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THE STRATIGRAPHY AND STRUCTURE OF THE McCOY GEOTHERMAL PROSPECT, CHURCHILL AND LANDER COUNTIES, NEVADA

by

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ABSTRACT

The McCoy geothermal system straddles the border of Lander and Churchill counties, central Nevada, in the middle of the Basin and Range Province. The study area occupies approximately 100 sq. km. near the intersection of the Augusta and Clan Alpine Mountains and the New Pass Range.

The geology of the area is dominated by rhyolite ash-flow tuffs and subordinate intermediate-composition lava flows of Oligocene age. These volcanics were emplaced on Permo-Pennsylvanian massive cherts and Triassic dolomitic limestones.

At least two episodes of hydrothermal activity can be recognized at McCoy. The oldest event altered and mineralized the volcanic and sedimentary rocks, producing the McCoy and Wild Horse mercury deposits. The youngest event produced travertine and siliceous sinter deposits which intercalate with alluvium, and appear to be related to the high heat flow found at the McCoy prospect.

The oldest recognized faults at McCoy produced several east-west grabens and horsts. These fault zones were active before and during the deposition of the volcanics. The Wild Horse and McCoy mercury mines occur along one of these east-west fault zones. Basin and Range faulting began subsequent to 23 m.y. ago, and produced a complex array of polygonal blocks which were subsequently eroded into subparallel cuestas.

Fluid movement in the geothermal system is controlled by the intersections of the east-west and north-south faults. There is no known igneous source for the thermal energy in this system. However its intramontane location is atypical of known geothermal systems in the Basin and Range, which may preclude deep circulation through major basin-bounding faults.

ACKNOWLEDGEMENT

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INTRODUCTION

West-central Nevada is an area of high potential for geothermal energy. The McCoy geothermal prospect, one of several geothermal systems within this region, is the subject of this study (Fig. 1). The McCoy geothermal prospect was discovered in the mid-1970's by the geothermal resource division of Amax Inc. A detailed geologic map was required for accurate modeling of the large amount of geophysical and geochemical data that resulted from their exploration, and to delineate the structures which control subsurface permeability. This report describes the geology of the area, mapped at a scale of 1:24,000, from which the detailed geophysical data were collected. The study area also encompasses the thermal anomalies defined by a series of shallow thermal gradient holes (Fig. 2, 3).

The McCoy geothermal prospect, found on the basis of its mercury mineralization, is characterized by heat flow anomalies, thermal fluids at depth, and one of the largest travertine mounds known in the western United States. In contrast to most of the known geothermal resources in the Basin and Range province, which appear to be related to deep circulation along major faults, the McCoy prospect is situated in lowlands at the juncture of three mountain ranges (Fig. 1), far from the bounding faults of any major basin.

The McCoy area is covered to a large extent by ash-flow tuffs, which provide unique stratigraphic marker horizons allowing structures

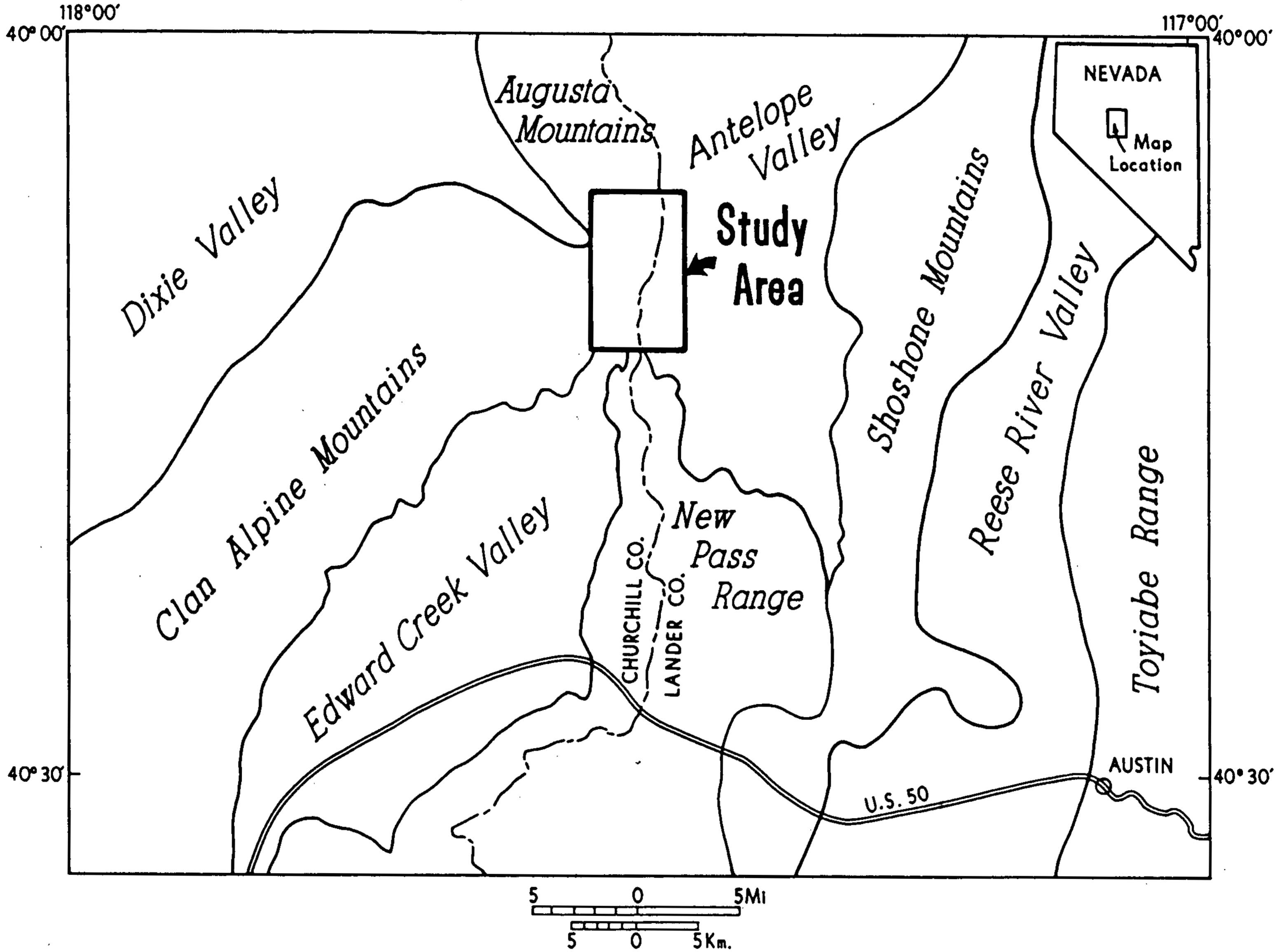

Figure 1. Index map of central Nevada.

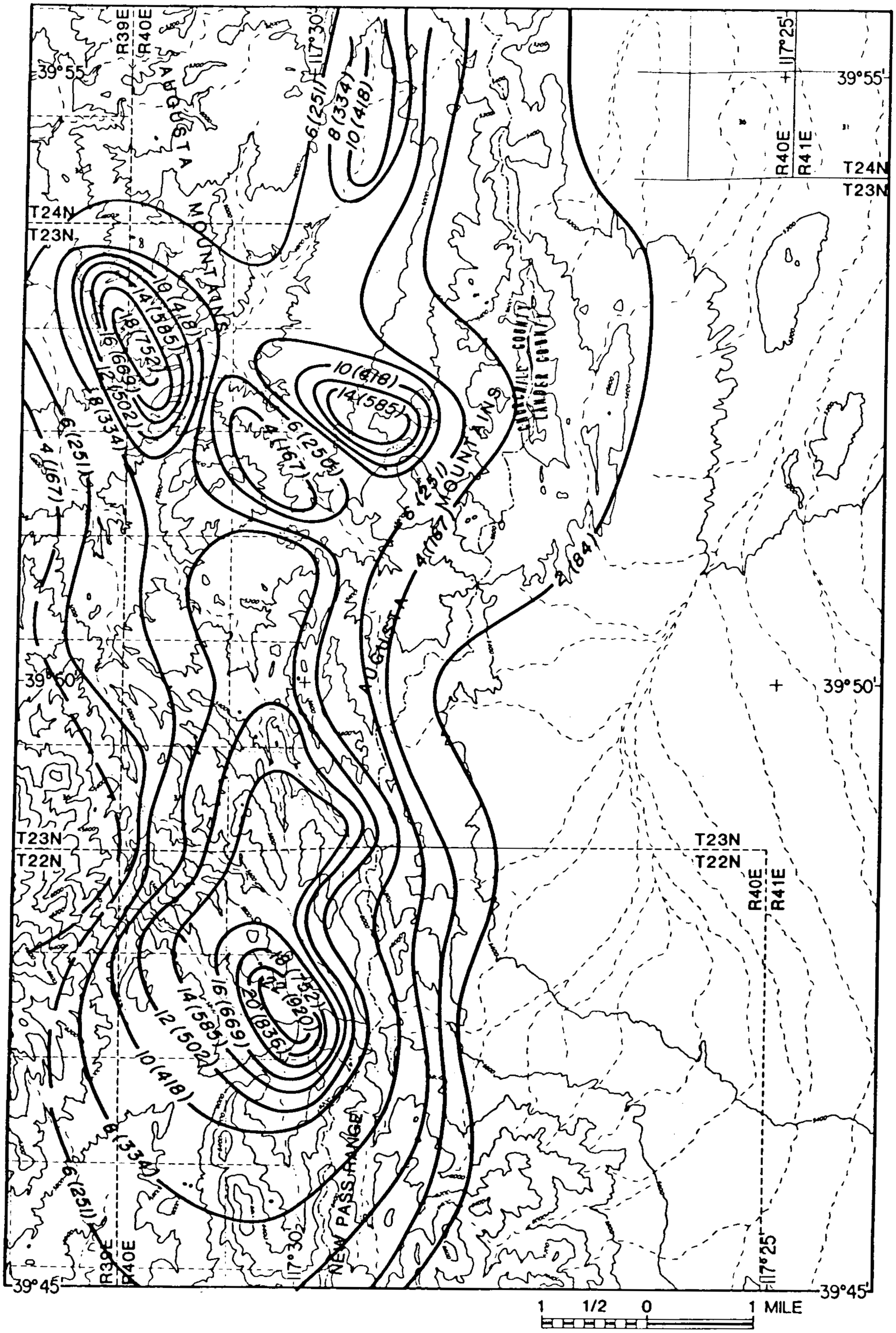

Figure 2. Contoured heat flow (HFU (mW/m^2)) at McCoy geothermal prospect.

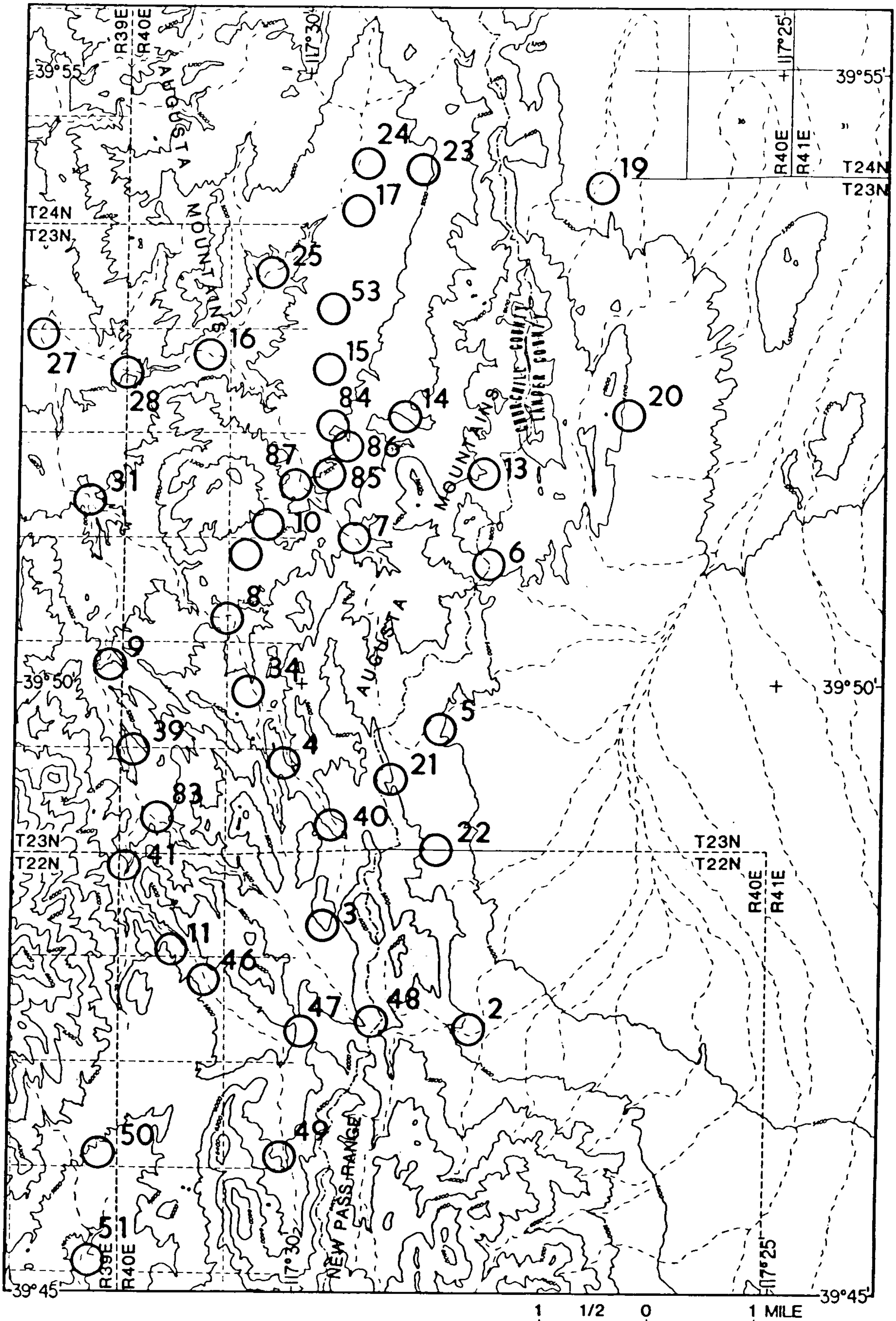

Figure 3. Location of shallow thermal gradient holes.

to be mapped in detail throughout the area. The mapping was done on aerial photographs and the volcanic units were correlated on the basis of petrography and textures. Spectrochemical oxide analyses and model compositions were determined for the ash-flow tuffs in order to compare them on a regional basis.

The area can be reached by dirt and gravel roads suitable for most passenger cars. U.S. 50 and state highway 8A are the nearest paved roads, both leading to Austin, Nevada, approximately 50 air kilometers southeast of the mapped area. The climate of the region is semi-arid and no permanent surface water exists within the mapped area. Vegetation consists of sagebrush and sparse juniper trees in the lower reaches, with the junipers becoming plentiful at higher elevations. The mapped area straddles the Lander County-Churchill County line, covering all of township 23 north, range 40 east, and 13 sections in township 22 north, range 40 east, Mount Diablo base meridian.

PREVIOUS INVESTIGATIONS

Little scientific work was done in the McCoy area prior to 1942. After the establishment of the McCoy and Wild Horse Mercury Mines, in 1916 and 1939, respectively, a strategic minerals investigation of the mine area was initiated by the U.S. Geological Survey (Dane and Ross, 1942). Although their interpretations of structures in the pre-Tertiary strata are similar to those described in this report, they were handicapped by the state of the art in ash-flow tuff studies and there are major differences in the structural interpretation of these units.

The sedimentary stratigraphy was locally defined by Dane and Ross in 1942 (Dane and Ross, 1942). It was later redefined for county geologic maps by Speed (in Stewart et al., 1977) and Willden (Willden and Speed, 1974) whose work was partly based on the work of Muller et al. (1951). The volcanic units in the McCoy area were first defined by McKee and Stewart (1971) in an effort to systematize the ash-flow tuff stratigraphy of central Nevada by K-Ar age dating and lithology. Other works relating these ashes to the Oligocene volcano-tectonic regime of central Nevada are those of Riehle et al. (1972) and Burke and McKee (1979).

A summary of the geophysical and geochemical surveys done by Amax Exploration, Inc. was given by Olsen et al. (1979).

GEOLOGIC SETTING

The McCoy geothermal prospect lies near the center of the Basin and Range physiographic province. The study area is surrounded by several Tertiary volcanic and Mesozoic plutonic complexes. The Fish Creek caldera (McKee, 1970) and the Mount Lewis cauldron (Wrucke and Silberman, 1975) border the western and eastern margins of northern Antelope Valley, respectively (Fig. 1). Southwest of McCoy, in the Clan Alpine Mountains, rhyolite domes, lava flows, and ash-flow tuffs fill a large volcano-tectonic depression (Riehle et al., 1972). Two Mesozoic plutonic complexes in this region are the Stillwater Gabbro Complex, in the Stillwater Range, and the Austin Pluton, in the Toiyabe Range (Willden and Speed, 1974; Stewart et al., 1977) (Fig. 1).

The oldest rocks at McCoy are Paleozoic (Dane and Ross, 1942). These consist of massive bedded cherts, sandstones, and conglomerates which were tightly folded and thrust over contemporaneous carbonate facies rocks during the Sonoma Orogeny. The Paleozoic rocks are overlain unconformably by a thick sequence of Triassic limestones and dolomitic limestones, themselves gently folded during the Nevadan Orogeny (Willden and Speed, 1974). After peneplanation, during the late Mesozoic and early Tertiary, Oligocene volcanics covered the pre-Tertiary rocks. The only area at McCoy where pre-Basin and Range Tertiary tectonism was recognized is near the Wild Horse and McCoy

Mercury Mines. Faulting in this locale resulted in the formation of thick fanglomerates (Dane and Ross, 1942) and controlled the distribution of several ash-flow tuff sheets. Basin and Range faulting in the McCoy area produced a series of polygonal rotated blocks, which dip from 10 to 40° eastward. Quaternary hydrothermal activity resulted in travertine and siliceous sinter. These surficial thermal deposits are coeval with Quaternary alluvium.

ASH-FLOW TUFFS

Over 70% of the exposed rocks at McCoy are ash-flow tuffs. These units provide good marker beds for stratigraphic correlation. Geologically, emplacement of each cooling unit is isochronous yielding horizons which enable one to work out the geometry and chronology of faults with high precision (Mackin, 1960). To utilize ash-flow tuffs in this fashion two post-depositional changes must be taken into account, welding and crystallization (Smith, 1960; Ross and Smith, 1961). Lateral and vertical zonation resulting from these processes were described by Smith (1960) and are reproduced in Fig. 4.

As an ash-flow is emplaced the shards are frequently hot and plastic, and the lower portion of the flow compresses and welds if the pressure of the overlying ash is sufficient. In many sheets the base and top are often cooled rapidly enough to prevent welding, while in the interior of the flow, welding is typically at a maximum. Differences in the degree of welding led Smith (1960) to recognize three zones, shown in Fig. 4A as a) the non-welded zone, b) the partially welded zone, and c) the densely welded zone.

The appearance of an ash-flow sheet may also be affected by crystallization. Crystallization in ash-flow tuffs results from the presence of volatiles and elevated temperatures. The two types of crystallization, primary devitrification and vapor phase crystallization, are synchronous with the welding process.

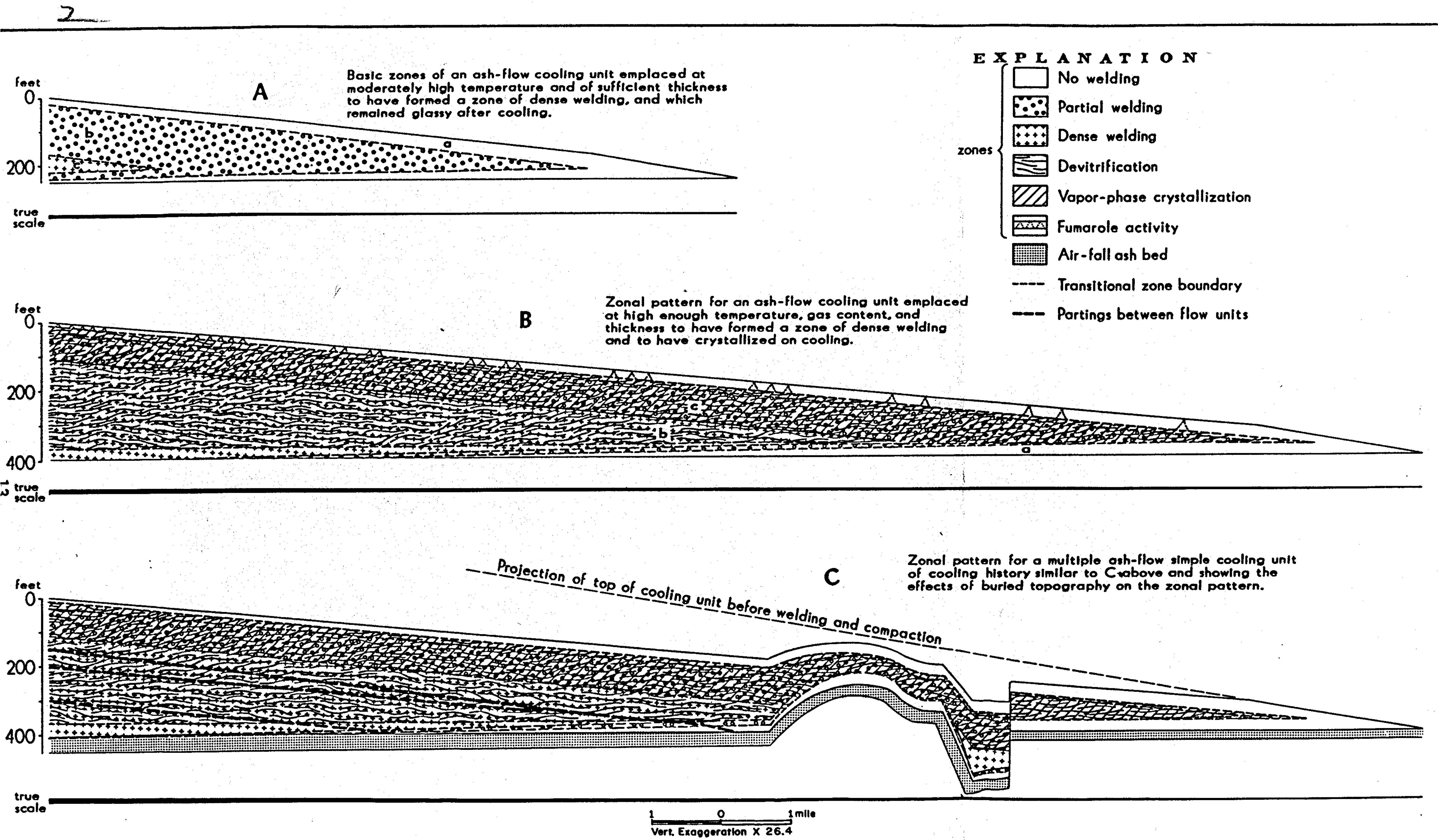

FIGURE 4. DIAGRAMS SHOWING THE ZONES OF SOME ASH-FLOW COOLING UNITS
(taken from Smith, 1960)

Primary devitrification occurs in the densely welded zone where ideally there is no pore space (Fig. 4B, Zone b). The volatiles in this zone stay in solution in the glass or collect at shard boundaries and increase the mobility of ions in the glass phase. These ions migrate to form crystals of cristobalite and alkali feldspar from the glass shards. Crystallization frequently follows the outlines of the shards (axiolitic devitrification). In densely welded ash immediately above the non-welded base the temperature is often too low to permit devitrification, resulting in a dense glass called the vitrophyre zone.

The partially welded zone contains appreciable pore space, and the volatiles exsolve into open spaces in the shard matrix. Aggregates of tridymite and alkali feldspar crystallize in these spaces. This zone is called the zone of vapor phase crystallization (Fig 4B, Zone c). The lower non-welded zone is usually too thin to accumulate sufficient volatiles to display vapor phase crystallization (Fig. 4B, Zone a).

When using zonation as a mapping tool, care must be taken to establish the variation within a unit. In any specific ash-flow tuff the existence and extent of zonation is determined by a multiplicity of factors, including temperature of eruption, thickness, volatile concentration, composition, amount and timing of eruptive pulses, paleotopography (discussed below), and distance from source area (discussed below). With such a large number of variables, the zonation of an ash-flow tuff may be considered unique and consistent within a restricted area.

Paleotopography may be easily taken into account when its effects on zonation are understood. Because of the fluidized nature of an ash-flow prior to emplacement, variations in topography result in differences in thickness and therefore zonation changes. There is a reduction in thickness over topographic highs causing the overall degree of welding to lessen or the densely welded zone to thin or disappear (Fig. 4C).

Flows may thicken in topographically low areas, leading to increased welding and a thickened vitrophyre. In low areas the vitrophyre will follow the outlines of the depression (Fig. 4C), and can be vertical where the ash-flow has encountered a steep fault scarp, indicating faulting previous to or synchronous with eruption of the tuff.

Ash-flow tuffs are classified into simple cooling units, compound cooling units, or composite cooling units. The difference between these categories is related to their cooling history.

An ash-flow tuff that contains a central densely welded zone and an upper and lower less-welded zone, as shown in Fig. 5A, is the prototype of the simple cooling unit. Variations in the initial conditions discussed above can cause a unit to lack one or more of these zones.

An ash-flow sheet can consist of several flow units. When these flows are closely spaced in time they can conserve heat long enough to weld as a simple cooling unit. Conversely, when sufficient time between eruptions is allowed for these tuffs to cool, they will form separate simple cooling units. Intermediate between these two cases is the compound cooling unit, shown in Fig. 5B. When the top of a flow has only time enough to cool slightly before being covered by

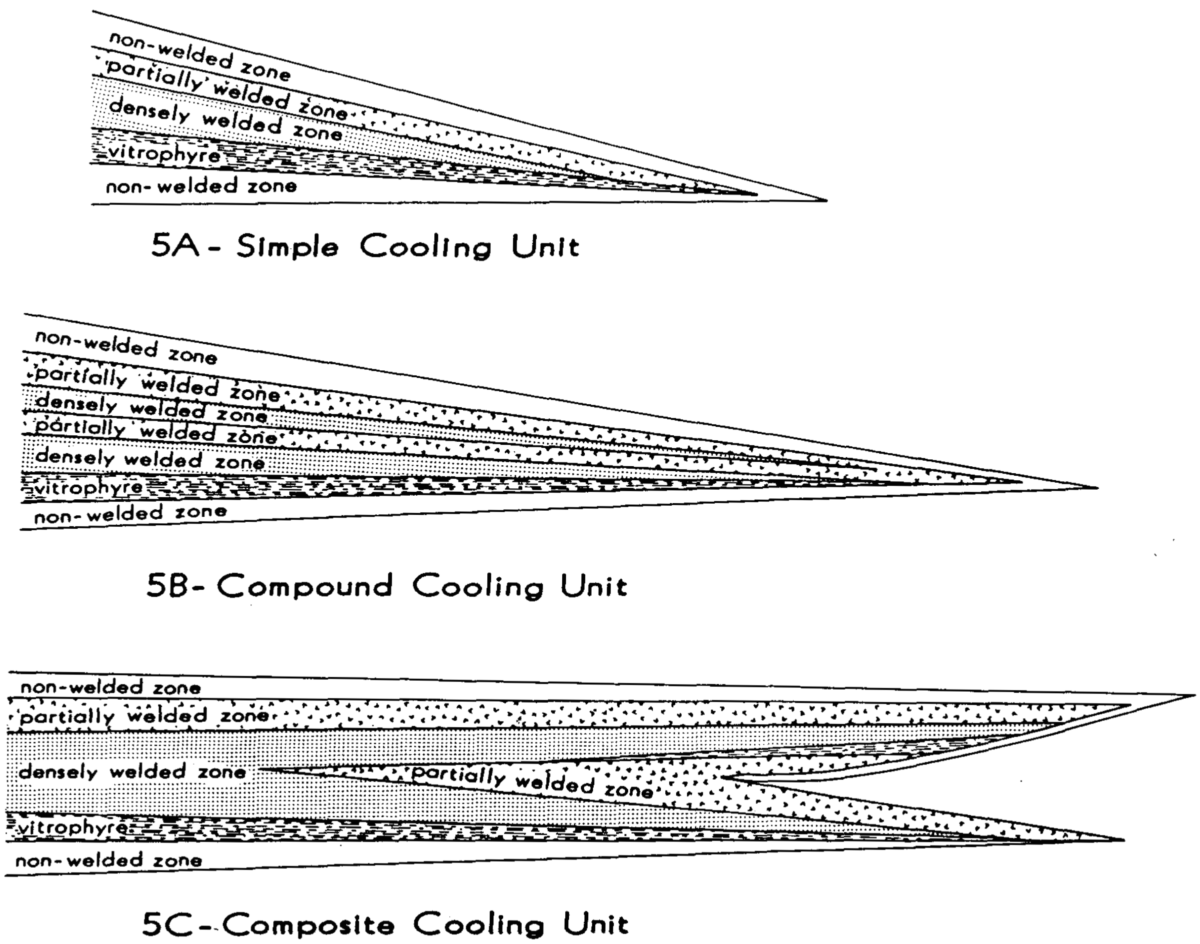

Figure 5. Classification of ash-flow tuffs.

another ash-flow pulse, a rhythmic alternation of densely welded and partially welded zones can result. This alternation in an ash-flow sheet raises its rank to a compound cooling unit.

Ash-flows lose heat in their distal portions due to mixing with cool air and thinning. While ash-flow pulses may form a compound or simple cooling unit in the main body of the sheet the distal portions may have cooled sufficiently to form two or more simple cooling units. This lateral change in rank defines a composite cooling unit (Fig. 5C).

The source vent of an ash-flow tuff or its proximity to this vent may be determined in several ways. The first is by recording a change in rank of the ash-flow tuff in question. Since an ash-flow is hottest near its source, mapping the transition from a simple to a compound cooling unit can define a center where the source is likely to be. Another method is to map intra-caldera vs. outflow rocks (i.e. Cunningham and Steven, 1977). Intra-caldera rocks are tectonically chaotic and may include a variety of collapse features. Areally restricted, thick ash-flow tuffs and tuffaceous sediments are common to calderas. Domes, lava flows, and shallow intrusives similar in composition to the ash-flow tuff sheet often define ring dikes formed by the collapse of a caldera. Outflow rocks are lava flows and widespread ash-flow tuffs, which thin distally.

PRE-TERTIARY STRATIGRAPHY

The only rocks representative of the Paleozoic Erathem at McCoy are those of the Pennsylvanian and Permian Havallah Formation, consisting of greenish-grey and dark grey chert, silicified siltstone, siltstone, calcareous siltstone, and limestone. The Havallah Formation has not been dated radiometrically or by fossils and was assigned a Pennsylvanian to Permian age by Stewart et al. (1977) because of its consistant stratigraphic position below Triassic strata. Above the Havallah is a tan to red sandstone and siltstone unit considered by Willden and Speed (1974) to be transitional between the Paleozoic and Mesozoic systems, referred to in this report as Permo-Triassic undifferentiated sedimentary rocks. The lithology of this unit is typical of the Paleozoic strata in this region but is markedly discordant to bedding of the subjacent Havallah while being conformable or near conformable with the overlying Triassic conglomerate.

The Triassic conglomerate is a prominent ledge-former consisting of red and green chert pebbles in a siliceous matrix. This unit and the superjacent fossiliferous Faveret Formation are the most easily recognized of any sedimentary rocks at McCoy. The Faveret Formation contains dark grey thin-bedded limestones interbedded with black shale and red to tan siltstones. A Lower Triassic age has been determined by the presence of abundant ammonites of the genus Acrocordiceras and pelecypods of the genus Daonella (Silberling, 1956). Above this unit is the Augusta Formation which consists of three members, the lower two of which are in the mapped area. The lower member is a massive, dark-grey, bioclastic, dolomitic limestone, and the middle member includes thin-bedded, grey limestone and calcareous shale. The upper member is a massive grey limestone (Muller et al., 1951).

TERTIARY STRATIGRAPHY

Extrusive Rocks

Dark colored pyroxene-hornblende andesites and dacites form the oldest Tertiary unit in the vicinity of McCoy. These volcanics rest unconformably on pre-Tertiary strata and are overlain by rhyolitic ash-flow tuffs. Most exposures in the mapped area are propylitically altered, slope formers, and frequently covered by slope wash. The base is not exposed and thus the thickness is unknown.

South of McCoy, in the Clan Alpine Mountains, similar flows are intercalated with epiclastic rocks and vary from 0 to 800 meters in thickness (Riehle et al., 1972). These flows have a K-Ar age of 35.9 m.y. which is consistent with the ages of the widespread andesite and dacite lava flows in Churchill (Willden and Speed, 1974) and Lander (Stewart et al., 1977) counties.

An isolated volcanic vent rising 100 meters above pre-Tertiary sediments lies in the extreme north of the mapped area. It consists of black lava flows with 40% phenocrysts of plagioclase, orthopyroxene, and clinopyroxene (see Table 1). The extent of the flows to the east, north and south is unknown due to the thickness of the overlying ash-flow tuffs and valley fill and the western margin of the vent is truncated by faulting and erosion which occurred prior to the deposition of the fanglomerate. The age of this vent is presumed to be comparable to the andesites discussed above.

Tertiary Fanglomerate

The Tertiary fanglomerate is an informal name first used by Dane and Ross (1942) to describe an unconsolidated deposit containing limestone and cherty dolomite cobbles and boulders which mantle the pre-Tertiary rocks in the neighborhood of the McCoy and Wild Horse Mercury Mines. This unit can be recognized by the light color of the soil matrix as well as the large size (up to 8 meters in diameter) of the boulders. Its original thickness must have exceeded 75 meters (Dane and Ross, 1942). The fanglomerate underlies the ash-flow tuffs in the north-east portion of the mapped area.

Tertiary Ash-Flow Tuffs at McCoy

The formation names used for the ash-flow tuffs in this study are those of McKee and Stewart (1971). The correlation of these units is shown in Fig. 6. In their report they attempted to systematize the ash-flow tuffs in the Desetoya Mountains, the New Pass Range, and the central part of the Shoshone Mountains (Fig. 1) by K-Ar age dating and regional mapping. The results of their study show that there is little continuity of formations between the Desetoya Mountains and the New Pass Range, but that many of the ash-flow tuffs in the New Pass Range and Shoshone Mountains are correlative and are easily grouped by mineralogy and extent. The ash-flow tuffs in this study were mapped by cooling unit. They are designated as Tertiary welled tuffs (Twt) followed by a number. The tuffs grouped into formations by McKee and Stewart (1971) have a number as a formation designation and a letter as a cooling unit designation. For example, Twt 6C denotes the third cooling unit from the bottom of Edwards Creek Tuff.

The ash-flow tuff stratigraphy used in this study agrees with that of McKee and Stewart (1971) with one exception. Detailed mapping has shown that several cooling units which do not appear in the type or reference section of Edwards Creek Tuff are mapped by McKee and Stewart (1977) as Edwards Creek Tuff. These cooling units differ in mineralogy from and are not coestensive with the Edwards Creek Tuff. The intra-Edwards Creek Tuff units are not large, so rather than complicate the map by separating them out Edwards Creek Tuff plus the aforementioned units were mapped as Twt 6.

Modal compositions and chemical analysis of each cooling unit are given in Tables 1 and 2, and the sample locations are shown in Fig. 8.

Older Tuffs

The older ash-flow tuffs, first described by McKee and Stewart (1971), comprise at least 4 cooling units of ash-flow tuffs which differ in their mineralogy. In this report they were mapped separately, and the mapping units Twt 1 to Twt 4 are discussed individually below.

Twt 1

Twt 1 consists of a simple cooling unit which rests unconformably on pre-Tertiary sedimentary rocks as well as Tertiary lava flows, fanglomerate, and an eroded remnant of a poorly welded ash-flow tuff. The eroded remnant fills a paleo-valley in the cuestas northeast of the McCoy Mine and is mapped for convenience as together with Twt 1. This remnant is a grey, vitric, poorly welded ash-flow tuff with 5 to 10% crystals of sanidine and plagioclase, a trace of biotite, a few vitrophyric lithic fragments up to .5 cm in diameter, and some argillized flattened pumice fragments approximately 2 cm in

Map Unit	Tv	Twt 1	Twt 1	Twt 2	Twt 2	Twt 3	Twt 4	Twt 5	Twt 5	Twt 6A	Twt 6A	Twt 6A	Twt 6A	Twt 6A	Twt 6A
Sample No.	Twt-V	130-80	132-80	135-80	137-80	15-79	17-79	23-79	24-79	SS-14	269-80	SS-15	SS-16	SS-17	SS-18
Welding	Dense	Poor	Partly	Partly	Partly	Dense	Partly	Vitro	Dense	Vitro	Partly	Partly	Partly	Partly	Partly
Devitrification	Yes	No	No	Yes	Yes	Yes	Yes	No	Yes	No	Yes	Yes	Yes	Yes	Yes
Shards %	53.0	87.5	91.9	86.2	69.8	50.6	76.6	84.2	76.2	89.9	88.3	87.1	86.2	82.2	85.7
Sanidine %	1.0	2.8	4.4	5.4	16.4	25.3	11.7	7.3	13.3	9.5	10.2	9.0	12.5	12.4	11.7
Plagioclase %	42.0	.2	.5	.8	6.7	10.2	3.8	5.0	6.7	.8	.9	2.9	.4	3.9	1.2
Quartz %							2.1								
Biotite %		.5	1.1	5.2	6.9	7.4	1.0		1.7	.1					
Hornblende %									.9		.2				
Cpx %	4.0			.5		2.5	.3	1.0							
Opx %							.2								
Opaques %		8.4	1.5			.8	.2					.2		1.0	1.4
Lithic Frag. %		.7	.5	1.8		2.9	4.1	2.5	1.2	.1		.8	.2		
Total Pheno. %	47.0	11.9	7.6	12.1	30.2	46.4	19.3	13.3	22.6	10.4	11.5	12.1	12.9	17.3	12.9

Map Unit	Twt 6A	Twt 6B	Twt 6B	Twt 6B	Ts2	Twt 6C	Twt 6C	Twt 6D	Twt 6D	Twt 6D	Twt 6D	Twt 6D	Twt 6D	Twt 6D	Int. Tuff
Sample No.	SS-19	327-80	SS-21	SS-22	26-79	SS-23	263-80	SS-24	16-80	17-80	SS-25	18-80	SS-26	SS-27	260-80
Welding	Partly	Vitro	Dense	Partly	Partly	Poor	Poor	Vitro	Dense	Vitro	Dense	Dense	Dense	Partly	Poor
Devitrification	Yes	No	Yes	No	Yes	No	No	No	No	No	Yes	Yes	Yes	Yes	No
Shards %	88.2	87.9	87.0	77.2	92.0	79.5	90.9	72.9	88.7	90.4	79.5	79.0	84.0	84.2	67.9
Sanidine %	9.0	5.7	8.6	15.0	2.7	8.4	5.3	22.6	9.4	7.8	17.3	19.2	14.5	12.7	10.8
Plagioclase %	1.9	4.3	4.1	7.6	4.9	2.7	.6	3.4	1.7	1.2	2.0	1.8	.6	2.0	1.2
Quartz %															
Biotite %	.8		.3	.1		1.0	1.9		.1	.1			.2	.9	4.4
Hornblende %					.2				.1						
Cpx %								.2		.3					
Opx %								.4		.2	.5				
Opaques %	.1					.4					.7		.7		3.0
Lithic Frag. %				.1	.2	8.0	1.1	.5						.2	12.6
Total Pheno. %	11.7	10.0	13.0	22.7	7.8	12.5	7.8	26.6	11.3	9.6	20.5	21.0	16.0	15.6	19.4

Table 1. McCoy Modal Compositions (Volume Percent)

Map Unit	Twt 6E	Twt 6E	Twt 6F	Twt 6F	Twt 6G	Twt 7A	Twt 7B	Twt 7B	Twt 7B	Twt 7C	Twt 8A	Twt 8B	Twt 8C
Sample No.	NS-10	343b-80	380-3-80	SS-30	P2-80	S65-80	242-80	243-80	244-80	245-80	35a-79	35b-79	505-80
Welding	Dense	Partly	Dense	Dense	Partly	Vitro	Poor	Partly	Partly	Dense	Partly	Partly	Poor
Devitrification	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Shards %	94.0	91.3	82.7	78.7	83.7	81.0	91.3	87.8	82.2	76.5	92.1	93.4	78.2
Sanidine %	4.3	5.1.	10.8	14.7	11.6	9.0	3.2	8.3	9.6	16.2	6.1	6.1	13.2
Plagioclase %	1.2	1.2	2.0	4.4	3.8	3.9	2.0	1.1	3.2	3.3	.5		
Quartz %													5.8
Biotite %	.5	2.4	.3	1.3	.2	6.0	3.0	2.8	3.1	2.8			
Hornblende %						tr							
Cpx %			3.1	1.5		.1							
Opx %													
Opaques %					.7		.3		.7	1.2	1.3	.3	
Lithic Frag. %									1.2				2.8
	6.0	8.7	17.3	21.9	16.3	19.0	8.7	12.2	16.6	23.5	7.9	6.4	19.0

Table 1 (Cont.) McCoy Modal Compositions (Volume Percent)

Map Unit	Twt 1	Twt 2	Twt 2	Twt 3	Twt 4	Twt 5	Twt 5	Twt 6A	Twt 6A	Twt 6A	Twt 6B	Twt 6B	Ts2	Twt 6C	Twt 6D
Sample No.	Mc/NV 132	Mc/NV 135	Mc/NV 137	Mc/NV 15-79	Mc/NV 40	Mc/NV 23	Mc/NV 24	Mc/NV SS-15	Mc/NV 269	Mc/NV SS-19	Mc/NV SS-21	Mc/NV SS-22	Mc/NV 14-79	Mc/NV 38	Mc/NV SS-24
SiO_2	68.7	72.6	69.8	66.4	73.0	73.3	74.9	73.9	75.8	73.6	76.0	74.5	70.2	73.1	70.7
TiO_2	.13	.14	.31	.42	.15	.13	.24	.15	.14	.19	.22	.28	.20	.20	.23
Al_2O_3	13.1	13.7	14.8	16.1	13.0	14.0	13.8	13.3	13.8	12.7	11.9	12.5	13.8	13.9	14.0
Fe_2O_3*	1.79	2.03	2.80	3.28	1.54	1.65	1.23	1.38	1.80	2.04	2.44	2.70	2.59	1.77	1.77
MnO	.05	.03	.03	.07	.03	.06	.02	.02	.03	.01	.03	.03	.05	.05	.05
MgO	.44	.51	.48	.76	.84	<.1	<.1	.06	.02	.37	.19	.55	<.1	<.1	.14
CaO	2.30	.72	1.50	2.80	1.53	.71	1.42	.68	.53	.97	1.02	1.74	.99	1.02	.80
Na_2O	3.19	2.61	3.51	3.52	2.41	3.15	3.59	3.77	3.54	3.31	3.12	3.08	2.75	2.67	2.98
K_2O	5.09	5.69	5.22	4.91	4.70	6.02	4.68	5.42	5.62	5.08	4.56	4.33	6.32	6.21	6.24
P_2O_5	.04	.03	.07	.11	.06	.01	.06	.01	.03	.02	.03	.08	.05	.02	.00
LOI	5.39	2.10	1.35	2.89	4.55	3.07	1.18	1.00	1.12	2.30	2.10	2.30	3.71	1.57	3.80
Total	100.2	100.12	99.85	101.32	101.74	101.96	101.04	99.70	102.35	100.63	101.65	102.10	100.64	100.52	99.75
CIPW Norms															
Q	25.83	33.32	25.63	20.34	36.58	30.44	33.19	29.74	32.60	32.34	38.05	35.85	28.01	31.68	27.57
C		1.91	.85	.18	1.27	1.07	.40	.01	.95	.06	.05		.79	.98	.90
or	30.08	33.62	30.85	29.01	27.77	35.57	27.66	32.03	33.21	30.02	26.95	25.59	37.35	36.70	36.87
ab	26.99	22.08	29.70	29.79	20.39	26.65	30.38	31.90	29.95	28.01	26.40	26.06	23.27	22.59	25.22
an	6.48	3.38	6.98	13.17	7.20	3.46	6.65	3.31	2.43	4.68	4.86	7.44	4.58	4.93	3.97
ac	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
wo	.58	---	---	---	---	---	---	---	---	---	---	---	---	---	---
di-wo	1.27	---	---	---	---	---	---	---	---	---	---	---	---	---	---
di-en	1.10	---	---	---	---	---	---	---	---	---	---	---	---	---	---
hy-en	---	1.27	1.20	1.89	2.09	---	---	.15	.05	.92	.47	1.37	---	---	.35
mt	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
il	.11	.06	.06	.15	.06	.13	.04	.04	.06	.02	.06	.06	.11	.11	.11
hm	1.79	2.03	2.80	3.28	1.54	1.65	1.23	1.38	1.80	2.04	2.44	2.70	2.59	1.77	1.77
tn	.18	---	---	---	---	---	---	---	---	---	---	.47	---	---	---
ru	---	1.11	.28	.34	.12	.06	.22	.13	.11	.18	.19	.05	.14	.14	.17
ap	.07	.07	.17	.26	.14	.02	.14	.02	.07	.05	.07	.19	.12	.05	---
Total	94.49	97.86	98.51	98.41	97.17	99.06	99.91	98.71	101.24	98.32	99.55	99.79	96.96	98.95	96.93

Table 2. Chemical Analyses and CIPW Norms of Ash-Flow Tuffs from McCoy

Map Unit	Twt 6D	Twt 6D	Twt 6E	Twt 6E	Twt 6F	Twt 6F	Twt 7C	Twt 8A
Sample No.	Mc/NV 18-80	Mc/NV SS-26	Mc/NV NS-10	Mc/NV 380-3	Mc/NV 343b-80	Mc/NV SS-30	Mc/NV 245	Mc/NV 228
SiO_2	72.6	71.7	74.0	76.3	77.9	73.5	71.3	75.0
TiO_2	.22	.25	.12	.10	.09	.18	.39	.08
Al_2O_3	14.8	14.2	11.9	13.0	11.6	13.8	15.9	12.9
Fe_2O_3*	2.09	2.19	1.60	1.71	1.50	2.16	2.21	1.13
MnO	.04	.03	.04	.07	.08	.03	.06	.08
MgO	.01	.21	.17	<.1	<.1	.13	.28	.01
CaO	.82	.92	.58	.30	.39	.62	1.69	.46
Na_2O	3.77	3.75	4.06	4.04	3.57	4.45	4.20	3.32
K_2O	5.47	5.63	4.92	4.88	4.29	5.08	4.71	5.09
P_2O_5	.01	.02	.01	.02	.01	.01	.06	.00
LOI	.71	1.30	2.30	1.07	1.65	1.00	1.48	3.00
Total	100.44	100.29	99.66	101.23	100.88	100.98	102.30	101.04
CIPW Norms								
Q	27.94	26.03	30.80	33.50	39.90	26.77	24.96	35.17
C	1.17	.31	---	.53	.39	----	.99	1.09
or	32.32	33.27	29.07	28.84	25.35	30.02	27.83	30.08
ab	31.90	31.90	33.77	34.19	30.21	37.65	35.54	28.09
an	4.00	4.43	---	1.36	1.87	2.68	7.99	2.28
ac	---	---	.52	---	---	---	---	---
wo	---	---	.58	---	---	---	---	---
di-wo	---	---	.49	---	---	---	---	---
di-en	---	---	.42	---	---	---	---	---
hy-en	.02	.52	---	---	---	.32	.70	.02
mt	---	---	---	---	---	---	---	.03
il	.09	.06	.09	.15	.17	.06	.13	.15
hm	2.09	2.19	1.42	1.71	1.50	2.16	.21	.11
tn	---	---	.18	---	---	.23	---	---
ru	.17	.22	---	.02	---	.05	.32	---
ap	.02	.05	.02	.05	.02	.02	.14	---
Total	99.74	98.99	97.37	100.35	99.42	99.98	100.82	98.04

Table 2 (Cont.). Chemical Analyses and CIPW Norms of Ash-Flow Tuffs from McCoy

length.

Twt 1 is a distinctive olive grey, vitric ash-flow tuff with 3% crystals of sanidine, plagioclase, and biotite. It generally crops out as a low ledge masked by talus and slope wash. Throughout the mapped area, ash-flow tuffs which have a similar welding and mineralogy and appear at the base of the ash-flow tuff section have been mapped as Twt 1. Correlation of these tuffs is uncertain due to the paucity of modal analysis of these rocks and the lack of outcrop continuity. Variations in welding and thickness apparently caused by topographic in-filling add to the difficulty in correlation. The K-Ar ages of a welded correlative from the western margin of the mapped area are 31.1 ± 1.2 m.y. (sanidine) and 29.2 ± 1.1 m.y. (biotite). The maximum observed thickness of this unit is 20 m and the minimum areal extent is approximately 360 km^2.

Twt 2 and 3

Twt 2 and 3 are distinctive biotite-rich ash-flow tuffs which outcrop from the eastern margin of Dixie Valley to the western border of the Shoshone Range. Twt 2 is a pink to white, devitrified, simple cooling unit containing 30% crystals of sanidine, plagioclase, and biotite, while Twt 3 is a black to grey compound cooling unit with 50% crystals of sanidine, plagioclase, biotite, and clinopyroxene. Twt 2 is usually found as a thin, poorly welded zone beneath the vitrophyre of Twt 3, but increases in thickness to 40 m in the paleo-valley northeast of the McCoy Mine, where it is densely welded. Twt 3 varies in thickness from 10 to 40 m as a result of in-filling of topography. It is a multiple-flow unit, and always contains at least one densely welded zone and frequently has a poorly welded zone at the top and bottom (see Fig. 6). Twt 3 has a K-Ar age of 28.7 ± 1.1 m.y. (McKee and Stewart, 1971).

Twt 4

Twt 4, called lithic eutaxite by McKee and Stewart (1971), is a distinctive, quartz-bearing, compound cooling unit. It contains up to 20% crystals of sanidine, plagioclase, quartz, and biotite, with abundant pumice fragments and small scattered black and red lithic fragments of shale. This unit has two outstanding features; 1) the densely welded zone is a classic example of a eutaxite, with numerous black glass fiamme (a flame-shaped welded pumice) up to 10 cm in diameter, and 2) the shards of the poorly welded zone are frequently altered to zeolites and clays, giving these zones a distinctive waxy luster with a red to green tint. The green tint is especially pronounced in areas of hydrothermal alteration. Twt 4 is characteristically associated with opal-cemented breccia in fault zones where breccia occurs. The non-welded top of Twt 4 is usually preserved, above which lenticular beds of sediment and air fall tuff (Ts1) occur. The thickness of Twt 4 varies from 125 m in Shoshone Canyon to 60 m at the western edge of Antelope Valley, a distance of 35 km. Twt 4 most often overlies Twt 3, but at a few localities lies unconformably on pre-Tertiary strata. The minimal areal extent of Twt 4 is approximately 360 km^2.

Northern Ash-Flow Tuffs (Twt 5)

Along the northeast margin of the mapped area are two cooling units of ash-flow tuff mapped by McKee and Stewart (1971) as Edwards Creek Tuff. Although they lie in the same stratigraphic position as the lower units of Edward Creek they differ in mineralogy, cooling history, and distribution.

The lower unit of the northern ash-flow tuffs is a vitrophyre containing 25% crystals of sanidine, plagioclase, biotite, and hornblende. Overlying the vitrophyre with no discernible cooling break is the middle unit, consisting of a red, densely welded devitrified zone and containing 13% crystals of sanidine, plagioclase, and clinopyroxene. The upper unit is a lavender, partially welded ash-flow tuff with 20% crystals of sanidine, biotite, and plagioclase, with white slightly flattened pumice up to 30 cm in length and abundant lithic fragments of densely welded ash-flow tuff up to 15 cm in diameter. The cooling relationship of the upper and middle units is obscured by the slope-forming nature of the upper unit.

The total observed thickness of these units is 55 m with an areal extent of 90 km^2.

Edwards Creek Tuff (and Interfingering Tuff)

The Edwards Creek Tuff, defined by McKee and Stewart (1971) consists of 5 cooling units of similar mineralogy. Although the description of these tuffs conforms to those found in the type section, several cooling units mapped as Edwards Creek do not appear in the type section, located 19 km south of the McCoy Mine.

Three of these cooling units were mapped as Twt 5, as mentioned above. One unit, Twt 6C, that consistently lies below the third cooling unit of McKee and Stewart (1971) in the mapped area and was grouped with Edwards Creek in the Twt 6 series, does not appear in the type or reference section (Fig. 6). Twt 6G, an areally restricted unit sitting on the fifth cooling unit of McKee and Stewart (1971) is also missing in the type and reference sections. This unit was also included with Twt 6.

The observed thickness of Twt 6 varies from 190 m in the south to 110 m in the northeast corner of the mapped area (Fig. 7a,b). This is due to the disappearance of Twt 6A in the northern area rather than the distance of Twt 6 from its source area.

McKee and Stewart (1971) published an average K-Ar age for the third and fourth cooling units of Edwards Creek Tuff (Twt 6D and 6E) as 27.7 ± 1 m.y.

Twt 6A

Twt 6A is the oldest cooling unit of the Edwards Creek Tuff. Within the mapped area it is grey to pale red, partially welded, and contains 19% crystals of plagioclase and sanidine, and a trace of hornblende. It is a multiple ash-flow simple cooling unit, the lower ash-flow being eutaxitic with white flattened pumice up to 10 cm in length while the upper flow is structureless. The basal vitrophyre is frequently covered and probably lenticular. Twt 6A is poorly welded 10 km west of the unit area, in the Shoshone Range. Twt 6A lies unconformably above Twt 4, separated from it by variable thicknesses of air-fall tuff and tuffaceous sediment (Ts1).

The minimum areal extent of Twt 6A is 360 km^2. It extends from the Shoshone Range to the eastern edge of Dixie Valley and at least as far south as the type section of McKee and Stewart (1971). It does

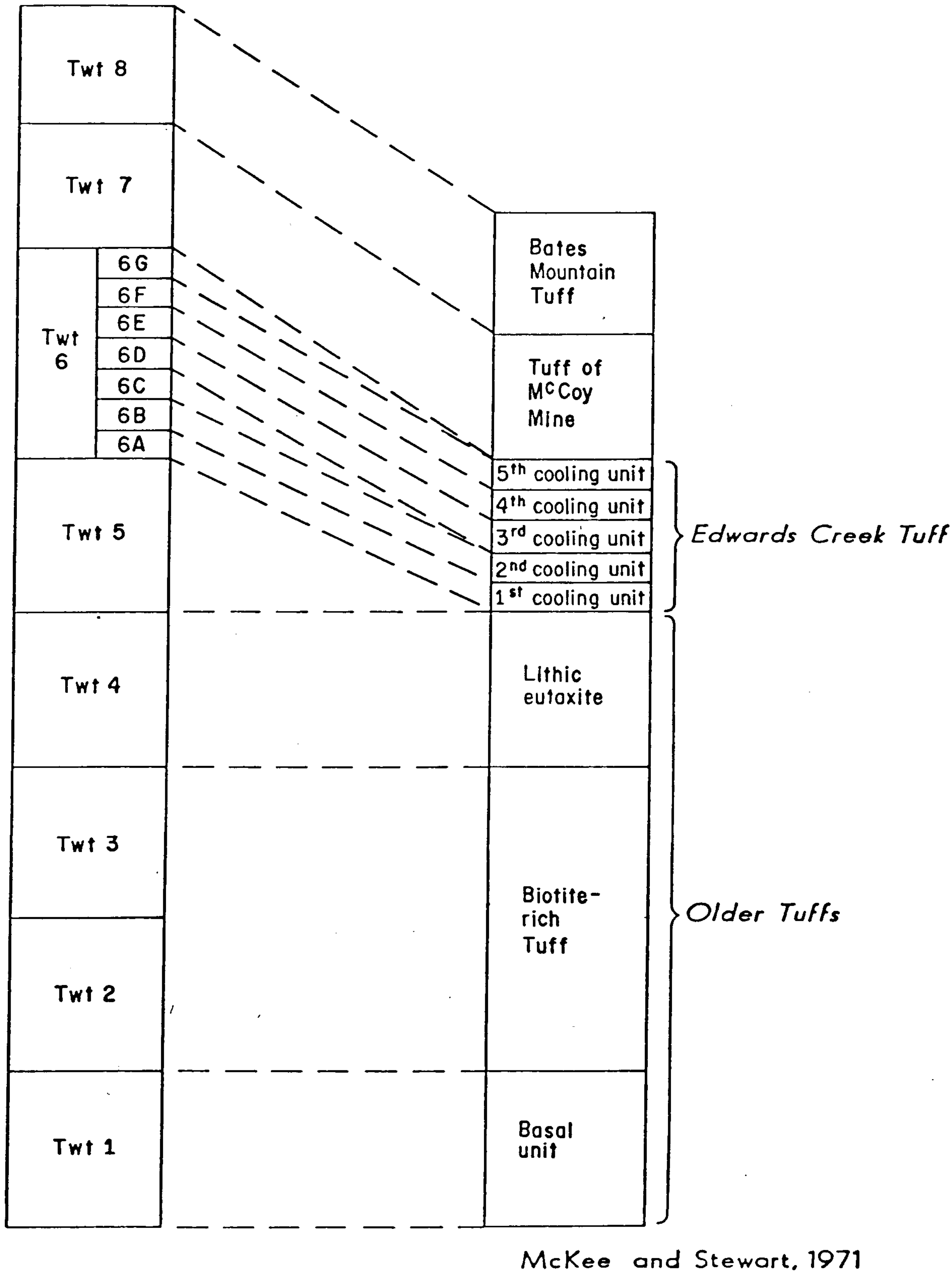

Figure 6 — Correlation of Map Units

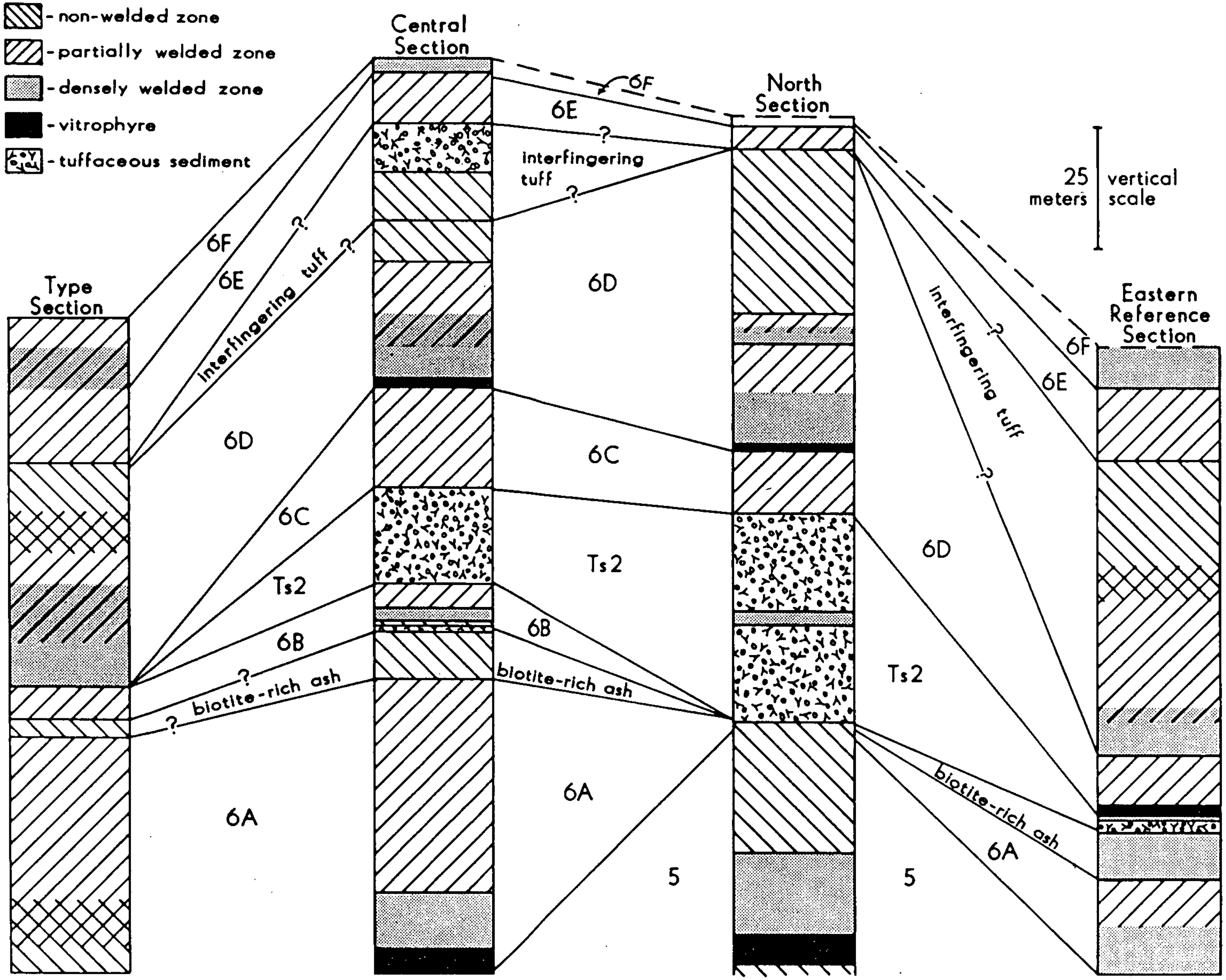

Figure 7 – Columnar sections of Edwards Creek Tuff from the Type Section in Edwards Creek Valley, to the Eastern Reference Section in Antelope. Line of section is shown in figure 8. Queries indicate questionable correlation, dashed lines indicate unknown thickness, and overlapping zone symbols indicate transitional zones.

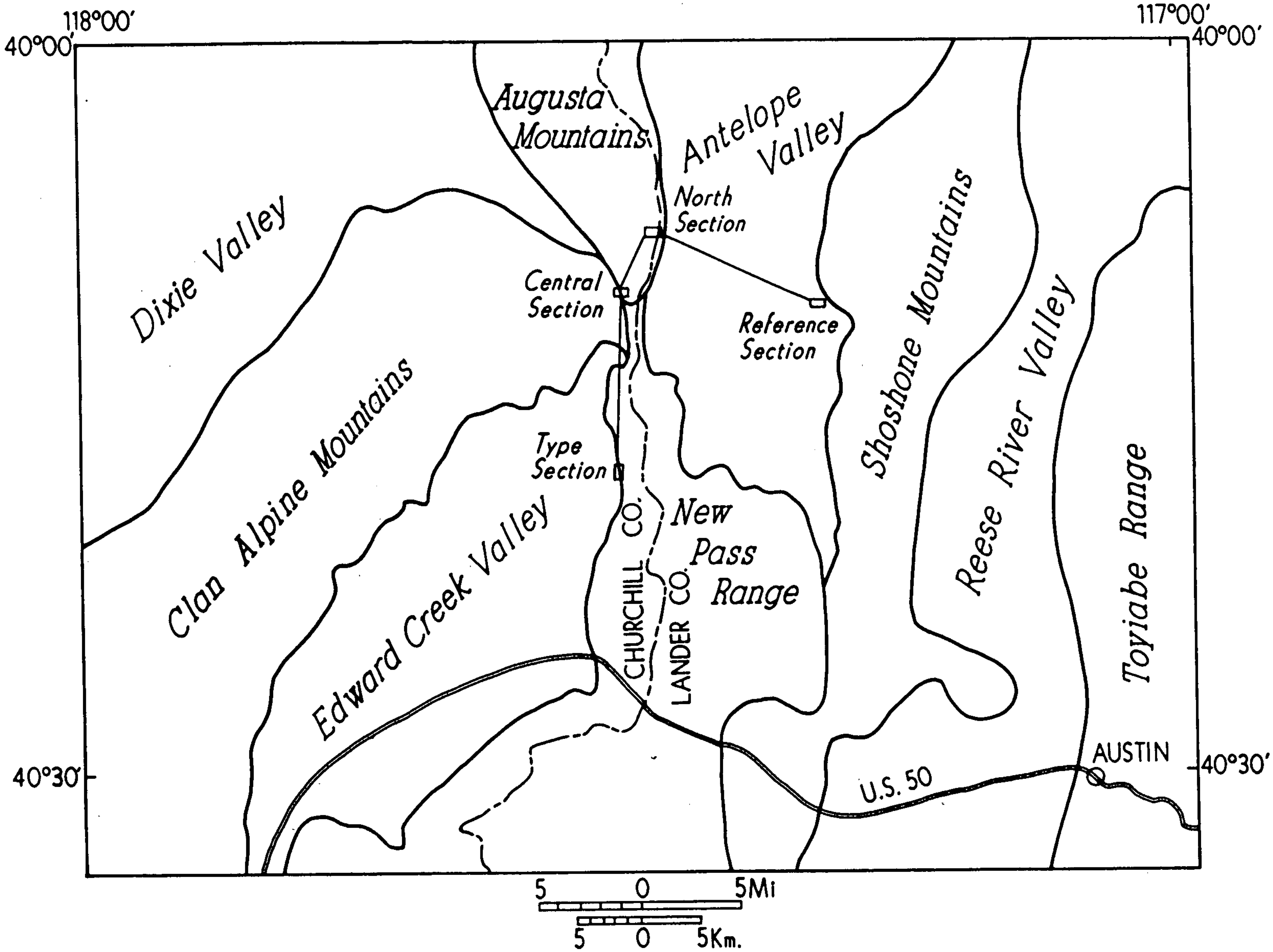

Figure 7b. Location of columnar sections.

not extend into the northeast portion of the mapped area, because of faulting in the mine area that produced topographic barriers.

Twt 6B

The most distinctive marker horizon of Twt 6 is Twt 6B, the second cooling unit of McKee and Stewart (1971). This brick red, densely welded, structureless, compound cooling unit contains less than 10% crystals of sanidine and plagioclase, and a trace of biotite. It consists of lenticular basal non-welded and vitrophyre zones, a ledge-forming densely welded devitrified zone, and upper partially welded and non-welded zones which are frequently preserved. Within the mapped area the densely welded zone shows no cooling breaks but several kilometers to the south the flow partings allow no doubt of its status as a compound cooling unit.

Twt 6B was found by McKee and Stewart (1971) in their reference section near Antelope Valley, although this unit was not located at that site during the present study. It was not found near Dixie Valley or in the northeast corner of the mapped area. Its minimum areal extent is 100 km^2. The observed thickness is about 10 m.

Ts2

The thickest accumulation of tuffaceous sediment (Ts2) in the McCoy area consistently occurs below Twt 6C. This sediment has cross-bedded to planar bedding and is crystal-rich. Ts2 is lenticular due to erosion prior to the deposition of 6C, with a thickness varying from 0 to 10 m. In a few localities Twt 6C either failed to surmount the topography of the tuffaceous sediments or was eroded, in these areas Twt 6D directly overlies the sediment.

North of the McCoy mine, where Twt 6B is absent, the tuffaceous sediment is significantly thicker (40 m) and lies on the upper unit of Twt 5. Here the sediment is more pumice-rich, crystal-poor, and interbedded with a thin, red, densely welded ash-flow tuff containing less than 10% crystals of plagioclase and sanidine and a trace of hornblende.

Twt 6C

Another good marker horizon in the mapped area is Twt 6C. Although frequently covered with slope wash, its mineralogy, large frothy pumice, and large lithic fragments readily distinguish this unit from the rest of Edwards Creek Tuff. Twt 6C is a light brown to green, friable, partially welded ash-flow tuff. It is a partially welded cooling unit consisting of 8% crystals of sanidine, biotite, and plagioclase, and it contains large white pumice up to 30 cm in length, black vitrophyre lithic fragments up to 10 cm across, and vapor phase minerals. In a few places Twt 6C is pink, densely welded, and loses its distinctive friable texture and the frothy nature of its pumice. Twt 6C has a minimum areal extent of 91 km^2 and a maximum observed thickness of 20 meters.

Twt 6D

Twt 6D is a compound cooling unit composed of at least 3 distinctive flow units. The basal portion is grey, perlitic, densely welded, and contains 11% crystals of sanidine, plagioclase, and a trace of biotite and hornblende. This unit is 2 m thick and can be distinguished by its yellow-orange stained fractures. Above this is a 23 m thick structureless, red, partially to densely welded flow unit with a severely weathered basal vitrophyre. This unit contains 9% crystals of sanidine and plagioclase as well as .5% crystals of clinopyroxene, orthopyroxene, and biotite. The upper unit has similar mineralogy but contains up to 1% biotite. It is partially welded, eutaxitic, and large cavities have formed from weathering. Twt 6D has an observed thickness of 50 meters where the non-welded top is preserved, and a minimum areal extent of 360 km^2. Twt 6D is the equivalent of McKee and Stewarts (1971) third cooling unit of Edwards Creek Tuff which was dated by them, using the K-Ar method, at 27.6 ± 1 m.y.

Interfingering Ash-Flow Tuff

Interfingering with Edwards Creek Tuff is a lavender to purple ash-flow tuff containing 26% crystals of sanidine, plagioclase, biotite, and moderately abundant lithics of densely welded ash-flow tuff. Within the reference section of Edwards Creek (McKee and Stewart, 1971) this unit is 70 m thick and lies between Twt 6D and 6E with no discernible cooling break. The distal portion of this unit extends into the mapped area in one locality and is represented by a 10 m thick partially welded zone overlain by 10 m of epiclastic sediments.

Twt 6E

Twt 6E, the fourth cooling unit of Edwards Creek Tuff (McKee and Stewart, 1971), is an easily recognizable horizon in the Twt 6 series. Usually occurring as a low cliff, this light purple, partially welded ash-flow tuff contains 8% crystals of sanidine, plagioclase, and biotite. In most places it is 10 m thick, but where it lies below Twt 6G it doubles in thickness and is densely welded. Twt 6E has a minimum areal extent of 160 km^2 and a K-Ar age of 27.7 ± 1 m.y. (McKee and Stewart, 1971).

Twt 6F

Twt 6F is a simple cooling unit. Cooling relationships within this unit are poorly defined due to poor outcrop. It is a red to grey ash-flow tuff with a densely and a partially welded zone that contains 13% crystals of sanidine and plagioclase. The partially welded vapor phase zone is eutaxitic and contains up to 1% biotite. The minimum areal extent of this unit is 160 km^2, the maximum observed thickness is 20 m.

Twt 6G

This unit is purple, densely welded, and contains 17% crystals of sanidine, plagioclase, and quartz, with an observed thickness of 15 m. It outcrops in a 3 km^2 area 1 km south of the Wild Horse Mine. Most of the details of Twt 6G are obscured by talus and faulting.

Tuff of McCoy Mine

The Tuff of McCoy Mine was informally designated as such by McKee and Stewart (1971) because of its numerous outcrops just south of McCoy Mine. Generally occurring as a soft slope capped by its upper densely welded unit (7C) and Bates Mountain Tuff, the Tuff of the McCoy Mine consists of at least four cooling units. The most notable aspects of this tuff are the consistent presence of biotite and the brittleness of the poorly welded zones. Brittleness in poorly welded ash-flow tuffs is attributed by Smith (1960) to induration by vapor phase minerals. The minimum thickness and age are, respectively, 60 m and 27.0 ± .9 m.y. (McKee and Stewart, 1971).

Twt 7A

Twt 7A consists of at least 2 cooling units. The lower is a white, poorly welded, crystal-poor ash-flow tuff containing sanidine, biotite, plagioclase, and a few small pumice and lithic fragments. The maximum thickness of this unit is 23 m.

The upper cooling unit is a lenticular vitrophyre containing 18% crystals of sanidine, biotite, and plagioclase. This unit consists of 30 cm of non-welded ash at the lower contact and is platy, vitric, and poorly welded near the upper contact. Therefore it is considered to be a simple cooling unit.

Twt 7B

The middle unit of the Tuff of McCoy Mine is a multiple-ash-flow simple cooling unit. It consists of several partially welded zones separated by flow breaks or less welded zones that manifest themselves as ledges and partings. It is grey, orange, or pale purple and contains 14% crystals of sanidine, biotite, and plagioclase as well as a few scattered pumice and lithic fragments. The case-hardened aspect is especially evident in this unit. Its thickness is at least 50 m.

Twt 7C

The dense welding and abundant biotite of Twt 7C makes it the best marker horizon of the upper ash-flow tuffs in the McCoy area. It is consistently red, structureless, densely welded, and contains 22% crystals of sanidine, biotite, and plagioclase. The observed thickness is 5 m.

Bates Mountain Tuff

The Bates Mountain Tuff was defined by Stewart and McKee (1968) at Bates Mountain in western Lander County. It consists of 5 cooling units with a total thickness of a few hundred meters. It has an areal extent of 5600 km^2 and is found in Nye, Lander, and Churchill Counties (Stewart et al., 1977).

The units of Bates Mountain Tuff present in the McCoy area are mapped as Twt 8A, 8B, and 8C, and correlate with units 1, 4, and possibly 5 of Sargent and McKee (1969). In the map area Bates Mountain Tuff can be recognized on aerial photographs because of the development of dendritic drainage patterns on dip slopes. Scarp slopes of Bates Mountain Tuff generally develop fewer cliff exposures than the other tuff units. The average age of the five Bates Mountain cooling units is 24.6 m.y. (Stewart et al., 1977).

Twt 8A

Twt 8A is a 46 m thick slightly eutaxitic compound cooling unit correlable in lithology, age, and chemistry to unit 1 of Sargent and McKee (1969). It consists of two partially welded zones separated by a flow break ledge and a basal vitrophyre. This unit is pale pink to red and contains less than 10% crystals of sanidine and plagioclase. All exposures of the lower vitrophyre exhibit secondary devitrification. The basal portion of both flows form low rounded cliffs, while the partially welded zones are slope formers. The K-Ar age of this unit is 25.3 ± 1.0 m.y. in the Shoshone Mountains (McKee and Stewart, 1971) and 24.7 ± 1.0 m.y. in the Simpson Park Mountains (Naeser and McKee, 1970). The observed thickness in the McCoy area is 50 m.

Twt 8B

The basal zone of Twt 8B is the most distinctive horizon of the Bates Mountain Tuff. It consists of a 1 m thick, red, densely welded zone with spherical cavities about 1 cm in diameter and contains less than 7% crystals of sanidine and plagioclase. This is the "swiss cheese" horizon of McKee and Stewart (1971) and unit 4 of Sargent and McKee (1969). A 2 m thick, pale red, eutaxitic, densely welded zone overlies the swiss cheese horizon and west of the McCoy Mine is in turn overlain by an 8 m thick, soft grey, partially welded, eutaxitic zone with vapor phase crystallization. The K-Ar age of the basal unit of Twt 8B is 23.9 ± .9 m.y. (McKee and Stewart, 1971). The total observed thickness of these units is 25 m.

Twt 8C

Twt 8C is another distinctive horizon in the Bates Mountain Tuff. It is a pink to grey, partially to poorly welded simple cooling unit containing 19% crystals of sanidine and quartz. This unit was dated by McKee and Stewart (1971) at 24.2 ± .9 m.y. Twt 8C is confined to one ridge 2 km north of Hole-in-the-Wall Well, where it is 10 m thick.

QUATERNARY ALLUVIUM

There appears to be more than one period of alluvium development in the study area. Several mounds of coarse alluvium up to 15 m in height occur near Hole-In-The-Wall Well #2. Alluvium is presently accumulating in valleys, and is locally overlain by or interbedded with calcareous travertine.

COMPOSITION AND CLASSIFICATION OF ASH-FLOW TUFFS

The chemical compositions of the ash-flow tuffs at McCoy were determined by X-ray fluorescence, flame photometry, and inductively coupled plasma spectrometry (ICP). Table 2 lists the major element contents of 24 samples and their respective norms. Sample locations are shown in Figure 8.

The silica values range from 66 to 78%. The lower end of this range, 66-72% characterizes the oldest ash-flow tuffs, Twt 6D, and the Tuff of McCoy Mine. The upper range of values, 73-78%, is comprised of Twt 4, 5, 6A-C, 6E-G, and Bates Mountain Tuff. All of the samples contain normative quartz, orthoclase, albite, anorthite, ilmenite, and hematite. A majority have normative corundum, hypersthene, rutile, and apatite. No modal topaz or muscovite were observed. Only a few contain normative titanite or acmite. Of the 3 rocks that do not have normative corundum, two contain normative wollastonite and diopside.

Compositional variations within a single cooling unit can be related to several processes, and the samples for analysis must be chosen accordingly. Several primary and secondary causes of chemical variation must be taken into account.

Primary zonation produces compositional zonation from high silica content at the base of the unit to a lower silica content at the top. The classic example of primary zonation is the Bishop Tuff (Hildreth, 1979). In order to detect compositional zonation at least

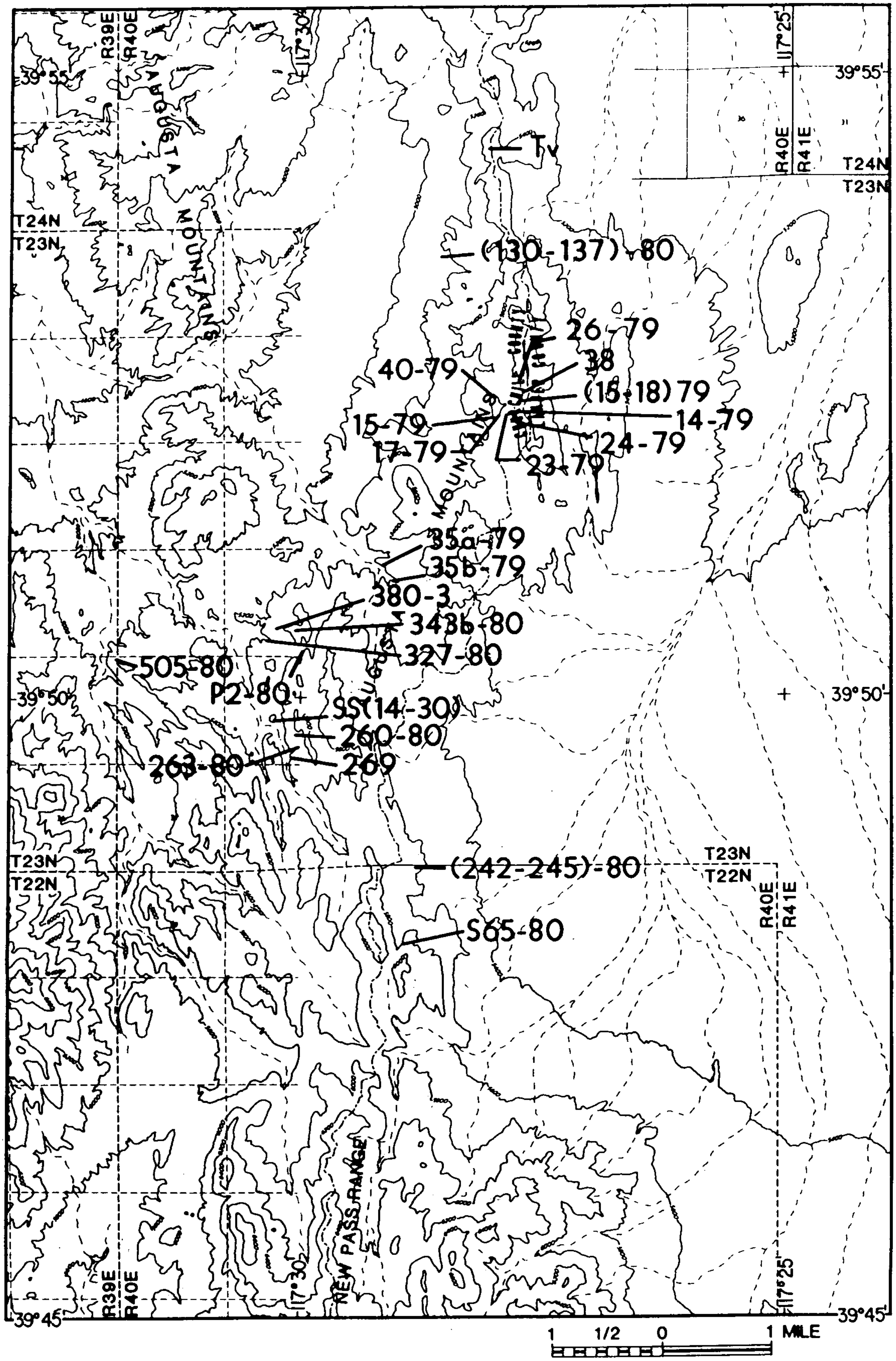

Figure 8. Sample locations.

two widely-spaced (vertically) samples were analyzed for most of the cooling units. Only one unit, Twt 2, shows this type of zonation.

Post-emplacement alteration consists of deuteric alkali exchange in feldspars (Scott, 1971a, b), hydration, secondary crystallization, primary crystallization, and ground-water alteration (Lipman, 1967; Lipman et al., 1969; Noble et al., 1967; Rosholt and Noble, 1969; Rosholt et al., 1971). The effects of hydration and secondary crystallization may be minimized by taking samples that have undergone primary crystallization. The extent of deuteric and ground-water alteration is dependent on the shard surface area and permeability, and thus may be minimized by choosing a densely welded sample.

Of the analyses in Table 2, several were vitrophyres and a few were partially welded. The partially welded samples were analyzed for comparison or when a densely welded, devitrified zone was lacking in the cooling unit. The state of welding and the presence or absence of devitrification for each of the analyses can be found in Table 1.

The ash-flow tuffs in the McCoy area were classified by plotting the normative feldspars on a ternary diagram (O'Connor, 1965). As shown in Figure 9, all units plot in the rhyolitic field except Twt 3, which plots as a quartz latite. The presence of normative corundum and lack of subequal Na_2O and K_2O indicate that these rhyolites are closest in composition to the average calc-alkaline rhyolite of Nockolds (1954).

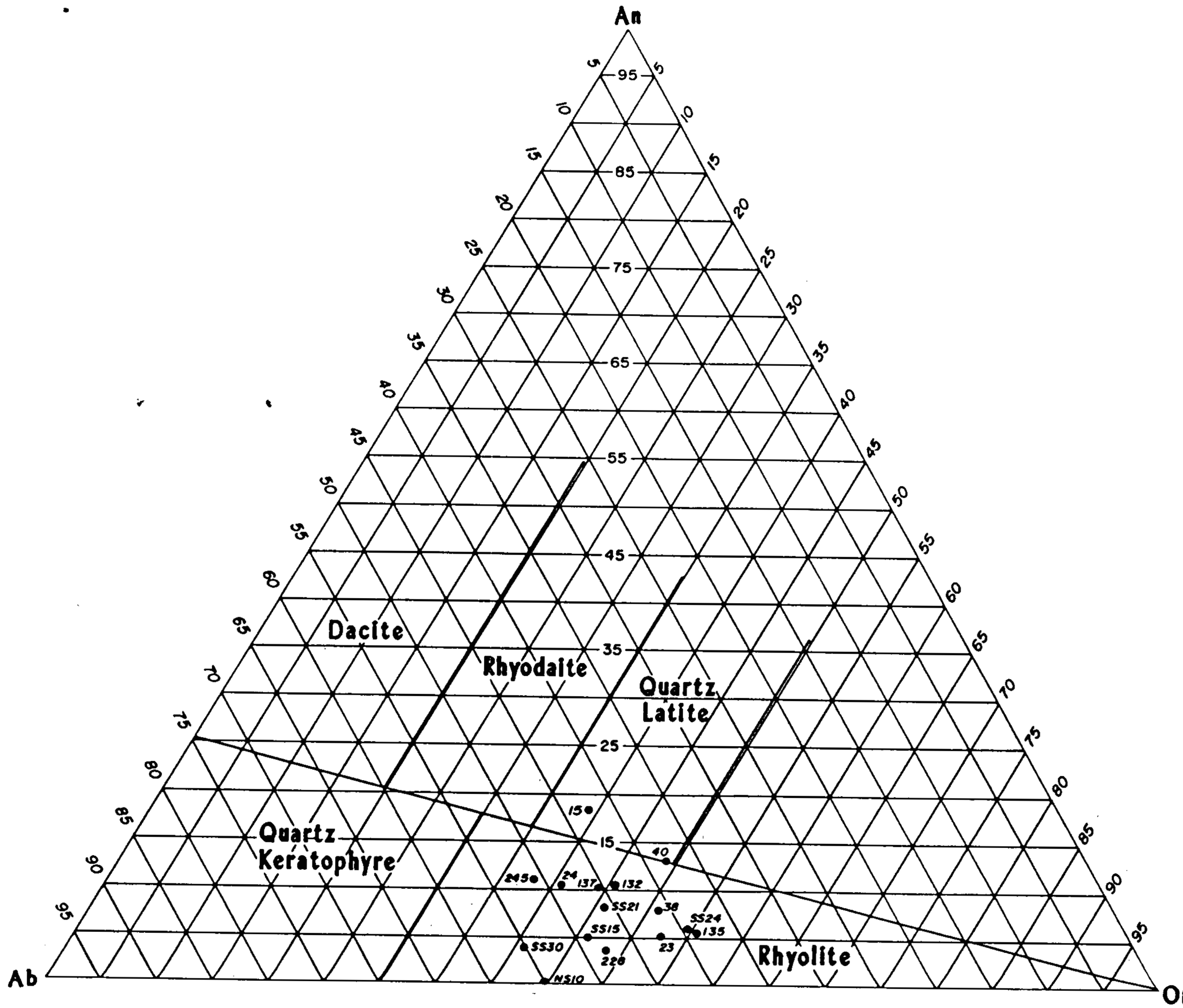

Figure 9. Ternary diagram of normative feldspar ratios, classification from O'Connor (1965).

STRUCTURE

Paleozoic Structure

The earliest of the two Paleozoic structural events likely to have affected this area is the Roberts Mountain thrust of probable Early Mississippian age (Gilluly and Gates, 1965). This thrust fault emplaced early Paleozoic siliceous sedimentary rocks over carbonate facies of comparable age. This thrust, if present in the McCoy area, must lie at considerable depth since the youngest rocks encountered in the 800 m drill hole were of Pennsylvanian age.

The second Paleozoic event is the Sonoman Orogeny of Late Paleozoic age. During this event the Havallah Formation was tightly folded and thrust eastward. Its basal contact is not exposed at McCoy but elsewhere it has been mapped consistently in thrust contact with the underlying rocks (Silberling and Roberts, 1962).

Mesozoic Structure

The only Mesozoic rocks present in the area mapped are those of the Triassic Augusta Sequence. This carbonate assemblage was folded during Jurassic or Cretaceous time (inferred from flat-lying Tertiary strata) into nearly orthogonal fold sets whose mean axial traces are northwest and southwest (Willden and Speed, 1974). The southwest-trending folds are broader and younger than those trending northwest. In the New Pass Range, Permian and Triassic rocks are folded in an anticline whose axis plunges 42°W, and whose axial surface dips 70°N (Willden and Speed, 1974).

Tertiary Structures

Little is known about pre-Basin and Range Tertiary structure in this area due to a depositional hiatus that lasted from Late Triassic to middle Tertiary time. The existence of thick Tertiary fanglomerate north of the mercury mines as well as the distribution of Twt 6A and 6B implies some significant structural activity prior to rhyolite volcanism, but these structures are largely covered. The structure or series of structures responsible for the erosion and deposition of the fanglomerate are apparently restricted to the area north of the Wild Horse Mine, although there was some subsidence 1 km south of the mine between the emplacement of Twt 6D and 6E.

The maximum age of Basin and Range faulting is 23 m.y., the age of the youngest ash-flow tuff. Ash-flow tuff zonation is an excellent indicator of fault scarps formed during or previous to emplacement. The tuffs of McCoy Mine and Bates Mountain were deposited in the McCoy area on very low topography, with little disruption from fault scarps. The minimum age of Basin and Range structures is not definable in the McCoy area, but the 15 m.y. old basalts in the Clan Alpine Mountains cover Basin and Range faults and are thus younger (Riehle et al., 1972).

Basin and Range faults vary in displacement from 5 to 500 meters and strike east-northeast to west-northwest, giving rise to a polygonal pattern. Faults of major displacement (Fig. 10, 11) trend northeast or northwest but due to splaying they commonly follow a rather angular path. There is no significantly predominant sense of faulting. Some of these structures have variable displacement along

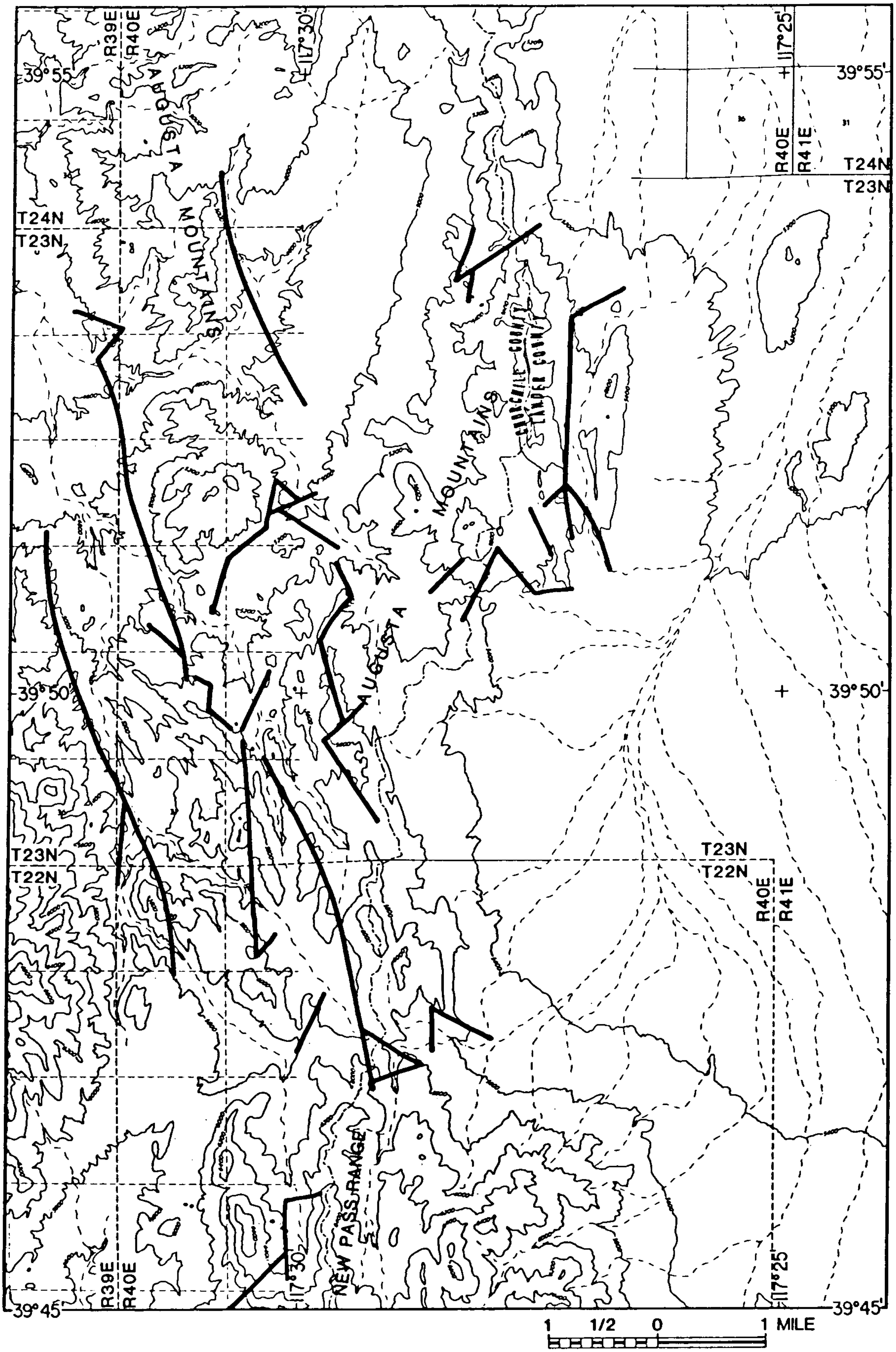

Figure 10. Faults with displacement greater than 70 m.

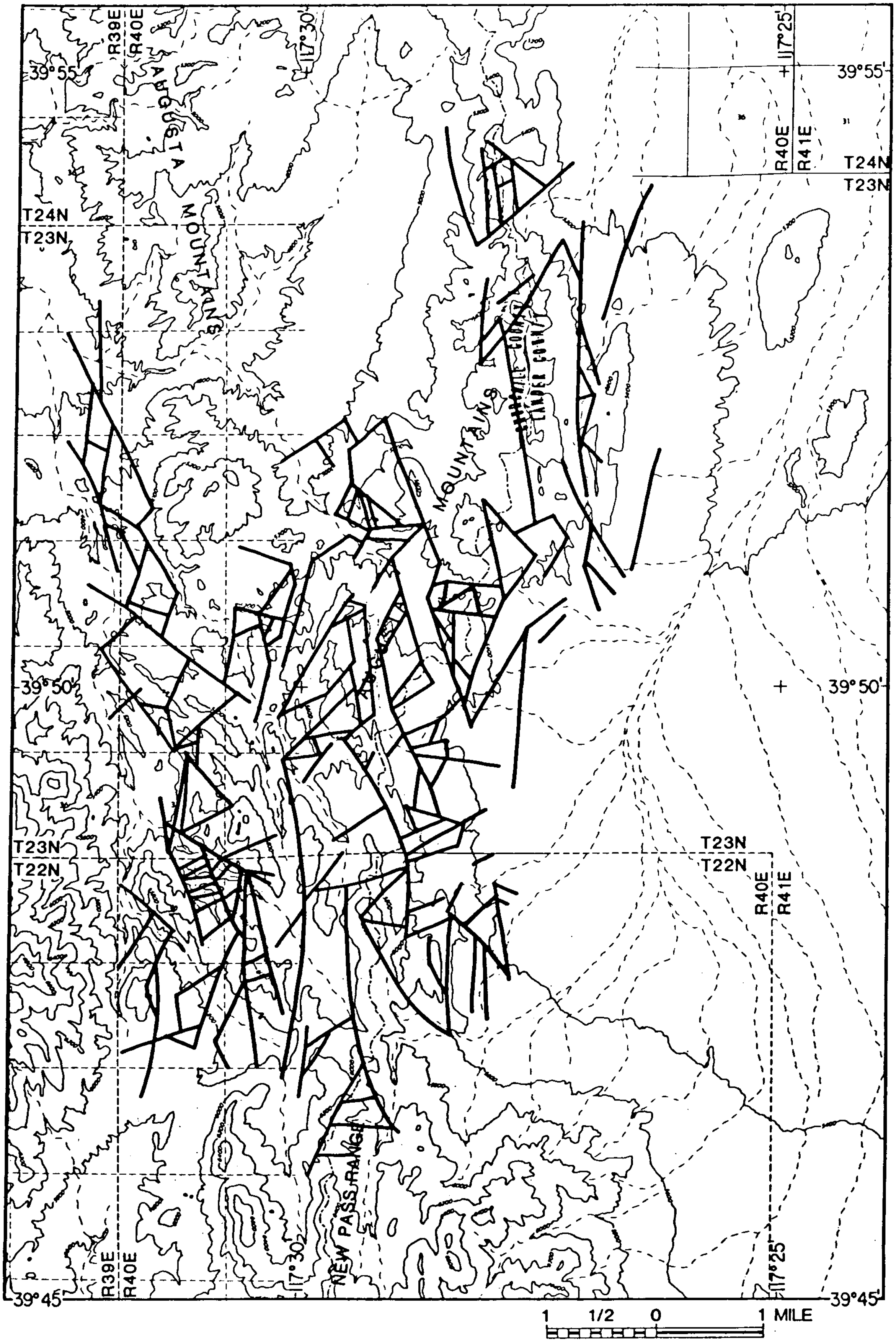

Figure 11. Faults with displacement less than 70 m.

strike.

Modern-day seismic activity and faulting have been observed in the vicinity of the McCoy area. The most recent activity was the Dixie Valley earthquakes in 1954 (Slemmons, 1966). These earthquakes reactivated several basin-bounding faults in Dixie Valley. Recent seismic studies suggest that the present seismic activity in the McCoy area has a small right-lateral component (Olsen et al., 1979).

GEOLOGIC HISTORY

The first Tertiary rocks to be deposited in Lander and Churchill counties (Stewart et al., 1977; Willden and Speed, 1974) were andesite and dacite lava flows and ash-flow tuffs about 36 m.y. ago. These flows accumulated on an erosional surface of low relief, cut into rocks of Paleozoic and Mesozoic age (Fig. 12A). After these flows were extruded, faulting in the northern part of the study area produced sufficient topography to erode large boulders of Triassic limestone and conglomerate to form a fanglomerate up to 80 m thick (Fig. 12B). After an erosional hiatus, during which the thickness of the fanglomerate was considerably reduced (Fig. 12C), an ash-flow tuff (Twt 1) was deposited in a northern canyon. This poorly welded ash-flow tuff was subsequently eroded below the rim of this canyon. Between 30 and 28 m.y. ago most of the topography remaining was filled by ash-flow tuff units Twt 2, 3, and 4, followed by minor ash-falls and erosion (Fig. 12D). A topographic barrier was then created by block faulting in the vicinity of the McCoy and Wild Horse Mercury Mines. This topographic barrier blocked the next two ash-flow tuffs, Twt 6A and B, from being deposited north and northeast of the future mine site. North of this barrier several cooling units of ash-flow tuff accumulated (Twt 5), as well as several tens of meters of tuffaceous sediment. This sediment eventually spilled over the topographic barrier, and it was partially eroded. The next ash-flow

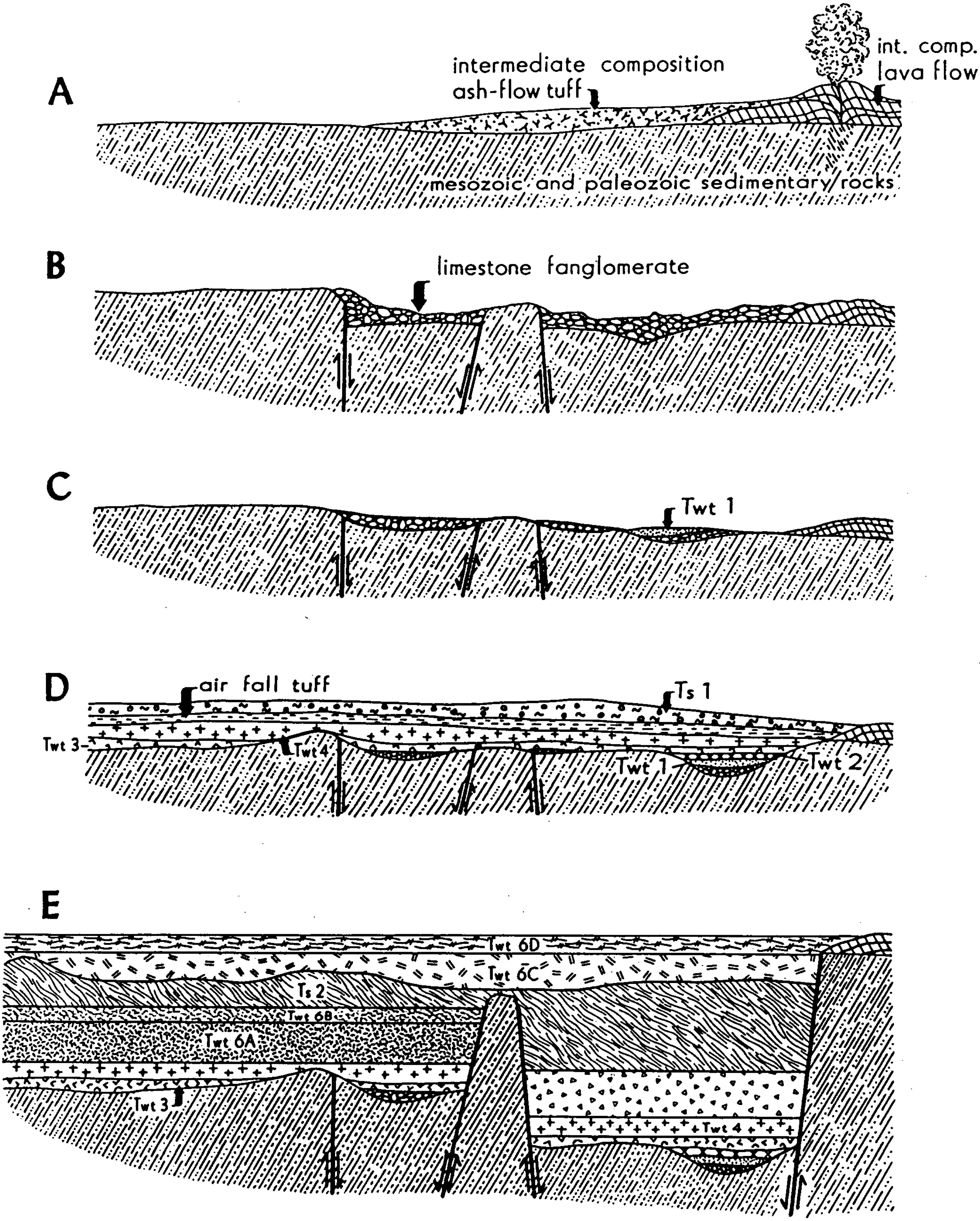

Figure 12. Geologic history (Sections oriented SW-NE).

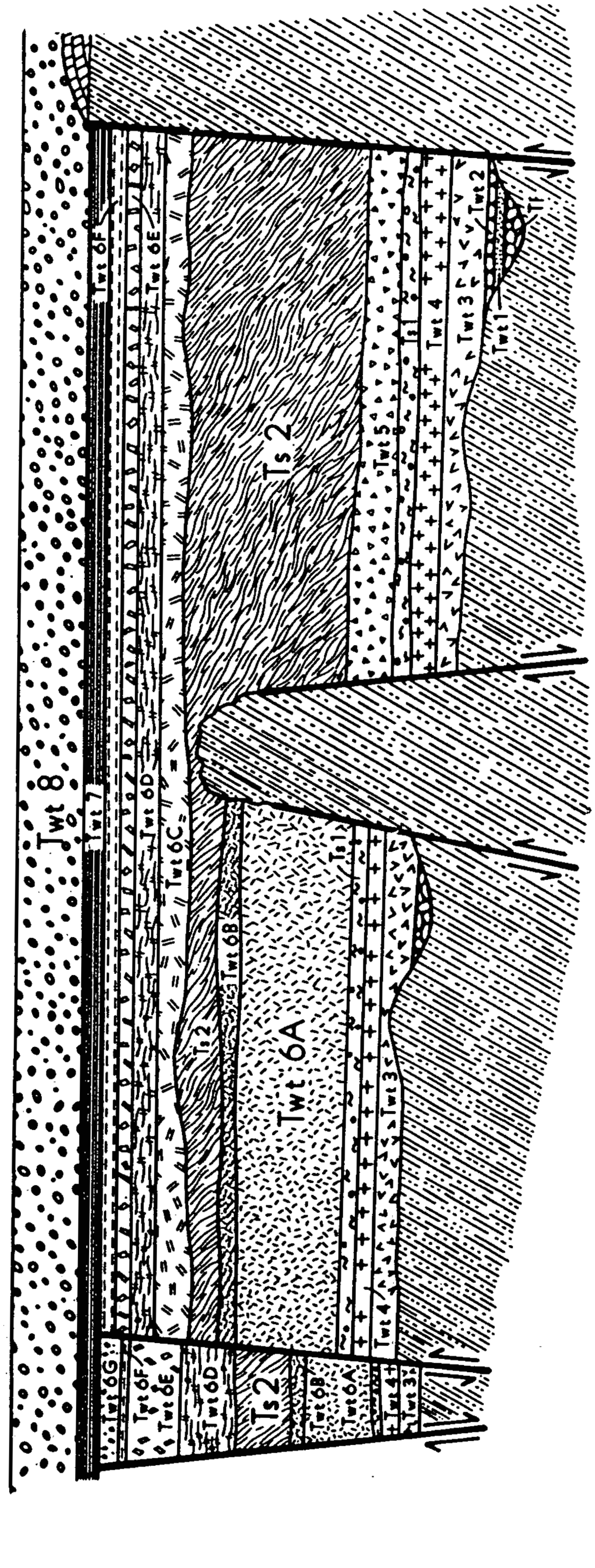

Figure 12 (cont.). Geologic history (Section oriented SW-NE).

tuff to be deposited, Twt 6C, filled the topographic lows created by the erosion of the tuffaceous sediment (Fig. 12E).

Approximately 27 m.y. ago Twt 6D was erupted and interfingered with ash-flow tuffs from the east. This was followed by local subsidence south of the McCoy Mine, and the emplacement of Twt 6E, F, and G (Fig. 12E and F). On top of Twt 6F and 6G the 26 m.y. old locally distributed tuff of McCoy Mine and the 23 m.y. old widespread Bates Mountain Tuff accumulated.

The onset of Basin and Range faulting occurred between the deposition of the 23 m.y. old Bates Mountain Tuff and the extrusion of the 15 m.y. old basalts found in the Clan Alpine Mountains, forming a series of subparallel cuestas. North-trending faults die out or are truncated in several places by east-trending faults, which appear to have been sporadically active from the time of the earliest ash-flow tuffs through the Basin and Range period of faulting.

Since the eruption of the young basalts, erosion and geothermal activity have been the dominant processes operating in this area. Some uplift has occurred, causing some alluvial deposits to be deeply incised. Carbonate-charged waters were vented onto the surface west of the McCoy Mine, forming an extensive deposit of travertine. In a few places silica saturated waters also reached the surface, forming siliceous sinter and apparently sealing several conduits. No surface activity is now present and these deposits are today being eroded.

SOURCES FOR THE ASH-FLOW TUFFS AT McCOY

There is no obvious source for most of the ash-flow tuffs at McCoy. No rhyolitic vent facies rocks or volcano-tectonic features were encountered during mapping. However, such indirect evidence such as the age of known volcanic centers and changes in welding and thickness in the ash-flow tuffs can be used to indicate transport direction. These lines of evidence are considered below. The thickness and welding changes are illustrated in Fig. 7.

The known volcanic centers near McCoy (Fig. 13) are the Mount Lewis cauldron, which formed 32-34 m.y. ago (Wrucke and Silberman, 1975), the Clan Alpine volcanic center, where activity was concentrated between 29-31 m.y. and 25-26 m.y. ago (Riehle et al., 1972), and the Fish Creek Caldera, which formed about 24.6 m.y. ago (McKee, 1970). The only ash-flow tuffs at McCoy whose ages match those of the volcanic centers listed above are the oldest tuffs, Twt 1, 2, and 3. These have been dated at 28.7, 29.2, and 31.1 m.y., respectively (Stewart and McKee, 1971). Twt 4 lies directly above Twt 3, which brackets the age of Twt 4 between 27.6 and 28.7 m.y. old. These ages are close to those of the earlier episode of volcanism at the Clan Alpine volcanic center.

The Clan Alpine volcanic center lies to the southwest of the McCoy area. The thickness of Twt 1, 2, and 3 do not increase to the southwest, while the thickness of Twt 4 does. Since Twt 1 and 2 are

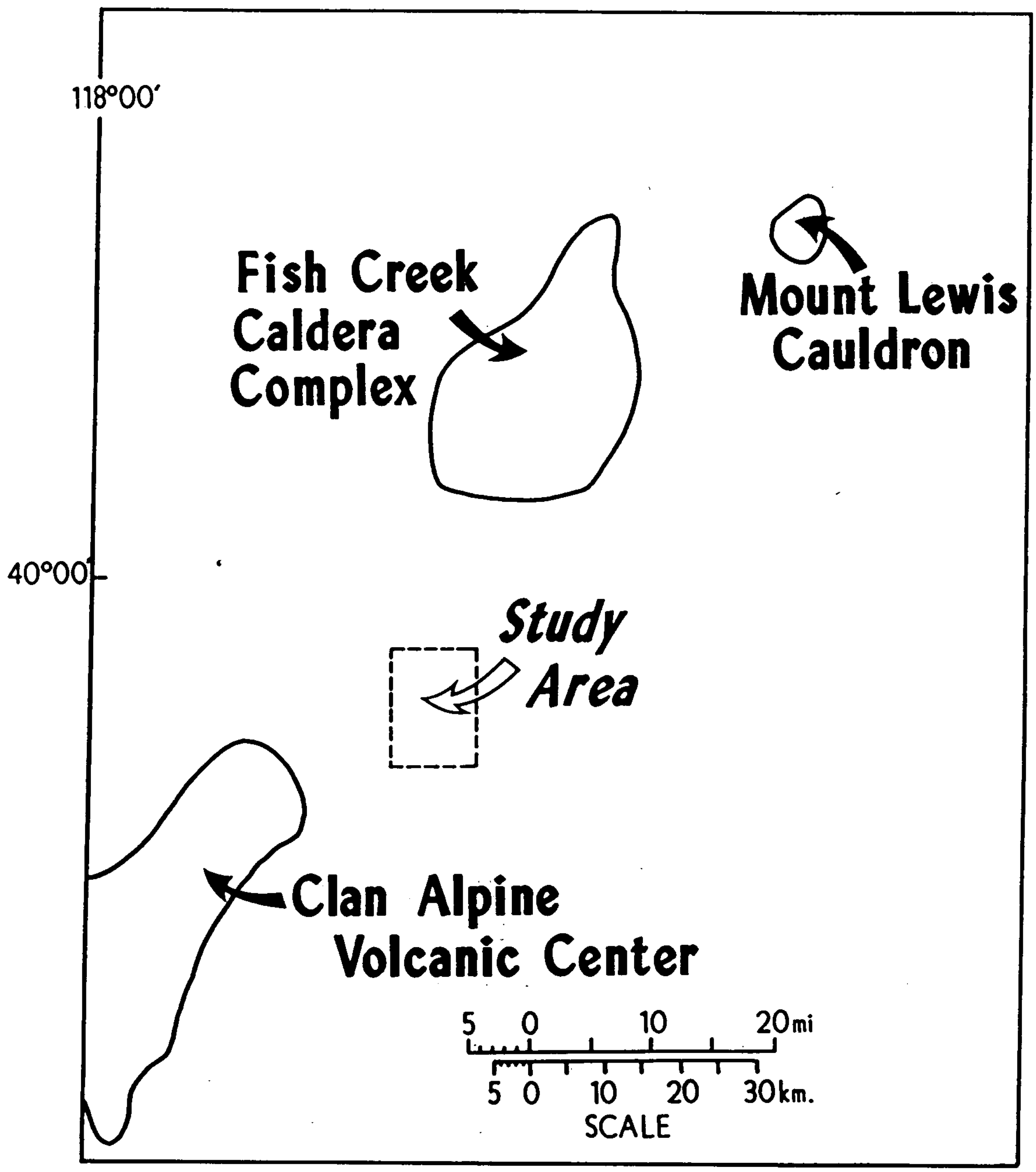

Figure 13. Tertiary volcanic centers near the McCoy prospect.

confined to the northeastern portion of the McCoy area, and Twt 2 and 3 exhibit a genetic relationship, it is unlikely that these units originated as far away as the Clan Alpine Mountains. However, the evidence given above for Twt 4 is consistent with a source in the Clan Alpine volcanic center.

The distribution of Twt 5 unit is limited to the northeast quarter of the mapped area. Since this distribution is attributed to a paleo-topographic barrier south and west of Twt 5, its source area would be to the north or east of McCoy.

McKee and Stewart (1971) have stated that the most likely source for the ash-flow tuffs grouped by them into the Edwards Creek Tuff was to the southwest of the McCoy area. As shown in Figure 7, the only unit in the Edwards Creek Tuff which increases in thickness or welding towards the southwest is Twt 6A. Twt 6B and 6C do not occur southwest or east of the McCoy area. South of McCoy, in Edwards Creek Valley, Twt 6C is absent and the welding of 6B decreases. A source area for Twt 6B and 6C consistent with these facts would be north or west of the McCoy area.

The only evidence that was found for a source direction of Twt 6D was a decrease in thickness at the reference section at the eastern edge of Antelope Valley. However, this reduction in thickness is due to the compaction of the upper non-welded zone where Twt 6D forms a compound cooling unit with the Interfingering Tuff. The thickness and welding of Twt 6E and 6F do not change significantly in the mapped area, and there is no evidence as to their source area.

The Tuff of McCoy Mine does not exhibit any lateral changes indicative of a source area direction. This unit has been dated at about 27 m.y., which could imply an origin in the Clan Alpine Mountains. The high biotite content of Twt 7 and the 26 m.y. old volcanics from the Clan Alpine volcanic center is consistent with this hypothesis.

As discussed in the stratigraphy section, the Bates Mountain Tuff originated several mountain ranges east of McCoy, in the Simpson Park Mountains.

ALTERATION AND MINERALIZATION

Hydrothermal alteration at McCoy is largely confined to the Wild Horse and McCoy mine areas. The two mines occupy positions within 1.5 km of each other, both occurring within silicified limestone. The ore consists of cinnibar and small amounts of mercuric chloride minerals in films, veinlets, crystal aggregates, and crusts along fractures and in small cavities. Gangue minerals are quartz, calcite, kaoline, barite, collophanite, pyrite, iron oxides, and stibnite (Stewart et al., 1977). The ore bodies are small and erratically distributed in the fractured and silicified limestone (Dane and Ross, 1942). Development consists of small open pits, glory holes, trenches, adits, and an inclined shaft (Stewart et al., 1977).

At the Black Devil mine, 4 km southwest of the Wild Horse mine, an intercalated sequence of fine- to coarse-grained alluvial sediments is partly replaced by psilomelane. The mineralization appears to be confined to an east-west trending graben.

Manganese also occurs in association with the travertine field and will be discussed in a later section.

Silicification and brecciation is found in the Havallah Formation along several pre-ash-flow tuff faults.

HEAT FLOW AND SURFACE HOT WATER DEPOSITS

The Basin and Range province is an area of high heat flow, thin crust, deep circulation of fluids along basin faults, and young igneous activity at the margins. Within the Basin and Range is the Battle Mountain Heat Flow High, a region of twice normal heat flow. The Battle Mountain Heat Flow High extends from Lovelock, Nevada in the south, to the Snake River Plain in the north (Brook et al., 1979).

Amax Inc. drilled over 50 shallow thermal gradient holes in the mapped area to determine the heat flow. As a result of this survey three areas of high heat flow and a north-south trend of elevated heat flow were defined. Heat flow values ranged from 38 to 960 mW/m^2 (Fig. 2) (Olsen et al., 1979).

Almost three square kilometers of bedded travertine lie on alluvium directly northwest of the McCoy Mine. The travertine is associated with manganese deposits, as is the fault running beneath the travertine and bounding the McCoy Mine. Manganese deposits also occur in the Black Devil mine, 4 km southeast of the Wild Horse Mine.

An eroded remnant of travertine mantles a small ridge 5.6 km south of Hole in the Wall Well no. 2 (Fig. 14). The backbone of this ridge is a vertical body of amorphous silica, which appears to fill the feeder vent of the travertine. Clasts of travertine occur in the silica, while the travertine surrounding the vent contains silica-filled cavities and pore spaces.

Siliceous sinter is found 500 m southwest of the silicified travertine. The sinter lies in a major drainage and is partially buried by alluvium. Its extent is not known.

DISCUSSION

Several lines of evidence indicate the thermal system at McCoy is fault controlled. Rocks encountered in drill holes as well as on the surface include Paleozoic metasediments, Triassic limestones, and Tertiary volcanics. These rocks have low primary permeability. In addition, the lack of solution features in limestones penetrated during drilling and the association of travertine and siliceous sinters with faults both point towards structural control of the geothermal system. Five structural trends can be distinguished on the basis of heat flow, travertine, and siliceous sinter (Fig. 14). The distinguishing characteristics of these trends are discussed below.

Trend 1

Structural trend 1 consist of one fault which extends northerly from east of the southern heat flow anomaly to where it intersects trend 2. Along this path it borders a heat flow high of approximately 627 mW/m^2. This fault is covered by alluvium along most of its path. Trend 1 bends to the northeast before being truncated by an east-west fault. Located at this bend is a 960 mW/m^2 heat flow anomaly. There is no surficial evidence of hot spring activity along trend 1.

Trend 2

In the southern part of the area trend 2 is represented by a

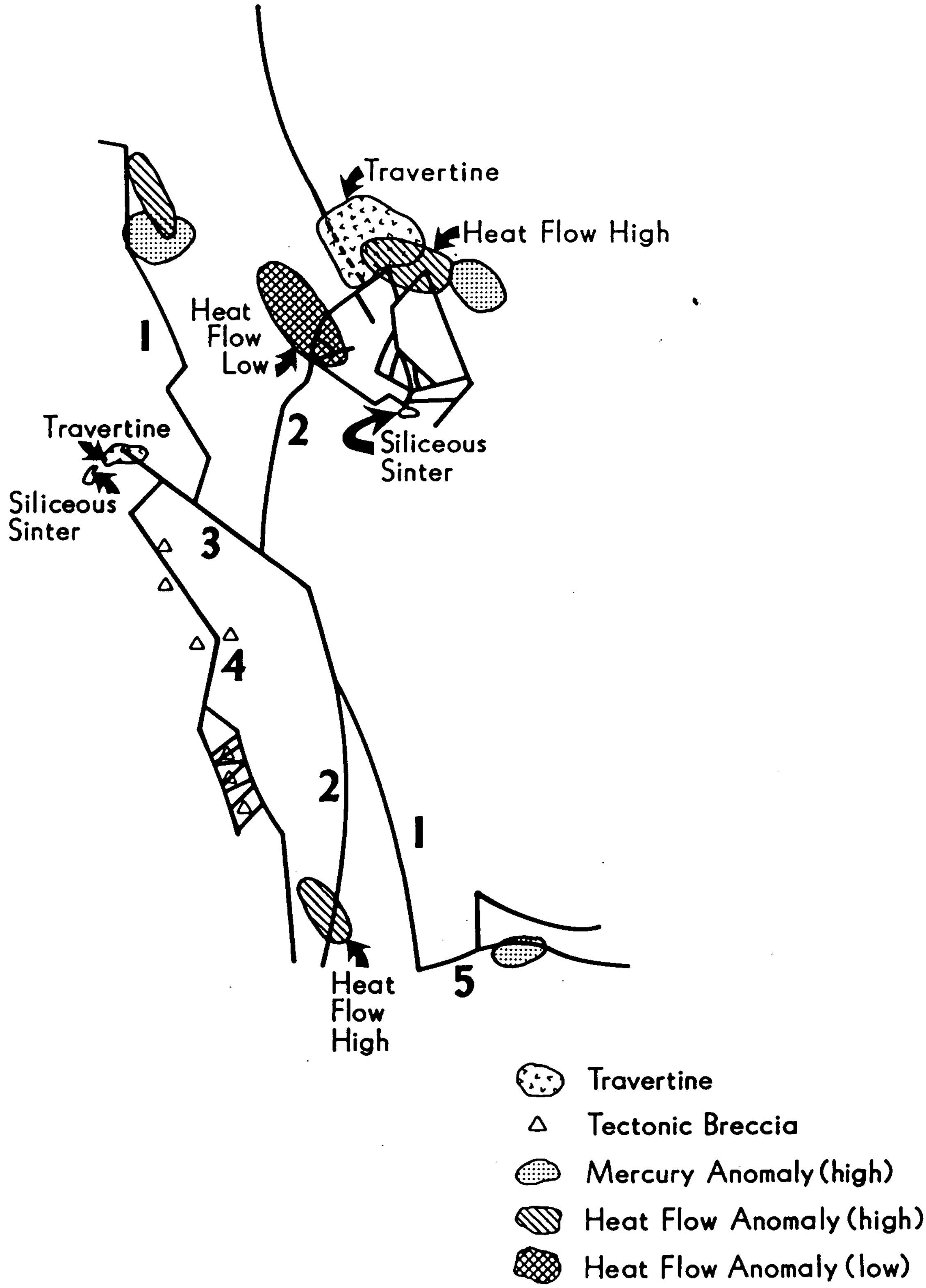

Figure 14 Structural trends associated with heat flow and surface thermal deposits

fault that parallels trend 1 and intersects the southern 500 mW/m^2 heat flow anomaly. The fault bounds a competent block of ash-flow tuff on the west. After intersecting trend 1, the trend 2 fault bends to the northeast and splays many times before intersecting east-west faults at the Wild Horse Mine. Heat flow in the vicinity of the east-west and north-south fault intersections at the Wild Horse Mine is low (<170 mW/m^2). This may be due to silicification and sealing of fluid conduits. However no evidence of recent surficial geothermal activity was recognized in the mine area. That other portions of the system have been silicified is demonstrated by the silicified feeder zone along trend 3. The relationships of siliceous sinter to a geothermal system is discussed later in this section.

From the Wild Horse Mine trend 2 faults curve northwest through the McCoy Mine. These faults border an extensive field of travertine intercalated with alluvium and a 600 mW/m^2 heat flow anomaly. These faults are also associated with manganese oxide deposition in the travertine as well as in the mine area. From the Wild Horse Mine trend 2 curves northwest through the McCoy Mine and then continues northwest.

Trends 3 and 4

Trend 3 is a low-displacement fault near which travertine and siliceous sinter occur. Precipitation of silica from thermal water indicates that subsurface temperatures of the water probably exceeded 180°C. However, the heat flow in the vicinity of the siliceous sinter is low (<200 mW/m^2). This suggests that the water conduits may have been sealed by silica precipitation, reducing the heat flow due to convection. The spacial proximity and age of sinter deposits along trend 3 and trend 2 implies that they are manifestations of the same geothermal system. The most likely routes of communication of the trend 3 sinter deposits with the present heat flow anomaly are trends 3 and 4. Trend 4 is a series of extensively brecciated fault zones running from the sinter to the southern heat flow anomaly.

Trend 5

Trend 5 extends from just east of the southern anomaly to the western edge of Antelope Valley. While only slightly anomalous in heat flow, trace element analysis has shown mercury enrichment in drill hole cuttings along this trend This may indicate a possible coincidence of structural controls for the fluid which deposited the mercury sulfides at the Wild Horse and McCoy Mines and the fluid of the present geothermal system. The concentration of mercury in drill chips from the thermal gradient holes is contoured in Figure 15. The mercury contours in the McCoy area are roughly parallel to the heat flow contours.

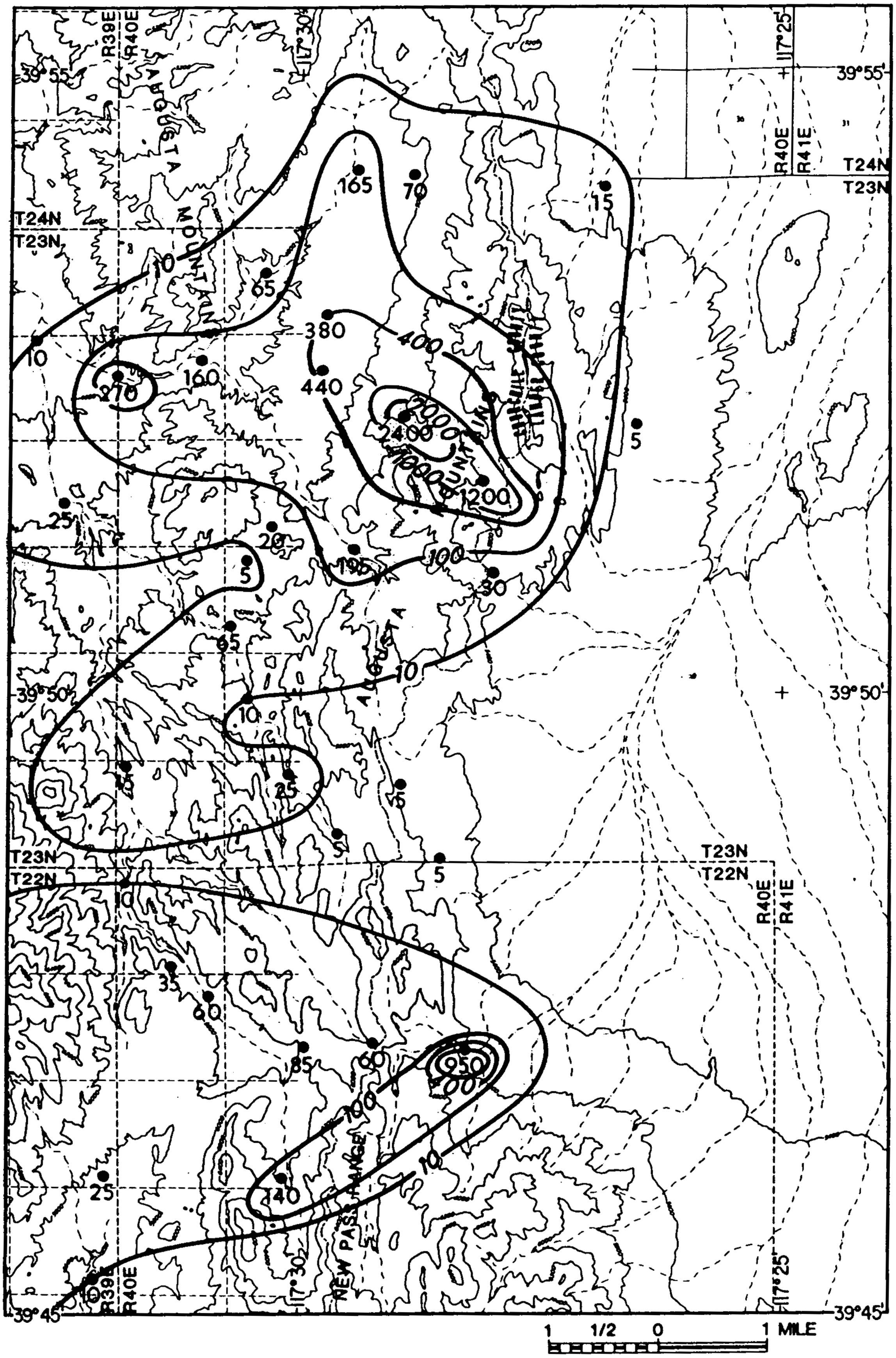

Figure 15. Contoured mercury concentrations (ppb) from drill chips.

CONCLUSIONS

The volcanic rocks at the McCoy geothermal prospect consist of at least 20 cooling units of rhyolitic ash flow tuffs overlying intermediate composition lava flows, all of Oligocene age. Only one cooling unit, Twt 2, was found to be compositionally zoned downward from a quartz-latite to a rhyolite. The other ash flow tuffs vary nonsystematically within the rhyolite composition field of O'Connor (1965).

No calderas or vent facies related to the ash flow tuffs were found within the mapped area. The thickness and welding variations of the ash flow tuffs indicate a northeast to northwest source direction for units Twt 1, 2, 3, 5, 6B, and 6C. The most likely source area for units Twt 4 and 7 is the Clan Alpine volcanic center, southwest of the mapped area. Twt 8 (Bates Mountain Tuff) is known to have originated west of McCoy, in the Simpson Park Mountains.

The oldest recognized Tertiary faults in the McCoy prospect produced several east-west trending horsts and grabens. These structures were active before, during and after ash-flow tuff deposition. Anomalously high mercury concentration in drill chips, manganese oxide mineralization, and two mercury mines occur along some of the east-west trending faults. The mercury and manganese mineralization post-dates the ash-flow tuffs.

Basin and Range faulting began after the emplacement of the youngest ash-flow tuff 23 m.y. ago. No evidence of the minimum age for Basin and Range faulting was found at the McCoy prospect.

At least two episodes of hydrothermal activity can be recognized in the prospect area. The oldest event altered and mineralized the volcanic and sedimentary rocks, producing the Wild Horse and McCoy Mercury Mines. The youngest event deposited calcareous travertine, siliceous sinter, and manganese oxide in and on Quaternary alluvium.

The geothermal system at McCoy is structurally controlled. The elongate north-trending heat flow pattern follows the pattern of Basin and Range faulting, and the major heat flow anomalies occur at the intersections of north-south and east-west trending faults. This pattern is also followed by mercury enrichment in drill hole cuttings (Fig. 15), suggesting that the present-day hot water conduits coincide with those used by the hydrothermal fluid responsible for the mercury mineralization at the Wild Horse and McCoy mines.

A recent age for the system may be inferred from the position of the travertine and siliceous sinter on alluvium and in present-day drainages.

APPENDIX

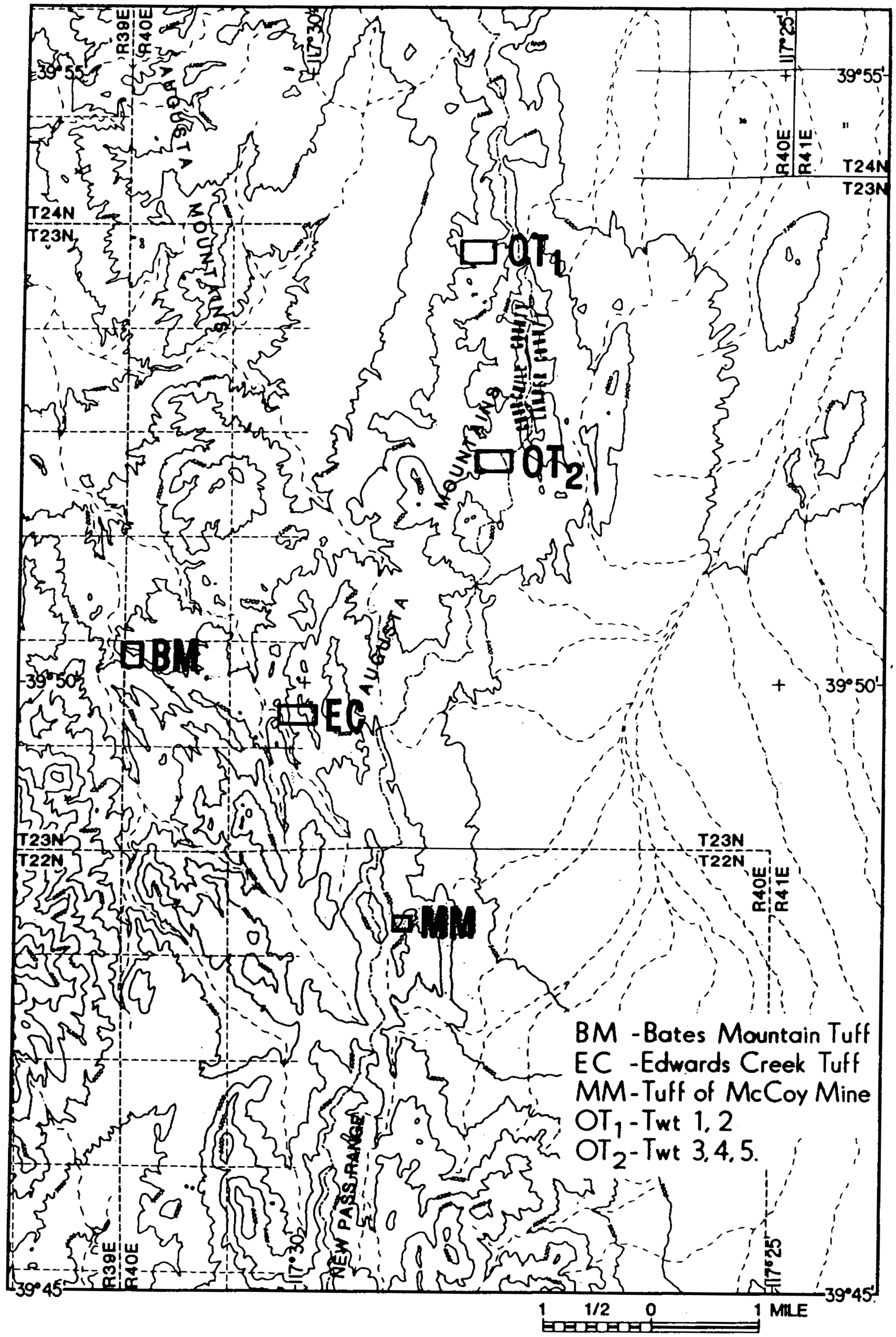

Figure 16. Location of stratigraphic sections.

Stratigraphic Section of Bates Mountain Tuff

Unit		Thickness in meters
8C	Medium grey tuff, partially welded, 20% crystals of feldspar and smoky quartz, contains moderately abundant pumice with vapor phase crystallization, forms a low slope....................................	5
	Partial Cooling Break	
8C	Orange tuff, poorly welded, 15% crystals of feldspar and smoky quartz, forms a low slope.....................	8
	Partial Cooling Break	
8C	Pale pink tuff, poorly welded, 15% crystals of feldspar and smoky quartz, forms a low slope.................	3
	Complete Cooling Break	
8B	Grey tuff, partially welded, 5-10% crystals of feldspar, contains black, grey, and white fiamme with vapor phase crystallization and 5 cm cavities which increase in abundance upwards, forms a low ledge....	6
	Maroon, densely welded tuff, 10% crystals of feldspar, contains dull black to glassy fiamme up to 30 cm in length, forms a low ledge........................	2
	Partial Cooling Break	
8B	Light grey tuff, partially welded, 15% crystals of feldspar, contains occasional light grey fiamme, forms a low slope....................................	14
	Mottled red-black densely welded tuff, 15% crystals of feldspar, forms weathered boulders along a low ledge..	3
	Complete Cooling Break	
8A	Dark purple to bleached white tuff, poorly to partially welded, 15% crystals of feldspar, contains occasional fiamme which are usually the color of the rock, forms a steep slope..............	43
	Mottled red-black densely welded tuff, 10-15% crystals of feldspar contains abundant 1-10 cm cavities which frequently have oxidized rims, forms a steep slope..	2

Stratigraphic Section of Bates Mountain Tuff

Unit		Thickness in meters
8A (cont.)	Black tuff, densely welded to vitrophyric, 15% crystals of feldspar, contains occasional white or black glass fiamme, forms a low ledge....................	2
	Black tuff, brown, or grey, vitric poorly to partially welded, 1-10% crystals of feldspar, contains white or black glassy fiamme, forms a low slope..........	3

Complete Cooling Break

Stratigraphic Section of the Tuff of McCoy Mine

Unit		Thickness in meters
7C	Maroon tuff, densely welded, 15% crystals of feldspar and biotite, the biotite is very abundant, forms a prominent ledge....................................	4
	Complete Cooling Break	
7B	Light purple tuff, poorly welded, 10% crystals of feldspar and biotite, contains small white pumice which increases in abundance upwards, forms a steep slope...	38
	Complete Cooling Break	
7B	Orange-brown tuff, poorly welded, 15% crystals of feldspar, 2% of biotite, contains a few small white pumice with vapor phase crystallization and a few brown lithic fragments about .5 cm in diameter, forms steep slopes.................................	7
7B	Light grey tuff, poorly welded, 15% crystals of feldspar, 2% of biotite, contains a few small dull red pumice and scattered small red lithic fragments, forms a steep slope......................	8
	Complete Cooling Break	
7A	Black vitrophyre tuff, 20% crystals of feldspar, 3% biotite, forms a low ledge..........................	4
	Complete Cooling Break	
7A	White tuff, poorly welded, 5% crystals of feldspar, 1% biotite, orange or white pumice with vapor phase crystallization, forms a low slope with no outcrop exposure at the base................................	32
	Complete? Cooling Break	

Reference Section of Units Twt 1 and 2

This section represents the oldest ash-flow tuffs in the McCoy area. In this locale (Fig. 16) they are thick, distinct cooling units. Elsewhere in the McCoy area they occur as a thickened, biotite-poor, non-welded base of Twt 3. Included at the base of this section is an eroded remnant of an ash-flow tuff.

Older Ashes

Unit		Thickness in meters
2	Red tuff, densely to partially welded, 5% crystals of feldspar, 5% biotite, forms a steep cliff...........	25
	Partial Cooling Break	
1	Grey tuff, partially welded, 3% crystals of feldspar, .5% biotite, forms a steep slope....................	14
	Pale green tuff, densely welded, 3% crystals of feldspar and a trace of biotite, contains a few small white fiamme, forms a steep slope.........................	2
	Dark grey lava flow, forms a low slope..............	1
	Light grey tuff, poorly welded, .3% crystals of feldspar and a trace of biotite, forms a moderate slope......	4
	Complete Cooling Break	
Remnant Ash-flow Tuff	Grey to white tuff, poorly welded, 5% crystals of feldspar and biotite, contains a few small black lithic fragments and 2 cm white pumice, forms a low slope..	11

Reference Section of Units Twt 3, 4, and 5

This section (Fig. 16) was chosen to represent the upper portion of the older tuffs because it clearly shows the northern thickening of Ts2. Also, in this section Twt 5 underlies Ts2 and demonstrates the mutually exclusive relationship of Twt 5 and Twt 6A and B. The thickness given for Ts1 is less than the true thickness due to a normal fault, but the displacement on this fault is minimal, less than 5 m.

Unit		Thickness in meters
Ts2	Tuffaceous sediment, forms a steep slope............	20
	Red-brown tuff, densely welded, 7% crystals of feldspar, forms a low ledge..................................	2
	Tuffaceous sediment, forms a moderate slope.........	20
5	Lavender tuff, poorly welded, 20% crystals of feldspar and biotite, contains large white pumice and lithic fragments up to 5 cm in diameter, forms a low slope..	27
	Red tuff, densely welded, 18% crystals of feldspar, 2% biotite, forms a low ledge..........................	17
	Black vitrophyre, 13% crystals of feldspar, 1% clinopyroxene, forms a low ledge....................	6
	Poorly welded zone of above, forms a low slope......	2
	Complete Cooling Break	
Ts1	Tuffaceous sediment, forms a low slope..............	6
4	White tuff, poorly to partially welded, 15% crystals of feldspar, 2% quartz, 1% biotite, contains abundant pumice with a waxy luster, forms a low slope........	15
	Light brown to grey tuff, densely welded, 15% crystals of feldspar, 2% quartz, 1% biotite, contains abundant black to dark grey fiamme up to 15 cm in length, forms a resistant ridge....................	8
	Light grey tuff, partially welded, 15% crystals of feldspar, 2% quartz, 1% biotite, contains orange	

Unit		Thickness in meters
	to white pumice and small black lithic fragments, forms a moderate slope............................	23
3	Pink tuff, partially welded, 35% crystals of feldspar, 7% biotite, 2% clinopyroxene, welding increases and color deepens downsection, forms a moderate slope...	6
	Black tuff, densely welded, 35% crystals of feldspar, 7% biotite, 2% clinopyroxene, forms a moderate slope...	11
	Black vitrophyre tuff, 35% crystals of feldspar, 7% biotite, 2% clinopyroxene, forms a low ledge........	6
	Grey tuff, poorly welded base of above, forms a moderate slope..	15

Complete Cooling Break

Reference Section of Edwards Creek Tuff

for the McCoy Area

All of the units in Edwards Creek Tuff except Twt 6G are present in this section. There are no major faults in this section (Fig. 16) although the dips of units 6A-D are steepened with respect to 6E and F. Of particular interest in this section is the intercalation of a distal portion of the Interfingering Tuff with units 6D and E.

Unit		Thickness in meters
6F	Red tuff, densely welded, 10% crystals of feldspar, 2% biotite, slightly eutaxitic with white, grey or black fiamme, forms a low ledge....................	3
	Partial Cooling Break	
6E	Orange to grey tuff, partially to poorly welded, 5% crystals of feldspar, 1% biotite, a few small white fiamme, forms a moderate slope capped by a prominent ledge..................................	12
	Complete Cooling Break	
	Tuffaceous sediment, forms a steep slope...........	10
Interfingering Tuff	Pale purple tuff, poorly welded, 12% crystals of feldspar, 4% biotite, contains lithic fragments of extrusive rock, forms a steep slope.............	10
	Complete Cooling Break	
6D	Light grey tuff, poorly welded, 15% crystals of feldspar and a trace of biotite, forms a low slope..........	9
	Red tuff, densely welded, 10% crystals of feldspar and a trace of biotite, contains a few glassy fiamme which are not visible on a weathered surface, forms a prominent cliff............................	6
	Red tuff, densely welded, 10% crystals of feldspar, contains a few small fiamme, forms a prominent cliff..	20
	White to grey tuff, densely welded, 20% crystals of feldspar, forms a low ledge........................	1
	Complete Cooling Break	

Unit		Thickness in meters
6C	Red-brown tuff, partially welded, vitric, 10% crystals of feldspar, 2% biotite, contains abundant lithic fragments of black extrusive rocks, forms a steep slope...	21
	Complete Cooling Break	
Ts2	Tuffaceous sediment.................................	20
6B	Orange-pink tuff, partially welded, 5% crystals of feldspar and a trace of biotite, contains a few small lithic fragments of extrusive rock, forms a low slope...	5
	Red tuff, densely welded, 5% crystals of feldspar and a trace of biotite, forms a prominent ledge...........	3
	Covered slope..	1
	Complete Cooling Break	
	Tuffaceous sediment.................................	1
?	Lavender tuff, poorly welded, 8% crystals of feldspar, 5% biotite, 6% clinopyroxene, forms a low slope.....	10
6A	Pink tuff, partially welded, 10% crystals of feldspar, 1% biotite, forms a steep slope with rounded ledges...	8
	Pink to red tuff, partially welded, 12% crystals of feldspar, contains large white pumice, forms a steep slope...	35
	Red tuff, densely welded, 12% crystals of feldspar, contains 1-5 cm cavities which increase in abundance upward, forms a steep slope...............	12
	Black vitrophyre tuff, 12% crystals of feldspar, contains a few black or white fiamme, forms a low slope...	5

Reference Section of McKee and Stewart (1971) on the Eastern Edge of Antelope Valley

McKee and Stewart (1971) used this area on the east edge of Antelope Valley (Fig. 16) as a Reference Section to define the Edwards Creek Tuff. Missing from this section are Twt B and C, which are widespread in the McCoy area. The Interfingering Tuff reaches a thickness of 50 m in this locale.

Unit		Thickness in meters
6E	Pale purple tuff, partially welded, 5% crystals of feldspar and biotite, forms a moderate slope capped by a low ledge..............................	15
?	Covered slope...	12
Interfingering Tuff	Purple tuff, poorly to partially welded, 5% crystals of feldspar and a trace of biotite, platy morphology, forms a moderate slope..............................	14
	Pale purple tuff, partially welded, 12% crystals of feldspar, 4% biotite, contains moderately abundant lithic fragments of extrusive rock and a few small white pumice, welding increases and color deepens downward, forms a steep cliff in this section but is usually a slope former..........................	35
	Partial Cooling Break	
6D	Red tuff, partially welded, 10-15% crystals of feldspar, contains large pumice and weathered cavities, forms a prominent ledge............................	12
	Red tuff, partially to densely welded, 15% crystals of feldspar, contains pumice up to .5 meter in length, forms a low ledge..........................	10
	White tuff, densely welded, 20% crystals of feldspar, forms a steep ledge................................	1

Unit		Thickness in meters
6D (cont.)	Tuffaceous sediment, forms a low slope.............	3
6A?	Grey tuff, densely welded, 10-15% crystals of feldspar, 2% biotite, moderately abundant lithic fragments of	

extrusive rock, forms a steep slope................. 10

Cooling Reversal

6A Grey to white tuff, partially welded, 10-15% crystals of feldspar, 1% biotite, contains a few lithic fragments of extrusive rock, forms a moderate slope... 9

Grey to white tuff, densely welded, 10-15% crystals of feldspar, forms a prominent ledge.................. 10

Tuffaceous sediment, forms a low slope.............. 6

REFERENCES

Brook, C. A., Moriner, R. H., Mabey, D. R., Swanson, J. R., Guffonti, M., and Muffler, L. J. P., 1979, Hydrothermal convection systems with reservoir temperatures ≥ 90° C, in Muffler, L. J. P., ed., Assessment of geothermal resources of the United States, U. S. Geol. Survey Circ. 790.

Burke, D. B., and McKee, E. H., 1979, Mid-Cenozoic volcano-tectonic troughs in central Nevada: Geol. Soc. Amer. Bull., v. 90, p. 181-184.

Cunningham, C. G., and Steven, T. A., 1977, Mount Belknap and Red Hills Caldera and associated rocks, Marysvale volcanic field, west-central Utah: U. S. Geol. Survey Open File Report 77-568, 40 p.

Dane, C. H., and Ross, C. P., 1942, The Wild Horse quicksilver district, Lander County, Nevada, U. S. Geol. Survey Bull. 931-k, p. 259-278.

Gilluly, J., and Gates, O., 1965, Tectonic and igneous geology of the northern Shoshone Range, Nevada: U. S. Geol. Survey Prof. Paper 465.

Hildreth, W., 1979, The Bishop Tuff: evidence for the origin of compositional zonation in silicic magma chambers, in Ash Flow Tuffs, Chapin, C. E., and Elston, W. E., ed., Geol. Soc. Amer. Sp. Paper 180, 211 p.

Lipman, P. W., 1967, Mineralogical and chemical variations within an ash-flow sheet from Aso Caldera, southwest Japan: Cont. Min. Pet., v. 16, no. 4, p. 300-327.

Lipman, P. W., Christiansen, R. L., and Van Alstine, R. E., 1969, Retention of alkalis by calc-alkaline rhyolites during crystallization and hydration: Am. Min., v. 54, p. 286-291.

Mackin, J. H., 1960, Structural significance of Tertiary volcanic rocks in southwestern Utah: Am. J. Sci., v. 258, p. 81-131.

McKee, E. H., 1970, Fish Creek Mountain Tuff and volcanic center, Lander County, Nevada: U. S. Geol. Survey Prof. Paper 681, 17 p.

McKee, E. H., and Stewart, J. H., 1971, Stratigraphy and potassium-argon ages of some Tertiary tuffs from Lander and Churchill counties, central Nevada: U. S. Geol. Survey Bull. 1311-B, 28 p.

Muller, S. W., Ferguson, H. G., and Roberts, R. J., 1951, Geology of the Mount Tobin Quadrangle, Nevada: U. S. Geol. Survey Geol. Quadrangle Map GQ-7.

Naeser, C. W., and McKee, E. H., 1970, Fission-Track and potassium-argon ages of ash-flow tuffs, north-central Nevada: Geol. Soc. Amer. Bull., v. 81, no. 11, p. 3375-3384.

Noble, D. C., Smith, V. C., Peck, L. C., 1967, Loss of halogens from crystallized and glassy silicic volcanic rocks: Geochem. et Cosmochem. Acta, v. 31, po. 215-223.

Nockolds, S. R., 1954, Average chemical compositions of some igneous rocks: Bull. Geol. Soc. Amer., v. 65, p. 1007-1032.

O'Connor, J. J., 1965, A classification for quartz rich igneous rocks based on feldspar ratio: U. S. Geol. Survey Prof. Paper 525B, p. B79-B84.

Olson, H. J., Dellechaie, F., Pilkington, H. D., Lange, A. L., 1979, The McCoy geothermal prospect: status report of a possible new discovery in Churchill and Lander Counties, Nevada: Geotherm. Resc. Counc., Trans., v. 3, p. 515-518.

Riehle, J. R., McKee, E. H., Speed, R. C., 1972, Tertiary volcanic center, west-central Nevada: Geol. Soc. Amer. Bull., v. 83, p. 1383-1389.

Rosholt, J. N., and Noble, D. C., 1969, Loss of uranium from crystallized silicic volcanic rocks: Earth and Planetary Sci. News Letters, v. 6, p. 268-270.

Rosholt, J. N., Prijana, and Noble, D. C., 1971, Mobility of uranium and thorium in glassy and crystallized silicic volcanic rocks: Econ. Geol., v. 66, 1971, p. 1061-1069.

Sargent, K. A., and McKee, E. H., 1969, The Bates Mountain Tuff in northern Nye County, Nevada: U. S. Geol. Survey Bull. 1294-E, 12 p.

Scott, R. B., 1971a, Alkali exchange during devitrification and hydration of glasses in ignimbrite cooling units: Jour. Geol., v. 79, p. 100-110.

Scott, R. B., 1971b, Chemical variations in glass shards and interstitial dust of ignimbrite cooling units: Am. J. Sci., v. 270, p. 166-173.

Silberling, N. J., 1956, "Tracyceras zone" in the Upper Triassic of the western United States: Jour. Paleo., v. 30, no. 5, p. 1147-1153.

Silberling, N. J., and Roberts, R. J., 1962, Pre-Tertiary stratigraphy and structure of northwest Nevada: Geol. Soc. Amer. Spec. Paper 72, 58 p.

Slemmons, D. B., 1966, Guidebook for Nevada earthquake areas: 2nd U.S.-Japan Conf. on Research Related to Earthquake Predictions, 79 p.

Smith, R. L., 1960, Zones and zonal variations in welded ash-flows: U. S. Geol. Survey Prof. Paper 354-F, p. 140-159.

Smith, R. L., and Ross, C. S., 1961, Ash-Flow Tuffs: their origin, geologic relations, and identification: U. S. Geol. Survey Prof. Paper 366, 80 p.

Stewart, J. H., and McKee, E. H., 1968, Geologic map of the Mount Callaghan quadrangle, Lander County, Nevada: U. S. Geol. Survey Geol. Quadrangle Map GQ-730.

Stewart, J. H., McKee, E. H., and Stager, H. K., 1977, Geology and Mineral deposits of Lander County, Nevada: Nevada Bur. Mines and Geol., Bull. 88, 106 p.

White, D. E., 1970, Geochemistry applied to the discovery, evaluation, and exploration of geothermal energy resources, in United Nations Symposium on development and utilization of geothermal resources, Pisa: Geothermics Spec. Issue, v. 2, p. 58-80.

Willden, R., and Speed, R. C., 1974, Geology and mineral resources of Churchill County, Nevada: Nev. Bur. Mines and Geology, Bull. 83, 95 p.

Wrucke, C. T., and Silberman, M. L., 1975, Cauldron subsidence of Oligocene age at Mount Lewis, northern Shoshone Range, Nevada: U. S. Geol. Survey Prof. Paper 876, 20 p.