on granitic mountain walls. Masses of debris spilling out of hanging valleys on the south wall are probably rock glaciers. The morainal deposits of this canyon are well illustrated in Figure 16.

1.0

72.5 Returning to U. S. Highway 395 and turning left (north) we proceed toward Lee Vining. To our right is the prominent Tahoe-aged proglacial delta of Lee Vining Creek Canyon. The course of the road along this west shoreline of Mono Lake follows the main Sierra Nevada fault escarpment. The hillside to our left is cut by a prominent ancient shoreline at an approximate elevation of 6900 feet. Lake beds overlain by colluvium are exposed in roadcuts along the left side of the road. 60.6

0.7

73.2 Center of Lee Vining. 61.3

3.0

76.2 Roadcut on the left exposes Tahoe till beneath 4 to 10 feet of bedded lake sediments. About 8 feet of overlying slope-wash debris completes the section. Five to ten percent of the granitic boulders show signs of weathering and decay. The lake beds consist of grayish-light brown silt and sand layers intercalated with dark brown carbonaceous layers and very light gray calcareous tufa layers from ⅛ to 2 inches thick. Isolated pebbles and granule-pebble gravel pockets are scattered within the lake beds. The slope-wash debris is a massive silty sand, light gray-yellow in color, with pebbles up to 4 inches in diameter. 64.3

4.0

80.2 Turnoff to Lundy Lake. 68.3

0.3

80.5 STOP 20 – Lake beds overlying till. In the small creek on the west side of the road iron-stained, finely-laminated, clayey-silty-sandy lake sediments overlie the Tahoe till. The till protruded above the surface while the sediments were being deposited.

0.3

80.8 Return to Highway 395 and head north. 68.3

To the left are faulted Tahoe moraines of Mill Creek (Lundy Canyon) which are cut by a secession of lake shorelines (Shelton, 1966, fig. 342, p. 360).

The grade from the floor of Mono Basin to Conway Summit is through deeply-weathered quartz monzonite.

4.2

85.0 Mono Basin Vista, 1.2 miles south of Conway Summit. 72.5

The following discussion of Mono Basin is by R. P. Sharp from (Wahrhaftig and others, 1965). "Mono Basin . . . is a roughly triangular depression about 30 miles long in a northeasterly direction and 20 miles wide along its southwest base, which is part of the eastern front of the Sierra Nevada. The floor of the basin rises from 6400 feet at Mono Lake to 7000 feet around the margins. Its northern wall is a low escarpment 1000-2000 feet high in the late Tertiary volcanic rocks of the Bodie Hills. Granitic rocks are exposed in part of this escarpment at Conway Summit. Its southwestern wall is the rugged east face of the Sierra Nevada, as much as 6500 feet high. This wall has several steps and one offset where the southwest end of the Mono Basin extends about 4 miles west into the Sierra. Furthermore, this wall is cut by several deep glaciated canyons. The southeast border of the basin is indistinct; the land rises gradually from the basin floor to the Glass Mountain-Bald Mountain ridge. Locally, as on the north side of Cowtrack Mountain, this border is marked by a fault scarp 1000 feet high."

"The Mono Basin has been the site of volcanic activity periodically from mid-Pleistocene to the Recent. The mountains bordering the basin on the north, east, and south are predominantly Tertiary and Quaternary volcanics (Gilbert, 1938, 1941). On the north shore of Mono Lake, directly below [us], is Black Point, a subaqueous cinder eruption whose internal layering is nearly flat (Christensen and Gilbert, 1964). The two islands in the lake both have cinder cones and flows (the northern of the two, Negit, consists entirely of volcanics). The lack of shore features or calcareous tufa on their surfaces indicates that they erupted after the lake fell to its present level or lower."

"The escarpments bordering the Mono Basin are fault scarps, and most of the faults are probably still active . . . Terminal moraines of the Mill Creek (Lundy Canyon) glacier, at the northwest corner of the Mono Basin, are offset as much as 50 feet along the Sierra Nevada boundary fault, while the moraines of the Lee Vining Creek glacier, which cross this fault about 7 miles farther southeast, are not offset (Russell, 1889; Putnam, 1949, 1950)."

"During the Pleistocene, glaciers advanced beyond the mouths of the canyons of the Sierra Nevada as narrow tongues which were bordered by lateral moraines as much as 500 feet high (Russell, 1889; Blackwelder, 1931; Putnam, 1950; Sharp and Birman, 1963). Contemporaneous with the glacial maxima were high lake stands in Mono Basin. The highest stand, correlated with the Tahoe glaciation, is marked by indistinct and eroded beaches at an altitude of 7170-7180 feet, when the lake was more than 900 feet deep (Putnam, 1949). At this altitude, the lake could have overflowed through a low pass on the east side of its basin into Adobe Valley and thence into the Owens River system. The narrowness of the floors of canyons along the overflow route suggests that the discharge of water that reached the Owens River was probably small. The little-eroded beaches corresponding to the high lake level of the Tioga glaciation reach an altitude of 7070 feet and the lake did not overflow (Putnam, 1950). These shorelines cut Tahoe moraines, and Tioga meltwater built deltas into the Pleistocene lake to correspond to them. Putnam (1950) has recognized about 36 younger shorelines and has correlated the more prominent (at altitudes of about 6800 feet) with groups of prominent recessional moraines in the valleys of Lee Vining and Rush Creeks."

Recent geophysical studies (Pakiser, Press, and Kane, 1960; Pakiser, Kane, and Jackson, 1964) suggest that the central part of the Mono Basin is a structural graben. However the amount of sedimentary and volcanic fill in the basin is debated. Gilbert and others (1968) contend from geologic data that the basin is merely a shallow downwarp, whereas Pakiser and others (1964) consider it to be a deep volcano-tectonic depression.

END OF LOG

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