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Synchronous Oligocene and Miocene Extension and Magmatism in the Vicinity of Caldera Complexes in Southeastern Nevada

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ABSTRACT

The 23- to 13-Ma Caliente and 17- to 12-Ma Kane Springs Wash caldera complexes, the youngest of a series of major silicic magmatic centers that erupted progressively from northerly to southerly locations in the eastern part of the Basin and Range province during the Oligocene and Miocene, recorded synchronous magmatism and extensional tectonism. The northernmost and older of the two, the Caliente caldera complex, experienced two episodes of extension synchronous with magmatism. As Caliente eruptive products evolved from calc-alkaline magmas (23-17 Ma) to more alkaline bimodal high-silica rhyolitic magmas (15.5-13 Ma), and local basalt flows (12 Ma) outside the caldera complex, the main episode of extension in the Caliente area resulted in north-northwest-striking, right-oblique- and dip-slip faults, subordinate conjugate north-northeast-striking, left-oblique- and dip-slip faults, and concurrent tilting and counter-clockwise vertical-axis rotation. The younger extensional episode (post-12 Ma) in the Caliente area, characterized mostly by north-striking basin-range normal faults, postdated volcanic rocks in the Caliente area, although basalts of the same age are present in other parts of the Basin and Range. The younger of the two caldera complexes, the Kane Springs Wash, reached its peralkaline and volumetric eruptive climax at about 14.5 Ma during the greatest rate of extension, as measured by progressive tilting of strata along listric growth faults. Extensional tectonism in the Kane Wash area was heterogeneous in distribution, degree, style, and timing and included common north-northwest-striking, right-oblique-slip faults, north-northeast-striking, left-lateral strike-slip and oblique-slip faults, north-northeast- to north-striking, steeply dipping normal faults, magmatic dilation in calderas, and sparse west-dipping low-angle normal faults. Although drier peralkaline Kane Springs Wash magmatism caused no significant mineralization, wetter calc-alkaline to alkaline Caliente magmatism formed several economic mineral deposits, the most significant of which were developed in the late 19th- and early 20th-century Ferguson (Delamar) mining district. At the turn of the century, the mining camp of Delamar was the most populous and technologically sophisticated community in the region. Its approximately 3,000 residents enjoyed a high standard of living, but paid a substantial price for their affluence in terms of personal health and safety.

INTRODUCTION

The general association between extension and magmatism in rift systems of both continents and oceanic basins has long been recognized worldwide. The Basin and Range province during the Cenozoic provides the best-studied case of such magmatism associated with widely distributed extensional strain (e.g., Mackin, 1960; Christiansen and Lipman, 1972; Eaton, 1982; Gans and others, 1989; Axen and others, 1993; Faulds, 1994). However, questions concerning temporal and spatial relations between extension and magmatism and the genetic tie between them continue to be debated (e.g., Christiansen, 1989; Best and Christiansen, 1991; Axen and others, 1993; Faulds and others, 1995).

In southeastern Nevada, Scott and others (1995a) report a close spatial and temporal relation between magmatism and extension at the Kane Springs Wash caldera complex, where the maximum rate of growth faulting coincides with the climax of peralkaline magmatism. Rowley and others (1992, 1995, in press) and Rowley (in press) report on the close association between caldera magmatism and extension accommodated by strike-slip, oblique-slip, normal-slip, and growth faults and by east-west transverse zones in the Caliente caldera complex area and other areas in the Great Basin. Anderson and others (1994) record coeval extension and magmatism in the Las Vegas-Lake Mead area, and Faulds and others (1995) report largely coeval extension and magmatism in the extensional corridor south of Lake Mead.

In the process of creating detailed 1:24,000-scale geologic maps in the field trip area, we have learned that mapping at this scale or larger is commonly necessary to recognize the geometric relationships supporting the conclusion that local extension and volcanism overlapped temporally. The necessity for detailed mapping is related to both the heterogeneity and complexity of deformation. Educated by this experience, we suggest that detailed mapping of areas in and around calderas be done before concluding whether or not extension has been synchronous with magmatism. We intend to pass on the essence of this experience to field trip participants.

The purpose of this field trip is to observe the nature of synchronous heterogeneous extensional tectonism and magmatism related to Miocene caldera complexes in southeastern Nevada. This trip is arranged from youngest to oldest events because the youngest are the easiest to interpret, and thus the trip ends with observations of Oligocene deformation, the interpretation of which is more speculative and controversial. During the first part of the first day, we will emphasize growth fault-relations and coeval magmatism near the Kane Springs Wash caldera complex During the last part of the first day and the second day, we will observe styles of extensional faulting in and adjacent to the sychronously erupting Caliente caldera complex, which developed along east-trending transverse zones. During the last part of the second day, we will see the commercial results of synchronous magmatism and extension when we explore some of the geology, mines, and pits of the Ferguson gold district and camp at the Delamar ghost town, where archeologist Dawna Ferris will interpret the history and significance of the site. On the last day we will observe evidence of changes in style and timing of extensional deformation in the North Pahroc Range from the southern end near the Caliente area northward near the Oligocene Indian Peak caldera comples (Fig. 1).

We appreciate the constructive reviews of Paul Carrara and Bill Perry. Also we depended heavily upon the computer graphics of Ray Sabala and the encouragement from Ren Thompson during intercalation of the manuscript and computer graphics.

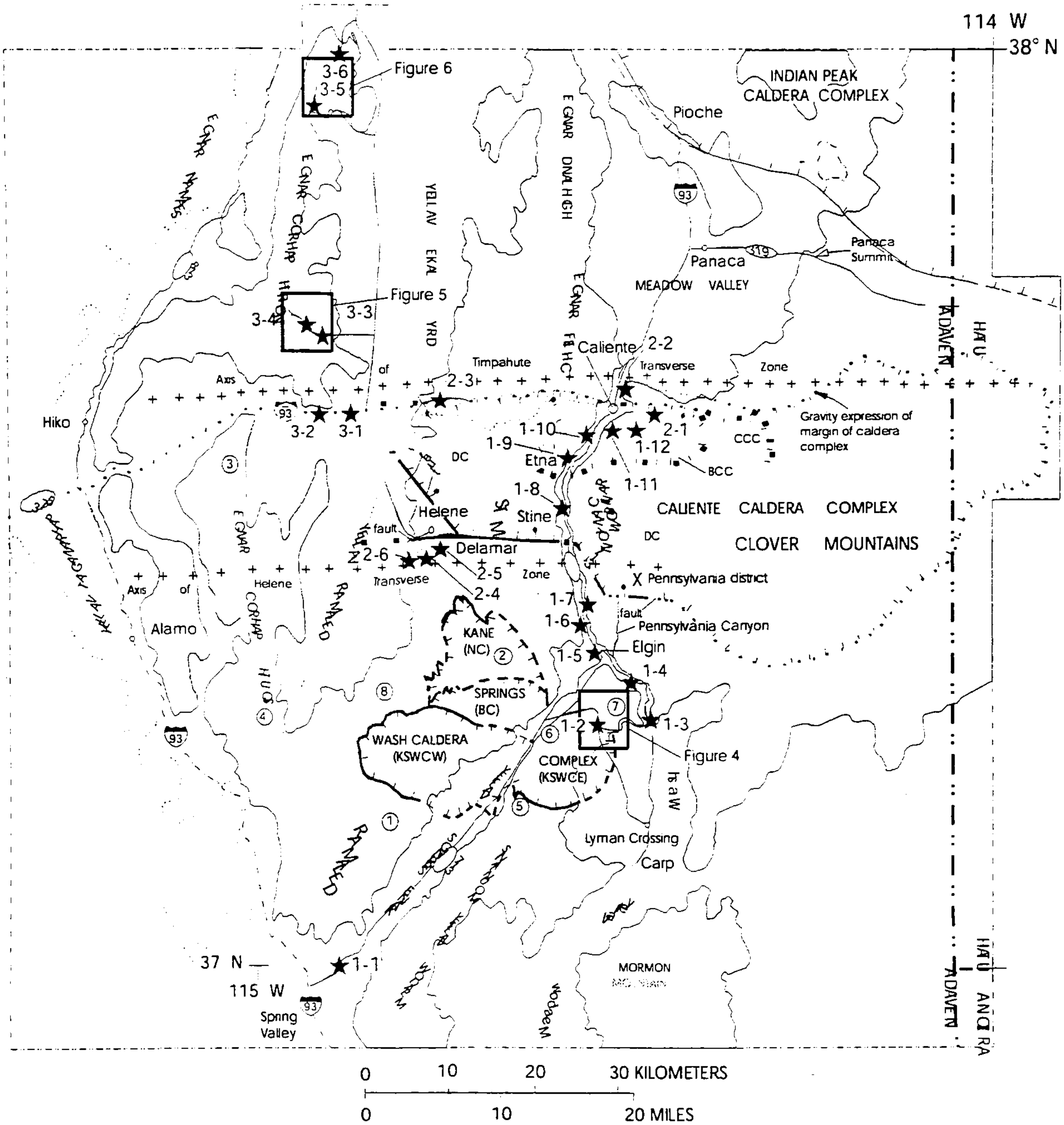
GEOLOGIC SETTING

In the field trip area, prior to and during Neogene extension, about 1 km of Tertiary ash-flow tuffs and other volcanic strata covered an angular unconformity that formed after Paleozoic strata had been deformed by the Sevier-age thrusts. These thrusts are only locally exposed (Tschanz and Pampeyan, 1970), and their structural patterns do not seem to influence patterns of Tertiary extension or magmatism. The andesitic to rhyolitic ash-flows tuffs were derived from several caldera complexes: some Oligocene tuffs came from the Central Nevada caldera complex about 100 km west of the field trip area and other Oligocene and Miocene tuffs came from the Indian Peak, Caliente, and Kane Springs Wash caldera complexes (Fig. 1). These tuffs thin southward and many pinch out close to the southern boundary of the field trip area along the northern boundary of an east-west amagmatic corridor (Fig. 2). Heterogeneous extensional deformation began during accumulation of these ash-flow tuffs, creating angular unconformities (Scott and others, 1995a; Rowley, in press), but because the periods between faulting and subsequent volcanism were short and offsets on faults during these periods were small, only limited local deposition of tuffaceous sedimentary rocks occurred. After volcanism ceased at about 12 Ma, extensional deformation continued in the form of basin-range style normal faulting to produce the modern morphology of the Basin and Range province. Unlike most of the Basin and Range that is characterized by north-trending ranges and alluvial basins, much of the field trip area contains nearly continuous bedrock exposures in a conspicuous east-west zone (Fig. 1).

The east-west zone of bedrock exposure includes several important geophysical and geologic boundaries. The heterogeneously extended Basin and Range terrane in the field trip area lies about 75 km west of the moderately extended transition zone between the Colorado Plateau and the Basin and Range and lies about 120 km west of the relatively unextended Colorado Plateau (Fig. 2). The Caliente caldera complex and temporally overlapping shallow plutonism and volcanism in southwestern Utah form the Delamar-Iron Springs igneous belt (Rowley and others, 1995) that is the axis of this east-west zone. The final phase of the southward migration of the "ignimbrite flare-up" occurred in the middle Miocene when the last major ash-flow outflow sheets from the Caliente and Kane Springs Wash caldera complexes were emplaced near the northern boundary of the amagmatic corridor (Fig. 2). The steep gravity gradient (Blank and Kucks, 1989) that steps up to the south closely coincides with the southern end of thick volcanic cover over Paleozoic rocks south of the calderas. The east-west zone of bedrock also closely coincides with the southern Intermountain seismic belt (Smith and others, 1989).

Kane Springs Wash Caldera Complex

The Kane Springs Wash caldera complex is the southernmost and youngest caldera complex in the southward sweep of caldera volcanism in eastern Nevada and western Utah between 34 and 12 Ma (Stewart and Carlson, 1976; Best and others, 1989a) and includes at least three nested calderas covering more than a 30-km-by-25-km area of the Delamar Mountains and Meadow Valley Mountains (Scott and others 1995b) (Fig. 1). The youngest of the calderas in the complex, the Kane Springs Wash caldera was first recognized in the Delamar Mountains by Noble (1968), and the peralkaline composition of the unit was further investigated by Noble and Parker (1974). Detailed mapping within the Kane Springs Wash caldera and thorough petrologic studies of the magmas that erupted from that caldera were the subject of a Ph.D. dissertation (Novak, 1985; 1984; Novak and Mahood, 1986). Subsequently, the Kane Springs Wash caldera and surrounding areas were mapped at a scale of 1:24,000 by a U.S. Geological Survey team in the late 1980s and early 1990s (Scott and others, 1990a, 1990b, 1990c;



EXPLANATION

Ranges

Basins

Caldera boundaries, hachures inside caldera, dashed where approximately located

Faults that act as caldera boundaries, bar and ball on downthrown side, arrows shows direction of strike-dip motion

① Structural domains shown in Figure 3

★1-2 Field trip stops; day number - stop number

+ + + + Axis of transverse zone

Individual caldera

NC	Narrow Canyon caldera
BC	Boulder Canyon caldera
KSWCW	Kane Springs Wash caldera, western part
KSWCC	Kane Springs Wash caldera, eastern part
DC	Delamar caldera
BBC	Buckboard Canyon caldera
CCC	Clover Creek caldera

Figure 1. Map showing the location of major geographic features and caldrea complexes.

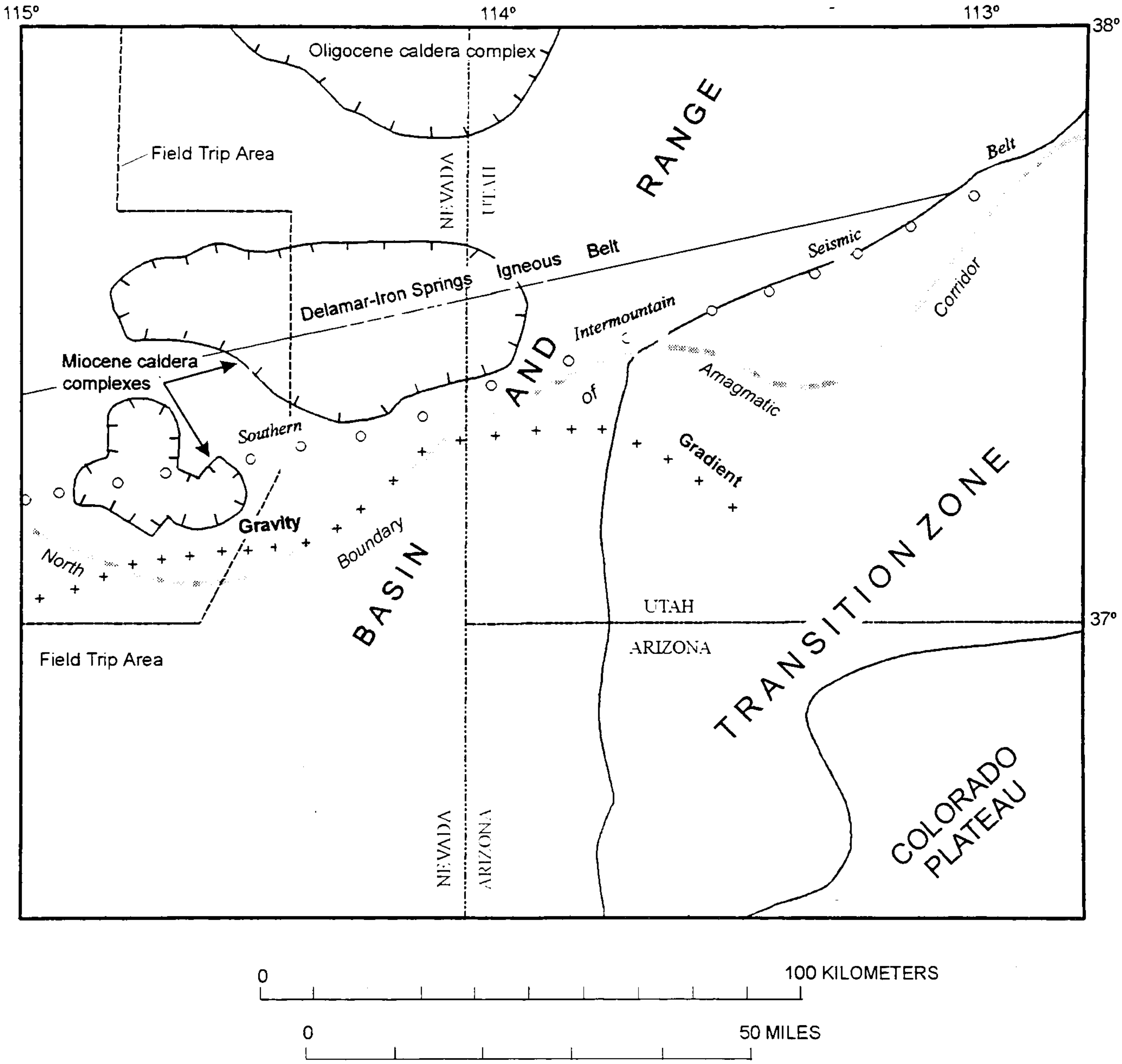


Figure 2. Major geophysical and physiographic boundaries in and near the field trip area.

Swadley and others, 1994a; Page and others, 1990; Scott and others, 1991a). During this mapping, an older nested caldera, the Narrow Canyon caldera, was recognized indicating that the Kane Springs Wash caldera was part of a caldera complex (Scott and others, 1991b), and an unrecognized eastern half of the Kane Springs Wash caldera in the Meadow Valley Mountains was detected (Harding, 1991; Harding and others, 1995). Later, another caldera in the complex, the Boulder Canyon caldera, was postulated based on geophysical evidence (Scott and others, 1995a).

The earliest magmatism associated with the Kane Springs Wash caldera complex began about 17.1 Ma by eruptions of rhyolite lava flows in Delamar Valley. These lava flows are distinguished from contemporary calc-alkalic rocks of the Caliente caldera complex by being more peralkaline than Caliente rocks. This initial activity was followed by eruption(1) of the Delamar Lake Tuff at 16.1 Ma, probably from a caldera buried in Delamar Valley, (2) [by eruption] of the tuff of Narrow Canyon at 15.8 Ma from the Narrow Canyon caldera, (3) [by eruption] of the tuff of Boulder Canyon at 15.1 Ma from the postulated Boulder Canyon caldera, and (4) [by eruption] of members of the Kane Wash Tuff from 14.7 to 14.4 Ma from the Kane Springs Wash caldera (Table 1) (Fig. 1). These members consist of the 14.7-Ma Grapevine Spring Member, the 14.55-Ma lower cooling unit of the Gregerson Basin Member, and 14.4-Ma upper cooling unit of the Gregerson Basin Member. Each of these major magmatic phases of the complex were characterized by increases in peralkalinity and Zr abundances (Scott and others 1995a). Post-collapse, caldera-filling volcanic and plutonic activity continued until 12 Ma.

Prior to Kane Springs Wash caldera complex activity, Tertiary stratigraphic relationships in the Kane Wash

Table 1. Major bedrock Tertiary units in the Kane Wash area indicating caldera complex sources, ages, and compositions of units, but excluding post-collapse caldera-filling units.

Unit	Caldera complex	Age[1]	Composition
Mafic flows south of Elgin	separate from caldera	8.0	ud, mafic
Tuff of Etna	ud, probably Caliente	14.0[2]	metaluminous rhyolite
Basaltic andesite flows above Kane Springs Tuff	separate from caldera	14.4[3]	basaltic andesite
Upper cooling unit, Gregerson Basin Mbr., Kane Wash Tuff	Kane Springs Wash	14.4	zoned peralkaline rhyolite
Lower cooling unit, Gregerson Basin Mbr., Kane Wash Tuff	Kane Springs Wash	14.55	zoned peralkaline rhyolite
Grapevine Spring Mbr., Kane Wash Tuff,	Kane Springs Wash	14.7	zoned peralkaline rhyolite
Sunflower Mountain Tuff	near Kane Springs Wash	15.4[4]	metaluminous rhyolite
Tuff of Narrow Canyon	Kane Springs Wash	15.8	metaluminous rhyolite
Delamar Lake Tuff	near Kane Springs Wash	16.1	metaluminous rhyolite
Hiko Tuff	Caliente	18.2	calc-alkalic zoned rhyolite
Harmony Hills Tuff	east of Caliente	22.2	calc-alkalic andesite
Pahranagat Formation	Central Nevada	22.6	calc-alkalic zoned rhyolite
Bauers Tuff Mbr., Condor Canyon Fm.	Caliente	22.7	calc-alkalic zoned rhyolite
Leach Canyon Formation	Caliente (?)	23.8	calc-alkalic rhyolite
Shingle Pass Tuff, intermediate unit	Central Nevada	~26.5	calc-alkalic rhyolite
Baldhills Tuff Mbr., Isom Formation	near Indian Peak	27.0	calc-alkalic trachyte
Monotony Tuff	Central Nevada	27.3	calc-alkalic dacite

[1]Ages in Ma. [2]based on position below 13.8 Ma flow and above 14.4 Ma tuff. [3]dates are 14.5±1.0 and 15.1±1.3 Ma but flows are above the upper cooling of the Gregerson Basin Member. [4]date has been corrected by adding 0.4 Ma based on consistent laboratory differences. ud, undetermined. Data from Scott and others (1995a and b).

area seem relatively simple (Table 1), but actually represent a complex intercalation of ash-flow tuffs from several known caldera complexes and unrecognized calderas. In the southern Delamar Mountains, Oligocene ash-flow tuffs pinch out southward to record distal edges of ash flows that originated from the Central Nevada caldera-complex about 75 km west-northwest of the field trip area and from an unidentified source near the Indian Peak caldera complex. In stratigraphic order these tuffs include the Monotony Tuff, the Baldhills Tuff Member of the Isom Formation, and an intermediate cooling unit of the Shingle Pass Tuff. Four Miocene ash-flow tuffs that predate the Kane Springs Wash caldera complex were derived from known calderas of the Caliente caldera complex or from other nearby calderas; in stratigraphic order these consist of the Leach Canyon Formation, Bauers Tuff Member of the Condor Canyon Formation, Harmony Hills Tuff, and Hiko Tuff. An ash-flow tuff from the Central Nevada caldera complex, the Pahranagat Formation, is sandwiched between the Bauers and Harmony Hills tuffs. All these rocks have calc-alkalic affinities.

The most pervasive style of extensional deformation in the Kane Wash area is expressed by progressive tilting of strata by synextensional growth faults; however, the degree, direction of dip, and distribution of this style of deformation is heterogeneous. Despite the heterogeneity, growth-fault deformation reached its maximum at the volumetric peak of volcanism and at the peak of magmatic evolution of the peralkaline magmas in the Kane Springs Wash caldera complex (Fig. 3). In our study, we assume that the amount of tilting is related to the amount of extension. Although a nonlinear relationship exists between stratal dip and percent of extension, the period of greatest change in dip per unit time is probably the best indication of the period of most rapid extension (~16-14.5 Ma). We will observe several examples of progressive tilting, the best of which will be seen at Stop 1-2 (Fig. 4) where the Harmony Hills Tuff dips an average of 60°, Hiko Tuff 46°, tuff of Narrow Canyon 30°, Grapevine Spring Member 20°, Gregerson Basin Member 17°, and tuff of Etna 5-10° (curve 7 of figure 3). At a location inaccessible on this trip but visible at a distance from Stop 1-4, the Gregerson Basin Member dips as steeply as 80° and the overlying tuff of Etna is nearly horizontal, forming the most extreme example of fanning of strata on synextensional faults.

Caliente Caldera Complex

The Caliente caldera complex, spanning an area about 80 km east-west and 35 km north-south, consists of numerous nested calderas that range in age from at least 23 Ma to 13 Ma. Its existence was first noted by Williams (1967) based on his study of ash-flow tuffs in the southeastern Great Basin, some of which he speculated to have been derived from the complex. Noble and McKee (1972) first mapped it in reconnaissance scale, and this portrayal was modified by later reconnaissance mapping by Ekren and others (1977), who recognized most of its currently known broad features. In the late 1980's, detailed geologic mapping began in the caldera complex, resulting in several maps (Rowley and Shroba, 1991; Rowley and others, 1994; Swadley and Rowley, 1994) and reports (Rowley and others, 1992, 1995), and a field-trip guidebook (Best and others, 1993). The caldera is extremely elongated, parallel to the middle and late Cenozoic extension direction, and it is extremely long lived. These anomalous attributes are considered to be due to an origin related to that of the two transverse zones that bound it, the Timpahute on the north and the Helene on the south (Rowley, in press). In other words, the Caliente caldera complex is a new type of caldera, akin to several "volcano-tectonic troughs" described by Burke and McKee (1979) in the western Great Basin. They evolved this way because of synchronous extension and magmatism (Rowley, in press).

Several of the inset calderas in the Caliente caldera complex have been named, but the sources of some other tuffs derived from the complex have not been identified (Rowley and others, 1995). The oldest known so far is the Clover Creek caldera, the source of the densely welded Bauers Tuff Member and probably the slightly older yet similar Swett Tuff Member, both of the Condor Canyon Formation. A fault-bounded mass of the caldera is exposed on the northern side of the complex, north of Caliente (Rowley and Shroba, 1991; Rowley and others, 1994). The age of the Bauers is 22.8 Ma based on $^{40}Ar/^{39}Ar$ ages by Best and others (1989a) on the tuff and by Rowley and others (1994) on its intracaldera intrusion. The Bauers is spread over an area of about 23,000 km^2 in southeastern Nevada and southwestern Utah.

The next youngest caldera mapped in the Caliente caldera complex is the Delamar caldera, which makes up most of the western part of the complex (Ekren and others, 1977). The Delamar caldera is the main source of the moderately welded Hiko Tuff (18.2 Ma; Rowley and others, 1995), but a vent for Hiko Tuff that is about 2 km in maximum diameter has been mapped about 3 km south of Delamar, well outside the Delamar caldera. The Hiko is spread over an area of about 7,000 km^2 in southeastern Nevada. It lithologically is very similar to the Racer Canyon Tuff, which has been mapped over at least 3,000 km^2 of southwestern Utah. The source caldera of the Racer Canyon has not been mapped but probably it underlies the eastern end of the Caliente caldera complex in Utah (Siders and others, 1990; Siders, 1991). The Racer Canyon appears to be only slightly older than the Hiko and it is likely that the two units were derived from al

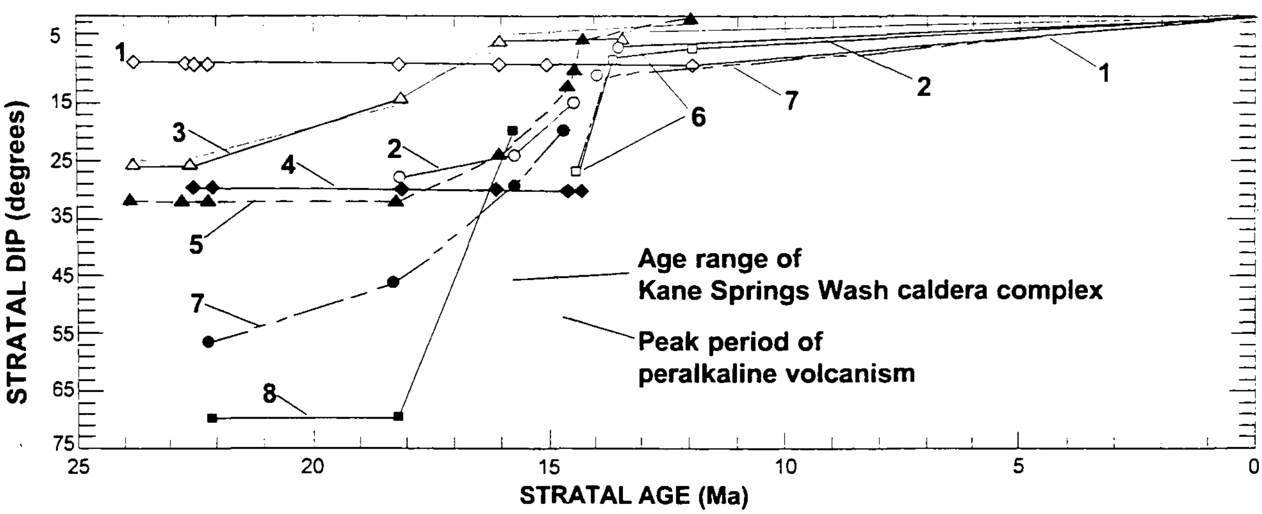
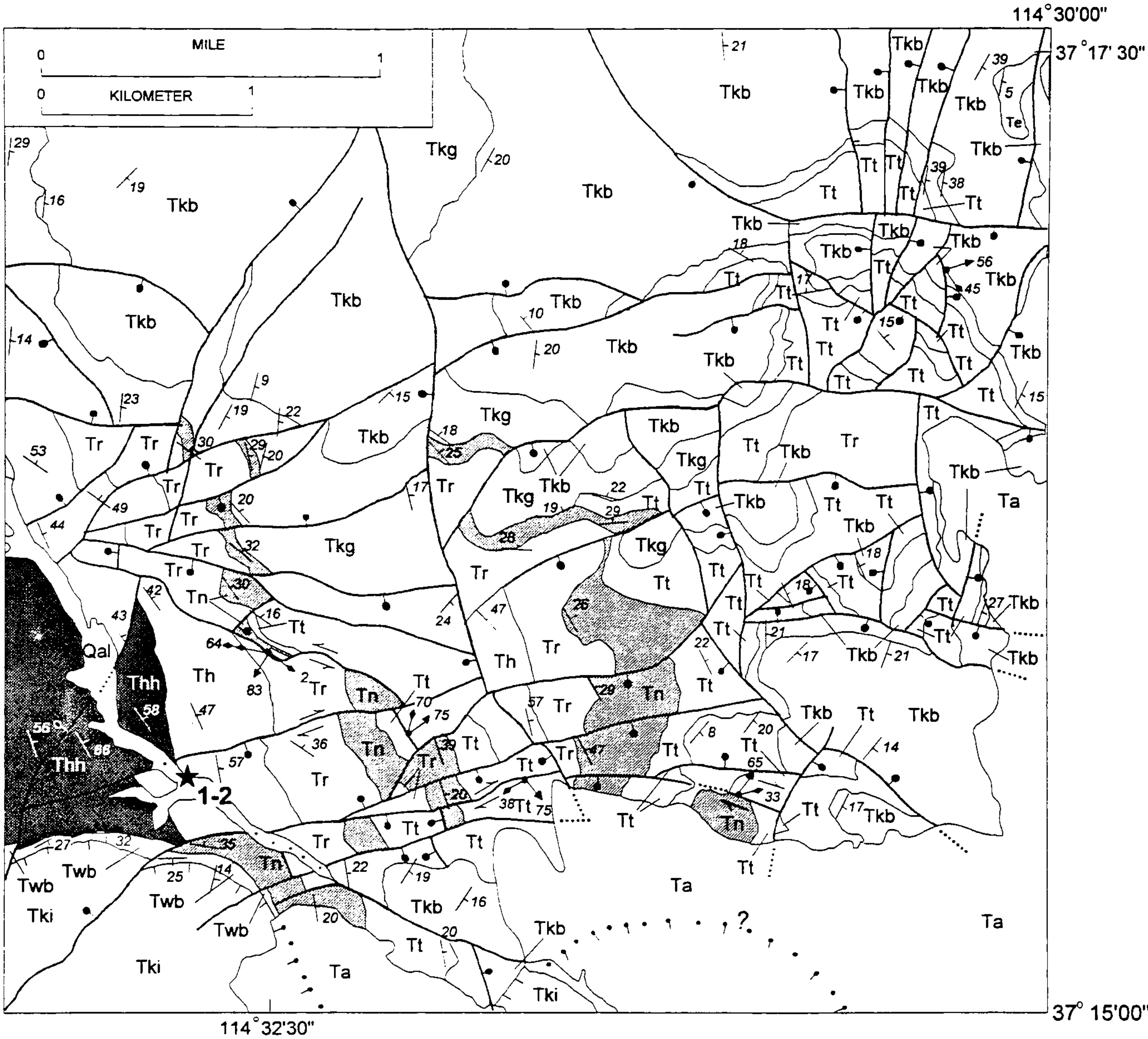


Figure 3. Evidence of growth faulting expressed by a plot of age of strata versus degree of stratal dip. Number on each curve refers to a circled location shown on figure 1; age range for the Kane Springs Wash caldera complex does not include post-collapse caldera-filling volcanism that continued until about 12 Ma (modified from Scott and others, 1995a).



EXPLANATION (see Table 1 for more map unit information)

Qal	Quaternary alluvium
Ta	Tertiary alluvium
Te	tuff of Etna
Twb	wall breccia of Kane Springs Wash caldera
Tkb	Gregerson Basin Mbr., Kane Wash Tuff
Tki	intracaldera Kane Wash Tuff
Tkg	Grapevine Spring Mbr., Kane Wash Tuff
Tt	nonwelded tuff
Tn	tuff of Narrow Canyon
Tr	rhyolite flow
Th	Hiko Tuff
Thh	Harmony Hills Tuff

45 18 56 Normal faults, bar and ball on downthrown side, dotted where concealed. Arrow shows direction and amount of fault dip, diamond shows trend and plunge of slickenline, double diamond shows trend and plunge of younger slickenline

Strike-slip or oblique-slip fault, arrows show direction of relative motion

Caldera margin, hachure on inside of margin, dotted where concealed

★ 1-2 Field trip stop

Figure 4. Generalized geologic map in the vicinity of Stop 1-2

most simultaneous eruption at opposite ends of the Caliente caldera complex of the same magma chamber. In places, the two tuff units have been mistakenly assigned to the other during geologic mapping; additional work on correlation is being done by C.S. Grommé, A.L. Deino, and M.G. Best (oral commun., 1995). The Buckboard Canyon caldera, the source of the small, poorly welded tuff of Rainbow Canyon (15.5-15.2 Ma), is probably a small trap-door caldera that subsided on its northern side, near Caliente. Outflow ash-flow tuff of the tuff of Rainbow Canyon has not been recognized outside the Caliente caldera complex. Other tuffs derived from the Caliente caldera complex have been identified but their source calderas have not been located. These include the poorly to moderately welded tuff of Tepee Rocks (17.8 Ma), named for exposures of apparent outflow facies east of Caliente. The tuff of Tepee Rocks is barely distinguishable from the Hiko Tuff on the basis of detailed petrography and chemistry. The poorly welded tuff of Kershaw Canyon (15.5?-14.0 Ma) overlies the tuff of Rainbow Canyon south of Caliente, but mapping has not yet determined whether these exposures are intracaldera or outflow. The moderately welded tuff of Sawmill Canyon is a single small outflow sheet intercalated within the tuff of Kershaw Canyon in Rainbow Canyon. The moderately to well welded tuff of Etna (14.0 Ma) is a single outflow sheet that caps most of the rim of Rainbow Canyon. The Ox Valley Tuff, which very much resembles the tuff of Etna but appears to be distinct on the basis of detailed petrography, occurs as outflow sheets in Utah. It is not well dated and may be as young as 13 Ma. All tuffs from the Caliente caldera complex are rhyolites, but of those, the older (pre-17 Ma) are low-silica rhyolite and considered part of the calc-alkaline suite, whereas the younger tuffs are high-silica rhyolite considered to be part of the bimodal suite.

Two episodes of Cenozoic extensional deformation took place in and near the Caliente caldera complex (Rowley and others, 1992; Rowley, in press). The main episode resulted mostly in north-northwest-striking high-angle oblique faults (right-lateral and normal) and a conjugate subordinate set of northeast-striking high-angle oblique faults (left-lateral and normal). In addition, the east-striking faults of the transverse zones were active at the same time, as was the north-striking, west-verging 15-Ma Highland Peak detachment fault in the Chief and Highland Ranges (Axen and others, 1988; Rowley and others, 1992, 1994). Many of the high-angle oblique faults are growth faults, and upward fanning of intracaldera strata is common. The main episode of extension is well constrained by dikes of the porphyry of Meadow Valley Wash that were intruded into the largest of the high-angle oblique faults, not only in the caldera complex but also dozens of kilometers outside it. About a dozen dikes have been dated by $^{40}Ar/^{39}Ar$ methods by Larry Snee at 21-16 Ma (Rowley and others, 1995). Mapping suggests that the main episode began as early as 25 Ma, and faults of the episode cut rocks as young as 12 Ma (Rowley and others, 1992; Rowley, in press). The maximum rate of tilting took place at about 20-17 Ma.

The second episode of extension is the basin-range episode, in which normal faults that strike mostly north produced north-trending basins and ranges. The area of the Clover and Bull Valley Mountains and northern Delamar Mountains that is underlain by the Caliente caldera complex, however, is for the most part, not broken into north-south ranges and basins but instead makesup a large east-trending highland. This is thought to be due to the effect of the transverse zones that underlie the northern and southern sides of this highland and that continued to be active during the basin-range episode. The basin-range episode in the area of the caldera complex began after 12 Ma and continued to the present time.

Gold mining districts surround the western Caliente caldera complex. Most of these are lined up along the two transverse zones, which mapping shows to have been active throughout the entire time of caldera volcanism and through both episodes of extension. The Chief district north of Caliente is a small epithermal gold district on the Timpahute transverse zone controlled by a quartz monzonite intrusion, the Cobalt Canyon stock, that has $^{40}Ar/^{39}Ar$ dates of 24.8 Ma (Rowley and others, 1992, 1994); the lower parts of the stock may contain porphyry copper deposits (Rowley and others, 1994). Along the Helene transverse zone, three other epithermal gold districts are known. The Taylor (Easter) mine lies inside the southern part of the Delamar caldera west of Rainbow Canyon and contains significant gold values (Rowley and others, 1992). It occurs along an east-striking, steeply north-dipping normal fault that cuts Hiko intracaldera tuff and is interpreted to be due to an underlying granitic source feeder for abundant rhyolite dikes and domes along the Helene transverse zone that in some places intertongue with Hiko intracaldera tuff and in other places are younger than it. The Pennsylvania mining district occurs south of the Caliente caldera complex and east of Rainbow Canyon. It also is genetically related to rhyolite dikes and domes of an inferred age similar to those at the Taylor mine, but mineralization is along a north-striking, east-dipping detachment fault. The main gold deposit was mined at a small pit and the ore was treated by conventional heap-leach methods. Of the districts along the Helene transverse zone, however, the largest was the Ferguson (Delamar) district, of which virtually all production was in and just east and northeast of the ghost town of Delamar. The district is just southwest of the Caliente caldera complex and along the Helene transverse zone that bounds and controls the southern margin of the complex. The ore occurs in quartzite of the Late Proterozoic and Lower Cambrian Stirling Quartzite and the Lower Cambrian Wood Canyon Formation and Zabriskie Quartzite. Most ore is in lode bodies associated with quartz veins that are tied genetically to east-striking rhyolite dikes (Callaghan, 1937). As near the Taylor mine, the rhyolites are similar in age to, and younger than, the 18.2 Hiko Tuff intracaldera fill. A granitic intrusion is inferred to underlie the district and areas to the east and to be the source of the rhyolites.

The Ferguson (Delamar) district initially boomed during the last decade of the 19th century, which was a period of little activity in Nevada's mining history. Bullion taxes paid by the DeLaMar Nevada Mining Company on the nearly 10 million dollars in gold values extracted before 1902 sustained the regional economy and contributed substantially to State coffers. Mining continued intermittently until 1945 and raised the total production to nearly 15 million dollars (Townley, 1972; Tschanz and Pampeyan, 1970, Ferris, 1991).

Life in the Ferguson district was both "the best of times, the worst of times" for its 3,000 residents. Mine and mill workers were paid good wages and could purchase gourmet foods, luxury items, and sophisticated pleasures. The district was, however, notorious for the reputed health risks associated with the extraction of its gold from 1892 to1909. Late 19th-century technological innovations had greatly increased the efficiency of mining and milling operations. Heavy machinery, powered by steam, electrical, and gasoline engines, proliferated in the mines and mills, replacing many manual laborers. This modernization subjected the remaining work force to new occupational hazards, especially catastrophic accidents. Dry drilling and crushing of the silica-rich ore-bearing rock of the Stirling Quartzite, Wood Canyon Formation, and Zabriskie Quartzite produced clouds of fine particles, later described as the "Delamar death dust" (Murbarger, 1956; Townley, 1972; Cerveri, 1975). The dust clogged the lungs of many workers, causing the debilitating (and often fatal) condition of silicosis. During the boom years, Delamar was called "the Widowmaker" because of the high mortality rates associated with its mining industry (Townley, 1972).

Transverse Zones

The dominant northerly-trending basins and ranges, which are caused by late Cenozoic (mostly post-10 Ma) basin-range faults, mask structures of other trends. Yet upon careful inspection of even the topography, one may notice that some range fronts trend anomalously eastward and some other ranges terminate at the same latitude as neighboring ranges. Easterly alignments of mining districts also are well known (e.g., Hilpert and Roberts, 1964; Roberts, 1964). Hamilton and Myers (1966) and Davis and Burchfiel (1973) recognized the significance of easterly faults in the Great Basin that acted like transform faults in the ocean basins. Based on plotting tilts of basin ranges, Slemmons (1967) suggested three west-northwest-striking "transverse zones" across Nevada based on the distribution of young faults. Aeromagnetic and gravity maps added significantly more substance to these speculations, and it became more apparent that the Great Basin contains profound easterly structures and igneous belts (e.g., Stewart and others., 1977). Ekren and others (1976) described five easterly-striking "lineaments," the longest of them 320 km, in the Great Basin and recognized that they are defined primarily by alignments of intrusions, volcanic centers, faults of the same strike, and interruptions of topography and geophysical anomalies. Other workers have applied such terms as "accommodation zones," "transfer zones," or "continental transform faults" to these features. Rowley and others (in press) and Rowley (in press) retained Slemmons' wording of transverse zones, instead of lineaments, and summarized those that have been identified in the Great Basin. As suggested by most previous workers, the controversial features are probably boundaries that separate domains of different style, amount, or rate of strain.

Igneous belts in the Great Basin are linear belts of intrusions, volcanic centers, and associated extensional faults that are of similar age in each part of the belt and that commonly are partly bounded by transverse zones. Rowley and others (in press) and Rowley (in press) considered that most large transverse zones formed parallel to the extension direction, which in the Great Basin was oriented east-northeast during the middle Cenozoic and east-west during the late Cenozoic (Zoback and others, 1981). Transverse zones formed partly at the same time as northerly-striking faults that created the dominant topographic grain to the Great Basin, and thus transverse zones, northerly-striking faults, and igneous belts play a major role, in conjunction with the brittle-ductile transition zone, in the spreading of brittle crust in the Great Basin and other highly extended areas in the world (Rowley and others, in press; Rowley, in press).

Several transverse zones bear heavily on the tectonic development of the area that we will visit on the field trip (Fig. 1). The Timpahute "lineament" defines the northern side of the Caliente caldera complex (Ekren and others, 1976); we refer to it as the Timpahute transverse zone (Rowley and others, 1996; Rowley, in press). The Helene transverse zone defines the southern side of the Caliente caldera complex. These tectonic boundaries suggest that the Caliente caldera complex is a different type of caldera, in which subsidence was partly along tectonic faults that strike easterly. We will visit some of these faults, which contain oblique slickensides and are parts of broad transverse zones that are at least 10 km wide and are at least 220 km (the Timpahute) and 110 km (the Helene) long. These transverse zones also control most gold districts in the area. Transverse zones in the Basin and

Range also have important implications for controlling migration of fluids such as ground water, geothermal water, and perhaps even petroleum (Rowley, in press).

North Pahroc Range

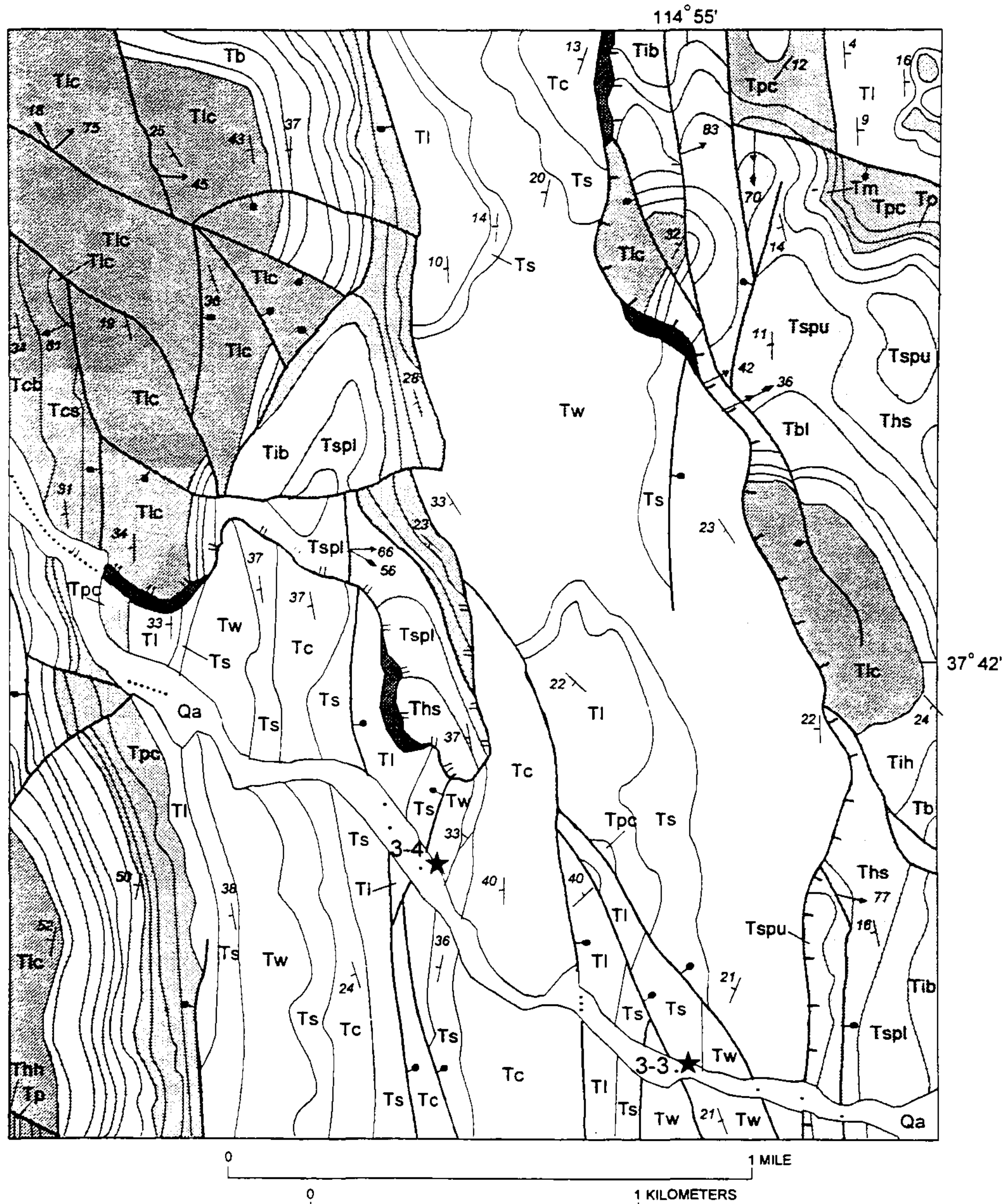
No calderas are recognized in the North Pahroc Range. However, this range contains one of the most complete sequences of ash-flow sheets in southeastern Nevada (Table 2) because it was centrally located relative to the Central Nevada, Indian Peak, and Caliente caldera complexes (Best and others, 1989b). Even though none of the ash-flow tuffs from the Kane Springs Wash caldera complex occur in the North Pahroc Range, the Delamar Lake Tuff and Kane Wash Tuff are exposed directly south of the Timpahute transverse zone (Fig. 1), but not north of it (Scott and Swadley, 1992). Conversely, 30.6- to 27.9-Ma ash-flow tuffs (Cottonwood Wash Tuff, Wah Wah Springs Formation, and Lund Formation of the Needles Range Group) from the Indian Peak caldera complex probably did not accumulate south of the Timpahute transverse zone west of the Caliente caldera complex (Fig. 5 of Best and others, 1989b). In the southern and central part of the North Pahroc Range, about 500 m of interlayered boulder conglomerate, siltstone, and lacustrine limestone were deposited for at least 4 m.y., during which ash-flow tuffs from the 31.3-Ma Windous Butte Formation through the 27.3-Ma Monotony Tuff were intercalated within the sedimentary sequence. After emplacement of each ash flow during this period, deposition of sediments was reestablished. No record of an equivalent depositional basin exists south of the Timpahute transverse zone west of the Caliente caldera complex. Apparently the Timpahute transverse zone acted as the southern boundary of a depositional basin northwest of the Caliente caldera, in which basin filling began prior to volcanism and continued to contained both sediments and ash-flow tuffs until about 27.3 Ma, when ash flows of the Monotony Tuff spilled south of the Timpahute transverse zone. It should be noted that east of the Dry Lake Valley - Delamar Valley area, the Timpahute transverse zone did not limit the extent of the Needles Range Group. East of Pennsylvania Canyon in the southern Clover Mountains (Fig. 1), a similar paleoenvironment allowed accumulation of ash-flow sheets of the Needles Range Group interstratified with lacustrine deposits. After about 18 Ma, the transverse zone blocked emplacement of the Kane Wash Tuff north of the zone in the North Pahroc Range (Scott and others, 1995b).

The arched North Pahroc Range appears deceptively simple from a distance. At the southern end of the range, Tertiary strata were deposited conformably on each other. Here, arching occurred after about 18 Ma and the arch was cut by high-, moderate-, and low-angle normal faults that dip both toward and away from the north-trending axis of the arch. Faults that dip toward the axis are readily recognized because they repeat the section, but faults that dip away from the axis omit section, making them more difficult to recognize. The low- and moderate-angle normal faults postdate most high-angle faults (Fig. 5) (Scott, 1992); the moderate-angle faults display brittle roll-over structures and imbricate normal fault zones in their hanging walls.

Although the central part of the North Pahroc Range contains evidence of minor late Oligocene angular unconformities (Taylor, 1989; Scott and others, 1994), the northern part of the range contains evidence of two distinct late Oligocene angular unconformities (Fig. 6) (Scott and others, 1995c). The older (~ 29 Ma) of the two unconformities separates a sequence consisting of the east-dipping Windous Butte Formation up through the tuff of Deadman Spring from an overlying sequence consisting of a local, undated, nonwelded, white rhyolitic ash-flow tuff up through the Monotony Tuff. The nonwelded tuff buried most of the topography created by west-dipping normal faults that repeat the older volcanic strata. In a few localities, the contact between the readily eroded nonwelded tuff and an underlying, resistant, moderately welded, silicified upper zone of the tuff of Deadman Spring is well exposed. Commonly, the nonwelded tuff is stripped off, leaving the top of the tuff of Deadman Spring denuded, exposing the details of the geometry of west-dipping normal faults that commonly have centimeter- to meter-scale offsets spaced only centimeters to meters apart. These structures provide evidence of pervasive, nearly penetrative extensional deformation. The tuff of Deadman Spring and older units have been smeared out, attenuated by brittle-behavior extension. Cumulatively, this style of deformation is capable of significant extension, yet is extremely difficult to represent at a scale of 1:24,000 or smaller.

After deposition of strata as young as the 27.3-Ma Monotony Tuff over the older unconformity, the northern part of the range began to arch. Following early stages of arching, the 27.0-Ma Baldhills Tuff Member of the Isom Formation and the 26.7-Ma Upper Member of the Shingle Pass Tuff were plastered on the younger (~ 27 Ma) of the two unconformities at three localities on the western side of the arch (Fig. 6). Minor arching of the range continued after emplacement of these younger units. Subsequently, west-dipping, steep normal faults cut the arch, repeating section on the east limb but omitting section on the west limb.

A few kilometers north of figure 6, in the east-dipping limb of the arch and below the older unconformity, the-west offsets on west-dipping normal faults is opposite the up-to-the-west tilt of the strata; the geometric effect is that the offset and stratal tilt essentially cancel one another. Thus, from a distance where these small-offset faults are not evident, and



EXPLANATION (only some of the units are identified by symbols for map simplicity; see Table 2 for more map unit information)

Qa	Quaternary alluvium
Thh	Harmony Hills Tuff
Tp	Pahranagat Formation
Tcb	Bauers Tuff Mbr., Condor Canyon Formation
Tcs	Swett Tuff Mbr., Condor Canyon Formation
Tlc	Leach Canyon Formation
Tih	Hole-in-the-Wall Tuff Mbr., Isom Formation
Tb	basaltic lava flows
Tbl	Blawn Formation
Tspu	Upper Mbr., Shingle Pass Tuff
Ths	tuff of Hancock Summit
Tspl	Lower Mbr., Shingle Pass Tuff
Tib	Baldhills Tuff Mbr., Isom Formation
Tm	Monotony Tuff
To	local ash-flow tuff
Tn	local nonwelded tuff
Tpc	Petroglyph Cliff Ignimbrite
Tl	Lund Formation
Ts	boulder conglomerate, siltstone, and limestone
Tw	Wah Wah Springs Formation
Ts	boulder conglomerate, siltstone, and limestone
Tc	Cottonwood Wash Tuff
Ts	boulder conglomerate, siltstone, and limestone

Thh through Tlc

Tih through Tib

Tm through Tpc

Ts, Tl, Tw, Tc

Steep normal faults, bar and ball on downthrown side dotted where concealed; arrow shows direction and amount of fault dip, diamond shows trend and plunge of slickenlines

Moderate-angle normal fault, hachures on downthrown-side, dotted where concealed

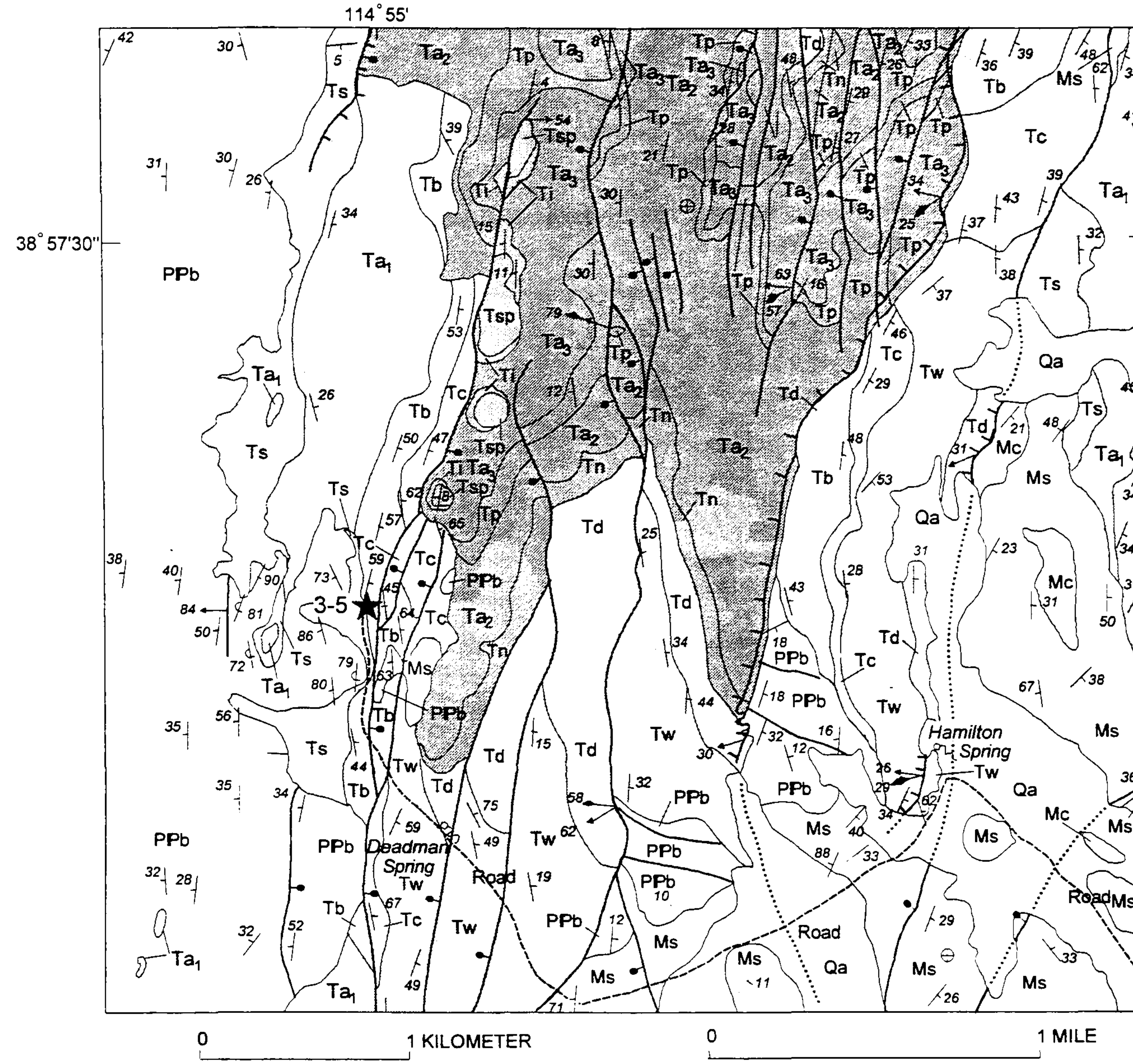
Low-angle normal fault, double hachures on downthrown side, dotted where concealed

70 45 Arrow shows direction and amount of fault dip and diamond shows amount and direction of trend and plunge of slickenlines

Shear zone

★3-3 Field trip stop

Figure 5. Generalized geologic map in the vicinity of Stop 3-3 and Stop 3-4.



EXPLANATION (See Table 2 for more map unit information)

Qa Quaternary alluvium
Tsp Upper Mbr., Shingle Pass Tuff
Ti Baldhills Tuff Mbr., Isom Formation
Ta_3 andesitic lava flows and mudflows
Tp Petroglyph Cliff Ignimbrite
Ta_2 andesitic lava flows and mudflows
Tn nonwelded ash-flow tuff
Td tuff of Deadman Spring
Tw Wah Wah Springs Formation
Tc Cottonwood Wash Tuff
Tb Windous Butte Formation
Ta_1 andesitic lava flows and mudflows
Ts prevolcanic conglomerate and limestone
PPb Bird Spring Formation
Ms Scotty Wash Quartzite
Mc Chairman Shale

Patterns used to distinguish rock units separated by angular unconformities

Tsp through Ti

Ta_3 through Tn

Ts through Td

PPb through Mc

44 63 Steep normal faults, bar and ball on downthrown side, dotted where concealed. Arrow shows direction and amount of dip, diamond shows trend and plunge of slickenlines

Moderate-angle normal fault, hachures on downthrown side, dotted where concealed

★ 3-5 Field trip stop

Figure 6. Generalized geologic map in the vicinity of Stop 3-5.

the contact between the nonwelded tuff and the tuff of Deadman Spring seems to be concordant. If the contact between the two units were not remarkably distinct, the faults could easily go unnoticed. Thus, attenuation of the older strata by numerous normal faults could easily be missed. Also, because the flattening foliation in the Deadman Spring is quite indistinct (Scott and others, 1995c), the steeper dip of the older tuff and its structural significance could go unrecorded.

Table 2. Caldera complex sources, ages, and compositions of major ash-flow tuffs in the southern and northern parts of the North Pahroc Range.

[1]Ash-flow Tuff	Caldera complex	[2]Age	[3]Composition
Hiko Tuff	Caliente	18.2	zoned rhyolite
Harmony Hills Tuff	east of Caliente	22.2	andesite
Pahranagat Fm.	Central Nevada	22.6	zoned rhyolite
Bauers Tuff Mbr., Condor Canyon Fm	Caliente	22.7	zoned rhyolite
Swett Tuff Mbr., Condor Canyon Fm.	Caliente	<23.8	rhyolite
Leach Canyon Fm.	Caliente (?)	23.8	rhyolite
Hole-in-the-Wall Tuff Mbr., Isom Fm	near Indian Peak	ud	trachyte
Upper Mbr., Shingle Pass Tuff	Central Nevada	26.0	rhyolite
tuff of Hancock Summit	unknown	ud	rhyolite
Lower Mbr., Shingle Pass Tuff	Central Nevada	26.7	rhyolite
Baldhills Tuff Mbr., Isom Formation	near Indian Peak	27.0	trachyte
Monotony Tuff	Central Nevada	27.3	dacite
Petroglyph Cliff Ignimbrite	unknown	27.6	trachyte
Lund Fm.	Indian Peak	27.9	dacite
Wah Wah Springs Fm.	Indian Peak	~29.5	dacite
Cottonwood Wash Tuff	Indian Peak	~30.6	dacite
Windous Butte Fm.	Central Nevada	31.3	zoned rhyolite

[1] Local ash-flow tuffs are not included; [2]Ages in Ma; ud, undetermined; [3]all tuffs have calc-alkalic compositions. Data from Scott and others (1995a and b).

West of the arched range, a narrow (<2 km wide) north-trending horst block of essentially unfaulted and distinctly banded Permian and Pennsylvanian Bird Spring Formation has been mapped intermittently over a distance of more than 22 km. Yet the unfaulted Bird Spring block is bounded by highly faulted Tertiary strata. On its western margin 1 km west of figure 6, a steeply to shallowly dipping normal fault containing slickenline evidence of left-oblique slip separates the horst from Tertiary strata broken by north-northwest-striking faults whose orientation is compatible with either extension faults or Reidel shear faults to the horst-bounding left-lateral slip. On the northeastern margin of the horst, a breccia zone and altered rocks mark a moderately east-dipping fault detaches the unfaulted horst and east-dipping faulted Tertiary strata (Fig. 6, near 114°55'). About 0.7 km east of where this fault dies out to the south, another east-dipping normal fault acts as the detachment plane and continues southward 0.3 km west of Deadman Spring. At several locations a basal conglomerate (Ts) and Oligocene volcanic strata (Ta_1 through Tc) are preserved in depositional contact atop the horst (Fig. 6). None of the 29-Ma through post 18-Ma periods of extension affected the horst, and therefore, the detaching fault must predate the earliest period of deformation but probably continued to operate as extension proceeded (Scott and others, 1995c).

Explanations for the change in timing of arching and change in style and timing of unconformities along the 45-km-long North Pahroc Range challenge us and require speculation. Taylor and Bartley (1992) suggested that a pre-volcanic down-to-the-east period of extension, with a breakaway of Paleozoic strata east of the Seaman Range, may account for the formation of the sedimentary basin described above. However, throughout the range, the consistent west dip of Paleozoic structural blocks predicted by their model is not seen after palinspastic rotation of younger volcanic strata. Axen and others (1988, 1993) and Bartley and others (1988) called upon 15 Ma down-to-the-west extension along the Highland detachment in the Highland Range to explain the young extension in the North Pahroc Range; however, only the pre-29-Ma extension in the northern part of the range consistently has the down-to-the-west extension geometry. The arched range has both down-to-the-east and down-to-the-west fault geometries. Taylor (1989) used concave-down normal faults to rotate strata to construct an arch in the central part of the North Pahroc Range, but the faults mapped by Scott and others (1992, 1994, 1995c) appear to have a concave up listric geometry.

Geologic mapping by Scott and others (1992, 1994, 1995c) favors a complex sequence of events: 1) Prevolcanic extension created a sedimentary basin with a relatively disorganized pattern of extension that requires neither a uniform pattern of west-dipping Paleozoic strata, nor the distinct Seaman breakaway depicted by Taylor and Bartley (1992). Offset on the Timpahute transverse zone, which formed the southern boundary of the basin, accommodated extension to the north without significant extension to the south. Mapping (Scott and others, 1995a, 1995b) south of the Timpahute does not reveal evidence for prevolcanic extension there that was predicted by Axen (1993). 2) Down-to-the-west extension of about 29 Ma in the northern part of the North Pahroc Range may have been related to synchronous extension and magmatic activity in the nearby Indian Peak caldera complex. However, Myron Best, who has mapped the complex, does not find evidence of extension that overlaps with caldera magmatism (Brigham Young Univ., written commun., 1995). 3) Because arching began as early as 27 Ma in the northern part of the range but began as late as 18 Ma in the southern, the cause of arching is difficult to explain. The arch may be driven by uplift of massive horst blocks that arched and extended their carapace of Tertiary strata, similar to asymmetric uplifts described by Anderson and Barnhard (1993a, 1993b). We suggest that the change in timing of arching may be related to a southward sweep of thermal perturbations in the mantle that drive both deformation and magmatism. Axen and others (1993) reviewed evidence for such a southward sweep of deformation and magmatism. Both the abundance of local andesitic lava flows in the northern and central parts of the range, which span from >31.3 to about 27 Ma, and the weak alteration of the older strata in the southern part of the range support this interpretation.

FIELD TRIP ROAD LOG

DAY ONE Thursday 24 October 1996

We will meet at a prearranged site in Las Vegas at 6 AM. From the intersection of I-15 and US 95 in Las Vegas, drive 22 miles on I-15 northeast to the intersection of US 93. Turn left (northwest) onto US 93 and proceed 40 miles to the intersection with NV 317 where the road log begins (Fig. 1). We will observe the character of synchronous extension and magmatism first in and near the Kane Springs Wash caldera complex and then in and near the Caliente caldera complex.

Interval miles

Cumulative miles

0.0 — 0.0 Road log begins at intersection of US 93 and unpaved NV 317. Turn right on NV 317 and proceed northeast up Kane Springs Valley.

2.9 — 2.9 **STOP 1-1 (Scott and Harding)** Orientation view to the left (north-northwest) shows the south end of the Delamar Mountains dominated by a west-dipping ramp of Devonian to Cambrian strata that forms the hanging wall of the Delamar thrust fault (Page and others, 1990; Swadley and others, 1994a). The footwall syncline of Permian and Pennsylvanian strata is obscured by Tertiary volcanic rocks and alluvium from this perspective. A small down-to-the-west normal fault in the volcanic strata reversed motion on the thrust fault. Gently southeast-dipping Tertiary ash-flow tuffs include the 27.3-Ma Monotony Tuff through the 14.5-Ma Kane Wash Tuff and overlie the angular unconformity above Paleozoic strata. View to the right (east to northeast) shows the Meadow Valley Mountains, the southern part of which consists of Cambrian to Devonian strata and the northern part of which includes strata from the 27.3-Ma Monotony Tuff to the Kane Wash Tuff (Scott and others, 1995a).

8.3 — 11.2 As we continue northeast, on the right in the Meadow Valley Mountains the 23.8-Ma Leach Canyon Formation and 22.2-Ma Harmony Hills Tuff near the base of bedrock exposures dip southeast at attitudes significantly greater than those of the Kane Wash Tuff and a 12-Ma capping basalt. We will see widespread examples of this synextensional fanning of strata during the next 3 days, and we interpret these relationships to indicate that concurrent extensional growth faulting and related tilting overlaps with emplacement of ash-flow tuffs derived from the local Kane Springs Wash caldera complex (Scott and others, 1995a). But on the left in the Delamar Mountains, all volcanic strata are parallel, only dipping gently toward us. Thus, the style and degree of deformation from one side of the valley to the other are heterogeneous. At several localities, Tertiary strata have slid southeastward into the alluvium of Kane Springs Valley. The valley is an asymmetric graben with the larger offset on the Kane Springs Wash fault zone bounding the northwest front of the Meadow Valley Mountains. Splays of this fault zone are as young as middle Pleistocene and form scarps as much as 7 m high and a horst 40 m high southeast of the road (Swadley and others, 1994a). Thining of the tuff of Narrow Canyon over area now occupied by the Meadow Valley Mountains suggests that the Kane Springs Wash fault may have initiated as long ago as about 16 Ma. Magmatic dilation in the Kane Springs Wash caldera in the Meadow Valley Mountains and the absence of such extension to the west in the Delamar Mountains requires the fault to act as a boundary between these areas by about 14.5 Ma.

9.0 20.2 At 9 o'clock, the south edge of the Kane Springs Wash caldera in the Delamar Mountains is delineated by dark basalts and caldera-filling units that are plastered against well-layered, lighter-colored precaldera and Kane Wash Tuff outflow units. The caldera-filling rocks dip less than 10° to the southeast, are nearly unfaulted, and contain almost no dikes, indicating a lack of extension during caldera filling. The 14.7- to 14.4-Ma Kane Springs Wash caldera is the youngest caldera of the 17.1- to 14.4-Ma Kane Springs Wash caldera complex (Scott and others, 1990a). At 3 o'clock, the range front of the Meadow Valley Mountains consists of Kane Wash Tuff outflow units that show no indication of a continuation of the caldera margin.

4.3 24.5 At 3 o'clock, the location of the southern edge of the Kane Springs Wash caldera in the Meadow Valley Mountains requires about 4.3 miles (7 km) of left-lateral movement on the Kane Springs Wash fault zone. Slip indicators on the fault include nearly horizontal to nearly dip slip. Apparently early movement beginning as early as 16 Ma(?) was dominantly strike slip; by 8 Ma the dominant movement was dip slip. After 8 Ma, east-northeast-trending, strike-slip faults cut the Kane Springs Wash fault zone near Meadow Valley Wash. In contrast to the west part of the caldera in the Delamar Mountains, caldera fill in the east part of the caldera was progressively tilted, repeated by normal faults, and intruded by numerous dikes that feed caldera-filling units, providing evidence of extension during caldera filling (Scott and others, 1991a; Harding and others, 1995; Best and others, 1993). At 9 o'clock, the highest exposures consist of a late stage resurgent syenite dome capped by trachyte lava flows and a thin remnant of a carapace of trachytic ash-flow tuff. Contact relations suggest that extrusive units were emplaced first and were subsequently intruded by several phases of syenite magmas. Local normal faults form grabens that extend the crest of the dome.

2.9 27.4 At 9 o'clock, the north edge of the Kane Springs Wash caldera in the Delamar Mountains is located a few hundred meters north of the perlite prospect in late caldera filling aphyric rhyolite lava flows (Bob Scott, unpub.mapping). At this locality, and particularly at exposures of this unit about 1 km to the south, significant amounts of nonhydrated obsidian remnants (ranging from pebble to boulder size) are common. This material was selected by Native American toolmakers for projectile points, such as dart points and arrowheads, as well as for chopping and cutting implements. Prehistoric cultures known to have used the geologic resources of the Kane Springs Valley include the Virgin (Branch) Anasazi and Western (Parowan) Fremont. Cultural materials from these Puebloan groups occur in the archeological record of eastern Nevada from approximately 0 until 1300 A.D. Kane Springs Valley obsidian has also been recovered from Virgin Anasazi sites along the Muddy and Virgin Rivers, approximately 160 km to the south (Lyneis and others, 1989). Southern Paiute groups used this valley after 1000 A.D. and were the only Native Americans in the region at the time of Anglo-European contact in the early 19th century (Fowler and others, 1973). On the southeastern side of the road, in the east part of the caldera, aphyric topaz-bearing rhyolite dikes cut late-stage caldera fill; topaz crystal a few millimeters long occur in lithophysal cavities. Inflow facies of the Gregerson Basin Member of the Kane Springs Wash Tuff form the dark base of the mountain front.

4.2 31.6 At 3 o'clock, the north edge of the Kane Springs Wash caldera in the Meadow Valley Mountains occurs at the base of the topographic high; this is a case of topographic inversion where resistant caldera-filling units are high-standing above the more readily eroded precaldera units (Best and others, 1993).

0.3 31.9 Turn right on the road to Lyman Crossing. After crossing Holocene and Pleistocene fans, we will drive over exposures of Harmony Hills Tuff and of Hiko Tuff. On our right, topographic highs consist of intracaldera rocks, and near the base of these slopes, south-dipping caldera wall breccias mark the north wall of the Kane Springs Wash caldera.

3.2 35.1 **STOP 1-2 (Scott and Harding)** We will walk northeast up section through 60°-dipping 22.2-Ma Harmony Hills Tuff, 45°-dipping 18.2-Ma Hiko Tuff, 30°-dipping pumice-rich tuff derived from the 15.8-Ma Narrow Canyon caldera (earlier caldera of the Kane Springs Wash caldera complex) (Scott and others, 1991b, 1995a, 1995b), and into the 20°-dipping 14.7-Ma Grapevine Spring Member of the Kane Wash Tuff (Fig. 4). Note that these strata dip northeast, unlike the strata in the area we saw south of the east part of the Kane Springs Wash caldera that dip to the southeast. Numerous east-striking, generally right-lateral oblique-slip faults and west-dipping normal faults cut the section; the latter repeat the sequence making it impractical to continue walking through the two cooling units of the upper 14.55-14.4-Ma Gregerson Basin Member of the Kane Wash Tuff that dip at about 15° to the 14-Ma tuff of Etna that dips at about 5° (Fig. 4). Return to vehicles.

0.7 35.8 On the right we pass the last exposures of the caldera wall. Pumice-rich tuff of Narrow Canyon is in the foreground; caldera wall breccia is about half way up the slope, and intracaldera Kane Wash Tuff continues to the skyline. Caldera wall breccia dips about 30° to the south into the caldera. Meadow Valley Wash and the Mormon Mountains are directly ahead. As we drive down the alluvial fan, note the exposures in washes of subangular to subrounded side-stream fan material. This fan is considered to be a coarse-grained facies equivalent of the Muddy Creek Formation (12-5 Ma) because remnants of secondary carbonate horizons of the upper surfaces of these fans merge with those of the well-rounded main-stream alluvium that lies well above fan deposits of Horse Spring Formation age (20-12 Ma) which we will see farther up Meadow Valley Wash. Both the Muddy Creek and Horse Spring Formations were deposited during an aggradational period.

7.8 43.6 Across Meadow Valley Wash note impressive exposures of the main stream alluvium equivalent to Muddy Creek Formation.

0.3 43.9 Go through the ranch gate at Union Pacific tracks. Last vehicle close the gate! Continue east across Meadow Valley Wash. Keep your speed up across the loose sand.

0.4 44.3 Turn left (north) at the junction with Meadow Valley Wash road. As we drive upstream along Meadow Valley Wash, notice younger terraces against the mainstream deposits. Meadow Valley Wash is a perennial stream that originates about 65 km north of Caliente and ultimately drains into the Colorado River system. The stream is spring-fed and receives snowmelt runoff from the adjacent mountain ranges. Scouring floods were common occurrences in Meadow Valley Wash, prior to the extensive floodplain modifications made by the Union Pacific Railroad. The channel supports riparian vegetation, including the native cottonwoods, willows, rushes, cattails, and the introduced saltcedar. Two native fish species, the Meadow Valley Wash Desert Sucker and the Meadow Valley Wash Speckled Dace, occur in the stream. A variety of wildlife find habitat along its banks, including beaver that have constructed many dams along the stream.

7.3 51.6 We will see the youngest of a series of basalts that are interstratified with alluvial-fan deposits to form a growth-fault-induced fanning expressed as decreasing dips with decreasing age. Because this basalt is 8.1 Ma (collected by Ernie Anderson and K-Ar dated by H.H. Mehnert), the overlying conglomerate is interpreted to as a coarse-grained facies equivalent of the fine-grained Muddy Creek Formation mapped by Schmidt (1994) 50 km to the south along Meadow Valley Wash.

1.1 52.7 **STOP 1-3 (Scott and Anderson)** We will briefly inspect the oldest and most steeply dipping basalt (13.3 and 13.2 Ma; collected by Ernie Anderson and K-Ar dated by H. H Menhert) and view the slightly more steeply dipping 14-Ma underlying gray tuff of Etna at the south end of Rainbow Canyon. Return to the vehicles and continue into Rainbow Canyon, a beautiful area whose fascinating history has been described by Averett (1995).

4.5 57.2 **STOP 1-4 (Scott)** During lunch break, view spectacular examples of synextensional growth-fault fanning of tilted strata on both sides of the road. On the northeast side of the road, the lowest part of the section consists of a steeply dipping light-colored basal Tertiary lacustrine limestone that contains a thin biotite-rich tuff that may be a distal edge of the 29.5-Ma Wah Wah Springs Formation. If so, this is the westernmost example of the Needles Range Group found south of the Timpahute transverse zone. The limestone is overlain by dark purple to green undated andesite lava flows, which are overlain by Harmony Hills Tuff, Hiko Tuff, Kane Wash Tuff and an undated yellow nonwelded tuff that is probably correlative with the tuff of Acklin Canyon, which we will see later today, all capped by the nearly flat-lying tuff of Etna. On the southwest side of the road, the same relationships are present but are locally more extreme. For example, in several areas too far in the interior for us to reach on this trip, the 14.55- to 14.4-Ma Gregerson Basin Member of the Kane Wash Tuff dips 80° and dips of overlying units decrease to the nearly flat-lying 14-Ma tuff of Etna. The local rate of extension and rotation must have been dramatic during this 0.5 million year period.

1.5 58.7 On either side of the road we pass through an intrusive/extrusive rhyolite lava dome complex. At this lower elevation, high-angle flow foliation is dominant but at higher elevations, low-angle foliation is observed. Petrographically the dome resembles the tuff of Etna. Also the tuff of Etna thins against the dome and is locally intercalated with extrusive parts of the dome complex; therefore, the intrusive complex may be a candidate for a source of the tuff of Etna.

0.7 59.4 We have crossed the Kane Springs Wash fault zone where Rainbow Canyon widens into the Elgin alluvial basin. The fault zone continues across the wash toward the northeast into the Clover Mountains. About 1.5 km north of here, a triple fault junction is formed where the Kane Springs Wash fault zone intersects the west-dipping Pennsylvania Canyon normal fault that follows Pennsylvania Canyon due north of the junction and an unnamed south-dipping normal fault that strikes east of the junction. Thus, during the middle Miocene as 7 km of strike-slip movement occurred on the Kane Springs Wash fault zone, the Pennsylvania Canyon fault acted principally as a breakaway normal fault. About 500 m of alluvium accumulated into the ensuing structural hole in the Elgin basin.

The left-lateral Kane Springs Wash fault zone makes three left steps, and on the footwall side (east) of each of these steps, a late middle Miocene intrusive/extrusive rhyolite dome was emplaced. We drove through one of these domes centered 1.5 km southeast of here, a second occurs about 4 km south of here, and a third occurs in Pennsylvania Canyon about 1 km north of here. The locations of these domes relative to the fault can be explained by a footwall isostatic uplift theory outlined by Ellis and King (1991). They predict extension in the upper part of the footwall. We suggest that such an extensional environment should be enhanced at left steps of a left-lateral fault. These domes have not been dated but are probably 14 Ma or slightly younger based on map relations (Bob Scott, unpub. mapping). To the northwest, up Meadow Valley Wash, Rainbow Canyon opens into a relatively broad alluvial basin.

0.8 60.2 Turn left to stay on main road and to cross bridge over Meadow Valley Wash to the west side. Elgin consists of the small group of buildings we bypassed on the east side of the wash.

0.1 60.3 **STOP 1-5 (Scott and Hudson)** Stop at junction with paved NV 317. To the southwest, behind Bradshaw's apple orchard, are good exposures of the conglomerate and sandstone of Elgin, an aggradational upper Miocene basin-fill sequence that fills the small, informally named, Elgin basin (Bob Scott, unpub. mapping). To the south is the rhyolite dome we drove through; the Kane Springs Wash fault zone lies at the base of the slope of the Meadow Valley Mountains. Although the central part of the conglomerate and sandstone of Elgin is nearly flat lying, the margins of the alluvial unit are significantly deformed by uplift. To the east of the dome on the southeast margin of the basin, an 8-Ma basalt (collected by Ernie Anderson, whole rock K-Ar date by H.H. Mehnert; reported in Scott and others, 1995a) and the overlying conglomerate and sandstone of Elgin have been rotated locally to dip as much as 60° toward us by late Miocene or younger dip-slip movement on the Kane Springs Wash fault zone. Such an implied change in the timing of the apparent stress field from left-lateral oblique slip to dip slip on the Kane Springs Wash fault is compatible with that predicted regionally by Zoback and others (1981). The Kane Springs Wash fault zone has been further deformed by a series of west-northwest-striking faults that have as much as 300 m of right-lateral offset on individual faults defined by nearly horizontal slickenlines.

Hudson and others (1995, in press) reported significant amounts of counter-clockwise vertical-axis rotation based on paleomagnetic studies in the vicinity of the Caliente caldera complex to the north and in areas east of the caldera extending to the boundary between the Basin and Range and the Colorado Plateau transition zone (Fig. 2). They proposed a model (Hudson and others, in press) to explain as much as 90° of rotation along a corridor about 100 km long in an east-west direction and about 40 km wide in a north-south direction that includes the caldera complex and eastward to the transition zone boundary: Left-lateral shear distributed along and south of the Timpahute transverse zone (that forms the northern boundary of the corridor) caused counter-clockwise rotation of originally north-striking, domino-like, structural blocks that now strike north-northwest to west. This rotation requires right-lateral slip on northwest-striking faults that separate the structural blocks. North-striking faults that were present before rotation were bent to the northwest at the southern boundary of the corridor and were bent back to the north at the northern boundary of the corridor. Although such northwest-striking faults commonly record right-lateral slip in the corridor, the north-northwest striking faults that cut the eastern boundary of the Elgin basin could not have experienced appreciable counterclockwise rotation because there is no appreciable counterclockwise rotation of the north-northeast-striking left-lateral Kane Springs Wash fault.

On the western margin of the Elgin basin, the conglomerate and sandstone of Elgin has been gently deformed as part of the west-dipping dip slope of the Delamar Mountains. Here underlying 13.4-Ma basalts dip at 8-10° (Scott and others, 1995a). An undeformed Pliocene(?) pediment gravel truncates the conglomerate and sandstone of Elgin close to the Delamar Mountains. On the east side of the basin, more impressive deformation has occurred. Northeast of Meadow Valley Wash, the conglomerate and sandstone of Elgin dips at 12 to 18° generally to the west-southwest. The northeastern margin of Elgin basin formed along the Pennsylvanian Canyon fault, which follows Pennsylvania Canyon (Fig. 1). The fault dips between 30 and 35° to the west; its footwall exposes Cambrian strata overlain by prevolcanic conglomerate and lacustrine limestone and by pre-29.5(?) Ma andesite lava flows. Dark exposures on this dip slope consist of thin (less than 25 m thick) recemented sheets of monolithologic, brecciated rock that were derived from young unnamed lava flows and rhyolitic ash-flow tuffs such as the tuff of Etna and the Gregerson Basin Member of the Kane Wash Tuff, now stripped off the upthrown eastern side of the Pennsylvania Canyon fault. As many as five of these sheets are intercalated within the conglomerate and sandstone of Elgin. Continue up Meadow Valley Wash.

0.5 60.8 On our right are the cliffs of pale-brown conglomerate and sandstone of Elgin and dark-gray breccia sheets mentioned at the last stop. Rainbow Canyon narrows again, and as we continue north; the rocks dip gently to the south, and to the north basalt lava flows underlying the conglomerate and sandstone of Elgin form steep cliffs. The Delamar Mountains are on the left (west), and the Clover Mountains are on the right (east).

0.9 61.7 Contact between thick tuff of Etna below and several basalt flows above. Despite its thickness, the tuff of Etna is interpreted by us to be outflow here.

0.4 62.1 **STOP 1-6 (Rowley and Nealey)** Here we will take a quick-look at the tuff of Etna, a 14-Ma distinctive moderately welded rhyolite ash-flow tuff that is widespread above rocks of the Caliente caldera complex to the north, as well as north and south of the Caliente caldera complex. It was probably derived from the central to eastern part of the Caliente caldera complex and, if so, is among the youngest products; it is lithologically and chemically similar, but not identical to, the Ox Valley Tuff of Utah, derived from the eastern end of the caldera complex and perhaps 1 m.y. younger than the tuff of Etna (Rowley and others, 1995). Throughout the area covered by the tuff of Etna, faults of the main episode of Tertiary extension (pre-20 Ma to 12 Ma) at the latitude of the caldera complex locally displaced the tuff of Etna, but their vertical throw is rarely more than 100 m, which is much less than vertical offset of older rocks. Faults of the succeeding episode of extension (post-10 Ma), the basin-range episode, in contrast, locally displaced the tuff of Etna and other rocks many hundreds of meters vertically.

0.9 63.0 Large landslides make up the canyon walls on both sides of the road. Many of the talus boulders strewn on the slopes of Rainbow Canyon contain examples of prehistoric rock art or "petroglyphs." Stone tools were used to abrade or peck designs through the dark varnish (or patina) layer, exposing the lighter colored tuff below. Bighorn sheep, anthropomorphic (human) figures, and geometric elements are the most common design motifs seen in the canyon. No scientific method has, as yet, been perfected to provide verifiable absolute dates for petroglyphs. Archeologists can only speculate as to when this rock art was created, which cultural group produced it, and what the meaning or function of these designs may have been.

0.6 63.6 Underpass to railroad. To right (east), across Meadow Valley Wash, note dark outcrops of one of the two moderately welded ash-flow (outflow) cooling units (14.55 and 14.4 Ma) of the Gregerson Basin Member of the Kane Wash Tuff (Scott and others, 1995b). About 100 m of yellow, partially welded tuff of the outflow tuff of Acklin Canyon, derived from the Caliente caldera complex, overlie the Gregerson Basin and underlie the tuff of Etna.

0.5 64.1 **STOP 1-7 (Rowley and Nealey)** Brief stop to see the two cooling units of the Gregerson Basin Member on right. As we continue north, red outcrops of Gregerson Basin are seen on both sides of the canyon directly overlying the slide plane of a large Toreva-block-type landslide that makes up much of the slope above us.

2.3 66.4 Underpass to railroad. On either side of the canyon walls, more Gregerson Basin Member is overlain by tuff of Acklin Canyon. As we continue north, road continues downsection into a zone of abundant rhyolite volcanic domes and local pyroclastic products of these domes, all underlying the Gregerson Basin Member. Such domes, however, probably do not occur at this stratigraphic level very far south of this latitude, as indicated by map relations east and west of Rainbow Canyon where pre-Gregerson Basin Member rocks are exposed. As we continue north, the Gregerson Basin Member and the tuff of Acklin Canyon thin and pinch out on these rhyolite domes, and younger domes occur in the interval from the Gregerson Basin Member to above the tuff of Etna. This zone of rhyolite has been mapped as an east-striking belt for about 40 km and here is about 7 km wide (north-south). It is an expression of the Helene transverse zone (Fig. 1), which bounds the south side of the Caliente caldera complex, which is 7 km north of this point. As we go north, strongly hydrothermally altered multicolored rocks, are seen from the road. These generally red altered rocks partly led to the name Rainbow Canyon. The Helene transverse zone contains the Delamar mining distinct, Taylor (Easter) mine, and Pennsylvania mining district--all Miocene epithermal gold districts--and elevated gold values are known or suspected in this area (Bart Ekren, personal commun., 1993). The altered rocks have been mined for clay in several places east of the road.

1.1 67.5 Local rhyolitic tuffs from one of the domes on the left.

0.5 68.0 Look up a short, deep, side canyon to the right to see highly altered rhyolite domes and their tuffs, intertongued with dark cooling units of the Gregerson Basin Member; the main clay mine is at the top of the hill on the north side of this side canyon. East of these light-gray and red rhyolitic rocks, altered andesite flows that were tectonically elevated along a north-striking fault are the dark-gray rocks that form the ridge east of the side canyon.

1.3 69.3 Clay mines on right.

0.3 69.6 Old Elliot ranch on left at an underpass to the railroad, described by Averett (1995). On the right tuffs of the Gregerson Basin Member occur on the top of the hill that contains the south bridge abutment; here the tuffs overlie dome rocks.

0.3 69.9 Most of the rocks to the right consist of intracaldera tuff of Acklin Canyon. Many north-northwest-striking rhyolite dikes that cut the tuff were probably feeders for domes now largely eroded away. These intracaldera rocks near the south margin of the Caliente caldera complex are on the east side of a north-northwest-striking, right-lateral fault zone that has been intruded by many dikes. On the west side of this fault zone and continuing on the left of the road for another mile, dome rocks are intercalated with tuffs of the Gregerson Basin Member south of the caldera margin. Another series of north-northwest-striking, right-lateral fault zones that contain dikes occurs in the rugged country to the right of the highway.

0.4 70.3 Light-gray rhyolite dome on the right.

0.5 70.8 Light-gray dome on the right. On the left. the dark tuffs of the Gregerson Basin Member occur above dome rocks, which are in turn overlain by at least 100 m of unidentified (Acklin Canyon?) tuffs that are capped by the tuff of Etna at the top of a mesa.

0.4 71.2 Entrance to Rock Springs Canyon on left. The south margin of the Caliente caldera complex coincides with Rock Springs Canyon, although this margin is offset east and west of Rainbow Canyon by generally north-northwest striking right-lateral faults. North of Rock Springs Canyon, about 30 m of horizontal white tuffs from a local dome overlie light-brown intracaldera tuffs of the Hiko Tuff in the Delamar caldera of the Caliente caldera complex. Two rock shelters with cultural deposits occur in the white tuffaceous outcrops located about 1.5 km west of the canyon's entrance (Fowler and others, 1973). The shelters were used intermittently by three distinctive Native American groups from approximately 0 A.D. until the mid-19th century. The ceiling and walls of one shelter contain numerous examples of painted rock art or "pictographs." Bighorn sheep, human figures, and geometric elements were painted in red, yellow, and orange pigments, possibly derived from mineral sources here in Rainbow Canyon. Artifacts recovered from these sites include Anasazi, Fremont, and southern Paiute pottery sherds, stone tools, bone gaming pieces, fragments of basketry, yucca fiber cordage, and a Fremont-style deer hide moccasin. Of particular interest to archeologists were the remains of cultigens, including corn, beans, squash, and pumpkins. These seeds and other plant materials support the inference that horticulture was practiced by prehistoric groups in Meadow Valley Wash. The Anasazi and Fremont abandoned eastern Nevada by approximately 1300 A.D. Ethnographic reports indicate that the Southern Paiute continued to grow crops in Meadow Valley Wash until the disruption of their traditional lifeways by Anglo-European settlers in the mid-19th century (Flower and others, 1973). Meadow Valley Wash was the principal water source for the Ferguson (Delamar) gold mining district (Townley, 1972Ferris, 1991). In 1895, a stream-powered water pumping station was constructed adjacent to the stream, near the mouth of Rock Springs Canyon. Two 3.5-inch iron pipelines carried water west for a distance of 18 km to large storage tanks above the town of Delamar. Two booster stations, located at intervals along the pipeline, were required to pump the water up the steep gradients of the Delamar Mountains. From 1902 until 1909, an electric power plant for the district was also located in Meadow Valley Wash. Portions of that plant's foundation are still visible in the stream channel. Electricity was produced using a combination of hydro-electric and coal-fired generators. The power line paralleled the route of the water pipeline to Delamar.

0.6 71.8 **STOP 1-8 (Ferris and Rowley)** Look up Rock Springs Canyon and talk of the area's history as well as the geology of the south margin of the Caliente caldera complex. Acklin Canyon enters on the right. Light-yellow intracaldera tuff of Acklin Canyon can be seen on both sides of Acklin canyon, where it was deposited in its unnamed source caldera of the Caliente caldera complex. A north-northwest striking oblique (right-lateral and normal) fault cuts the canyon walls about 200 m east of here and juxtaposes the tuff of Acklin Canyon to the east against poorly exposed Hiko Tuff to the west (alongside the road here). This is a strand of the north-northwest-striking Dula Canyon fault zone, a major oblique fault zone mapped for at least 15 km to the north and 10 km to the south. The amount of right-lateral offset is undetermined but is probably at least 10 km based on the offset of the margin of the Caliente caldera complex south of here. Another strand of the Dula Canyon fault zone crosses Acklin Canyon about 1 km east of here. This fault zone is one of many that represent the main episode (pre-20 to 12 Ma) of extension in this part of Nevada and was active during development of the Caliente caldera complex.

0.5 72.3 On the left is a building from the abandoned turn-of-the-century town of Stine, a former railroad stop that serviced the power station 1.1 miles to the south.

0.4 72.7 On the left, a rhyolite volcanic dome forms Baldy Mountain. On the right are dark-yellowish-brown and gray outcrops of the porphyry of Meadow Valley Wash, a distinctive series of largely dacitic porphyritic dikes and plugs that intruded along faults of the main episode of extension. This porphyry is found not only throughout the area of the western caldera complex but also well outside the complex. It occurs as far away as the Panaca Summit area, well north of the caldera complex, about 30 km northeast of the town of Caliente (Fig. 1). Larry Snee has dated several of these dikes by $^{40}Ar/^{39}Ar$ methods; they range in age from 20 to 18 Ma (Rowley and others, 1992; Unruh and others, 1995). These dikes and their ages are critical evidence of synchronous faulting and caldera magmatism.

0.9 73.6 Roadcuts on the right expose a rhyolite volcanic dome containing flow foliation. Jagged outcrops across Meadow Valley Wash to the left are tabular zones of fault breccia and slickensided surfaces of two fault zones. Beyond these outcrops and the red knob and 30 m up the valley wall is a gray planar surface of slickensided rock of another fault zone. Directly north of these rocks, Chokecherry Canyon joins Rainbow Canyon; the rocks at that junction consist of one or more rhyolite volcanic domes and local tuffs from these domes.

0.7 74.3 On the left is Dula Canyon, in the bottom of which is the main strand of the Dula Canyon fault zone. The rocks are strikingly different on either side of the canyon: a rhyolite dome and tuffs capped by tuff of Etna occur on the south side; whereas pale-brown intracaldera Hiko Tuff capped by white tuffs (probably the tuff of Kershaw Canyon) occurs on the north.

0.7 75.0 Ranch is on the right. Roadcuts expose intracaldera Hiko Tuff.

0.3 75.3 To left is a conspicuous example of numerous faults in the area that drops the red tuff of Rainbow Canyon on the south against Hiko Tuff on the north.

0.6 75.9 Former railroad siding of Etna. Dark-gray tuff of Etna caps the canyon on all sides. Lower on the canyon sides is the red and light-gray tuff of Rainbow Canyon. To the north, the gray tuff of

Kershaw Canyon overlies the tuff of Rainbow Canyon.

0.1 76.0. **STOP 1-9 (Ferris)** Brief stop to visit Etna Cave. On the west side of the canyon, a sandy wash leads to a water-diversion tunnel constructed by the Union Pacific Railroad to channel flood flows. West of this tunnel is Etna Cave and its associated rock art site, where red painted pictographs can be seen on the nearby tuff outcrops. Etna Cave was excavated in the mid-1930s by S.M. Wheeler, working under the Civilian Conservation Corps. The hundreds of artifacts recovered document a 7,000 year occupational sequence by several prehistoric cultural groups. The earliest of these were the Desert Archaic people, who inhabited the canyon more than 6,500 years ago. Dart points, grinding tools, basket fragments, and organic remains attributed to Desert Archaic occupations were recovered from the deepest strata (Wheeler, 1973). Archeologists believe that their subsistence strategy involved seasonal movements by small families as they hunted game and collected seeds, nuts, and roots from a wide variety of plants. By approximately 2,000 years ago, the Virgin Anasazi and Western Fremont were using Etna Cave. They are often referred to as Puebloan peoples because the Anasazi and Fremont constructed sedentary villages or "pueblos" at many locations in the American Southwest. Here in Rainbow Canyon, no pueblos have been documented, suggesting that use by these groups may have been seasonal (Fowler and others, 1973). Puebloan subsistence was organized around the hunting of bighorn sheep, deer, and rabbits, as well as the collection of pinyon nuts, the seeds of Indian rice grass, and other native plants. Unlike the earlier Desert Archaic people, the Anasazi and Fremont grew crops, perhaps planting small fields of corn, beans, and squash in the floodplain of Meadow Valley Wash. They made carefully crafted pottery and stone tools. Many organic artifacts, including hide moccasins, bone tools, and cordage, were recovered from Etna Cave. The organic materials have helped archeologists to date when the two groups were using this site. By 1150 A.D., the Anasazi had disappeared from the archeological record of southern Nevada; the Fremont appear to have remained here until about 1300 A.D. Pottery sherds and stone tools associated with the Southern Paiute were recovered in the upper strata of Etna Cave. This cultural group is believed to have migrated into the Great Basin at about 1000 A.D. Unlike the Anasazi and Fremont, the southern Paiute remain in the region today.

0.5 76.5 Around the curve, we see the pink tuff of Rainbow Canyon at road level on left, with thin gray tuff of Kershaw Canyon much higher above it. On the right, across an oblique fault under the canyon floor, the tuff of Kershaw Canyon is much thicker and makes up the upper half of the right valley wall. If the sun is right, you can see many faults, most of them normal faults of moderate throw, defining several horsts and grabens. Intertongued with the tuff of Kershaw Canyon on the right are several dark, thin cooling units of the Gregerson Basin Member that overlie a thick dark cooling unit of the tuff of Sawmill Canyon.

1.3 77.8 Old Conaway Ranch is on the right. Canyon walls are formed by the thick intracaldera tuff of Rainbow Canyon within its half-graben Buckboard Canyon caldera. Buckboard Canyon enters on the left several hundred meters ahead. Conaway Ranch was the site of a historic 19th century ranch (Averett, 1995). During the 1870s and 1880s, early settlers homesteaded ranches in Rainbow Canyon (Averett, 1995). They raised cattle and produce for sale to the booming mining towns of Pioche and later Delamar. Many of the ranches today use public and private lands for cattle grazing. At the turn of the century, Rainbow Canyon was the scene of frenzied railroad construction, as the Union Pacific and the San Pedro, Los Angeles, and Salt Lake Railroad competed to be the first to complete a line between Salt Lake City and Los Angeles. The competition developed into a railroad war, with parallel grades being built along the east and west sides of Rainbow Canyon. Rival construction gangs nearly came to blows on several occasions. The dispute was finally resolved in 1902, after months of court battles, when the two companies agreed to share joint ownership of the line. Problems of a different nature lay ahead for the new partnership. The railroad grade had been built on the valley floor, just above the water level. Between 1902 and 1907, several catastrophic floods washed away major portions of the new line, causing long and costly delays in service. Subsequent relocations of the grade and the construction of a tunnel system finally elevated the grade above the flood zone.

0.1 77.9 Go left on small dirt road and cross the railroad tracks.

0.6 78.5 **STOP 1-10 (Rowley and Nealey)** Stop at base of cliffs that consist almost entirely of multicolored cooling units of the partially welded tuff of Rainbow Canyon (about 15 Ma according to dating by Larry Snee and H.H. Mehnert). A fan-like arrangement of these cooling units is seen on the west canyon wall, in which dips decrease with decreasing age. This fanning is the result of displacement along growth faults that were active synchronous with emplacement of the tuffs. Tuff of Etna caps the east cliffs; sandwiched between it and the top of the tuff of Rainbow Canyon is a thin stratigraphic section of gray tuff of Kershaw Canyon. A major north-northwest-striking oblique fault passes into the canyon wall just south of where we park the cars and underlies the steep gulch in the wall.

0.6 79.1 Return to the paved road and turn left.

0.7 79.8 As we come around the curve were Rainbow Canyon widens into a valley, notice that the tuff of Kershaw Canyon near the top of the canyon on the left is thickening northward. Both it and the layer of tuff of Etna on top dip much less than the underlying tuff of Rainbow Canyon. Two dark tuff ledges of the Gregerson Basin Member lie within the tuff of Kershaw Canyon. On the right, look north at Kershaw Canyon; the light-gray tuff of Kershaw Canyon is much thicker here and makes up most of the walls of Kershaw Canyon. This tuff contains intertongued dark layers of the Gregerson Basin Member and is capped by the tuff of Etna.

0.4 80.2 Take road to the right into Kershaw-Ryan State Park, the site of a former homestead (Ryan Ranch) that was donated to the State of Nevada (Averett, 1995).

0.4 80.6 **STOP 1-11 (Rowley and Nealey)** Stop here to examine a growth fault on the north side of Kershaw Canyon. Here the lower cooling unit of the Gregerson Basin Member is offset more than its upper cooling unit and, on top, the tuff of Etna is fractured but not offset. This is a relatively minor oblique fault (right-lateral and normal), on which we see the effects of differential vertical (normal) movement. As we return to the main road, notice growth-fault fanning that is visible on the west side of Rainbow Canyon and is more evidence of simultaneous extensional faulting and caldera volcanism.

0.4 81.0 Return to the main road and turn right.

0.7 81.7 On the left, the pink tuff of Etna forms a large cliff at and above road level on the west side of the valley and its multiple subledges suggest that it may be a compound cooling unit. Nonetheless, paleomagnetic data through this section (Hudson and others, in press) indicate the entire unit probably cooled within a couple of hundred years.

0.4 82.1 On the right, the gray to pale-brown tuff of Etna dips down to road level. It is overlain by conglomerate that may have filled a small basin that formed above caldera rocks by continued movement along the Timpahute transverse zone that bounds the northern side of the Caliente caldera complex.

0.4 82.5 Go under the railroad bridge.

0.5 83.0 Junction of Nevada 317 with U.S. 93 near the south end of Caliente. Turn right into town, and in a few hundred meters pass the train station on the right, now mainly housing city offices and the library. This 1923 Mission-style Union Pacific Railroad Station is included on the National Register of Historic Places. During the 1930s and 1940s, a hotel and restaurant in the station provided accommodations for travelers on the Union Pacific line. Steeply northeast-dipping fanglomerate on the east wall of the valley contains white and yellow airfall tuffs that are correlated in age with the tuff of Kershaw Canyon.

0.7 83.7 Just past post office on the left, turn right on North Spring Street and cross the Union Pacific Railroad tracks, then right (south) on Clover Street along a row of stores.

0.1 83.8 Turn left on South Spring Street and head up a side canyon; the road turns to dirt and passes through the sequence of fanglomerate and minor tuffs.

1.5 85.3 At a low pass, take a sharp right (west) along a dirt road to overlook of Caliente, near a relay tower.

0.6 85.9 **STOP 1-12 (Rowley, Anderson, and Ferris)** From this overview on the top of the tuff of Etna, we will discuss the north margin of the Caliente caldera complex and faults that are synchronous with caldera magmatism. The Clover Creek caldera, which we will examine tomorrow morning, is well exposed northeast of Caliente in the canyon of Clover Creek. This caldera is the source of the Bauers Tuff Member (22.7 Ma; Best and others, 1989a) of the Condor Canyon Formation (Rowley and others, 1995). North-northwest of Caliente, along the canyon of Meadow Valley Wash, and above the canyon west of Caliente, two north- to north-northeast-striking faults, each characterized by at least 2 km of left slip, are well exposed. A south-dipping low-angle normal fault passes just below the scarp we are standing on, and thus, the tuff of Etna here in the hanging wall is shattered. The Delamar caldera, source of the Hiko Tuff, is inset into the Clover Creek caldera and underlies us at depth, but its nearest exposures are in

English Canyon 2 km to the east. The Buckboard Canyon caldera, source of the tuff of Rainbow Canyon, is in turn inset into the Delamar caldera and probably also is below us, although it is concealed here by the fanglomerate and tuff of Kershaw Canyon, as well as the tuff of Etna above them, that overlie this caldera. As you scan the panorama, note that younger rocks are progressively less deformed. Return to U.S. 93.

2.2 88.1 Turn left on U.S. 93 to our motel.

DAY TWO Friday 25 October 1996

We will start the day looking at structural and magmatic features in the northern part of the Caliente caldera complex. We will end the day in the Delamar mining district southwest of the caldera complex and camp north of the downtown part of the ghost town of Delamar.

0 0. After breakfast, meet at the junction of Nevada 317 and U.S. 93 and head north on U.S. 93.

1.0 1.0 Turn right (east) at the green sign pointing to the Caliente Youth Center. In 50 m, take the right (southeast) fork onto a dirt road that starts just right of the electrical transformer. This road goes up the canyon of Clover Creek.

0.4 1.4 Bear left at the fork. The canyon walls that consist of intracaldera facies of the Bauers Tuff Member start to narrow. Only about 400 m of the top of this unit is exposed. A little farther east still in densely welded intracaldera tuff, the road follows the axis of a locally overturned, east-striking anticline that was first observed by Ernie Anderson.

0.7 2.1 **STOP 2-1 (Rowley and Anderson)** The wash of English Canyon enters from the south and passes under the railroad tracks. Walk south up English Canyon to see three calderas. Examine intracaldera Bauers Tuff Member (Clover Creek caldera) first, then in 0.5 km, see the fault contact that separates this caldera from the Delamar caldera to the south. The fault dips steeply south and exhibits oblique slip (right-lateral and normal) where exposed about 1 km to the east. This fault is the caldera topographic margin but it is unlike any margin described in the literature because it is a linear fault with oblique slip. Ernie Anderson has shown by structural analysis that the east-striking anticline described above and this fault are part of the same deformation. Both structures are manifestations of the Timpahute transverse zone. The uppermost Hiko Tuff occurs on the east side of the canyon, whereas the west side of the canyon consists largely of a post-Hiko fanglomerate sequence that is similar to the sequence overlying the Hiko Tuff east of Caliente. Continue upstream to see megabreccia beds within the Hiko Tuff that represent landsliding off the north caldera margin that we just observed.

1.1 3.2 Return to U.S. 93. Turn right (north), out of town, along the west side of Meadow Valley Wash. Altered dark lava flows of Indian Cove (21.9 Ma) are exposed on the left side of the canyon of Meadow Valley Wash, whereas the Bauers Tuff Member occurs on the right. A north-striking fault (Meadow Valley Wash fault of Rowley and others, 1994) that underlies the road separates these rocks. Some hot springs follow the fault and provide geothermal heat for the trailer park on the left.

0.6 3.8 Antelope Canyon enters on the left. At the entrance to the canyon left of U.S. 93, the lava flows of Indian Cove rest on the upper part of intracaldera Bauers Tuff Member, all dipping steeply eastward. About 0.5 km to the west, these rocks are cut by the high-angle oblique (left lateral and normal) gravel pit fault zone (Rowley and others, 1994) that is similar to the Meadow Valley Wash fault. West of the gravel pit fault zone is the Lower Cambrian Zabriskie Quartzite and overlying Lower Cambrian Pioche Shale; a quarry in the Zabriskie is mined for road metal. The gravel pit fault zone formed during the main episode of extension (Miocene) in the area; it cuts the east-dipping, low-angle (largely bedding-parallel) Stampede fault. The Stampede fault is well exposed in the north wall of Antelope Canyon north of the quarry, in which Pioche and Zabriskie are in the footwall and Cambrian Lyndon Limestone, Chisholm Shale, and Highland Peak Formation are in the hanging wall. The Pioche is thin and locally faulted out. Rowley and others (1994) considered the Stampede fault to be an early Tertiary detachment fault, as did Taylor and Bartley (1992) and Axen and others (1993), but its similarities with bedding-parallel attenuation faults in northwestern Utah and northeastern Nevada led Rowley and others (in press) and Rowley (in press) to interpret it to be of Sevier age (Late Cretaceous and perhaps earliest Tertiary hinterland collapse). To our right, making up the lower 30 m of the canyon wall, is an intracaldera intrusion within the Clover Creek caldera, dated by $^{40}Ar/^{39}Ar$ methods by Larry Snee at 22.8 Ma (Rowley and others, 1994), the accepted age of the Bauers Tuff Member. This is the only exposed mass of intracaldera intrusion found in the Caliente caldera complex; intracaldera intrusions are unusually deep in this caldera.

0.8 4.6 Hill on the left consists of intrusive rock of the porphyry of Meadow Valley Wash, which occurs along many of the middle Cenozoic faults in this canyon. Other rocks extending for about a kilometer to the west (left) include outflow Tertiary volcanic rocks, faulted down against Cambrian sedimentary rocks farther west. The gravel pit fault zone under us separates rocks of the Clover Creek caldera on the east from extra-caldera rocks on the west. The embayment on the right contains a landslide that rests on a relatively small west-northwest striking normal fault of the Chief Canyon fault zone (Rowley and Shroba, 1991) that drops outflow Harmony Hills Tuff (22.5-22.0 Ma) on the north onto intracaldera Bauers Tuff Member on the south.

0.5 5.1 White columns on the right consist of a dike of porphyry of Meadow Valley Wash, which was dated by $^{40}Ar/^{39}Ar$ methods at 19.4 Ma by Larry Snee (Rowley and Shroba, 1991; Rowley and others, 1992, 1994). This dike intrudes along the northwest-striking main strand of the Chief Canyon fault zone, which here separates Harmony Hills Tuff on the south from lava flows of Indian Cove on the north. This is an oblique fault (right lateral and normal) of significant throw that belongs to the main episode of extension.

0.4 5.5 **STOP 2-2 (Rowley and Nealey)** Pull off on the right, just past a bend to the right followed by a small hill on the left that contains good roadcut exposures of volcanic mudflow breccia of the lava flows of Indian Cove. Walk back to the dike of porphyry of Meadow Valley Wash; note the distinctive large phenocrysts. The Chief Canyon fault zone passes just south of the small hill that contains the good roadcuts, then veers north and passes along the east side of the Chief Range. About 5 km north-northwest of the stop is the small Chief mining district, an epithermal gold district formed in roof rocks of the 24.8-Ma Cobalt Canyon stock and in mineralized fault breccia of the Stampede fault; this dating was done by $^{40}Ar/^{39}Ar$ methods by Larry Snee. The mining district and the implications of the porphyry of Meadow Valley Wash are discussed by Rowley and others (1992).

0.5 6.0 House on the left. The embayment on the right is Indian Cove. The rocks here consist of andesite lava flows, flow breccia, and mudflow breccia of the lava flows of Indian Cove.

0.2 6.2 Turn around on the left to return south on US 93 to Caliente. As we turn around, note that we are in the southern end of the Panaca basin that is filled with light-yellowish-brown basin-fill sediments of late Miocene and Pliocene age. The basin was breached later by through-flowing drainage to the Colorado River along Meadow Valley Wash (Rowley and Shroba, 1991; Rowley and others, 1992). The basin and the north-trending Chief Range result from basin-range faulting. The youngest episode of extension in the area probably began after 12 Ma and continues to the present.

4.9 11.1 Intersection of NV 317 and U.S. 93 near the south side of Caliente. Continue southwest along U.S. 93, which bears right (west-northwest) past the town limits and climbs into the Delamar Mountains along the floor of Newman Canyon.

1.2 12.3 House on the right. The gravel pit fault zone strikes toward us in the bottom of the tributary east and behind the house; a dike of porphyry of Meadow Valley was emplaced along the fault and is exposed about 100 m up the gulch. This dike and fault zone are cut by the east-striking Newman Canyon detachment fault, which dips toward us just above the dark spur, which consists of intracaldera Bauers Tuff Member east of the gravel pit fault zone, and dives below us in the gravel pit east of the house. The hanging wall of the Newman Canyon detachment fault contains conglomerate and sandstone (called the sedimentary rocks of Newman Canyon by Rowley and others, 1994) and interbedded tuff of Kershaw Canyon; these rocks are overlain by a layer of tuff of Etna that caps the hill west of the house and the hills and mesas above Newman Canyon for the next several kilometers to the west. A Toreva block of the tuff of Etna is on the left.

1.9 14.2 Vertical roadcuts on both sides contain the tuff of Etna, which here is overlain by more light-brown sedimentary rocks of Newman Canyon that are especially well exposed in a small Miocene depositional basin north of the road. A bed of pumice in the conglomerate and sandstone from this depositional basin yielded a K-Ar date by H.H. Mehnert of 13.8 Ma (Rowley and others, 1994), thereby constraining the age of the tuff of Etna.

2.9 17.1 Cross the north-northwest-striking oblique-slip Dula Canyon fault, which drops the sedimentary rocks of Newman Canyon, tuff of Etna, and a nonresistant overlying cover of basin-fill sediments on the east against resistant intracaldera Hiko Tuff on the west. Within about 200 m on the right, we pass roadcuts of Hiko and interbedded megabreccia and volcanic mudflow breccia deposits that were deposited in the Delamar caldera from its then-steep north rim. This caldera margin is only about 1 km north of our position and is an east-striking fault, the westward extension of the fault we saw this morning at Stop 2-2.

3.7 20.8 Oak Springs Summit, the pass over the Delamar Mountains is in the Hiko Tuff and interbedded breccias. Head down toward Dry Lake Valley.

1.7 22.5 A dirt road on the right. The covered flats we are crossing are underlain by nonresistant, fault-brecciated rocks of the north margin of the Caliente caldera complex. Behind us, to Oak Springs Summit, all rocks are of the Delamar caldera. To the right just inside the caldera margin are examples of megabreccia blocks, locally larger than houses. The mountain at 2 o'clock consists of a gently north-dipping sedimentary section that extends up section from red rocks in the top of the Lower Cambrian Zabriskie Quartzite, on the right just north of U.S. 93, through the Pioche Shale, Lyndon Limestone, Chisholm Shale, and lower part of the Lower and Middle Cambrian Highland Peak Formation. The mountain is capped by the Step Ridge Member of the Highland Peak Formation.

0.7 23.2 **STOP 2-3 (Rowley)** Walk north to a west-draining gulch that exposes the fault zone that defines the northern margin of the Delamar caldera. East-striking fault planes containing chiefly oblique slickensides are common. Although the caldera contains the above-described megabreccias that are typical of caldera margins, it also displays features atypical of calderas such as this topographic margin that is an oblique-slip fault zone, part of the Timpahute transverse zone. To the left (south) of U.S. 93, the hills consist of intracaldera Hiko Tuff.

1.4 24.6 Orange bed just to the right of the road is the Condor Member of the Highland Peak Formation. Hills north and south of the road are Cambrian sedimentary rocks. The hills to the south are also west of the Caliente caldera complex; the Delamar caldera margin here is interpreted also to be a fault, which strikes north-northeast. A little farther, we drive into Dry Lake Valley.

3.0 27.6 Turn left off U.S. 93 onto a dirt road to the ghost town of Delamar.

1.0 28.6 Climb up a low Quaternary fault scarp. This fault bounds the entire east side of Dry Lake Valley.

3.2 31.8 On the left is the road to Grassy Spring, once a stop along the Pioche to Delamar freight and stage line. Continue straight ahead. The hills at 8-10 o'clock are made up of intracaldera Hiko Tuff. Closer hills at 11-12 o'clock, however, are outside the caldera and consist of largely east-dipping Cambrian sedimentary rocks overlain to the east by Tertiary andesite lava flows and outflow ash-flow tuffs. These rocks are separated from those in the Delamar caldera east of them by the north-northwest-striking Monkey Wrench fault zone, another large oblique-slip fault (right lateral and normal) that makes up the caldera margin and that contains numerous dikes and plugs of the porphyry of Meadow Valley Wash.

1.5 33.3 Turn left at the sign to Delamar.

1.0 34.3 On the left, the east-dipping Cambrian section exposes up section the very top of the Zabriskie Quartzite, through Pioche Shale, Lyndon Limestone, Chisholm Shale, and then the lower Highland Peak Formation (as high as the Burnt Canyon Member) at the crest of the hills. These rocks are overlain by the Tertiary Baldhills Tuff Member of the Isom Formation, Shingle Pass Formation, Bauers Tuff Member of the Condor Canyon Formation, andesitic lava flows of a large stratovolcano, and Hiko-age rhyolite volcanic domes that formed along the faulted (Monkey Wrench fault zone) caldera margin.

2.9 37.2 Light-brown hill at 9 o'clock consists of the east-dipping Lower Cambrian Wood Canyon Formation, capped by Zabriskie Quartzite. An east-dipping rhyolite dike is emplaced along the north side of the hill and is marked by prospect pits along it. The gulch north of this hill is called Monkey Wrench Wash, named for the monkey wrench that was used to chip off the first pieces of gold ore in the district.

1.0 38.2 Road on the left goes to the site of Helene, a mining camp (most structures were tents) that was established in 1892 after the initial gold discoveries in the Ferguson (Delamar) mining district. These early claims were developed into the Magnolia mine, a headframe of which is seen at 10 o'clock. Helene was located on the flats below and to the west of the headframe. On the left is an east-trending ridge; the south side of the ridge contains the Magnolia mine and consists of the Wood Canyon Formation and Zabriskie Quartzite. The north side of the ridge includes a section extending from Pioche Shale through the lower Highland Peak Formation. Just north of us, an east-striking fault defines the south side of the ridge and continues up the canyon (Helene Wash) to the east. This fault, which has a rhyolite dike intruded along it 4 km east of here, is part of the Helene transverse zone.

0.4 38.6 Cemetery on the right was used as a public cemetery for the residents of the Ferguson district. Foundation on left may be the tollhouse for the road we are starting up, into Delamar.

0.9 39.5 Roadcut on the left exposes a white, altered, east-striking rhyolite dike, one of many dikes in the district of this strike and composition. The dikes appear to be a hallmark of the Helene transverse zone and are the same age as development of the caldera complex and as mineralization. The dikes are interpreted to be related to an intrusion of inferred granitic composition at depth. The granitic intrusion is the inferred source of convective overturn of the ground water that led to mineralization in the east-west fractures and faults of the transverse zone that were being formed at the time of mineralization. The quartzite along the road here is mapped by Pete Rowley as the Late Proterozoic and Lower Cambrian Stirling Quartzite.

0.3 39.8 Tailings from the main Delamar mill are ahead and to the right. The remains of this mill are ahead, and relics of the main street (east-west) of Delamar are seen beyond the tailings. The west end of this street containing the main business district climbs onto a low ridge called Nob Hill, which contained some of the fanciest homes. The town dump and the residences of many Chinese and Native Americans were located in the bottom of the canyon south of the main street. On the high east-trending ridge beyond the canyon that contains the town, we can see a historic road that works its way west up around lower parts of the ridge where it drops from sight into the major west-flowing canyon of Cedar Wash. Cedar Wash contained the stockyards, a road, and water and electric lines. The water and electric lines crossed this high east-trending ridge in a saddle about 0.5 km east of where the historic road crosses the ridge. The remains of an old wooden water tank are barely discernible rubble on the saddle. We will camp tonight on the vegetated dunes of the tailings just east of Nob Hill.

0.2 40.0 Stone building on left.

0.1 40.1 Delamar mill on right; water tanks on left.

0.1 40.2 Glory Hole is up the hill to left.

0.1 40.3 Foundations of company row homes are on the left. At the bend, the house with a roof, near the rusted sedan, was Agnes Horn's home. Agnes was one of the last residents of Delamar; she is buried in the public cemetery southwest of Helene.

0.1 40.4 Intersection with Main Street. Bear right (west) onto Main Street, past historic walls of buildings.

0.2 40.6 Arch on right marks the Delamar Bank building. The historic road that climbs the ridge to the south and then to Cedar Wash takes off to the left. In about 100 m, main street forks; the right fork climbs onto Nob Hill, and the left fork goes down the lower gulch through the town dump. Return east to the road intersection.

0.2 40.8 Back at milestop 40.4. Continue east up the canyon.

0.1 40.9 The road to the left climbs up to the Hog Pen glory hole and then to the main glory hole. On the east-trending ridge to the south, the road at 3 o'clock ends at the Flagstaff mine.

0.2 41.1 April Fool mill and office buildings are on the left and tailings from the mill are on the right.

0.2 41.3 Headframe on the right is to the Jumbo mine; other claims are located along the road containing new drill sites. Turn left onto switchback.

0.1 41.4 Take left fork in road.

0.1 41.5 **STOP 2-4 (Rowley and Ferris)** Stop at the tailings to the April Fool mine. The mine consists of a series of narrow pits that develop a fault-controlled gold vein. Discuss the history of the Delamar district from this panorama.

0.6 42.1 Return to milepost 40.9 and turn right onto the road to the glory hole.

0.1 42.2 On second switchback, the pit is the Hog Pen glory hole.

0.2 42.4 **STOP 2-5 (Rowley and Ferris)** Stop on tailings just past entrance to glory hole. Walk into the glory hole to see veins, faults, and a large, altered, east-striking rhyolite dike. Discuss the history of epithermal mineralization in the district. Also, from this panorama discuss more of the history and archeology of the district. Return to the base of Nob Hill where we will park and walk down road to the right to our camping/dinner spot.

2.0 44.4 **STOP 2-6 (Ferris)** After dinner, Dawna Ferris will give us a fire side chat about the history of Delamar.

DAY THREE Saturday 26 October 1996

As we view the North Pahroc Range from south to north, observe changes in the age and style of deformation. In the south part of the range, extension and arching of the range is post-18 Ma and movement on the nearby fault that forms a segment of the Timpahute transverse zone is bracketed between about 18.2 and 18.0 Ma, synchronous with the eruption of the Hiko Tuff from the nearby Delamar caldera of the Caliente caldera complex. But in the north part of the range, two distinct angular unconformities were formed about 29 Ma and 27 Ma, overlapping the period of volcanism associated with the 32- to 27-Ma Indian Peak caldera complex 30 m to the northeast. Not only does the style of deformation change along the range, but the timing of arching changes from post-18 Ma in the south to post-27 Ma in the north.

13.0 13.0 At junction of Delamar Valley Road and US 93, turn left to west.

3.9 16.9 **STOP 3-1 (Scott)** We are near the divide between Delamar Valley to the south and Dry Lake Valley to the north, both of which have internal drainages and playas. To the southwest is the South Pahroc Range where between 22 and 15 Ma growth faults rotated strata to dip westward. To the north the North Pahroc Range forms a north-trending arch (Scott and others, 1992). The oldest Tertiary volcanic strata exposed here are the 30.6-Ma Cottonwood Wash Tuff (Best and others, 1989b) of the Needles Range Group and the youngest strata are the 18.2-Ma Hiko Tuff (Table 2). Normal faults dip both toward the axis of the arch (repeating the section in map view), and away from the axis (attenuating the section in map view), thus creating a complex map pattern (Scott, 1992). In this southern part of the range, the volcanic strata show no evidence of progressive tilting because the strata are essentially parallel to one another. Continue west on US 93.

2.1 19.0 **STOP 3-2 (Scott)** At this stop we can view evidence of the timing of deformation at the southern end of the North Pahroc Range. About 0.5 km north of us, the largest hill consists of 20-30°-east-dipping Hiko Tuff that is capped by nearly horizontal basalt. A whole-rock K-Ar date of 18.1±0.9 Ma was determined by H.H. Mehnert for the basalt (Scott and others, 1995b), and a $^{40}Ar/^{39}Ar$ sanidine date of 18.2±0.14 Ma was determined by Larry Snee for the Hiko Tuff (Scott and others, 1995a). About 3 km north of us, the prominent east-west-trending Timpahute transverse zone, which extends along the northern part of the Caliente caldera complex westward to the Timpahute Range (Ekren and others, 1976), is expressed as a nearly vertical strike-slip fault containing evidence of both right- and left-lateral horizontal slip (Scott and Swadley, 1992). On the south side of that fault, thick fault-scarp colluvium of Hiko Tuff accumulated on the downthrown side of the Timpahute transverse zone. The 18.1-Ma basalt overlies both the scarp colluvium and the truncated 18.2-Ma Hiko Tuff. Thus, within the 1.1 million years allowed by the 2 sigma error on the basalt and tuff dates, the Hiko Tuff was emplaced, the fault associated with the Timpahute transverse zone uplifted the north block, the Hiko Tuff tilted eastward and eroded onto the south block, and scarp-colluvium accumulated before eruption of the basalt. Unfortunately no exposures of the 18.1-Ma basalt exist north of the transverse zone on the arched North Pahroc Range to provide a minimum age of arching in the southern part of the range. Turn vehicles around and head back to the east on US 93.

2.8 21.8 Turn left to the north through cattle guard just past 73-mile marker onto unpaved Dry Lake Valley road. Notice east-dipping exposures of gray 22.7-Ma Bauers Tuff Member of the Condor Canyon Formation, light-gray 22.6-Ma Pahranagat Formation, greenish-gray 22.2-Ma Harmony Hills Tuff, and the capping, brown boulders of the Hiko Tuff to the west. Isolated exposures of Hiko Tuff appear on either side of us, repeated by west-dipping normal faults.

5.6 27.4 At junction with road, turn left to the west across cattle guard and head for the North Pahroc Range.

4.1 31.5 **STOP 3-3 (Scott)** Brief stop to view a moderately dipping normal fault about 2 km north of us (Fig. 5). Note that we have crossed from the east-dipping to the west-dipping limb of the arched range. A red monolithologic breccia of the Hole-in-the-Wall Tuff Member of the Isom Formation (26-24 Ma) dips 30-45° to the east (shown on Fig. 5 with a shear zone pattern). The breccia separates an upper plate that locally includes the Petroglyph Cliff Ignimbrite (27.6 Ma) up section through the Leach Canyon Formation (23.8 Ma) from a lower plate that locally includes sedimentary rocks below the Cottonwood Wash Tuff (~30.6 Ma) up section through the Harmony Hills Tuff. In both plates, strata dip between about 10-40° to the west and are repeated on steeply east-dipping normal faults that do not cut the lower-angle fault separating the plates. Thus, the lower-angle fault is younger than, or perhaps coeval with, the steeper-dipping normal faults (Scott, 1992).

0.7 32.2 **STOP 3-4 (Scott)** Walk northward along a low ridge of west-dipping Wah Wah Springs Formation (~ 29.5 Ma) to view a nearly horizontal low-angle normal fault with the same general upper plate- and lower plate-relations viewed at Stop 3-3. As we walk along the ridge note the flat attitude of the fault. The emplacement of each of the dacitic ash-flow tuffs of the Needles Range Group (Cottonwood Wash Tuff and Wah Wah Springs and Lund Formations) interrupted the deposition of poorly exposed sequence of interbedded lacustrine limestone, coarse boulder- to pebble-conglomerate of Paleozoic clasts, and tuffaceous sandstone. Instead of the monolithologic breccia seen along the moderately dipping normal fault at Stop 3-3, this fault contains sheared Paleozoic boulders. Presumably movement on this fault dragged Paleozoic boulders of the Tertiary sedimentary units into the fault zone, used the boulders as "ball bearings", and sheared them. At this locality, the tuff of Hancock Summit (between 26.7 and 27 Ma) overlies the fault and the Wah Wah Springs Formation underlies it (Fig. 5). The fault continues to the east, turns abruptly to the north following the topography and over a short distance becomes a high-angle west-dipping normal fault. Similar geometric relations to the west show this upper plate to be shaped like a flat-bottomed boat with steep gunwales (Scott, 1992). Lund and others (1993) has found similar upper crustal, shallowly keeled, low-angle normal faults in the arched Grant Range about 65 km northwest of here. As is the case at the previous stop, steep normal faults below and above the low-angle fault stop abruptly at the fault boundary. Two other similar low-angle normal fault blocks occur south of here but are less accessible (Scott and others, 1992). The age of arching and faulting in this southern part of the range is younger than the 18.2-Ma Hiko Tuff but a minimum age for either is uncertain. No evidence of an angular unconformity exists in the sequence of Tertiary strata.

4.8 37.0 Turn vehicles around and retrace route to the east to junction with Dry Lake Valley road. Turn left to the north. As we drive up valley, we will be passing from the Pahroc Spring quadrangle, through the Wheatgrass quadrangle, into the Deadman Spring quadrangle. Taylor (1989) mapped the northern part of the Wheatgrass Spring and the southern parts of the Deadman Spring and Deadman Spring NE quadrangles for her dissertation, and published several summaries of this work (Taylor and others, 1989; Taylor, 1990; Taylor and Bartley, 1992). New maps covering all of the Wheatgrass Spring, Deadman Spring, and Deadman Spring NE quadrangles were based in part on previous mapping by Taylor (Scott and others, 1994; Swadley and others, 1994b; Scott and others, 1995c).

The southernmost indication of an angular unconformity in the volcanic sequence in the south part of the Wheatgrass Springs quadrangle in the North Pahroc Range was observed where the 27.6-Ma Petroglyph Cliff Ignimbrite dips 5-10° more steeply than the overlying 27.3-Ma Monotony Tuff (Scott and others, 1994). North of this locality Taylor (1989) found evidence for two angular unconformities of similar age, an older one between 30 and 27.9 Ma and a younger one between 27.9 and 27.6 Ma. Toward the north, angular unconformities of similar age become more pronounced.

The west side of the North Pahroc Range is marked by the west-dipping White River fault (Tschanz and Pampeyan, 1970). At its south end the fault is quite sinuous and is a low-angle fault with dips as low as 10°, but dips become steeper about 10 km farther to the north where dips of 60-80° are typical, and slip indicators record oblique left-lateral slip. The pattern of northwest-striking secondary Reidel or tension faults, which can be observed at the 1:24,000 map scale, match this kinematic geometry.

In this central part of the range, numerous moderately east-dipping master normal faults form brittle-behavior roll-over structures, in which strata in the hanging wall dip more steeply closer to the listric fault and east-dipping imbricate normal faults are common (Scott, 1990). These geometries require the master faults to be listric. Unfortunately, we are too far from the range to see these features.

East of the road, Dry Lake playa partly overlaps the site of the late Pleistocene pluvial Lake Bristol. Evidence of late Pleistocene marshes, beach deposits, and spring deposits also are present (Swadley, 1995; Swadley and Simonds, 1994). Numerous Quaternary (early Pleistocene to late Holocene) faults cut the alluvial deposits on both sides of the Dry Lake Valley. The prominent north-striking, down-to-the-west Dry Lake fault extends over 46 km along the east side of the valley and has early Pleistocene scarps as high as 9 m. A smaller antithetic fault forms an asymmetric graben along most of the west side of the Dry Lake fault. The east-facing fault scarps of the west side of the valley are less than 1 m high. In addition to young faults, the alluvium in both the Dry Lake Valley and the Delamar Valley is cut by slightly sinuous, active and inactive fissures as long as 4 km and as wide as 5 m. One active fissure that cuts the Lincoln County road on the east side of the valley requires recurrent detours as it propagates northward. To the south in Delamar Valley most of the fissures were found to be parallel to, and on trend with, north-northeast-striking normal faults in adjacent bedrock. For this reason we originally postulated that the fissures might have a tectonic origin (Swadley and Scott, 1988). However, subsequent mapping showed that most of the fissures in Dry Lake valley are not parallel to bedrock faults and form irregular, polygonal, abutting relations. The lack of water withdrawal in the valley prior to formation of the fissures and the lack of parallelism between fissures and bedrock faults suggests that formation of fissures from water withdrawal, tectonism, and differential compaction of alluvium over buried fault scarps are unlikely. The late Pleistocene climate that was characterized with Lake Bristol, marshes, and springs must have undergone significant changes to the present climate. This climatic change caused a drastic drop in the water table. Therefore, the most likely origin of the fissures is desiccation of the sedimentary fill (Swadley, 1995). Probably parallelism of traces of bedrock faults and fissures in Delamar Valley can be explained by the basin fill acquiring the stress field from the bedrock during desiccation.

14.6 51.6 Turn left to the west at junction with road to Deadman Spring. On the right are exposures of west-dipping Devonian Simonson Dolomite and Guilmette Formation.

1.2 52.8 Bear to the right to the northwest on smaller ungraded road. To our right in the notch in the hills, the top of the Guilmette, most of the West Range Limestone, the Pilot Shale, and the base of the Joana Limestone have been omitted by a west-dipping normal fault. Also in that notch west of the fault in Paleozoic strata, an east-dipping block consisting of strata from the 31.3-Ma Windous Butte Formation through an andesitic flow (27.9 to 29.5 Ma) overlies the Joana Limestone along a second west-dipping normal fault. We will drive down section through exposures of the andesite, an underlying monolithologic andesitic mudflow (large greenish boulders), an unnamed partially welded rhyolitic ash-flow tuff, and the 29.5-Ma Wah Wah Springs Formation. Below the lowest of the Tertiary strata are exposures of jumbled blocks of the Mississippian Scotty Wash Quartzite above low-lying exposures of highly deformed Chainman Shale. We cross low mounds of Holocene spring deposits similar to the modern deposits at Hamilton Spring near the cottonwood tree ahead.

2.4 55.2 Take the left cutoff to Deadman Spring and stay on the main track. Follow our route on figure 6. The cottonwood tree and corral at Hamilton Spring that we bypassed are part of an abandoned homestead. On our right we pass an east-dipping ridge of the Wah Wah Springs Formation separated by an angular unconformity from the underlying nearly flat-lying Permian-Pennsylvanian Bird Spring Formation and Mississippian Scotty Wash Quartzite and Chainman Shale. Beyond a west-dipping normal fault, the valley to the right is floored by tuff of Deadman Spring (27.9 to 29.5 Ma)

1.7 56.9 View to right to the north at 2 o'clock shows the axis of the arched range. The lowest exposures are the Wah Wah Springs Formation and the overlying tuff of Deadman Spring. Higher exposures include two dark andesitic units separated by the pale-red Petroglyph Cliff Ignimbrite. The upper of the two is the andesite and mudflow facies of Hamilton Spring (Ta_3 of Fig. 6), the lower is the formation of Black Rock Spring (Ta_2 of Fig. 6) that includes mudflow facies and andesitic lava-flow facies. As we begin driving through the west-dipping ramp of the arch, note that only strata younger than the tuff of Deadman Spring dip westward; older strata continue to dip eastward. To the south, the tuff of Deadman Spring and older strata also dip east under the west-dipping younger strata on the west side of the range, but the arch of the range is less obvious there because it is broken by numerous normal faults that dip both toward and away from the crest of the arch. West-dipping normal faults that repeat the older strata in map view commonly do not cut the younger arched strata (Fig. 6).

0.4 57.3 Pass by Deadman Spring and bear right to the northwest. Note that we cross the east-dipping Wah Wah Springs Formation and begin to drive close to the Tertiary-Paleozoic contact to our left. Paleozoic strata are the Bird Spring Formation.

0.9 58.2 **STOP 3-5 (Scott)** Lunch and walk to inspect units and structures shown in figure 6. Note the east-dipping 31.3-Ma Windous Butte Formation, 30.6-Ma Cottonwood Wash Tuff, and 29.5-Ma Wah Wah Springs Formation; and the tuff of Deadman Spring have been truncated along an angular unconformity, which formed about 29 Ma. Above that angular unconformity, a locally exposed nonwelded ash-flow tuff, andesite lava flows and mudflows, 27.6-Ma Petroglyph Cliff Ignimbrite, and more andesite lava flows and mudflows dip gently westward expressing the west-dipping limb of the arch. Above a second, but less distinct, 27-Ma angular unconformity, nearly flat lying 27.0-Ma Baldhills Tuff Member of the Isom Formation and the 26.0-Ma Upper Member of the Shingle Pass Tuff perch as isolated outliers on the west-dipping layer of dark andesite lava flows and mud flows. The Baldhills Tuff Member pinches out up-slope, suggesting that it pinched out against the topographic high of the arch.

After observing the close relation between volcanism and deformation in vicinities of the Caliente and Kane Springs Wash caldera complexes, the obvious question is whether or not the distinct period of extension that formed the east-dipping panels of pre-29-Ma strata and the 27-Ma arching is related to the nearby Indian Peak caldera complex that was active from about 32 to 27 Ma. About 20 km northeast of here in the Dry Lake Valley area closer to the Indian Peak caldera complex, Bartley (1989) found similar ages of deformation. In adjacent quadrangles northeast of the Deadman Spring area, Page and Ekren (1995) and Ekren and Page (1995) found an east-trending trough that accumulated ash-flow tuffs from the Needles Range Group erupted from the Indian Peak caldera complex; they suggest that the trough subsidence may have been concurrent with eruption. Also strata of the Needles Range Group in that area dip significantly more steeply than do adjacent Miocene strata suggesting a period of extension about 27 Ma. Thus, relationships in the north part of the North Pahroc Range and areas closer to the Indian Peak caldera complex are at variance with the conclusion of Best and Christiansen (1991) that from about 31 to 20 Ma extension was limited during the peak of volcanism in the Great Basin.

Exposures of the Bird Spring Formation east of the road contain strata that dip about 60° to the west and are overlain at a depositional contact by 31.3-29.5 Ma strata that dip about 50° to the east. Rotation of Tertiary strata to horizontal overturns the Permian-Pennsylvanian strata, forming a structure of uncertain origin. West of the road, the Paleozoic strata contain few faults in contrast to the highly faulted Tertiary strata. A few kilometers north of here abundant breccias and altered rocks mark the contact between Tertiary and Paleozoic rocks. Although exposures do not permit observation of the fault surface, Tertiary rocks must have decoupled from lower plate Paleozoic rocks as Tertiary strata slid to the east to deform independently. The age of this fault probably predates or is synchronous with the deformation of Tertiary strata under the 29-Ma angular unconformity. The fault and upper plate strata both dip eastward, and therefore, reconstruction requires that this fault increases dip with depth.

6.6 64.8 Retrace route to junction with Dry Lake Valley road. The last stop will be optional depending on time. If time is insufficient, we will turn right and drive to the junction with U.S. 93, turn right, and return to Las Vegas (about 150 miles).

If time is sufficient, turn left to the north and drive up Dry Lake Valley. On our left are exposures of west-dipping Simonson Dolomite at the base and Guilmette Formation at the top of the large ridge. Farther up the road, low hills on the left are also Guilmette Formation.

9.5 74.3 At road junction, bear left to the west. At road junction by the water tank (Coyote Spring), keep straight.

2.4 76.7 Take the left fork.

1.3 78.0 Take the left fork again.

0.2 78.2 **STOP 3-6 (Scott)** Leave vehicles at the small cliff of unnamed nonwelded rhyolitic tuff that overlies the 29-Ma angular unconformity and the tuff of Deadman Spring. Walk 300 m to the southwest to Cabin Spring. On the way note that the east limb of the North Pahroc arch dips about 10° to the east. To our right the nonwelded tuff has been stripped off the contact with the tuff of Deadman Spring. The moderately welded and silicified upper contact of the Deadman dips 30-40° eastward. Numerous west-dipping normal faults cut the Deadman but do not cut the overlying nonwelded tuff. These imbricate normal faults have offsets from the cm to 10 m scale, and the spacing between faults is typically only a few cm. This style of deformation is almost "penetrative", represents a form extension that is difficult to quantify, cumulatively greatly affects the geometry of the deformed units, and is extremely difficult to display on maps or in cross sections. Perhaps more important, in massive ash-flow tuffs, imbricate normal faults are very difficult to recognize and may be mistaken for fracturing. The tuff of Deadman Spring has indistinct planes of compaction foliation; therefore, if it were not for contrast in color and contrast in erosion of the silicified upper contact of the Deadman Spring relative to the overlying nonwelded tuff, the imbricate normal faults could easily be missed. Subtle imbricate normal faults may have been overlooked in areas where synvolcanic deformation has not been recognized.

END OF TRIP. Retrace route to the Dry Lake Valley road and to U.S. 93 and turn right toward Las Vegas.

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