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FIELD GUIDE TO OLIGOCENE-MIOCENE ASH-FLOWS AND SOURCE CALDERAS IN THE GREAT BASIN OF NEVADA

David A. John[1], editor

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[1]U.S. Geological Survey, Menlo Park, CA

INTRODUCTION

This field guide was prepared for a field trip to be held in conjunction with the Eighth International Conference on Geochronology, Cosmochronology and Isotopic Geology (ICOG8) scheduled for June 1994 in Berkeley, California. The road log and field guide covers the area between Caliente and Fallon, Nevada, and includes a stop near Soda Springs, California. The trip is 5 days long. Days 1 to 3 are covered in Part 1, which describes the Indian Peak and Central Nevada caldera complexes and exposures in White River Narrows and includes a road log between Caliente and Austin, Nevada. Part 2 describes day 4 and the morning of day 5. Included in this section are descriptions of the Stillwater caldera complex and its distal eruptive products and a road log from Austin to Fallon, Nevada. The afternoon of day 5 is covered in Part 3 which describes exposures of the Nine Hill Tuff near Soda Springs, California.

PART 1. INDIAN PEAK CALDERA COMPLEX, WHITE RIVER NARROWS ("OUTFLOW ALLEY"), THE CENTRAL NEVADA CALDERA COMPLEX, AND ROAD LOG FROM CALIENTE TO AUSTIN, NEVADA

Myron G. Best[1] , Eric H. Christiansen[1], Alan L. Deino[2] , and C. Sherman Grommé[3]

TERTIARY VOLCANISM IN THE GREAT BASIN: A BRIEF SYNOPSIS

Volcanism began north of what is now the Great Basin in the Paleocene and swept southward, entering the northern part of the province in the Eocene about 43 Ma. Subsequent activity in the central and eastern part of the province underlain by Precambrian crust continued southward along a roughly east-west trending front into southern Nevada in the Miocene (fig. 1; Best and others, 1989b). West of the old continental margin there is no simple pattern of transgression, and caldera-forming eruptions occurred over a broad area about 29-23 Ma. Before about 31 Ma most of the magma erupted was high-K andesite, dacite, and rhyolite as lava flows and minor pyroclastic material. From about 31 to 24 Ma similar lava flows were extruded, but their volume was clearly subordinate to a much greater volume--several tens of thousands of km^3--of rhyolitic and crystal-rich dacitic ash-flows. By the end of this period of peak volcanism--the ignimbrite flareup--a vast ash-flow plateau of limited relief had been created. Following about 22 Ma, ash-flow activity, which was chiefly rhyolitic, waned in the Great Basin and extrusions of lava flows flourished again. The oldest true basalts (IUGS classification) erupted about 22 Ma. The ignimbrite flareup was accompanied by limited regional tectonic extension, in contrast to earlier and especially subsequent periods of lava-dominant activity when extensional faulting prevailed; thus, tectonism and magmatism correlate complexly during the Tertiary of the Great Basin (Best and Christiansen, 1991).

None of the dozens of middle Tertiary calderas has any topographic expression at present, because of widespread late Cenozoic extensional faulting and consequent erosion. Instead, where visible, segments of massive, thick intracaldera prisms stand topographically high in range horsts.

[1] Brigham Young University, Provo, UT
[2] Institute of Human Origins, Berkeley, CA
[3] U.S. Geological Survey, Menlo Park, CA

Day 1
OVERVIEW

Stops this day highlight the internal structure and stratigraphy of the Oligocene Indian Peak caldera complex (figs. 1 and 2), a nest of eruptive loci that mimic the southward sweep of volcanism in the Great Basin as a whole (Best, Christiansen, and Blank, 1989). Unlike the contemporaneous but better known San Juan volcanic field of Colorado, extrusions of lava flows are very minor in the Indian Peak field and clearly no major composite volcanoes existed anytime during its prolonged history. Representatives of the vast outflow tuff sheets which surround the caldera complex (fig. 3) will be examined tomorrow. Following is a summary of pertinent features of the Indian Peak activity. Stratigraphic names of units seen on the field trip are indicated; restored volumes are based on 50 percent post-volcanic east-west crustal extension.

OUTLINE OF STRATIGRAPHY OF INDIAN PEAK CALDERA COMPLEX

Age (Ma)	Dacite tuff crystal-rich	Rhyolite tuff crystal-poor	Present area (km^2)	Restored volume (km^3)	Source
27±	Isom Formation*		28,000	1,300	SE part of complex
		Ripgut Formation		<1,000	Mt. Wilson caldera
27.9	Lund Formation		27,000	4,000±	White Rock caldera
		Ryan Spring Formation		<1,000	Indian Peak caldera
30.3±	Wah Wah Springs Formation		50,000	4,000±	Indian Peak caldera
30.6?	Cottonwood Wash Tuff		21,000	1,500+	N part of complex
32±		crystal-poor tuff		<500?	NE part of complex

*trachydacite

Evolved mafic magma, some of which leaked to the surface as local andesite lava flows, mixed with silicic crustal material to produce the voluminous crystal-rich dacite magmas. Mixing processes are indicated by relatively high concentrations of compatible elements (e.g., Ca, Sr, Cr) compared to other magmas from the volcanic field at a given silica concentration. High Sr- and low Nd-isotope ratios suggest that the silicic end member came from the continental crust. The late trachydacite Isom magmas were probably produced by fractional crystallization of andesite with minimal assimilation of crustal material, perhaps because the low melting temperature fraction was already removed from the crust or crystallization was enhanced during the waning stages of magmatism. The Isom tuffs have high concentrations of incompatible elements and but low pyroxene- and feldspar-compatible elements (Co, Sr, Ca), as well as lower Sr- and higher Nd-isotope ratios than the older dacitic tuffs erupted from the Indian Peak caldera complex. Nonetheless, both types of magma appear to have stalled, partially crystallized, and then erupted

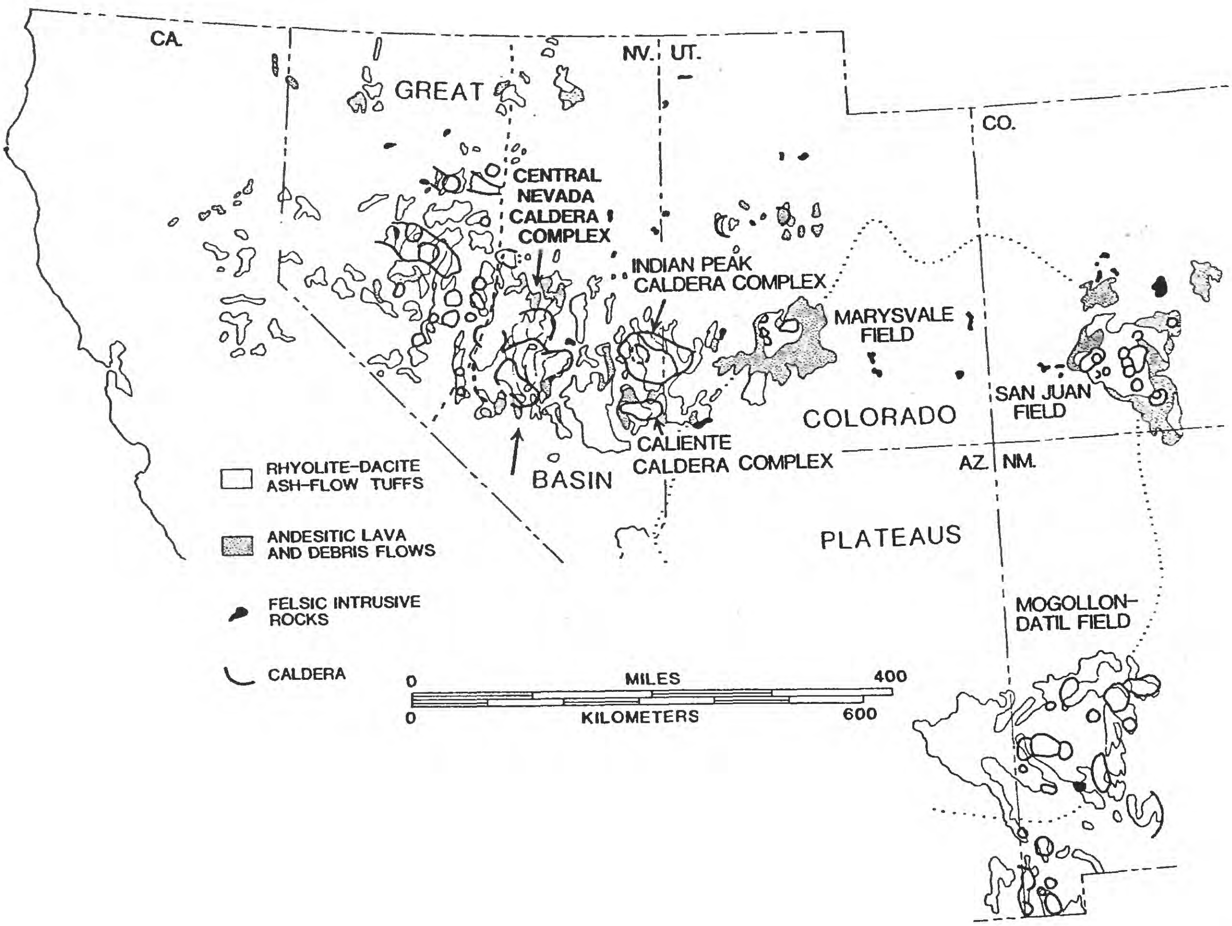


Figure 1. Generalized distribution of Oligocene and lower Miocene magmatic rocks and calderas in the Great Basin and in areas surrounding the Colorado Plateaus (dotted line). Intermediate composition lava flows in the Mogollon-Datil field not shown. The Central Nevada caldera complex lies just inboard of the Precambrian margin of the continent (dashed line).

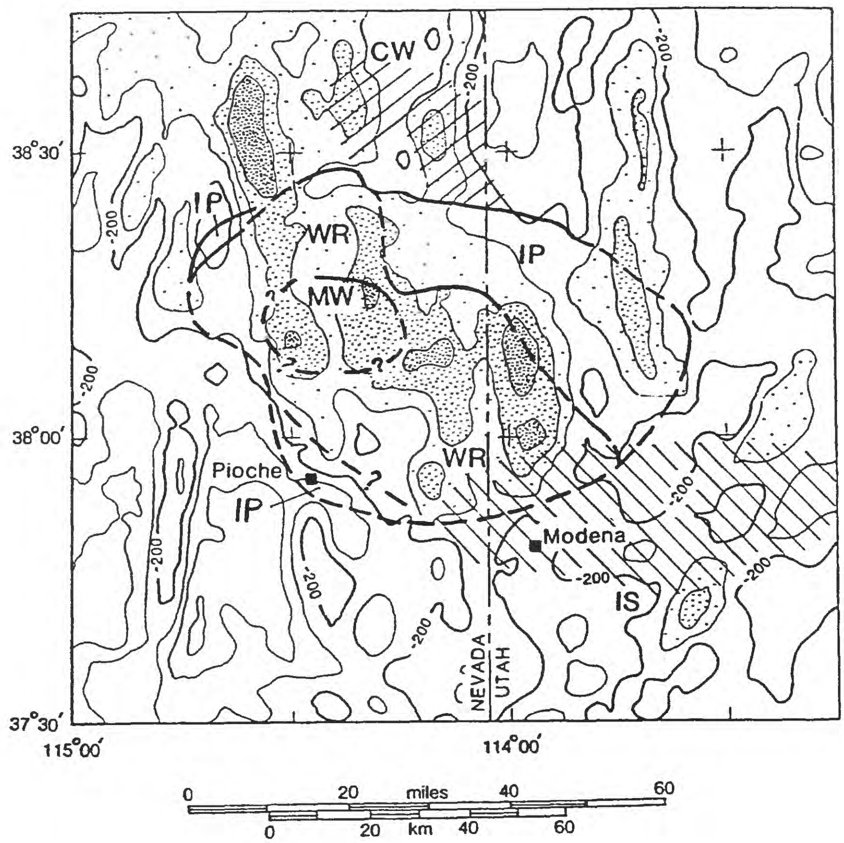


Figure 2. Bouguer gravity in and around the Indian Peak caldera complex (Best, Christiansen, and Blank, 1991). Assumed crustal density is 2.67 g/cm^3 and contour interval is 10 mgal, with progressively more negative areas below -200 mgal more strongly stippled. Persistent greatest gravity lows in White Rock caldera (WR, related to Lund Formation) reflect 4-6(?) km thickness of tuff in it and older Indian Peak caldera (IP, related to Wah Wah Springs Formation) which caved into the White Rock depression. Tuff is probably even thicker in the area of the Mt. Wilson caldera (MW, related to Ripgut Formation) which is superposed on the two older calderas.

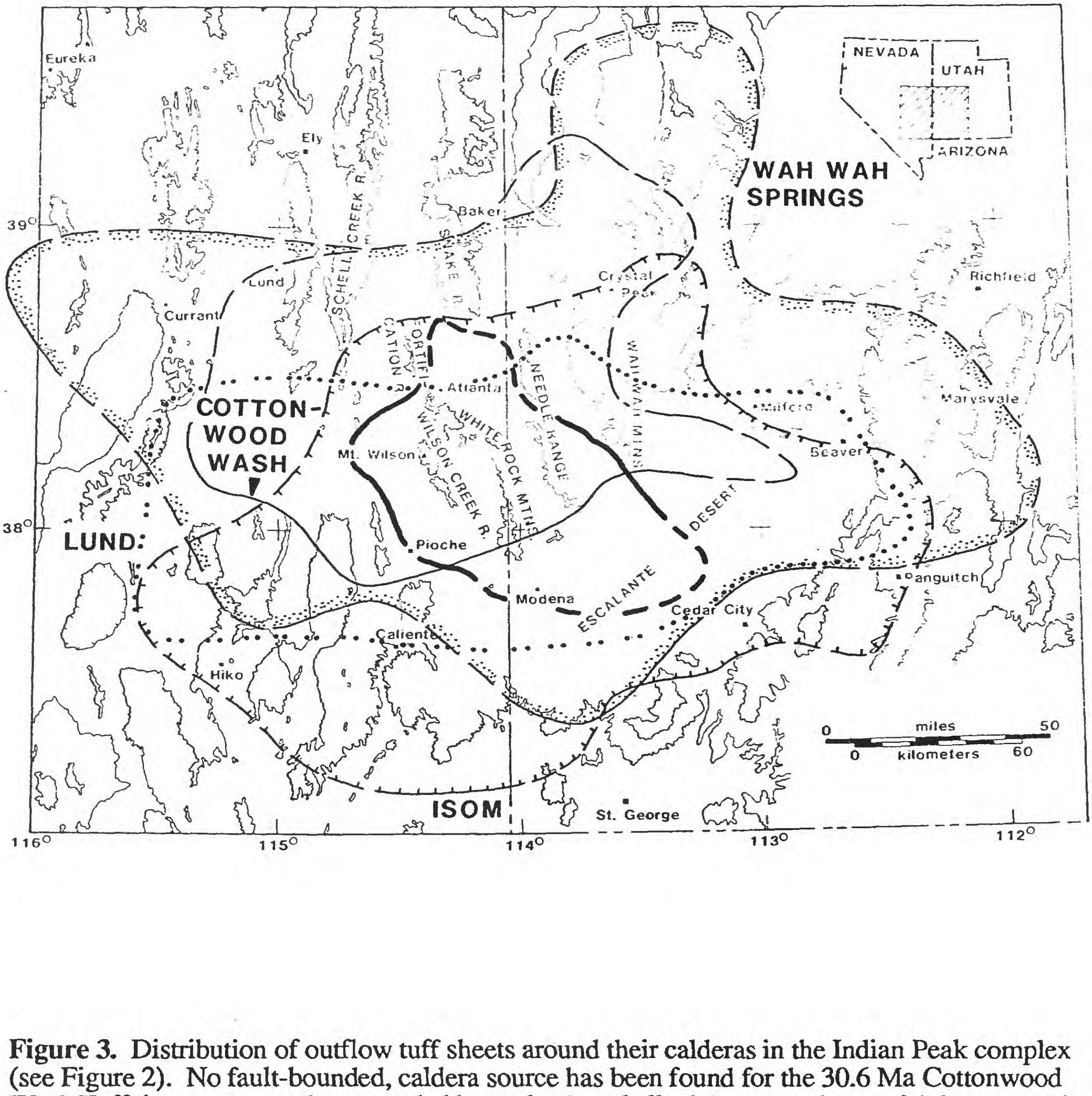


Figure 3. Distribution of outflow tuff sheets around their calderas in the Indian Peak complex (see Figure 2). No fault-bounded, caldera source has been found for the 30.6 Ma Cottonwood Wash Tuff; its source may be concealed beneath a broad alluvial area northeast of Atlanta near the center of the sheet or within the younger Indian Peak caldera. Trachydacite tuffs of the Isom Formation were erupted from another concealed source near Modena in the alluvial Escalante Desert.

from upper crustal magma chambers. Estimates of temperature and pressure for crystallization of phenocrysts in the Wah Wah Springs tuff prior to eruption are 850°C and <2 kb and for the Isom tuffs they are 950°C and < 2 kb. Caliente is located within and near the northeastern margin of the Caliente caldera complex (fig. 1), which comprises inset calderas that formed during eruption of several rhyolite and one trachyandesitic ash flows from about 24 to 12 Ma (Rowley and others, 1994). Unlike the Indian Peak caldera complex, extrusions of lava are common, and locally, together with associated volcanic debris flows, form composite volcanoes. Also in contrast to the older Indian Peak complex, the Caliente experienced concurrent extensional faulting, mostly during the latest Oligocene to middle Miocene and mostly along NNW-striking oblique-slip faults. The best-known outflow sheets that originated here are the Bauers Tuff Member of the Condor Canyon Formation (22.7 Ma) and the Hiko Tuff (18.6 Ma).

Mileage between stops	Cumulative mileage	
0.0	0.0	Leave Caliente heading north on US-93. Mileage is counted from Union Pacific train station. As we turn north, the outcrop to the east is about 400 m thickness of intracaldera rhyolitic Bauers Tuff Member in the west margin of its source, the Clover Creek caldera.
8.2	8.2	Entrance on west to Cathedral Gorge State Park. We are in the Panaca Formation, over 425 m of late Miocene and Pliocene lake beds, deposited in the closed Panaca Basin before establishment of through-going drainage of Meadow Valley Wash.
13.8	22.0	The Pioche Hills to west surrounding the town of that name consist of pervasively faulted lower Cambrian sedimentary rocks that lie near the southwest margin of the Indian Peak caldera. A major churn drilling program in the late 1940's and early 1950's by mine operators seeking extensions of ore bodies into grabens flanking the Pioche Hills horst failed, but many holes passed through alternating Wah Wah Springs tuff and Paleozoic sedimentary rock. Geologists in the 1950's invoked middle Tertiary thrusting--now discounted--or gravity sliding to explain the alternation of tuff and sedimentary rock. We interpret this as landslide breccia of sedimentary rock sloughed off the wall of the Indian Peak caldera as it was subsiding during continued eruption of the Wah Wah Springs ash flows. Gravity data support the location of the caldera wall near the Pioche Hills. The Pioche mines produced zinc, lead, silver, manganese, and gold since 1869 but have been closed for many years.
33.2	55.2	Turn right (east) onto gravel road just south of Pony Springs rest stop. Sign says Atlanta 21 or 25 miles (traveler's choice!). Wilson Creek Range to east is entirely within caldera complex. In the low foothills, a northward dipping pile of apparently unfaulted intracaldera tuff and wall breccia of the Lund Formation in its White Rock caldera source has a thickness of possibly 3 km. A 2 km thick pile of intracaldera tuff of the Ripgut Formation in its Mt. Wilson caldera source overlies the Lund about halfway up the flank of the range and all the way to the top at Mt. Wilson. Note switch back road to Mt. Wilson, our last stop today. Fortification Range to northeast is outside of caldera complex.
8.6	63.8	Turn right (south) onto dirt road.

2.7 66.5 **Stop 1-1** (Best) Intracaldera tuff and wall breccia of the Lund Formation in White Rock caldera. Hike about 1 km to east of road into saddle. Tuff of the Lund Formation is a crystal-rich dacite that contains phenocrysts, in order of decreasing abundance, of plagioclase, quartz, biotite, hornblende, Fe-Ti oxides, sanidine, and titanite (sphene). Intercalated lenses of breccia several meters thick and one km or more in strike length are expressed only as fragments of bleached Paleozoic carbonate rock no more than a few centimeters in diameter strewn across hill slopes. No exposures have been found to disclose the matrix surrounding the clasts. These breccia bodies must have been emplaced as landslides during continuous deposition of ash flows because an envelope of black vitrophyre surrounds each body, indicating underlying as well as overlying hot ejecta quenched against it. These landslides must have traveled at least 10 km to this place of deposition as that is the shortest distance to pre-volcanic rock along the margin of the White Rock caldera. Drive back (north) to main gravel road, turn right (east), heading toward range.

13.3 9.8 Pull off road. **Stop 1-2** (Best) Overview of topographic margin of Indian Peak caldera. Reddish-black silicified and brecciated Ordovician and Silurian dolomite on the south flank of the hill to the northeast is an allochthonous slice of rock that slid southward about 1 km into the Indian Peak caldera during eruption of Wah Wah Springs ash flows, and now rests on older Ordovician limestones forming the topographic escarpment of the depression. In some outcrops, argillized tuff of the Wah Wah Springs Formation forms a matrix around fragments of dolomite; in others, "veins" of tuff several centimeters in width lie in fractured dolomite. Locally within the allochthon are exposures several meters in width of altered tuff. The topographic margin of the caldera extends easterly for several kilometers beyond the hill. To this side, however, it makes a 90 degree turn to the north along the west flank of the hill. Breccia masses on either side of the road about 2 km north from this stop (one on the west is near the headframe of a mine) consist of shattered Ordovician quartzite and minor dolomite apparently resting on tuff of the Ryan Spring Formation. This intracaldera rhyolite tuff, which can be seen on either side of the road at this stop, was erupted after the Wah Wah Springs and indicates recurrent subsidence of the Indian Peak caldera near the site of earlier collapse. The topographic margin of the younger White Rock caldera lies just to the south of this stop. Continue north.

2.0 81.8 **Opitional Stop 1-3** (Best) Atlanta mine. Turn right (east) into area of waste dump from Atlanta open-pit mine and stop. OBTAIN PERMISSION TO ENTER ONTO MINE PROPERTY. CAUTION: OVERSTEP WALL OF PIT JUST TO SOUTH IS UNSTABLE. STAY WELL BACK FROM EDGE. Silicified and brecciated, reddish-black Paleozoic dolomite on the east wall of the pit and argillized, varicolored tuff on the west clearly delineate the topographic margin of the caldera. Commercial gold-silver and trivial manganese-uranium deposits in the district clearly are related in space and time with the Indian Peak caldera complex. Tuffs of the Wah Wah Springs and Ryan Spring Formations in the pit are altered and mineralized along with dolomite. Younger tuff of the Ripgut Formation exposed just west of the pit is somewhat altered whereas the overlying tuff of the Isom Formation emplaced about 27 Ma is unaltered. Recurrent shallow crustal magmatism in the area, together with the re-entrant configuration of the caldera margin and possibly the nature of the Paleozoic sequence, all may have combined to focus

		the exploitable mineralization. In Silver Park, 2.5 km west-southwest of Atlanta, dominantly silver mineralization reflects more distant hydrothermal activity. Proceed north on road.
0.6	82.4	Take right fork.
0.4	82.8	Take right fork again.
3.3	86.1	Turn right (south) onto dirt road. This intersection is near the northern topographic wall of Indian Peak caldera. Paleozoic rocks underlie hills to north. To south in foothills are large slide blocks of white Ordovician quartzite overlying a thick section of intracaldera tuff of the Wah Wah Springs Formation.
4.4	90.5	**Stop 1-4** (Best) Slide blocks of quartzite and dolomite in tuff in Indian Peak caldera. To northeast is tuff of the Ryan Spring Formation that overlies intracaldera tuff of the Wah Wah Springs Formation, which is exposed to west and south. The Ryan Spring tuff is one of three rhyolite magmas extruded from the Indian Peak magma system. All rhyolites are compositionally similar and contain prominent lithic clasts and phenocrysts of plagioclase and minor biotite, but some mineralogical and bulk chemical zonation is evident in the compound cooling units deposited within the immediately older caldera formed by eruption of crystal-rich dacite. The crystal-rich dacite tuffs are compositionally similar in that they contain abundant phenocrysts of plagioclase and lesser biotite, hornblende, and quartz; the Wah Wah Springs is unique in having more hornblende than biotite. Note brecciated slide masses of white Ordovician quartzite encased within Wah Wah Springs tuff, which here is approximately 2 km thick. To north and capping the hill is a pervasively fractured, but stratigraphically coherent, sequence of quartzite and dolomite about 100 m thick and 3 km wide that was emplaced onto the intracaldera Wah Wah Springs tuff in the caldera. An autochthonous section of these Ordovician strata lies on the topographic rim of the caldera at least 4 km to the north. Projection of the stratal attitude of this section over the caldera indicates about 2 km of downward displacement. Drive north back to Atlanta.
2.3	92.8	Exposures of early Miocene latite and rhyolite lava flows to west.
2.1	94.9	Turn left (west) onto gravel road.
25.6	120.5	Turn left (south) onto paved US-93.
26.4	146.9	Turn left (east) onto gravel road; a sign here indicates the Caselton and Prince mines are reached in other direction (west).
3.8	150.7	Take right fork to northeast.
8.4	159.1	Take left fork to northwest.
12.5	171.6	Switch-backs are in a 2 km thick intracaldera section of tuff and breccia (of Paleozoic carbonate rock) of the Ripgut Formation filling its Mt. Wilson caldera source. To west and below road at this mileage is a 40 m thick cliff of black vitrophyre in the formation.

1.5	173.1	Take right fork.
0.7	173.8	**Stop 1-5** (Best) Panoramic view of Indian Peak caldera complex from top of Mt. Wilson. Wheeler Peak--second highest point in Nevada (elevation 13,061 ft = 3984 m)--is the prominent peak 60 km due north in the southern Snake Range. Indian Peak (9790 ft = 2986 m) lies 40 km east in the Needle Range in Utah. Mt. Wilson where we are standing lies within three calderas. Segments of the oldest (approx. 30.3 Ma), the Indian Peak caldera, are well exposed just north of Indian Peak and, in successive ranges westward, the northern White Rock Mountains, the northern Wilson Creek Range (as seen at the last stop), and the northern Fairview Range across the valley to the west of here. Most of the Indian Peak caldera caved into the White Rock caldera as ash flows forming the Lund Formation were erupted at 27.9 Ma. The intracaldera Lund was seen at the first stop today in the foothills of the Wilson Creek Range just to the west of here. The topographic margin of the youngest caldera, the Mt. Wilson, which lies about 4 km north of here, is defined by southward thinning masses of landslide breccias that interfinger with Ripgut tuff and that are banked against a paleoescarpment cut into the Lund Formation. Intracaldera accumulations of tuff beneath Mt. Wilson are possibly 6-9 km thick. Drive down off mountain toward Pioche.
26.9	200.7	Turn left (south) onto US-93; drive past Pioche.
28.7	229.7	Arrive in Caliente; stay overnight.

DAY TWO
OVERVIEW

An extraordinarily complete, well-exposed section of regional ash-flow outflow sheets will be examined in White River Narrows along Nevada Highway 318. The fifteen sheets in this "outflow alley" section lie between their sources in three nearby caldera complexes: the Central Nevada to the west, the Indian Peak to the east, and the Caliente to the southeast. This section, and the one at the last stop today, are representative of numerous outflow volcanic sections emplaced during the ignimbrite flareup in the central and southeastern Great Basin which contain little or no sediment and have insignificant angular discordances between the outflow sheets; both aspects are indicative of regional tectonic quiescence during the ignimbrite flareup (Best and Christiansen, 1991). These same sections disclose little, if any, bedded ash fall (plinian) tuff at the base of the ash-flow deposits, in contrast to many pyroclastic sequences documented in the volcanological literature.

Mileage between stops	Cumulative mileage	
0.0	0.0	Leave Caliente heading west on NV 93. Mileage is counted from the Union Pacific train station. The highway passes through exposures of bedded volcanic sandstone and siltstones that accumulated in the Caliente depression after deposition of the Hiko Tuff.
10.5	10.5	Oak Springs Summit, crest of the Delamar Mountains. We are within the western lobe of the Caliente caldera complex at the Delamar caldera which is the source of the Hiko Tuff, erupted at 18.2±0.04 Ma.

27.1	37.6	Pass through Hiko Range. To the north and south are exposures of crystal-rich rhyolite outflow of the Hiko Tuff, which weathers into prominent and distinctive bulbous forms much like granite. It is overlain by a thin, middle Miocene, densely welded tuff derived from another caldera complex about 20 km to the southeast.
2.8	40.4	Turn right (north) onto NV 318.
4.7	45.7	Community of Hiko (native Paiute word for "white man's town").
7.0	52.7	Hiko Tuff and underlying Bauers Tuff Member of the Condor Canyon Formation, also derived from the Caliente complex. The same units are exposed for next two miles through Hiko Narrows.
12.9	65.6	**Stop 2-1 (Christiansen and Deino)** At the south end of White River Narrows are six regional ash-flow sheets, all but one of which are rhyolite and all but one derived from the Caliente complex. In descending order they are: Hiko tuff, crystal-rich trachyandesite Harmony Hills Tuff (exposed only in a small hill), Pahranagat Formation derived from the Central Nevada caldera complex at 22.63±0.01 Ma, Condor Canyon Formation, which consists of Bauers Tuff (22.74±0.04 Ma) and Swett Tuff Members, and Leach Canyon Formation (23.76±0.04 Ma) which has large columnar joints and extends northward into the Narrows. Continue north on highway.
1.2	66.8	**Stop 2-2 (Gromme and Christiansen)** At the N end of White River Narrows are four ash-flow sheets consisting of, in descending order beneath the Leach Canyon: thin, densely welded Hole-in-the-Wall Member of the Isom Formation, upper member of the Shingle Pass Tuff (26.03±0.04 Ma), and, at bottom of road cut, a crystal-rich rhyolite tuff of unknown stratigraphic identity. The three named units had three different sources, the Caliente caldera complex, the Indian Peak complex, and the Central Nevada caldera complex, respectively. Continue north on highway.
1.9	68.7	**Stop 2-3 (Gromme and Christiansen)** Intersection with gravel road on W to petroglyphs. Exposed in hill to west are, in descending order, hornblende-pyroxene andesite lava flow, Bald Hills Member of the Isom Formation, Monotony Tuff, and Petroglyph Cliff Ignimbrite. The Petroglyph Cliff (27.3-27.9 Ma), more correctly, a welded tuff breccia, is one of the oldest of the Isom-compositional-type tuffs in the Great Basin and is unusual because of its abundant lapilli- and block-size fragments. This cooling unit is found only here and in two ranges to the east and probably vented nearby. The distal part of the Monotony outflow sheet derived from the Central Nevada caldera complex at 27.33±0.06 Ma is fairly thick but poorly welded, and is host to the petroglyphs. Continue north on highway.
40.7	109.4	Sunnyside Ranch.
14.2	123.6	Turn left (west) on gravel road, crossing White River Valley to east flank of Grant Range.
12.8	136.4	**Stop 2-4 (Christiansen, Deino, and Gromme)** Intersection of 4-wheel drive trail to right (N). Hill to northeast is brown, 210-m-thick, Stone Cabin Formation (35.34±0.04 Ma) overlain in distance by the 280-m-thick Windous Butte Formation (31.31±0.11 Ma) seen here as a thin ledge of black

vitrophyre. Complete sections of these two rhyolite tuffs can be seen by hiking to north around west side of hill where the bottom part of the Stone Cabin contains 10-20 m of black vitrophyre underlain by several m of white to salmon-colored, weakly welded ash-flow tuff; beneath the Stone Cabin is a few tens of m of cross-bedded, well-sorted gray sandstone overlying Paleozoic rocks. By continuing around hill to east, one can go up section through the east-dipping Stone Cabin into the overlying conformable Windous Butte, which consists of a few m of weakly welded salmon-colored ash-flow tuff overlain by black vitrophyre and then brown devitrified tuff, both densely welded. Note the absence of bedded plinian ash-fall deposits at the base of these two tuff sheets. On the southeast side of the road, capping the low hill, is the outflow sheet of the crystal-rich, dacitic Wah Wah Springs Formation derived from the Indian Peak caldera at about 30.3 Ma. The lowest Wah Wah Springs here is a slabby weathering welded tuff that grades upward into about one m of dark gray vitrophyre and then into devitrified red-brown tuff. In the low rolling hills to the east are three, thin, devitrified, densely welded ash-flow tuff cooling units. The first is the red-brown lower member of the Shingle Pass Tuff emplaced at 26.67±0.05 Ma containing conspicuous phenocrysts of sanidine and lesser plagioclase and a few Fe-rich pyroxene and olivine manifest by rusty spots; this unit across a small gully is purplish and grusy weathering. The overlying cooling unit of unknown stratigraphic identity is a brown tuff containing obvious shards and sparse tiny smoky quartz phenocrysts. It is overlain by the upper member of the Shingle Pass Tuff, seen earlier today, which here is a purplish-gray tuff containing light gray pumice and phenocrysts of two feldspars and biotite. All of the named outflow sheets except the Wah Wah Springs were derived from the Central Nevada caldera complex to the west. Turn around and head east on gravel road back to NV 318.

12.8	149.2	Farming community of Lund. The Lund Formation is named for a railroad siding in southwestern Utah, not this town.
5.2	154.4	Lanes Ranch Motel and Restaurant, our overnight accommodation.

Day 3
OVERVIEW

A cluster of at least nine nested calderas and an ill-defined source area that are related to major outflow tuff sheets compose the central Nevada caldera complex (fig. 1) in the south central Great Basin. This complex of generally southwestward younging eruptive centers that lies near the western edge of the Precambrian basement in south central Nevada yielded on the order of 20,000 km^3 of ash-flow tuff as outflow sheets and caldera fillings. Early eruptions at 35.3, 34.8, and 29.6 Ma produced rhyolite whereas more voluminous eruptions occurred at 31.3 Ma, yielding rhyolite and dacite, and at 27.3, producing dacite. Multiple eruptions of rhyolite magma followed from 26.8 to 18.3 Ma.

The oldest magmas erupted to form the Stone Cabin Formation were equilibrated near the quartz-fayalite-magnetite (QFM) buffer; succeeding magmas which formed the outflow and intracaldera tuffs of the Windous Butte Formation, Monotony Tuff, and the titanite-bearing tuff of Orange Lichen Creek were progressively more oxidized. The cycle was repeated with eruption of the 26.7-Ma magma of the lower member of the Shingle Pass Tuff, which has phenocrysts of quartz, magnetite, and Fe-rich olivine, succeeded again by more oxidized magmas, culminating in the titanite-bearing Fraction Tuff erupted at 18.3 Ma. We have no explanation as yet for these two cycles of increasing degree of oxidation of the magmas. The compositionally zoned Stone Cabin magmas equilibrated at relatively low water fugacity and high pressure, about 4 kb (based on hornblende and feldspar geobarometers), or a depth of about 15 km. The 31.3 Ma Windous Butte Formation is a compositionally zoned sequence ranging from first erupted rhyolite to last erupted dacite (75 to 66 percent SiO_2) that equilibrated at 750 to 790°C and less than 4 kb. The dacite Monotony Tuff (27.3 Ma) is generally more mafic (68 to 70 percent SiO_2) than the Windous Butte outflow sheet and appears to have equilibrated at lower temperature (750°C) and pressure (3 kb). Major eruptions of compositionally zoned rhyolite magma from 26.7 to 26.0 Ma formed at least four rhyolite cooling units of the Shingle Pass Tuff. The lowest is mineralogically distinctive, containing quartz, two feldspars, Fe-rich olivine and pyroxene and only small quantities of biotite and amphibole; like the older Stone Cabin, the oldest Shingle Pass magma was relatively dry and last equilibrated near QFM at low pressures (about 3 kb) and 730 to 770°C. In contrast, the uppermost magma of the Shingle Pass Tuff crystallized at higher fugacities of oxygen and was quite wet, lacking quartz and anhydrous mafic phases. The outflow tuff of the Pahranagat Formation erupted at 22.64 Ma is laterally and vertically zoned from high- to low-silica rhyolite.

Long intervals of time prior to eruption of the Windous Butte, Monotony, and Pahranagat magmas were punctuated by many very small extrusions of andesite, dacite, and rhyolite lava flows and by small rhyolite ash-flow eruptions.

Mileage between stops	Cumulative mileage	
0.0	0.0	Leave Preston heading north on NV 318.
7.5	7.5	Intersection of US 6, turn left (southwest). Eight km northwest of this intersection is the easternmost known exposure of the Bates Mountain D/Nine Hill Tuff. This outflow sheet of welded ash-flow tuff will be seen at the last stop today and also on the last day of the field trip at the crest of the Sierra Nevada; it also occurs in the Sierra Foothills to the west--about 450 km from here.
5.0	12.5	In this vicinity is Windous Butte (just southeast of US 6), the type locality for the Windous Butte Formation which caps the buttes in this vicinity. Underlying slopes are white Currant Tuff, in turn underlain by intermediate composition lava flows that are widespread in this area.
12.5	25.0	White Pine Range straight ahead is composed of Paleozoic rocks.
10.8	35.8	Community of Currant; continue on US 6 to southwest into Railroad Valley.
14.0	49.8	To north is the east flank of the Pancake Range where alternating light- and dark-brown layers are the compound cooling unit of the middle member of the Stone Cabin Formation. The Railroad Valley oil field produces from a pre-Windous Butte, post-Stone Cabin tuff and the upper Eocene to lower Oligocene clastic Sheep Pass Formation.
7.7	57.5	Lockes Ranch.
1.7	59.2	Two cooling units of Monotony Tuff to southeast.

3.0	62.2	For the next four miles, the highway follows a Quaternary basalt lava flow. Hills on either side of highway are composed of altered tuff and Paleozoic rock, some of which comprise allochthonous slide masses resting on intracaldera tuff of the Windous Butte Formation. We are thus near the eastern margin of the Williams Ridge caldera that collapsed as Windous Butte ash flows were erupted.
3.9	66.1	Black Rock Summit.
9.1	75.2	Intersection with gravel road to south to Lunar Crater. The surrounding youthful alkaline basalt field of lava flows, about 70 cinder cones and at least two maars, developed chiefly since 6 Ma along a NNE-striking fissure system. Lunar Crater is a spectacular maar easily reached from this turnoff. Nearly every lava flow and ejecta deposit in the field contains megacrysts and Ti-Al-rich xenoliths of gabbro and clinopyroxenite, but only three vents erupted Cr-rich spinel peridotite of mantle origin. Late Cenozoic basaltic volcanism is concentrated along the margins of the Great Basin and its only expression within the interior is here in the Lunar Crater field. Youthful "Black Rock" lava flow to east contains abundant megacrysts of olivine, pyroxene, and feldspar.
1.4	76.6	Road cut in a 300 m-thick simple cooling unit of the Monotony Tuff.
1.0	77.6	Turn right (north) on gravel road to Moores Station. Mesa tilted toward us is capped by a 10-Ma basalt lava flow.
5.6	83.2	Turn sharp left (to south and then southwest) on obscure dirt track through sagebrush.
0.5	83.7	**Stop 3-1 (Best, Christiansen, Deino, and Gromme)** A 1700-m hole drilled here in the late 1960's by the U.S. Atomic Energy Commission penetrated only one unit of dacite tuff, which we now know to be equivalent to the Windous Butte Formation. To the northwest, across the valley, the entire one km escarpment of Morey Peak, a late Cenozoic horst, is composed of the same tuff. These two vast, but minimum, thicknesses are expressions of the Williams Ridge caldera. This caldera and its related ash-flow deposits are the largest in the Central Nevada complex and have similar dimensions as the Indian Peak caldera and related Wah Wah Springs Formation (fig. 4). These two calderas and tuff sheets are the largest in the Great Basin. The intracaldera dacitic tuff has the same paleomagnetic direction and $^{40}Ar/^{39}Ar$ age (mean of determinations on two samples of 31.32±0.08 Ma), within analytical uncertainty, as the rhyolitic outflow of the Windous Butte (mean of two, 31.31±0.11 Ma).
		Turn around and return to main gravel road.
0.5	84.2	Turn north on gravel road.
6.6	90.8	Intersection. Turn right (north).
2.3	93.1	Intersection. Turn right (north).
2.0	95.1	Intersection. Continue straight (north or right fork).

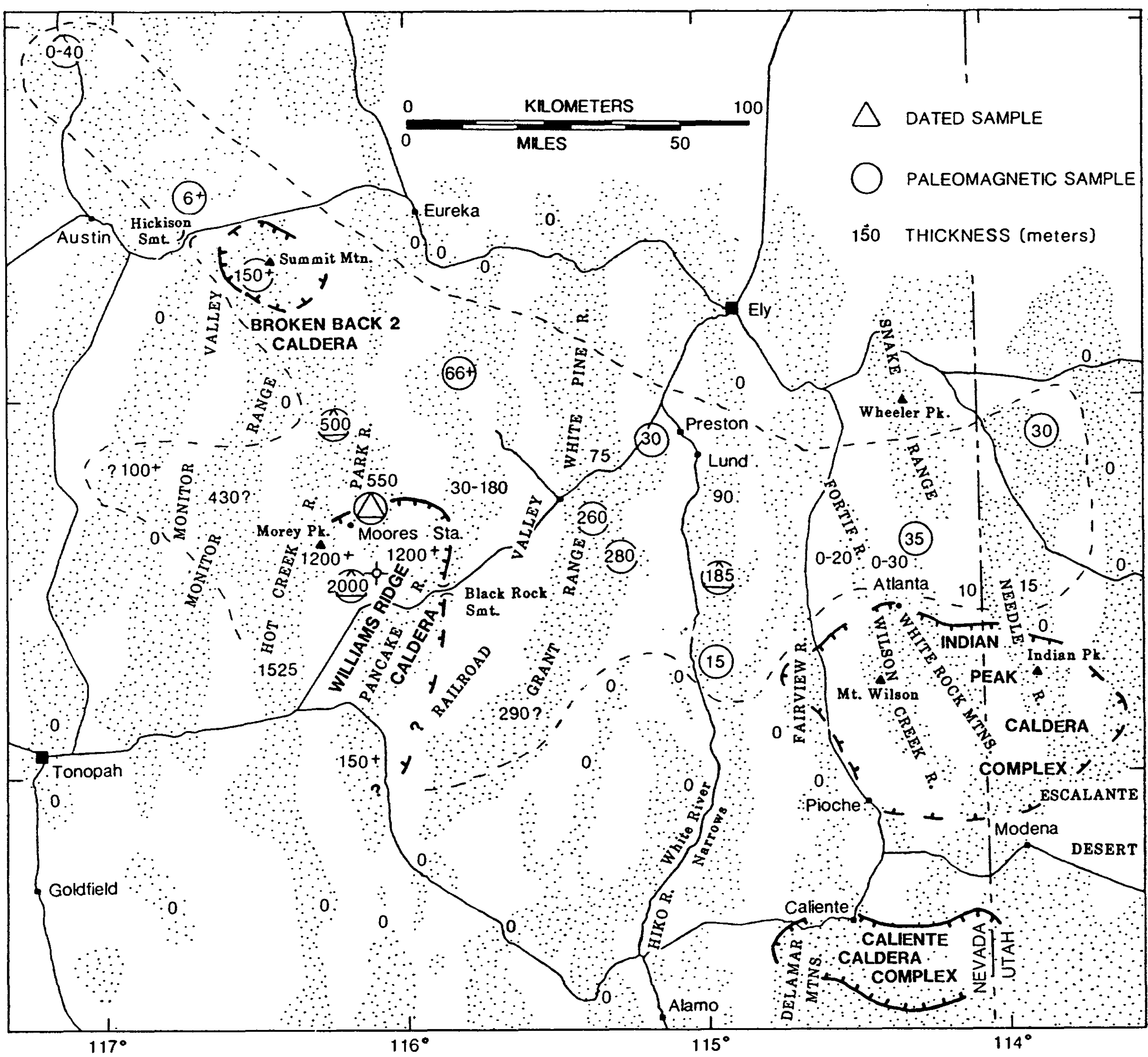


Figure 4. Distribution of the outflow tuff sheet of the Windous Butte Formation (dashed line) around its Williams Ridge caldera source. This map also shows locations of features referred to in roadlog.

0.7	95.8	Moores Station, a relic of the nineteenth century horse-drawn stage line from Ely to Tonopah, both early Nevada mining camps. Additional post-Windous Butte fill in the Williams Ridge caldera consists of local sedimentary deposits and lava flows and possibly a few hundred cubic kilometers of rhyolitic ash-flow tuffs, some of which are exposed in the hills surrounding Moores Station. Just beyond old two-story hotel continue straight north.
0.6	96.4	Intersection. Continue straight north.
4.8	101.2	Intersection. Take left fork to west.
0.9	102.1	Obscure intersection. Take less traveled right fork to north.
1.3	103.4	**Stop 3-2 (Best)** Almost the entire Park Range to northeast is an approximately 550 m-thick compound cooling unit of outflow Windous Butte Formation. This section, and the probably equally thick (but unmapped) exposures in the Hot Creek Range to the northwest represent unusually thick outflow just outside the Williams Ridge caldera, whose margin lies roughly 4 km south of here.
4.1	107.5	Cattleguard.
1.8	109.3	Intersection. Turn right (north).
1.4	110.7	Intersection with road to Hicks Station. Turn right (east). In the Park Range directly ahead the Windous Butte outflow is exposed in slightly more than the upper half of the section; it is underlain by a local rhyolite tuff emplaced at 32.05±0.07 Ma and older intermediate composition lava flows. Note the lack of evidence for a major composite volcano predating the eruption of the Windous Butte ash flows and collapse of the Williams Ridge caldera; even if most of such an edifice had coincidentally caved into the caldera there would still be far traveled, alluvial volcanic debris flows in the stratigraphic record, which, however, are definitely absent. This absence of stratigraphic evidence for composite volcanoes during the earlier part of the ignimbrite flareup in the Great Basin as a whole is incontestable.
4.2	114.9	Gate. Stay on main road.
2.9	117.8	Gate.
2.3	120.1	Upper and lower cooling units of Shingle Pass Tuff, seen at stop 2-4.
1.0	121.1	Intersection. Continue on main road (right).
1.1	122.2	Intersection. Stay on main road (left).
2.2	124.4	Intersection. Turn left (west) down into wash.
0.6	125.0	Intersection. Turn right (north).
2.3	127.3	Cattleguard.
0.2	127.5	Intersection. Turn left (west) into wash.

STRATIGRAPHIC SECTION IN "OUTFLOW ALLEY" IN AND NEAR THE PARK RANGE

	Maximum thickness (meters)	Age (Ma)
Tuff of Clipper Gap	20	23±
Bates D/Nine Hill Tuff	10	25.1
Shingle Pass Tuff, upper unit	5	26.0
lower unit	10	26.7
Tuff of Orange Lichen Creek	60	26.8
Tuff of Pott Hole Valley	100	27.0
Tuffs of Crested Wheat Ridge	200	29.6
Wah Wah Springs Formation	15	30±
Windous Butte Formation	550	31.3
Tuff of Cottonwood Canyon	55	32.1
Tuff of Pritchards Station	150	34.1
Intermediate composition lava flows	1000	
Stone Cabin Formation	200	34.3
Rhyolite lava flows	150	
Paleozoic rocks		

1.0	128.5	Intersection. Continue on main road (right).
5.9	134.4	Intersection. Turn left (west) off main road.
15.9	150.3	Intersection and buildings. Turn left (southwest).
1.0	151.3	Intersection. Turn right (west). From the valley floor (2000 m) to the tops of the highest peaks (highest is Summit Mtn. at 10,456 ft = 3189 m) the northern end of the Monitor Range ahead and to northwest is underlain by Pancake Summit Tuff (34.8±0.08 Ma) within its Broken Back 2 caldera source. The most detailed map published of this caldera is the reconnaissance 1:500,000 scale geologic map of Nevada (fig. 5).
7.3	158.6	Intersection. Turn right (north).
1.0	159.6	Intersection and stone buildings. Turn left (west).
1.3	160.9	Take lower road through ranch.
1.7	162.6	Intersection. Turn left (south).
1.2	163.8	Intensely argillically altered intracaldera Pancake Summit Tuff on the right (north) and talus of less altered intracaldera tuff off Bald Mt. on left.
2.0	165.8	Just before summit turn off to N on 4-wheel drive track through sagebrush; park 2-wheel drive vehicles and hike approximately 0.8 miles. **Stop 3-3 (Best and Gromme)** Above a slope where there are no exposures lie ledges of brecciated Paleozoic rock overlain by an ash-flow tuff that is apparently Windous Butte outflow. We interpret the Paleozoic rock to be landslide breccia sloughed off the wall of the caldera. Clasts in the breccia are of gray carbonate rock and black chert representing, respectively, the autochthonous eastern carbonate shelf facies and allochthonous western deep-

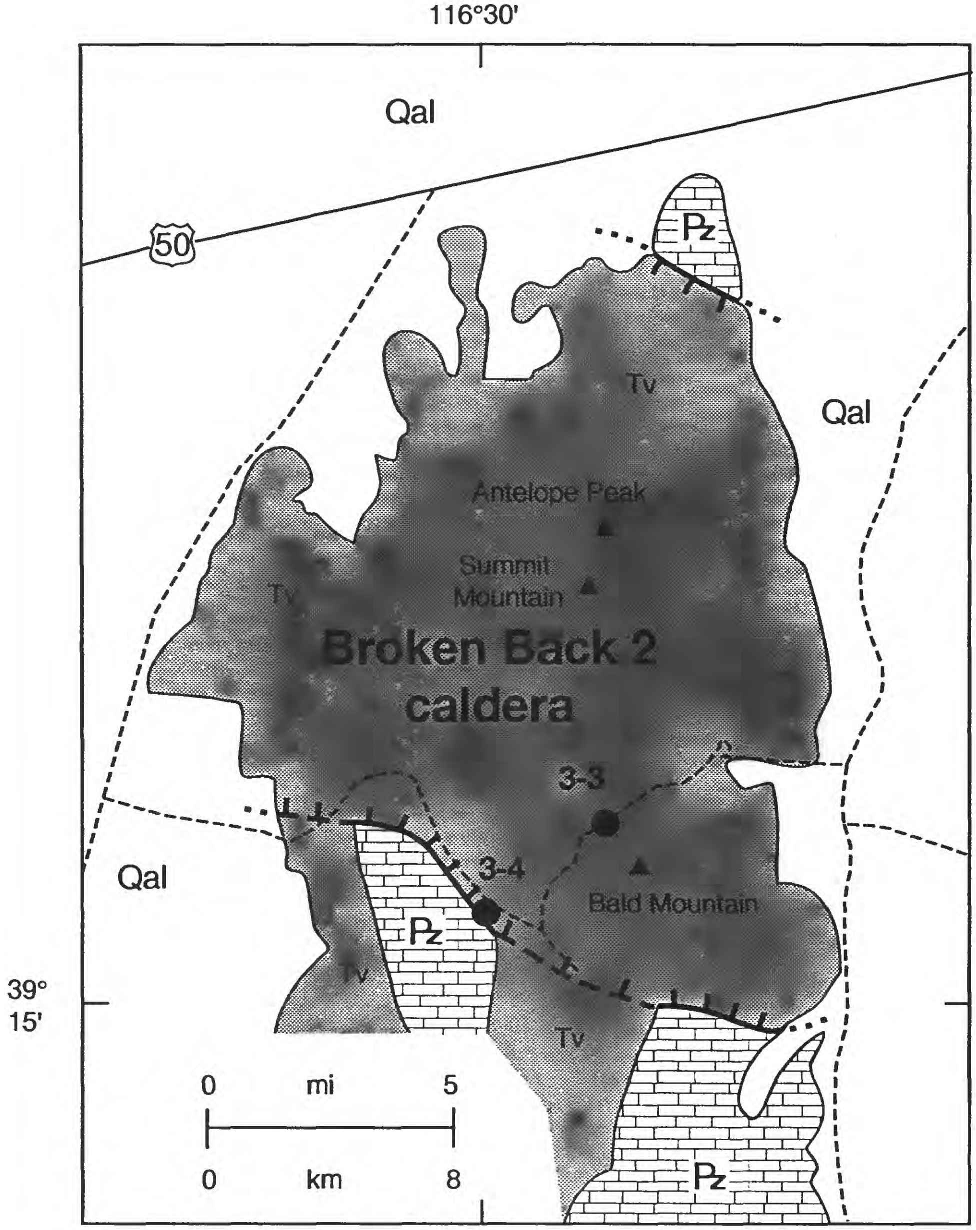


Figure 5. Sketch map of Broken Back 2 caldera, source of the Pancake Summit Tuff, showing field trip stops 3-3 and 3-4. Heavy hachured lines show approximate caldera walls. Qal, Quaternary alluvium; Tv, Tertiary volcanic rocks, mostly intracaldera Pancake Summit Tuff; Pz, Paleozoic sedimentary rocks.

		water oceanic facies in the late Devonian-early Mississippian Roberts Mountain thrust in nearby ranges. Walk back to vehicles at summit.
3.0	168.8	Intersection. Take right (northwest) fork to Monitor Valley.
0.8	169.6	**Stop 3.4 (Best and Gromme)** Exposures on right (north) are of argillically altered volcanic rock apparently overlain by breccia of gray Paleozoic carbonate rock; without careful mapping we can only suggest that this exposure is an altered intracaldera sequence of tuff and landslide breccia.
0.4	170.0	To left (west) is gray carbonate rock in place along wall of caldera. Alteration of tuff is widespread in western part of caldera.
0.2	170.2	Cattleguard.
2.1	172.3	Intersection just beyond summit. Turn left (south).
3.8	176.1	Cattleguard.
4.7	180.8	Intersection. Turn right (north).
14.7	195.5	Intersection with US 50. Turn left (west).
13.2	208.7	Hickison Summit. Roadcut in west-dipping Bates Mountain D/Nine Hill Tuff and underlying thin-bedded volcaniclastic sandstone and siltstone. As is typical of this tuff in central Nevada, it is densely welded, dark red-brown, crystal-poor containing sparse phenocrysts of sanidine.
25.1	233.8	Lander County Courthouse in downtown Austin; stay overnight.

PART 2. STILLWATER CALDERA COMPLEX AND ROAD LOG FROM AUSTIN TO FALLON, NEVADA

David A. John[1]

Day 4
Overview

Today and tomorrow morning will be spent examining the Stillwater caldera complex and outflow tuff sheets from calderas in this complex. The late Oligocene (approx. 29-23 Ma) Stillwater caldera complex is composed of three partly overlapping calderas and subjacent cogenetic granitic plutons that were steeply (≈60°) tilted by early Miocene extensional faulting (fig. 6; John, 1993a; John and others, 1993). Late Miocene to Holocene Basin and Range faulting has subsequently uplifted the Stillwater Range several km relative to the surrounding basins exposing the steeply tilted caldera complex. Major features of calderas in the Stillwater caldera complex are listed in table 1 and composite stratigraphic sections are shown in figure 7. The Job Canyon caldera and the underlying IXL pluton form the most well preserved caldera system and are exposed mostly in a single west-dipping homoclinal fault block that exposes about 10 km of caldera fill and underlying plutonic rocks at the north end of the complex (figs. 8 and 9). This morning we will look at outflow tuff from the Job Canyon caldera in the Louderback Mountains and at deeper parts of the IXL pluton. In addition, we will make brief stops to look at outflow tuff sheets from the Elevenmile Canyon and Poco Canyon calderas. We will spend this afternoon in the Poco Canyon caldera looking at several units of caldera fill and some of the structural features of this caldera. If time allows, we will hike to the roof of the IXL pluton.

Mileage between stops	Cumulative mileage	
0.0	0.0	Begin mileage in downtown Austin at Lander County Courthouse. Head west out of town on U.S. Highway 50.
25.2	25.2	Pony Express station (ruins and historic marker) at New Pass.
1.2	26.4	**Stop 4-1** Turnoff on the west side of New Pass. Walk back along north side of road for about 0.15 miles looking at exposures of the New Pass Tuff. The New Pass Tuff is a crystal-rich rhyolite and high-silica rhyolite (73-78 weight percent SiO_2) ash-flow tuff that contains about 40 percent phenocrysts composed almost entirely of quartz and sanidine. The New Pass Tuff is believed to be outflow from the Poco Canyon caldera in southern Stillwater Range (John, 1993a). The New Pass Tuff and its intracaldera equivalent, the tuff of Poco Canyon, are about 25.0 Ma (Deino, 1989; A.L. Deino, oral commun., 1993). At 0.15 miles, a dirt road angles down to Highway 50 from the north. Dark brown outcrops east of this road that underlie the New Pass Tuff are unit D of the Bates Mountain Tuff. This cooling unit and its possible lateral equivalent, the Nine Hill Tuff, are some of the most widespread ash-flow tuff units in the Great Basin extending from the west side of the Sierra Nevada in California to near Ely, Nevada (Best and others, 1989b). The Nine Hill Tuff will be viewed tomorrow near Donner Summit at stop 5-3.

[1] U.S. Geological Survey, Menlo Park, CA

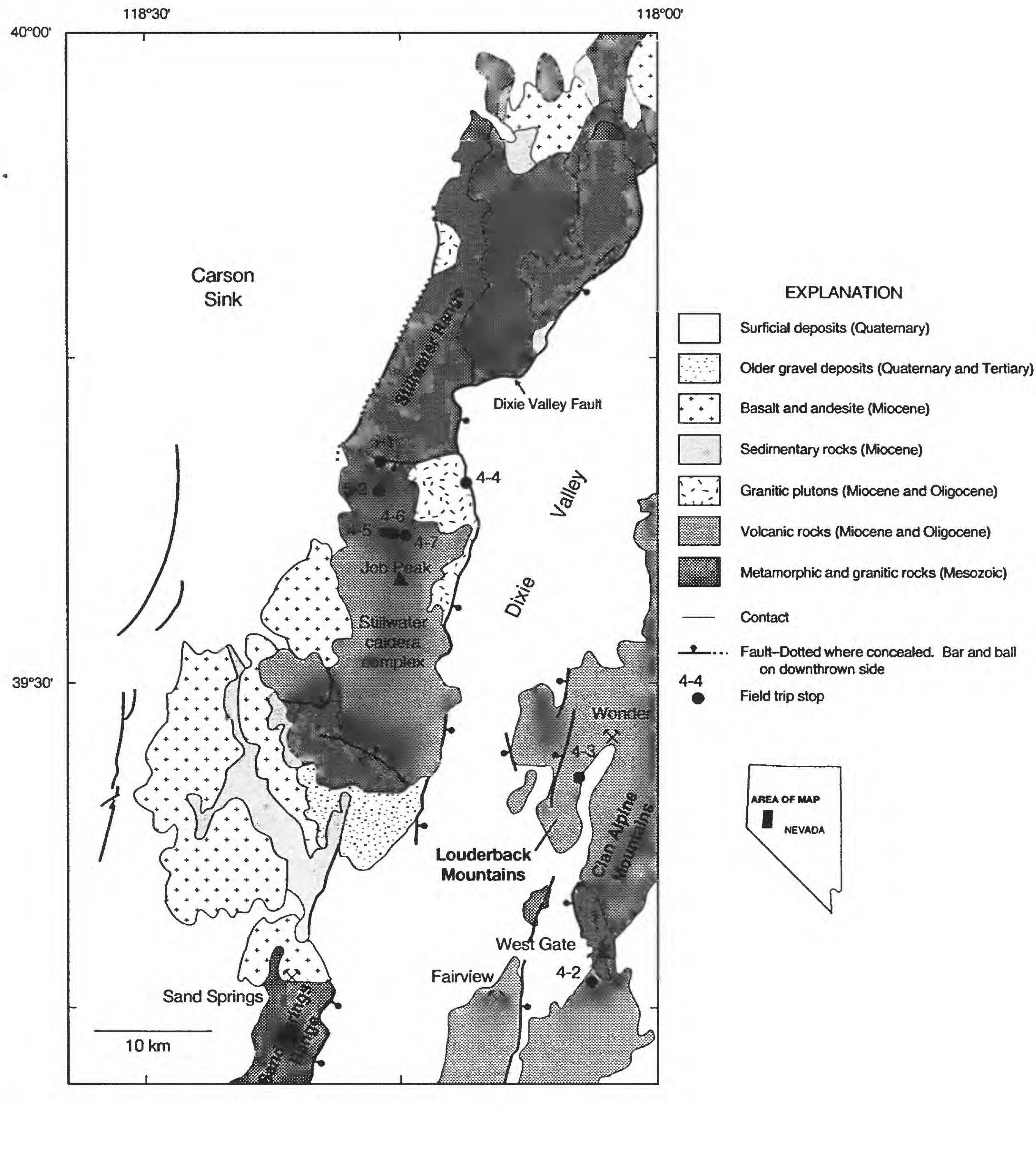


Figure 6. Generalized geologic map of the Stillwater Range and vicinity, west-central Nevada, showing location of the Stillwater caldera complex and field trip stops for day 4 and morning of day 5 except for stop 4-1.

18.9	45.3	Cold Springs cafe on left.
13.7	59.0	Middlegate cafe and junction with Nevada Highway 361 to Gabbs on left.
1.6	60.6	**Stop 4-2** Westgate. Make sharp left hand turn across Highway 50 to the old highway and park. Examine roadcuts on the far side of barbed wire fence. The rocks exposed here are part of the tuff of Elevenmile Canyon, a densely welded lithic- and crystal-rich dacite and low-silica rhyolite ash-flow tuff that was erupted from the Elevenmile Canyon caldera in the southern Stillwater Range. Note the small clasts of black phyllite in the tuff. These clasts are characteristic of this tuff. This outcrop of strongly propylitized outflow tuff was previously mapped as Mesozoic metavolcanic rocks by Corvalan (1962) and Willden and Speed (1974).
6.0	66.6	Intersection of Dixie Valley road, Nevada Route 121. Turn right.
2.8	69.4	Turnoff to Wonder on right and La Plata Canyon and Mountain Well on left. Turn right onto dirt road leading to Wonder.
0.7	70.1	Chalk Mountain at 12:00. Chalk Mountain is a horst composed mostly of light-colored Upper Triassic marble (Luning Formation) intruded by a late Oligocene granodiorite stock. Small polymetallic replacement and skarn deposits formed in marble on both sides of the mountain and were exploited in the small mines and prospect pits visible from the road.
0.4	70.5	View of the Louderback Mountains on the left and the southern Clan Alpine Mountains on the right. Top of the Louderback Mountains are composed of multiple cooling units of the tuff of Job Canyon that dip 30-40° east (to the right).
5.0	75.5	Road dips down into gully. At 11:00 the high brownish ridge consists of several cooling units of the tuff of Job Canyon. The greenish ridge at 12:00 is the overlying tuff of Elevenmile Canyon.
0.9	76.4	**Stop 4-3** Look at outcrop on the right side of road. This rock is typical of outflow facies tuff of Job Canyon that was erupted from the Job Canyon caldera in the Stillwater Range. Note that the outcrop is somewhat brecciated. Examine 10-m-high outcrop on left side of road. This outcrop also is tuff of Job Canyon. Walk to the right side of this outcrop and look at exposures just above the ground. Note that this large cliffy exposure is actually a block of the tuff of Job Canyon in a matrix of lithic-rich tuff of Elevenmile Canyon. The tuff of Elevenmile Canyon contains abundant pre-Tertiary lithic fragments and flattened green pumice clasts. The presence of very coarse blocks of the tuff of Job Canyon in the tuff of Elevenmile Canyon and apparent great (>800 m) thickness of the tuff of Elevenmile Canyon here suggests that it is intracaldera facies. Although mapping is incomplete, the Louderback Mountains and Wonder Mountain may be the faulted east part of the Elevenmile Canyon caldera which is named for exposures on the west side of Dixie Valley in the southern Stillwater Range (fig. 8).
		Turn around and drive back to the Dixie Valley road.
7.0	83.4	Turn right (north) onto Dixie Valley road.

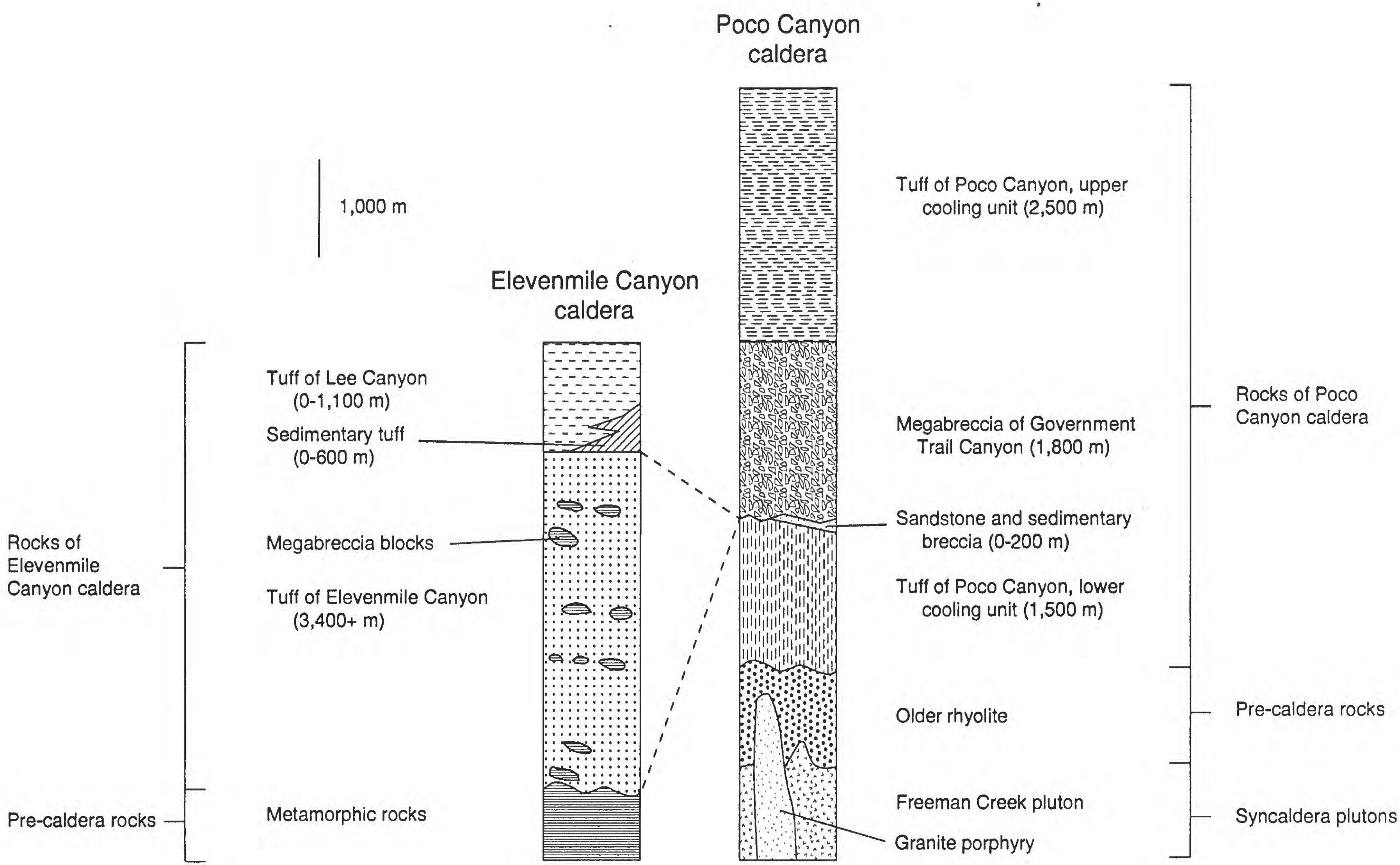


Figure 7. Summary composite stratigraphic sections for rocks in the Job Canyon, Poco Canyon, and Elevenmile Canyon calderas, southern Stillwater Range, Nevada.

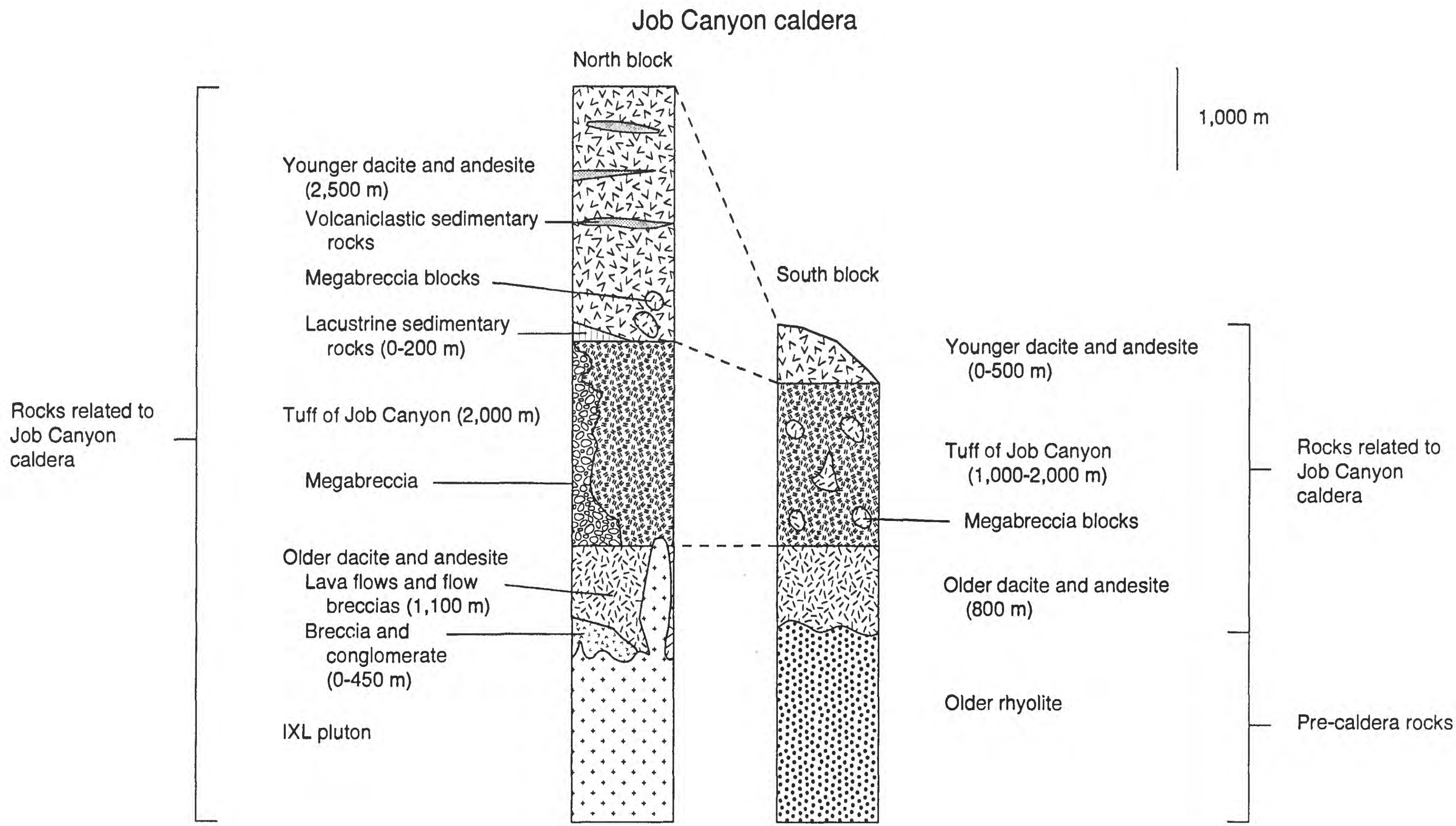


Figure 7 (continued)

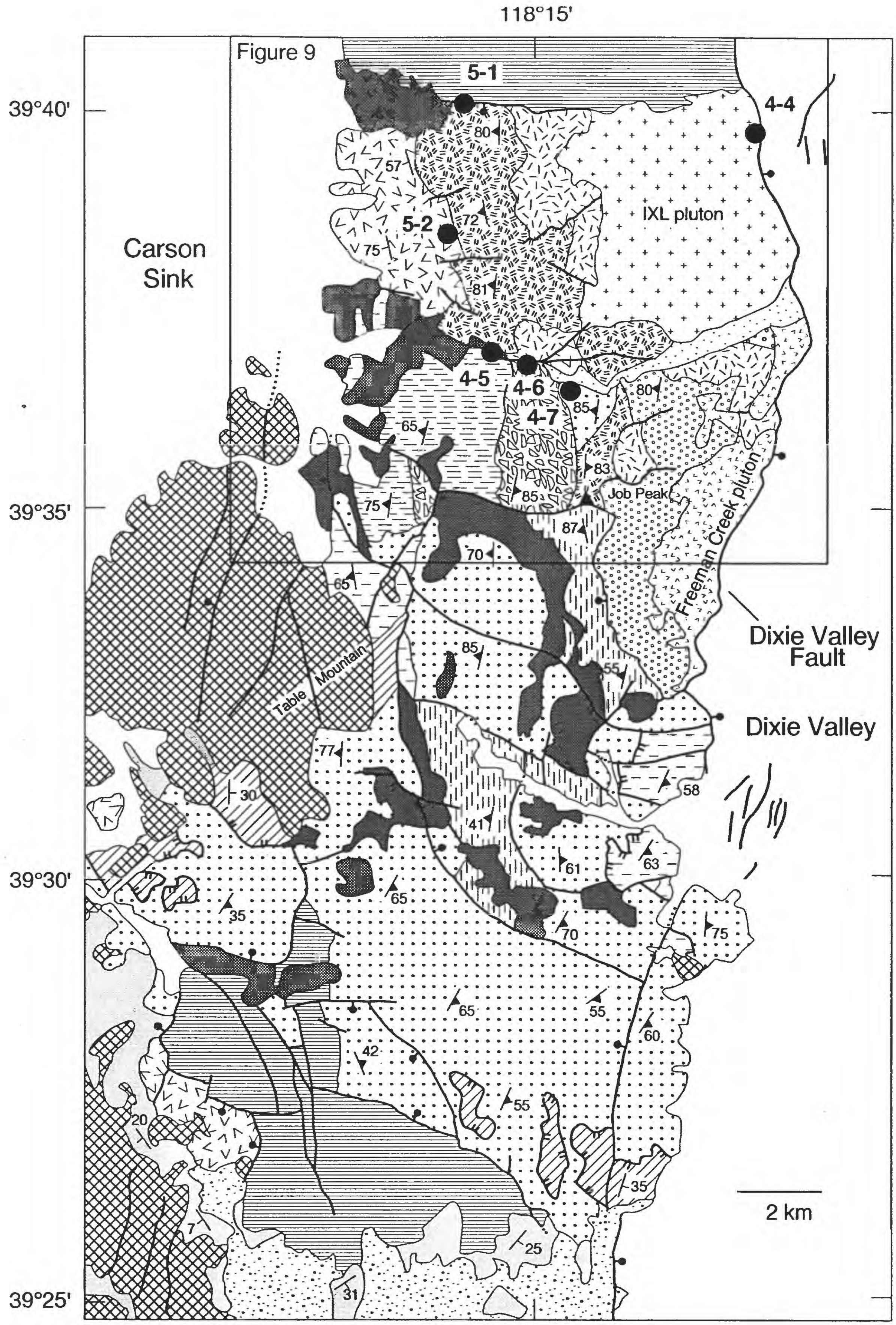


Figure 8. Generalized geologic map of theStillwater caldera complex, southern Stillwater Range, Nevada, showing field trip stops. Geology simplified from John (1992, 1993b, 1994, and unpub. mapping) and John and Silberling (1994).

EXPLANATION

Post-caldera rocks and deposits
- Surficial deposits (Quaternary)
- Older gravel deposits (Quaternary and Tertiary)
- Intermediate and mafic lavas (Miocene)
- Sedimentary rocks (Miocene)

Synextensional rocks
- Silicic intrusive rocks (Miocene and Oligocene?)

Caldera-related rocks (=Stillwater caldera complex)
- Granite porphyry (Miocene or Oligocene)
- Freeman Creek pluton (Miocene or Oligocene)
- Tuff of Lee Canyon (Oligocene)
- Megabreccia of Government Trail Canyon (Oligocene)
- Sedimentary tuff (Oligocene)
- Tuff of Elevenmile Canyon (Oligocene)
- Tuff of Poco Canyon (Oligocene)–
  - Upper cooling unit
  - Lower cooling unit
- IXL pluton (Oligocene)
- Younger dacite and andesite (Oligocene)
- Tuff of Job Canyon (Oligocene)
- Older dacite and andesite (Oligocene)

Pre-caldera rocks
- Older rhyolite (Oligocene)
- Metamorphic rocks (Mesozoic)

Contact

Fault–dotted where concealed. Bar and ball on downthrown side

Low-angle fault–double ticks on upper plate

87 Strike and dip of compaction foliation

72 Strike and dip of bedding

4-4 Fieldtrip stop

Figure 8 (explanation)

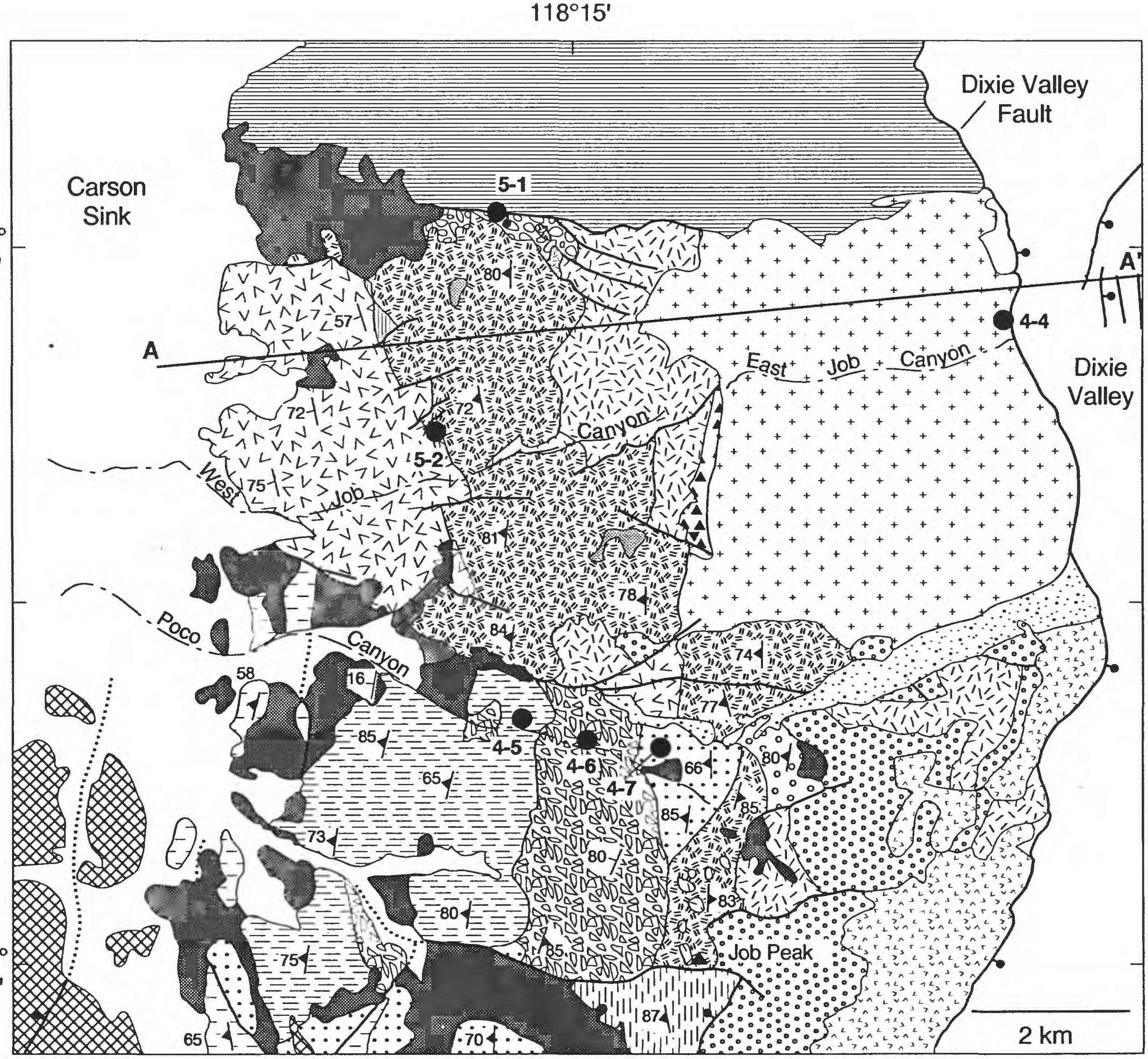


Figure 9. Geologic map and cross section of the Job Canyon caldera and the northern parts of the Poco Canyon and Elevenmile Canyon calderas, showing field trip stops.

EXPLANATION

Post-caldera rocks and deposits

- Surficial deposits (Quaternary and Tertiary)
- Basalt and basaltic andesite (Miocene)
- Silicic intrusive rocks (Miocene)
- Intermediate intrusive rocks (Miocene or Oligocene)

Poco Canyon caldera

- Granite porphyry (Miocene or Oligocene)
- Freeman Creek pluton (Miocene or Oligocene)
- Tuff of Poco Canyon (Oligocene)—Divided into:
  - Upper cooling unit
  - Lower cooling unit
- Megabreccia of Government Trail Canyon (Oligocene)

Elevenmile Canyon caldera

- Tuff of Lee Canyon (Oligocene)
- Tuff of Elevenmile Canyon (Oligocene)

Job Canyon caldera

- IXL pluton (Oligocene)
- Younger dacite and andesite (Oligocene)—Divided into:
  - Lacustrine sedimentary rocks
  - Lava flows and flow breccias
- Megabreccia (Oligocene)
- Tuff of Job Canyon (Oligocene)
- Older dacite and andesite (Oligocene)—Divided into:
  - Lava flows and flow breccia
  - Breccia and conglomerate

Pre-caldera rocks

- Older rhyolite (Oligocene)—Divided into:
  - Welded tuff
  - Lava flows and intrusive rocks
- Metamorphic rocks (Mesozoic)

Contact

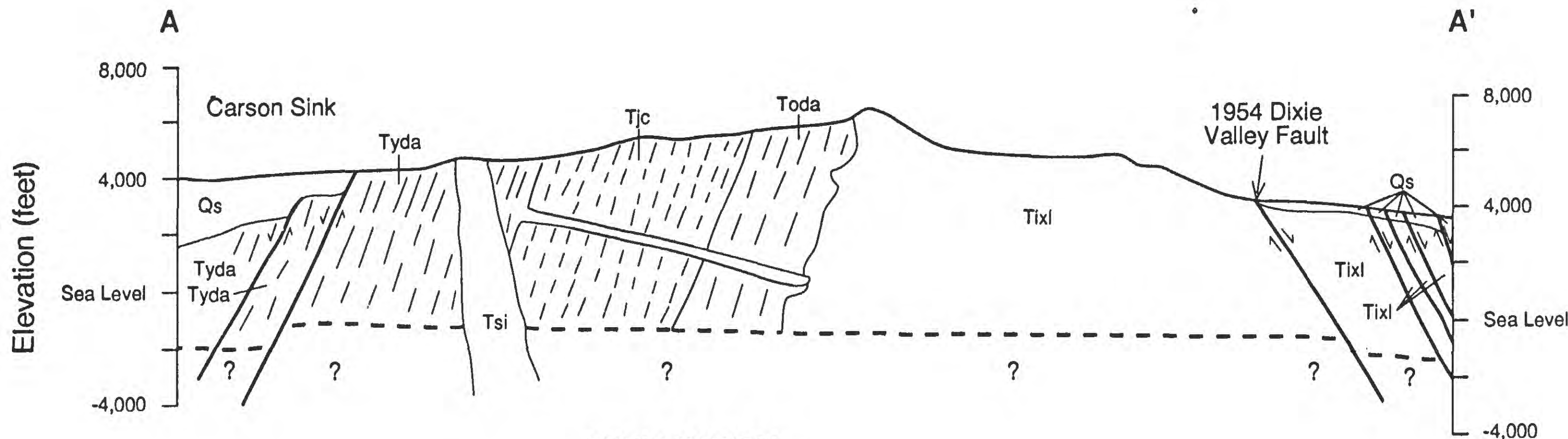
Fault–dashed where concealed. Bar and ball on downthrown side

87 Strike and dip of compaction foliation

72 Strike and dip of bedding

4-5 ● Field trip stops

Figure 9 (explanation)



EXPLANATION

Qs	Surficial deposits (Quaternary)	Tyda	Younger dacite and andesite (Oligocene)
Tsi	Silicic intrusive rocks (Miocene)	Tjc	Tuff of Job Canyon (Oligocene)
Tixl	IXL pluton (Oligocene)	Toda	Older dacite and andesite (Oligocene)

Figure9 (cross section)

TABLE 1. SUMMARY OF MAJOR FEATURES OF CALDERAS IN THE STILLWATER CALDERA COMPLEX, SOUTHERN STILLWATER RANGE, NEVADA

	Job Canyon caldera	**Poco Canyon caldera**	**Elevenmile Canyon caldera**
Age	Approx. 29-28 Ma	25-23 Ma	25-23 Ma
Caldera-related units	Younger dacite and andesite (lavas), tuff of Job Canyon, older dacite and andesite (lavas), IXL pluton	Tuff of Poco Canyon (2 cooling units), megabreccia of Government Trail Canyon, Freeman Creek pluton, granite porphyry	Tuff of Lee Canyon, sedimentary tuff unit, tuff of Elevenmile Canyon, Freeman Creek(?) pluton
Thickness of caldera fill	North block—±5 km; south block—≤2.5 km	>4 km along north margin; >1.5 km at south end	>3 km in south and central parts, <1 km at north end
Megabreccia	Lenses in intracaldera tuff along north wall and south side of north block; blocks in intracaldera tuff near south end	Blocks in upper cooling unit of (intracaldera) tuff of Poco Canyon; 1.8-km-thick megabreccia unit beneath upper cooling unit	Blocks and lenses in tuff along north and south walls; slide blocks in tuff as much as 6 km from south wall
Intrusive rocks	IXL pluton—fine- to medium-grained, biotite-hornblende granodiorite to quartz monzodiorite	Freeman Creek pluton—medium- to coarse-grained granite; granite porphyry—porphyroaphanitic rhyolite porphyry to medium-grained granite porphyry	Freeman Creek pluton—medium-grained granodiorite porphyry
Composition of caldera-related rocks and compositional zoning	Trachyandesite to rhyolite (approx. 55-75 % SiO_2), little variation in tuff (70-75 % SiO_2); IXL pluton—approx 60-68% SiO_2, felsic to mafic zoning from roof downward	Rhyolite to high-silica rhyolite (73-77% SiO_2), weak normal zoning; Freeman Creek pluton—72-74 % SiO_2; granite porphyry—approx. 71-75 % SiO_2	Trachydacite to rhyolite (approx. 61-74 % SiO_2); compositional zoning uncertain in extrusive rocks; 66-67% SiO_2 in plutonic rocks
Outflow facies rocks and regional distribution	Regional distribution unknown; outflow tuff extends 30 km SE to Louderback and southern Clan Alpine Mountains	Outflow tuff regionally widespread—New Pass Tuff in central Nevada (60 km E) and tuff of Chimney Spring(?) in western Nevada (150 km W)	Regional distribution unknown; outflow tuff extends 25-30 km E and SE to Louderback and southern Clan Alpine Mountains and north end of Fairview Peak
Caldera walls and bounding structures	Mesozoic rocks; sub-vertical fault penetrating at least 5 km deep	Tertiary volcanic rocks (Job Canyon caldera and older rhyolite unit); high-angle fault at north end	South wall—Mesozoic rocks, subvertical fault at least 3 km deep; north wall—Tertiary volcanic rocks, high-angle fault fault obscured by intrusive rocks
Caldera floor	Tertiary volcanic rocks where preserved	Tertiary volcanic rocks	South end—Mesozoic rocks; north end—Tertiary volcanic rocks
Caldera resurgence	North block—uncertain--possible piston-like uplift ≤1 km; south block—not evident	Not evident	Possible doming of center of caldera forming moat in southern third of caldera filled by sedimentary tuff unit

5.5 88.9 On left is gravel road leading to Elevenmile Canyon.

3.7 92.6 On right is view of Pirouette Mountain (low peak in foreground) and the Louderback Mountains which form the high ridge. Mapping of the Louderback Mountains is incomplete, but they are composed mostly of Tertiary tuff and lava that predate the Stillwater caldera complex and tuffs from the Job Canyon and Elevenmile Canyon calderas. Note the moderately to steeply dipping white rhyolite dikes. These dikes are part of an early Miocene (approx. 19 Ma), WNW-trending rhyolite dike swarm that cuts the southern end of the Elevenmile Canyon caldera in the Stillwater Range and continues east across Dixie Valley with no apparent lateral displacement. The lack of lateral displacement of these dikes indicates that the faults that formed Dixie Valley, including the range-bounding Dixie Valley Fault that last moved in 1954, are dip-slip faults with little or no oblique slip.

5.3 97.9 To the left is a view of the lower parts of the Stillwater caldera complex. The highest point on the skyline is Job Peak. The light-colored cliffs are underlain by the Freeman Creek pluton, which is composed mostly of coarse-grained biotite granite that forms the plutonic roots of the Poco Canyon caldera. The Freeman Creek pluton intrudes the older rhyolite unit, a sequence of rhyolite lava flows and intrusions, which forms the dark-colored outcrops. The older rhyolite unit is overlain by various intracaldera ash-flow tuffs, mostly the tuff of Job Canyon (north of Job Peak) and the lower cooling unit of the tuff of Poco Canyon (south of Job Peak). All these rocks dip steeply west away from us. The dark-colored band in the granite is a middle(?) Miocene diabase dike. South of the Freeman Creek pluton, the more subdued topography is underlain by a great thickness of intracaldera tuff of Elevenmile Canyon which dips moderately to steeply to the east (40°-75°). The approximately 2-m-high scarp from the 1954 Dixie Valley earthquake forms the prominent light band at the base of the range.

5.4 103.3 To the left is Little Box Canyon where the reddish-brown colored rock is granite porphyry which forms the east end of rhyolite porphyry ring fracture dike that we will see this afternoon. North of the dike, the dark-gray rounded hills are underlain by the granodioritic IXL pluton.

4.3 107.6 Turnoff to East Job Canyon on left. Make sharp left turn onto first gravel road.

1.7 109.3 Crossing pediment scarp from 1954 Dixie Valley earthquake. The pediment scarp is a compound late Quaternary feature that had relatively small displacement (about 30 cm) compared to the range front scarp (about 2 m) during the 1954 earthquake but has had at least 8 m of Quaternary displacement (Bell and Katzer, 1987). Most of the displacement of Dixie Valley has occurred along piedmont faults rather than the modern range front fault (Herring, 1967; Meister, 1967; Bell and Katzer, 1987).

0.8 110.1 **Stop 4-4**. Mouth of East Job Canyon along the main trace of the range front fault (modern Dixie Valley Fault). Here, the scarp from 1954 earthquake is approximately 2 meters high. The fault juxtaposes young alluvial fan deposits against grusy-weathering granodiorite of IXL pluton. Just north of the mouth of East Job Canyon is a west-dipping subsidiary fault that forms a small graben between it and the range front fault. Hike up the road about 400 m until the road starts to drop into the canyon. Turn up small side canyon to north to look at the lowest exposed part of the IXL pluton and hydrothermal alteration related to the Dixie Valley Fault. Alteration associated with the Dixie Valley Fault has been studied by Parry and others (1991) who describe several alteration zones in footwall granodiorite that are concentric to the trace of the fault.

Here, the IXL pluton has a medium-grained, equigranular texture. It has a color index of about 20-25 composed mostly of altered hornblende and is much more mafic than the upper part of the pluton which we may see this afternoon. Mafic inclusions are also notably more abundant. Note the locally pervasive hydrothermal alteration consisting of epidote + chlorite ± actinolite + bleached plagioclase (albite?) + pink K-feldspar. Several generations of veins are also evident: (1) epidote ± narrow albitic selvages along joints or narrow veins; (2) chlorite + pyrite ± calcite; and (3) white zeolites in shear zones. The epidote veins are scattered throughout the pluton and probably represent deuteric alteration of the cooling pluton. Parry and others (1991) showed that the zeolite veins are limited to the vicinity of the modern Dixie Valley Fault and probably resulted from hydrothermal fluids circulating along the fault. In addition, they describe biotite and sericite alteration that they suggest resulted from hydrothermal fluid circulation during early Miocene (25-21 Ma) faulting along an ancestral trace of Dixie Valley Fault.

Return to the vans, drive back to the pavement, turn right, and drive back to the turnoff to radar tower and Mountain Well.

22.2	132.3	Turnoff to radar tower, powerline, and Mountain Well. Turn right, go up the hill and continue straight on main road past radar tower. Continue on main dirt road past several other Navy radar installations.
2.4	134.7	Intersection of many dirt roads. Take far right fork
3.4	138.1	Low hills at 3:00 are latest Tertiary-early Quaternary gravels overlying middle Miocene sedimentary rocks
2.5	140.6	Turn off to La Plata Canyon on right (cattleguard). Continue straight.
0.7	141.3	Intersection of road to U.S. Highway 50 on left. Continue straight. Drive through middle Miocene sedimentary rocks locally covered by middle Miocene intermediate to mafic lavas, latest Tertiary or Quaternary gravel deposits, and Quaternary surficial deposits.
1.0	142.3	At 12:00 are basaltic andesite lavas.
0.2	142.5	At 2:00 high ridge is composed of Mesozoic metamorphic rocks. At 11:00 Miocene porphyritic dacite lavas overlie Miocene sedimentary rocks.
2.1	144.6	At 12:00 are Mesozoic metamorphic rocks.
2.0	146.6	Hill at 1:00 is hornblende andesite lavas that are about 15 Ma and are the oldest dated middle Miocene lavas at the south end of the Stillwater Range.

0.8	147.4	Summit. Road to right leads to La Plata Canyon. Hills at 12:00 are composed mostly of sedimentary megabreccia that was deposited along the north edge of middle Miocene sedimentary basin. At 9:00 are 15-14 Ma pyroxene dacite lavas. Dark green rocks in low foreground are propylitized andesites that predate eruption of the tuff of Elevenmile Canyon (≥25 Ma). Continue straight on main road.
0.7	148.1	Basalt dike intruding middle Miocene sedimentary rocks and sedimentary megabreccia.
0.3	148.4	Mountain Well. Ridge behind (west of) Mountain Well is a basalt dike that intrudes sedimentary megabreccia. Dike is about 13.7 Ma. Continue straight on main road. Most exposures for the next 6 miles are coarsely porphyritic dacite lavas and breccias (middle Miocene) that are locally overlain by Quaternary eolian sand deposits.
2.9	151.3	Outcrops of basalt on either side of road.
1.2	152.5	At 3:00 is dacite plug.
2.1	154.6	On right is turnoff to Sheep Canyon. Continue straight.
1.3	155.9	Overview of Carson Sink, a large late Cenozoic basin partly filled with the remnants of Pleistocene Lake Lahontan
2.4	158.3	Intersection with Stillwater road. Turn right (northeast).
2.2	160.5	Lake terraces from Pleistocene Lake Lahontan cut into middle Miocene (approx. 14-13 Ma) basaltic andesites.
3.3	163.8	Cross cattleguard at fence line. To the right along the fence are small tufa mounds.
2.8	167.5	Turnoff to West Job and Poco Canyons. Turn right and make **a brief stop** for an overview of the west side of the southern Stillwater Range. We are looking at the guts of the Job Canyon, Elevenmile, and Poco Canyon calderas. Most of the exposed rocks are steeply west dipping intracaldera fill. At 12:00 is Job Peak, the highest point in range at 8,785 ft, which is at the south end of the Job Canyon caldera. A major east-west-striking fault runs across the south face of Job Peak. The ridge between West Job and Poco Canyons is the north margin of the Poco Canyon and Elevenmile Canyon calderas.
0.4	167.9	Gravel quarry. Stay on main road that bears right around quarry.
1.4	169.3	Fork in the road. Take right hand fork and drive through Quaternary gravel terraces leading into Poco Canyon. Left hand fork leads to West Job Canyon.
1.3	170.6	Outcrop on left side of canyon is tuff of Lee Canyon, which is probably a late-stage eruption from the Elevenmile Canyon caldera. Compaction foliation in the tuff dips about 50°-60° west.
0.2	170.8	Dark rock cutting the tuff of Lee Canyon is glassy biotite rhyolite that forms a dike and dome complex. This rhyolite is part of the synextensional

magmatism that accompanied steep tilting of the calderas. Paleomagnetic data and the morphology of the intrusion suggest that it has not been tilted significantly in contrast to the steep dips of the tuff it intrudes. K-Ar ages of this rhyolite (24.6±0.8 Ma, biotite) and the tuff of Lee Canyon (24.2±0.8 Ma, biotite) are analytically indistinguishable.

1.1 171.9 Exposure of major angular unconformity on the south side of Poco Canyon. In this face, the late Oligocene (approx. 25-24 Ma), steeply dipping (approx. 75° west), intracaldera tuff of Poco Canyon is unconformably overlain by shallow dipping (≤15°), early Miocene (approx. 23-22 Ma) rhyolite tuffs and lavas. The isotopic ages and the angular discordance displayed in this outcrop combined with field, paleomagnetic, and K-Ar data from other exposures, including the vitrophyric rhyolite intrusion exposed near the mouth of Poco Canyon, indicate very rapid and short-lived extension of the southern Stillwater Range in earliest Miocene time (about 24-23 Ma).

0.7 172.6 On both sides of canyon are large (10s to 100s of meters in diameter) megabreccia blocks of the older rhyolite unit in the tuff of Poco Canyon.

0.4 173.0 **Stop 4-5** at fork in road. Good exposures of the lower part of the upper cooling unit of the tuff of Poco Canyon including partly vitric tuff containing abundant iridescent ("chatoyant") sanidine and smoky quartz phenocrysts. The tuff of Poco Canyon is believed to be the intracaldera facies equivalent to the New Pass Tuff, which is widely exposed at the north end of the Stillwater Range and in adjacent ranges to the east (Clan Alpine Mountains, New Pass Range, and Shoshone Mountains). John (1993a) suggested that the Poco Canyon caldera was also the source of the tuff of Chimney Spring, which crops out west of the Stillwater Range between the California State border and Carson Sink, and which had been previously correlated by Deino (1985, 1989) with the New Pass Tuff. However, recent mapping in the Olinghouse district by H.F. Bonham, Jr., and L.J. Garside (oral commun., 1992) suggests that the source of the tuff of Chimney Spring may be in the Pah Rah Range about 100 km west-northwest of the Poco Canyon caldera and that the correlation of the New Pass Tuff with the tuff of Chimney Spring may be invalid.

Road forks to the left; continue straight ahead. We are driving through poorly exposed megabreccia of Government Trail Canyon which underlies the upper cooling unit of the tuff of Poco Canyon.

0.3 173.3 Gully crossing that may not be possible for vans.

0.6 173.9 **Stop 4-6** Good exposures of the megabreccia of Government Trail Canyon where the road crosses the canyon and on north side of the canyon just to the east. The megabreccia of Government Trail Canyon is a heterogeneous unit consisting of variably-sized blocks of Tertiary volcanic units in a matrix of moderately welded, crystal-poor ash-flow tuff. The tuff matrix is commonly green colored and contains about 5 percent phenocrysts in contrast to overlying and underlying ash-flow tuff units that generally contain 30-50 percent phenocrysts. At this stop, most of the blocks in the breccia are relatively small (<2 m in diameter) and composed of the older rhyolite unit and the tuff of Job Canyon, and most of the breccia appears to be matrix supported. However, close examination of the "matrix" of the breccia suggests that tuff matrix itself has been brecciated and forms blocks in a second generation of tuff matrix. Many other exposures of this unit, notably in Government Trail Canyon about 2 km to the south, are clast-supported breccias that contain blocks as much as 200-300 m in diameter of the lower cooling unit of the tuff of Poco Canyon in addition to the aforementioned lithologies. The origin of the megabreccia of Government Trail Canyon is somewhat enigmatic; it clearly represents ash-flow tuff and breccia deposited during caldera collapse, but it is megascopically unlike caldera fill exposed either above or below it. The megabreccia is restricted spatially to lying directly beneath the upper cooling unit of the tuff of Poco Canyon (fig. 8) suggesting that it may be related to the Poco Canyon caldera. Preliminary geochemical data also suggest that the tuff matrix is compositionally similar to the tuff of Poco Canyon and the megabreccia probably formed during an early part of the eruption of the upper cooling unit of the tuff of Poco Canyon.

0.1 174.0 **Stop 4-7** at end of road at old shack. We are near the contact between the megabreccia of Government Trail Canyon and underlying megabreccia and mesobreccia in the tuff of Elevenmile Canyon which forms the steep face at the head of Poco Canyon. The prominent iron-stained, ridge-forming outcrops on the north side of the canyon are rhyolite porphyry that mark the approximate north margins of the Poco Canyon and Elevenmile Canyon calderas and probably are a ring-fracture dike related to the Poco Canyon caldera. Poorly exposed outcrops on the south side of the canyon are megabreccia blocks in the megabreccia of Government Trail Canyon. We will hike part way up the canyon (east) just to the left (north) of the spur that extends down to the cabin to look at the intracaldera tuff of Elevenmile Canyon. Then we will climb uphill to the north to look at the rhyolite porphyry dike. If time allows (and if people desire some more exercise), we will then hike east along the dike to the low saddle where outcrop of the dike ends. This break in the dike is underlain by lithic-choked tuff of Elevenmile Canyon (mesobreccia) along the caldera margin. We will then climb down the north side of this ridge to the small cabin crossing through densely welded tuff of Job Canyon. Then we will follow the jeep trail west from the cabin for about 1 km to look at the top of the IXL pluton where it intrudes the base of the Job Canyon caldera. Then retrace your steps and return back to the vans.

The tuff of Elevenmile Canyon is a crystal- and biotite-rich, densely welded ash-flow tuff that varies in composition from low-silica dacite to rhyolite (about 61 to 74 weight percent SiO_2 volatile-free). It fills the Elevenmile Canyon caldera which is about 20 km across from north to south and contains >3.5 km thickness of caldera-filling tuff in its central and southern parts (fig. 8). However, the tuff of Elevenmile Canyon is only about 800 m thick in Poco Canyon along the north edge of the caldera suggesting that the amount of caldera collapse was irregular. Outflow tuff from the caldera extends southeast across Dixie Valley to the southern Clan Alpine Mountains and the north end of Fairview Peak where we saw it at stop 4-2 this morning (fig. 6). The tuff of Elevenmile Canyon erupted between eruptions of the tuff of Poco Canyon as shown by clasts of the tuff of Poco Canyon in the tuff of Elevenmile Canyon and its stratigraphic position beneath of the upper cooling unit of the tuff of Poco Canyon in Poco Canyon (fig. 8). Most of the intracaldera tuff is strongly propyliticallly altered; consequently only a single biotite K-Ar age of 24.5±0.7 Ma has been determined which is analytically identical to K-Ar ages of the upper cooling unit of the tuff of Poco Canyon and the overlying tuff of Lee Canyon. Many of the prominent outcrops on the west face at the head of Poco Canyon are megabreccia blocks of andesite and of the older rhyolite unit that are enclosed in the tuff of Elevenmile Canyon. The tuff of Elevenmile Canyon is underlain by the tuff of Job Canyon which forms the ridgeline.

Rhyolite porphyry at the head of Poco Canyon forms the west end of a N80°W to N75°E-striking dike that is exposed nearly continuously for 7 km (fig. 8). The dike consists medium-grained rhyolite porphyry that has a porphyro-aphanitic texture and contains phenocrysts of quartz, plagioclase, K-feldspar, and biotite which grades eastward into medium-grained granite porphyry (fine-grained groundmass) and which eventually grades into medium-grained equigranular granite near its east end. The dike intrudes the IXL and Freeman Creek plutons, the older rhyolite unit, the tuffs of Job Canyon and Elevenmile Canyon, and the megabreccia of Government Trail Canyon. The dike is pervasively hydrothermally altered (generally sericite or clay minerals + pyrite); consequently, it has not been isotopically dated. Preliminary geochemical data suggest that it is related to the tuff of Poco Canyon and the Freeman Creek pluton. The geochemical data and the location of the dike along the north margin of the Poco Canyon caldera suggest that it is a ring-fracture intrusion related to the Poco Canyon magma system.

The lower part of the IXL pluton was looked at this morning (stop 4-4), and where exposed along the Dixie Valley Fault, it is an equigranular, medium-grained rock with a color index of about 25. In contrast, the upper part of the pluton which was emplaced at depths about 4-5 km shallower, has a conspicuous crowded porphyry texture consisting of medium-grained feldspar and scattered biotite and hornblende phenocrysts set in a fine-grained groundmass of quartz, feldspar, and biotite. The color index is about 10-12. Note the pink color of potassium feldspar and white color of plagioclase.

Whole-rock $\delta^{18}O$ values of the top of the pluton are markedly depleted (0 to -7 permil) despite the lack of obvious hydrothermal alteration. Deeper, apparently unexchanged parts of pluton have "normal" igneous values of +6 to +7 permil.

Return to vans and drive back down Poco Canyon. Return to Fallon.

4.7	178.7	Intersection of West Job Canyon and Poco Canyon roads. Continue straight.
1.8	180.5	Intersection of main road along west side of Stillwater Range. Turn left.
14.5	195.0	Beginning of pavement.
11.5	206.5	Intersection of U.S. Highway 50. Turn right.
4.7	211.2	Intersection of U.S Highways 50 and 95 in Fallon. Spend night in Fallon.

Day 5
Overview

This morning we will look at structural and stratigraphic features of the Job Canyon caldera. The first stop will view the north wall of the caldera and megabreccia deposited along the wall. The second stop will look at ash-flow tuff and post-collapse intermediate lavas that ponded inside the caldera. After lunch, we will drive back to Fallon, continue on past Reno, and make a brief stop along the crest of the Sierra Nevada to view the Nine Hill Tuff near Donner Summit. We will then continue on to Berkeley where the trip ends.

Mileage between stops	Cumulative mileage	
0.0	0.0	Road log begins at the intersection of U.S. Highways 50 and 95 (Maine Street) in downtown Fallon. Continue east on U.S. Highway 50 through Fallon.
1.2	1.2	At 9:00 is Rattlesnake Hill, a Quaternary basalt volcano that is mostly covered by sediments from Pleistocene Lake Lahontan.
3.5	4.7	Junction with Nevada Route 116 to Stillwater; turn left.
10.4	15.1	Town of Stillwater.
1.1	16.2	End of pavement. Continue straight.
0.9	17.1	Stillwater Wildlife Refuge Maintenance Station
5.3	22.4	On south (right) is turnoff to Mountain Well and La Plata Canyon. Continue east on main gravel road.
2.2	24.6	Lake terraces from Pleistocene Lake Lahontan cut into middle Miocene (approx. 14-13 Ma) basaltic andesites.
3.3	27.9	Cross cattleguard at fence line. To the right along the fence are small tufa mounds.
2.8	30.7	Turnoff to West Job and Poco Canyons. Continue straight on main road.
1.0	31.7	Windmill on left. At 2:00 are steeply west-dipping lavas of the younger dacite and andesite unit that ponded inside the Job Canyon caldera. At 1:00 are low hills composed of a rhyolite dome that intrudes the margin of the Job Canyon caldera. The high hills and ridgeline are underlain by Jurassic and Triassic metasedimentary rocks.
3.5	35.2	Turnoff to Cox Canyon. Turn right.
1.0	36.2	The contact of Quaternary gravels and Triassic marble here is probably a fault.
0.8	37.0	Road forks. Continue on straight (right fork) staying in the bottom of Cox Canyon. We are driving through a section of complexly folded and faulted, metamorphosed Jurassic and Triassic mudstone and limestone of the Jungo terrane, which is commonly referred to as "the Mudpile". In the lower parts of Cox Canyon, metavolcanic rocks and quartzite of unknown age (Jurassic?) and origin crop out (Page, 1965). Blocks of these rocks are present in megabreccia lenses in intracaldera tuff along the north wall of the Job Canyon caldera and require a minimum of 2 km of caldera collapse.

1.2	38.2	Gully crossing that may not be driveable by vans (pickup trucks and Blazer-type vehicles can easily cross this gully in 2-wheel drive). If necessary, park and walk up main canyon 0.9 miles (1.5 km).
0.9	39.1	**Stop 5-1** End of driveable road. Turn vehicles around and park. Hike south about 100 meters in Cox Canyon until the canyon turns east and a small gully enters from the south. Hike up this gully about 100 meters climbing to the second outcrop in the bottom of the gully. Here, we are standing just inside the north wall of the Job Canyon caldera. Rocks exposed uphill and to the south are intracaldera fill whereas rocks exposed downhill and to the north are Mesozoic wallrocks. Rocks cropping out in the gully are megabreccia blocks composed mostly of Mesozoic marble. Other types of blocks in megabreccia include metavolcanic rocks, quartzite, and the older dacite and andesite unit. This outcrop has a well developed rind of welded tuff on its west side. Note the lithic-rich nature of the tuff and the partial silicification of it by quartz microveins. Steeply west dipping (about 60°), densely welded tuff of Job Canyon crops out just uphill from this outcrop. The approximate wall of the caldera is exposed on the west side of this gully and is best seen from the bottom of Cox Canyon. The wall is marked by a change from megabreccia blocks and poorly exposed tuff to coherent Mesozoic strata exposed just north of the gully. The caldera wall continues east up Cox Canyon to the low saddle along the top of the range. The low ridges exposed just east of here in Cox Canyon are composed mostly of megabreccia and lithic-rich tuff. Return to the vans and drive back down Cox Canyon.
3.9	43.0	Intersection of main road. Turn left.
4.3	47.3	Intersection of road to West Job and Poco Canyons. Turn left.
0.4	47.7	Gravel quarry. Stay on main road that bears right around quarry.
1.4	49.1	Fork in the road. Turn left to drive to West Job Canyon. Right fork runs up Poco Canyon. For the next 3 miles we will be driving mostly through Quaternary gravels.
1.7	50.8	Road drops into West Job Canyon. Straight ahead at 12:00 are dacite and andesite lavas and flow breccias of the younger dacite and andesite unit which ponded inside the northern half of the Job Canyon caldera. These rocks dip about 80° west as shown by interbedded sedimentary units. Probable contacts between flow units are evident in the dark knob in the middle distance. Continue up West Job Canyon driving through pediment gravels.
1.6	52.4	**Stop 5-2** Drill road that was reclaimed by the BLM in 1992. Hike north about 300 m across the gravel-covered pediments following the reclaimed road to an old prospect exposed in the first drainage. The primary purpose of this stop is to look at the basal part of the younger dacite and andesite unit and the upper part of the intracaldera tuff of Job Canyon. Start at the prospect and walk down the drainage to the west. We will be walking upsection from near the top of the tuff. The prospect explores a N75°E striking, 70°NW dipping zone of sheeted, milky quartz ± calcite veins cutting the tuff of Job Canyon and an andesite dike. The veins locally contain small amounts of chalcopyrite and Cu-oxide minerals. The veins occur along a ENE-striking fault that has

only minor displacement. Walk down the drainage observing the densely welded tuff of Job Canyon which dips steeply to the west and a crosscutting propylitized andesite dike. Note the phenocryst content of the intracaldera tuff which is usually markedly less than in outflow tuff which we saw yesterday at stop 4-3. Cross the contact between the tuff and the younger dacite and andesite unit; the lower part of the lava sequence consists of propylitized porphyritic andesite lavas interbedded with several zones of silicic waterlain tuffs and sediments. The thickest section of sedimentary rocks may be composed mostly of subaqueous silicic ash flows that show fining upward, graded bedding sequences and local cross bedding. Elsewhere, these sedimentary rocks are composed of fine-grained sandstone, siltstone, and shale and reworked pumice-rich tuff. The sedimentary horizons are restricted to the lower several hundred meters of the younger dacite and andesite unit, and they commonly thicken along ENE- to WNW-striking faults that were active during their deposition. They locally reach thicknesses of about 200 m.

Return to vans, turn around, and drive back down West Job Canyon.

3.3	55.7	Intersection of West Job Canyon and Poco Canyon roads. Turn right and return to main road.
1.8	57.5	Intersection of main road along west side of Stillwater Range. Turn left.
14.5	72.0	Beginning of pavement.
11.5	83.5	Intersection of U.S. Highway 50. Turn right.
4.7	88.2	Intersection of U.S Highways 50 and 95 in Fallon. End of road log; for a detailed Roadlog of the geology along Interstate 80 and U.S. Highway 50 between Fallon and Reno, see Benedetto and others (1991).

PART 3. NINE HILL TUFF NEAR SODA SPRINGS, CALIFORNIA

Alan L. Deino[1]

Day 5--Afternoon

Proceed west on Interstate 80 through Reno and continue 36 miles. A few miles beyond the crest of the Sierra Nevada, exit Hwy. 80 at the Norden/Soda Springs turnoff. Proceed east past the village of Soda Springs for 0.7 mi. and turn right at Serene Road. Proceed southeast along Serene Road 2.3 mi to the outlet to Serene Lakes and the juncture with the Soda Springs Road.

Stop 5-3 Roadcuts at this spot provide excellent exposure of the lower part of the Nine Hill Tuff. This simple ash-flow tuff cooling unit of zoned crystal-poor high-silica rhyolite to crystal-vitric low-silica rhyolite to rhyodacite has the widest known distribution of any ash-flow tuff in the western United States. It extends over a lateral distance of about 550 km, found at its extremes in the Sierran foothills near Mokelumne Hill, and in eastern Nevada near Ely in the vicinity of Preston Reservoir (east of the Carson Sink the tuff is generally known as Unit D of the Bates Mountain Tuff; McKee and Stewart, 1971); Grommé and others, 1972). Maximum thicknesses of about 340 m occur in western Nevada in the type area near Carson City. The tuff remains fairly thick throughout western Nevada, but in many distal localities the unit is only a few meters to a few tens of meters thick; the average thickness is probably about 20–30 m. This extremely energetic eruption of 850–940°C magma produced a typically densely welded deposit, often exhibiting spectacular large and small scale rheomorphic features where proximal to the presumed source area in the Carson Sink–Carson City area.

The exposures of the tuff along the Soda Springs Road show a characteristic upward zonation from a 2–3 m of unwelded basal chilled zone, 0.5 m of glassy welded vitrophyre, and pink to buff densely welded crystal-poor rhyolite. The darker brown, more crystal-rich rhyodacitic upper phase of the Nine Hill can be found capping the top of the hill immediately above the roadcut about 14 m above the base of the tuff. The tuff is only about 16 m thick here in total, and as is typical of the Nine Hill Tuff in the Sierra Nevada, this unit caps the ash-flow stratigraphy. The Nine Hill Tuff here rests on a biotite-rich tuff of unknown affinity, which in turn overlies several hundred meters of unnamed ash-flow tuffs.

The compositional transition from the stratigraphically lower high-silica rhyolite to the overlying low-silica rhyolite to rhyodacite is abrupt, occurring over a few tens of centimeters. The transition represents a drop in SiO_2 of from 76 to 72 percent , an increase in phenocrysts from 3 to 12 percent, and an increase in pumice, amongst many other chemical and textural changes (Deino, 1985). The rhyolite contains a few percent sodic sanidine, with minor quartz and plagioclase, and trace amounts of biotite + ilmenite + magnetite + zircon + apatite ± orthopyroxene ± clinopyroxene ± hornblende ± allanite ± sphene ± pyrite. Sodic sanidine is joined by intensely resorbed anorthoclase in the rhyodacite. The high-silica rhyolite, presumably emplaced during the more energetic early part of Nine Hill eruption sequence, is found throughout the overall distribution area. The distribution of the rhyodacite, however, is restricted primarily to western Nevada between Pyramid Lake and Carson City, and adjacent areas of California. The Norden/Soda Springs area is the furthest south in the Sierra Nevada that has both the upper and lower components of the Nine Hill Tuff.

In traversing the Sierra Nevada, the Nine Hill Tuff apparently incorporated a lot of granitic debris in its base. Look closely especially in the unwelded tuff near the base to find cloudy, large feldspars which are presumed xenocrysts, as well as granitic xenoliths up to 1 cm in size. This

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[1] Institute of Human Origins, Berkeley, CA

much older, probably Mesozoic foreign material apparently affected early K-Ar dating efforts at nearby Beacon Hill, about one-quarter mile east of Donner Pass (Dalrymple, 1963). This study reported an age of 34.1 ± 1.4 Ma from a sample of the Nine Hill Tuff near its base, whereas a sample near the top where the tuff is less contaminated yielded 26.7 ± 1.0 Ma (ages recalculated for new constants, Steiger and Jäeger, 1977). Subsequently, with the problem of potential contamination in mind, coarse-grained, clear K-feldspars hand-picked from the unwelded base gave a K-Ar age of 23.3 ± 0.6 Ma (Deino, 1985).

An extensive K-Ar dating effort was unable to resolve a precise age for the tuff (Deino, 1985), due perhaps in part to contamination but probably more to technical difficulties in dating sanidine by the K-Ar method. Eventually, $^{40}Ar/^{39}Ar$ single-crystal laser-fusion dating of five samples of the Nine Hill Tuff/Bates Mountain Tuff (Unit 'D') yielded the precise overall mean age of 25.11 ± 0.017 Ma (±0.008 Ma s.e.m.) with a total spread of mean ages of only 40,000 years (Deino, 1989).

Return to Highway 80 and head west toward Berkeley.

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