University of Nevada
Reno

Geology and Uranium Content
of Middle Tertiary Ash-Flow Tuffs
in the Northern Part of Dogskin Mountain, Nevada

A thesis submitted in partial fulfillment
of the requirements for the degree of
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by

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A composite thickness of more than 225 meters of middle Tertiary, rhyolitic, ash-flow tuffs are exposed in the northern part of Dogskin Mountain. The lower sequence of tuffs is composed of five cooling units erupted between 27 and 28 million years ago from at least two sources. Overlying the lower sequence of tuffs are three additional cooling units which were erupted from separate sources between 23 and 26 million years ago.

Early Tertiary structure was controlled by compression associated with the en echelon series of faults of the Walker Lane. This system of faults also defined zones of weakness which later controlled the strikes of Miocene to Recent normal faults.

All cooling units on Dogskin Mountain are potential uranium source rocks. Small uranium deposits occur in sediment-rich disconformities either at the base of the ash-flow tuff section or between the lower and upper sequence of tuffs.
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INTRODUCTION

GENERAL STATEMENT

This study was undertaken to describe and interpret the uranium-bearing tuffs of the Hartford Hill Rhyolite in the northern part of Dogskin Mountain. The major objectives of this study were: (1) map and describe cooling units within the ash-flow tuff assemblage known as the Hartford Hill Rhyolite; (2) define the uranium rich cooling units; (3) compare the uranium content of the glassy and devitrified zones of each cooling unit; and (4) develop a model relating crystallization, weathering and erosion of the tuffs to the formation of uranium ore deposits.

The northern portion of Dogskin Mountain was selected as the study area because of the abundance of tuffs and the occurrence of uranium deposits associated with these tuffs. In addition, the area was selected because of its close proximity to sections of the Hartford Hill Rhyolite recently described by Wallace (1975).

PHYSIOGRAPHIC SETTING AND LOCATION

Dogskin Mountain is located near the western margin of the Basin and Range physiographic province in southern Washoe County, Nevada (fig. 1). The area mapped lies in the northeast quarter of the U.S.C.S. fifteen minute quadrangle map of Dogskin Mountain, Nev.-Calif. The study area lies entirely within T.24N., R.19E., Mount
Figure 1. Index Map to Dogskin Mountain area and vicinity.

#1) region mapped in this study— — —
#2) Mine/Rainbow Canyon
#3) Red Rock Canyon
#4) Buckhorn Mine
#5) Field area of Bonham
#6) Field area of Deino
Diablo baseline and meridian. This township is located approximately 39°56' north latitude and 119°50' west longitude.

Dogskin Mountain is a northwest trending horst about ten miles long and as much as four miles wide. The area mapped consists of a portion within the northern third of this block. The highest points in the mapped area are in excess of 7,000 feet and local relief is more than 2,000 feet. The east side of the range rises abruptly from Winnemucca Valley. On the west side, topographic relief is more gentle and the canyons slope gradually into the valleys.

Drainage on the east side of the range is into Winnemucca Valley, then south through Warm Springs Valley and across Mullen Gap into the interior basin of Pyramid Lake. Drainage on the north and west sides of Dogskin Mountain is into Dry Creek which empties into Honey Lake, also an interior basin. All the streams in the area are intermittent; however, there are numerous perennial springs which supply partial flow to the streams.

The drainage pattern on Dogskin Mountain is a direct reflection of the rock type. The finely dissected dendritic pattern of the northern third of the mountain indicates a relatively soft rock type, that of the ash-flow tuffs. The coarse dendritic pattern of the southern two-thirds of Dogskin Mountain results from the more resistant granitic bedrock.

Vegetation consists of sparse coverage of sagebrush, junipers and an occasional pinon pine. The climate ranges from arid in the valleys to semi-arid in the higher elevations. Most of the precipitation occurs as winter snow or late spring to early summer thunder
showers.

Access to the area from Reno is either by traveling north on Nevada State Highway 33 (paved) to Winnemucca Ranch Road (graded) or northwest on U.S. 395 (paved) to Red Rock Canyon Road (graded) (fig. 1). The periphery of the area can be traveled by two wheel drive vehicle, but to travel across or along the crest of the area requires a four wheel drive vehicle.

METHODS AND PROCEDURES

Approximately sixty-five days were spent in the field during May through September, 1977. All mapping was done at 1:24,000 scale on a photographically enlarged part of the U.S.G.S. 15' Dogskin Mountain Nev.-Calif. quadrangle. Aerial photos (1:30,000 scale) were utilized to recognize structural trends but were not used in mapping. Stratigraphic sections were measured by use of a staff with a level sight at eye level. Dips and strikes were determined with a Brunton Compass. More than 400 rock samples were collected and returned to the lab where they were cut, ground and stained in sodium cobaltinitrite (Bailey and Stevens, 1960). This permitted easy determination of alkali feldspar with respect to plagioclase and quartz, and determination of the mineral ratios. One hundred and fifty thin sections were made from samples of the measured sections and from distinctive lithologic types. Point counts were done on all slides from the measured sections to determine the modal ratios. Twenty seven samples were analyzed by Wyoming Mineral Corporation's geochemical laboratory for fluorimetric uranium content. In addition, ten of these samples
were also analyzed for major oxides. Normative rock names based on
O'Connor's (1965) classification system were obtained from the chemical
results.

This report will follow the textural classification proposed
by Cook (1965) for ash-flow tuffs (Fig. 2). A characteristic of this
classification system is the use of the word "vitric" as a rock name
without regard to whether the rock is devitrified or not. The percent-
representation used by this system for the mineral ratios is 100% of
the phenocryst volume and not their rock volume. The graphic repre­
sentation of phenocryst volume and mineral ratios is shown in figure 5.
The numeric representation will be written as 10//60/30/7/3 (%pheno.//
%plag./%san./%qtz./%bio.) and is shown in various figures and positions
in the text.

PREVIOUS WORK

Relatively little has been published concerning the geology of
Dogskin Mountain. The only previous geologic mapping which included
Dogskin Mountain is the Washoe County Geologic Report published by the
Nevada Bureau of Mines (Bonham, 1969). In his report, Bonham mapped
the Tertiary ash-flow tuffs as Hartford Hill Rhyolite. He mapped the
Hartford Hill and granitic contact across Dogskin Mountain at a scale
of 1:250,000. No work to date has described the stratigraphy of the
cooling units of ash-flow tuffs in the northern Dogskin Mountains.

The stratigraphy of the Hartford Hill Rhyolite has been described
by several workers for nearby areas. These works can be divided into
two groups: pre-1960, and before development of the cooling unit
Figure 2. Textural composition triangle for ash-flow tuffs. Probably 90 percent of all ash-flow tuffs will fall below the 10 percent lithic line and to the right of the 50 percent crystal line. Diagram taken from Cook (1965).
concept (Smith, 1960; Ross and Smith, 1961); and post-1960, and after the use of the cooling unit concept (see page 10). Prior to 1960, workers mapped and described zones of lithologic and/or color change within the Hartford Hill. Brooks (1956) mapped such zones in the very well exposed sections along Mine and Rainbow Canyons (fig. 1).

McJannett (1957) described sections of Hartford Hill in the Red Rock Canyon/Buckhorn Mine area and also in the Mine/Rainbow Canyon area. Durrell (1959) described the Tertiary stratigraphy in the nearby Blairsden Quadrangle of California. Workers after 1960 mapped and described cooling units. Wallace (1975) studied the stratigraphy of the ash-flow cooling units in Rainbow and Mine Canyons and correlated the cooling units with mapped zones of Brooks (1956) and McJannett (1957). Holmes (1972) compiled a report which describes occurrences of uranium along the disconformities between cooling units at prospects on Dogskin Mountain and at other nearby locations. Garside (1973) briefly mentions the locations of high radioactivity in the tuffs on Dogskin Mountain. Cupp et al. (1977) summarizes the uranium favorability of the Hartford Hill Rhyolite in a recently published E.R.D.A. report.

Several authors have recently begun to intensely study the Tertiary silicic ash-flow tuffs of northwestern Nevada. Originally it had been common stratigraphic practice to group all tuffs which overlie Mesozoic basement and underlie andesite flows of the Alta and Kate Peak into one formation: the Hartford Hill Rhyolite (defined by Gianella [1936], revised by Thompson [1956], expanded by Bonham [1969] and Moore [1969]). However, as workers began to map cooling units
within the Hartford Hill Rhyolite it soon became apparent that the name Hartford Hill was only useful when used as a very broad and general term referring to the complete assemblage of pre-Alta silicic tuffs. In fact, it is now apparent that the Hartford Hill Rhyolite (originally defined as a formation) is composed of several distinctive groups which are in turn made up of cooling units of formation status.

Recent mapping of cooling units of pre-Alta ash-flow tuffs began with Bingler (1973) and his description of cooling units in the Wassuk Range east of Yerington. Wallace (1975), as previously mentioned, mapped cooling units in the Mine/Rainbow Canyon region of the Virginia Mountains. Proffett and Proffett (1976) described a thick stratigraphic section and formally named several of the tuffs in the Yerington District. Bingler (1978) mapped and formally named tuffs in the Carson City/Virginia City area. Several geologists from the U.S.G.S. (Bingler and Silberman, oral communication) are presently compiling a report of ash-flow tuffs in the Gillis and Gabbs Valley Ranges. Bonham (oral communication) of the Nevada Bureau of Mines is presently mapping ash-flow tuffs in the northern Pah Rah Range, and Deino from University of California at Berkeley is mapping the tuffs on Seven Lakes Mountain.

The new emphasis on study of middle Tertiary ash-flow tuffs in northwestern Nevada is apparent by the surge of investigations starting about 1973 and continuing through the ongoing projects. Recent publications of Proffett and Proffett (1976) and Bingler (1978) assign formal names to most of the major tuffs south of the Truckee River. Most of the ash-flow tuff cooling units north of the Truckee River
are separate cooling units and do not correlate with those formally named to the south. No published reports have described the tuffs north of the Truckee River and therefore formal names are lacking. Correlation of cooling units between areas north of the Truckee River is generally good. Gaps in mapping between areas north and south of the river make correlation between the two regions tentative in some cases. In this report, good correlation of the middle Tertiary ash-flow tuffs can be established with Wallace (1975) and with the ongoing studies of Bonham and Deino.

Bingler's (1978) work in the Carson City/Virginia City area not only formally named tuffs of formation status but also formally proposed abandonment of the term Hartford Hill Rhyolite. In this study, I will follow Bingler's (1978) recommendation and not refer to the silicic tuffs underlying the Alta as the Hartford Hill Rhyolite or the Hartford Hill Assemblage. Instead, I will refer to these rocks as the middle Tertiary ash-flow tuffs. The individual cooling units will be referred to either by formal names defined in published reports or by informal names. Formal names will be written as "The Singatse Tuff" or the "Nine Hill Tuff." Informal names will be written as "the tuff of Chimney Springs," or "the tuff of Dogskin Mountain." Informal group names will be written as "the tuff of the McKisnick Springs group."

THE COOLING UNIT CONCEPT

Ash-flow tuffs are turbulently emplaced as a result of violent eruptions of silicicous magmas from craters or fissures. The eruptions
are typically referred to as nuee ardente and deposit two basic rock
types: a basal ash-flow tuff; and an overlying air fall tuff (the
air fall tuff is often removed by the violence of the emplacement of
the next flow). The ash flows travel as semi-fluidized mixtures of
pyroclastic material and gas, initially filling gullies and channels.
Subsequent flows tend to smooth out and cover the underlying topography
until the surface expression is that of a flat sheet-like mass (fig. 3).
This thick sheet-like mass, which may be on the order of tens or hun-
dreds of meters thick, is usually the result of many ash flows emplaced
in very quick succession. The rapid nature of the emplacement of the
flows will generally recharge heat to the underlying flows and retard
their cooling. It is not until after the rapid emplacement of the
flows has ceased that the interior ash-flows are able to cool together
as a single unit. This type of unit has been identified and defined
as an ash-flow tuff cooling unit (Smith, 1960; Ross and Smith, 1961).

The concept of a cooling unit includes the preceding discussion
of emplacement as well as its cooling history and zonal development.
There are two separate and often overlapping trends of zonal develop-
ment in a cooling unit: the zone of compaction (welding) and the zone
of devitrification (crystallization). These zones (see fig. 3) start
to develop immediately upon deposition and culminate with the comple-
tion of cooling. (See Appendix I for a definition of the zonal con-
cept.)

The zones of compaction, hereto referred as welding, are the
direct result of lithostatic load on the still hot and plastically-
behaving pyroclastic material. The degree of welding is therefore
dependent upon the temperature and lithostatic gradient of the flows (Smith, 1960). The first zone to form is the result of rapid cooling of the basal part of the flow from contact with the cool underlying rocks. This zone takes on the texture of a chilled, non-collapsed tuff—the zone of non-welding. As the flows continue to be emplaced, their combined thickness will increase, thereby increasing their insulating capacity and lithostatic load. Such increases result in welding. Welding develops upward from the zone of non-welding, through a zone of partial welding, and into the zone of dense welding. Above the densely welded zone, the degree of welding decreases with the decrease of lithostatic load. This results in the densely welded zone being overlain by a second and generally thicker zone of partially and non-welded material. Where lateral thinning of the ash flows occur, such as at the distal ends and margins, the upper and lower zones merge (fig. 3). In this report, the partially welded zone of Smith (1960) has been subdivided into two parts: those of weakly welded, and those of moderately welded tuff. Weakly welded tuff shows compaction of pumice lapilli but no deformation of the groundmass. A moderately welded tuff shows compaction of pumice as well as deformation of the shards and groundmass. (See Appendix I for definitions of terms of welding.)

Crystallization of the glass shards and pumice fragments begins immediately upon emplacement. The retention of heat and the ensuing slow cooling causes the glass to "stew in its own juices." This causes devitrification of the shards and pumice and the migration of liberated volatiles along pressure and temperature gradients to
Figure 3. Schematic drawing of an ash-flow tuff cooling unit representing zones of welding and crystallization.
stable environments. The zones which develop as a result of (or lack of) crystallization are shown in the cross sections in Figure 3. These zones are: (1) the glassy zone; (2) the devitrified zone; and (3) the vapor zone. Not shown in Figure 3 is the secondarily devitrified zone which forms after the cooling of the unit. (See Appendix I for definitions of terms of crystallization.)

The glassy zone forms as a result of the very rapid cooling of the basal and uppermost flows of the cooling unit. In addition, a glassy zone may form at the very base of the densely welded zone where welding is so intense that it eliminates crystal growth. The glassy zone which forms at the base of the densely welded zone is called a vitrophyre.

The crystals within the devitrified zone generally consist of axiolitic and spherulitic intergrowths of cristobalite and alkalic feldspar (Ross and Smith, 1961; Smith, 1960). This crystallization develops as a result of the initial metastable condition of the glass. Occasionally, crystallization within the devitrified zone is so intense that spherulitic intergrowths completely obliterate the original shard structure.

The vapor phase zone develops in regions of low lithostatic pressure and high pore space. This zone usually develops in the upper section of the cooling unit and may overlap the upper margins of the devitrified zone. The crystallizing products are developed in pore space as platy crystal aggregates of tridymite, cristobalite and alkalic feldspars (Smith, 1960; Ross and Smith, 1961).

Secondarily devitrification develops after cooling and is caused
by the migration of ground water through the porous, non-welded to partially welded zones of the cooling unit. The cool aqueous solutions hydrate the rock and promote crystallization of zeolites and clays. This crystallization often gives a pale green tint to the rock. Iron oxide staining may accompany the secondary devitrification process.

Ash-flow tuffs are the products of late stage siliceous differentiates. In such differentiates, the silica, alkalies and volatile contents are increased. In most differentiates, the magma includes phenocrysts of various minerals. In the case of a rhyolite magma, these phenocrysts may include quartz, alkali feldspar (usually sanidine), plagioclase, minor amounts of biotite and trace amounts of hornblende and augite. A typical cooling unit generally contains these phenocrysts and shows a reversal in zones of the magma chamber; that is, the mafics and heavier phenocrysts increase towards the top of the cooling unit (Lipman, 1966). The amount of each mineral which is observed in the cooling unit is a reflection of the original magma composition and the crystallizing history of the magma.

Cooling units may be both extensive in their areal distribution and very constant in their chemical composition. The phenocryst volume and ratio of minerals change very little laterally across the cooling unit. Vertically, within a single cooling unit, the volume of phenocrysts may be observed to vary—in direct proportion to the degree of welding. In addition, there may be decreases in quartz and increases in mafics vertically, reflecting the reverse of a zoned magma chamber: a normally zoned cooling unit. The
converse, a reversely zoned cooling unit, may occur when the volcanic vent taps the magma chamber at depth and erupts the mafics and heavier phenocrysts first. However, even these changes of the mineral ratios are relatively minor when compared to the vast areal extent of the cooling unit. Because of this relatively constant chemical composition, each cooling unit can be identified on the basis of its unique suite of minerals, their ratios and the phenocryst volume. Furthermore, tops and bottoms of a cooling unit are distinctive. Not only will the phenocryst volume and mineral ratios change in the new cooling unit, but so will the degree of welding. Often disconformities of sediments, lava flows, or air fall tuffs will lie between cooling units. All these parameters, either combined or individually, indicate the contact between cooling units.
The general geology of southern Washoe County is described by Bonham (1969). The reader should refer to that report for an overall view of the stratigraphic section overlying the middle Tertiary ash-flow tuffs.

Rocks exposed in the study area are of Mesozoic, middle Tertiary and Quaternary age. Basically there are three major rock types: Mesozoic rocks, predominately plutonic; middle Tertiary volcanics, predominately ash-flow tuffs; and Quaternary sediments, primarily composed of alluvial deposits.

The main Mesozoic plutonic rock is a biotite-hornblende granodiorite. This rock makes up the bulk of Dogskin Mountain and is exposed along the southern boundary of the mapped area. The granodiorite is similar to rock types found on Fred and Petersen Mountains as well as in the Sierra Nevada. Bonham (1969) believes that the granodiorite in southern Washoe County is related to the Sierran Batholith. Roof pendants of metavolcanics and metasediments are reported by several authors (Glenn, 1968; Bonham, 1969) and have been observed at two isolated locations within the mapped area.

Middle Tertiary ash-flow tuffs nonconformably overlie the Mesozoic rocks. These tuffs represent the first of three phases of volcanism which occurred in the western Basin and Range during the
middle to late Tertiary (Silberman et al., 1976). Chemically the
tuffs represent a calc-alkaline suite of volcanic rocks. Silberman
et al. (1976) believe that this first phase of volcanism represents
a volcanic arc related to subduction along the California coast.
The latter phases, calc-alkaline intermediate (starting about 17
m.y.b.p.) and bimodal basalt-rhyolite (about 5-6 m.y.b.p. to present)
developed after the deposition of the middle Tertiary tuffs and are
not present in the mapped area.

The middle Tertiary ash-flow tuffs in Dogskin Mountain have
been subdivided and mapped as individual cooling units. Where cor­
relation of these cooling units with published reports of units in
other areas is possible, the formal names of the other workers are
adopted. Where correlation is not possible, the cooling units on
Dogskin Mountain are assigned informal names.

There are at least seven cooling units exposed along the
steeper northeastern side of Dogskin Mountain. The oldest of these
was emplaced about 28 million years ago and the youngest tuffs were
emplaced about 23 million years ago (correlated with dates from
Wallace [1975] and Bingler [1978]). Chemically the tuffs are all
very high in silica indicating origin from a rhyolitic magma. How­
ever, by modal analysis of the phenocryst content, the tuffs may
range from andesite to rhyolite. The tuffs in the northern portion
of Dogskin Mountain have an approximate total thickness of 225 meters.
MESOZOIC ROCKS

Peavine Sequence

The oldest rocks exposed in the northern part of Dogskin Mountain are two isolated occurrences of metavolcanic and metasedimentary rocks (Plate 1). These rocks are tentatively correlated with rocks of the Peavine sequence of Bonham (1969).

The metavolcanic rocks (Mmv, Plate 1) crop out at the base of the tuff section in the unnamed canyon on the east side of Dogskin Mountain (SE 1/4, SW 1/4 of sec. 15, T.24N., R.19E.). At this location the metavolcanics are truncated by a fault and have a total outcrop area of less than a quarter acre.

The metavolcanic rock is dark green to dark gray and is commonly porphyritic. The plagioclase phenocryst are generally small, ranging in length from 0.3-1.0 millimeters. The outcrops are massive with conspicuous epidote coating joints and fractures. Microscopically, the metamorphism of the groundmass makes recognition of the original minerals nearly impossible. The rock is altered to the greenschist facies with dominant albite, epidote and sericite. Apatite and magnetite are disseminated in the groundmass. Relic amphibole and pyroxenes are replaced by actinolite (?), chlorite and epidote. It was not possible to determine the original composition of the plagioclase due to the alteration. The metavolcanics appear to be derived from volcanic flows of intermediate composition.

The metasedimentary rocks (Mms, Plate 1) are exposed in the
canyon in the NE 1/4, NW 1/4 of sec. 28, T.24N., R.19E. The base of the metasediments is truncated by a fault and its top is onlapped by the lower section of the middle Tertiary ash-flow tuffs. At this location, less than 15 meters of a vertical section of metasediments is exposed and the total outcrop is smaller than that of the metavolcanics.

The metasedimentary rocks are massive, fine grained and show slight segregation of hornblende and biotite in the outcrop. No clear indication of bedding was observed in the field, although the segregated mineral layering may be confused for it. Under the microscope, the rock consists of a mosaic of quartz and plagioclase (An 30-45). Varying amounts of hornblende and biotite are present and show a slight preferred orientation. Triple point junctions of recrystallized quartz are present. Relict pyroxene grains are also present. The rock is a quartzofeldspathic schist and, as indicated by the orientation of hornblende and biotite, was subjected to metamorphism of the lower amphibolite facies.

The presence of andesine plagioclase, primary quartz and relict pyroxenes suggest that the rock was probably derived from sediments of volcanic rocks of intermediate composition. The degree of rounding of the grains is generally masked by the recrystallization of quartz. However, when the boundaries of the grains are observed, they appear to be angular. A suitable rock name, of this lithology, is metavolcaniclastic.

Rogers et al. (1974) believe the rocks of the Peavine sequence were deposited along the eastern margin of a magmatic arc, along a
transition between marine and continental environments. The volcanic rocks of the sequence are island arc tholeiitic to calc-alkaline in composition and were apparently derived from a subduction zone to the west (Rogers et al., 1974). The sedimentary rocks of the system were probably derived directly from the pile of volcanics.

Bonham (1969) tentatively assigns an age of late Triassic to Jurassic for rocks of the Peavine sequence. No fossils were observed in outcrops on Dogskin Mountain. Godwin (1958) has found fossil plant remains in Peavine sequence shale on the west side of Peavine Mountain. These fossils were dated by Axelrod as Jurassic. No accurate age of metamorphism has been reported; however, the regional metamorphism must pre-date the late Cretaceous Sierran intrusions.

Sierran Intrusions

The southern third of the mapped area consists of biotite, hornblende granodiorite (Mg, Plate 1) of Mesozoic age. Average specimens of the granodiorite are light to medium-gray, medium to coarse-grained, hypidomorphic granular. Their outcrops form the rugged and steep exposures of Dogskin Mountain to the south of the study area. Upon weathering, the rock disintegrates readily to form a coarse-grained sandy soil.

Under the microscope the rock contains about 50% subhedral to euhedral plagioclase (weak normal zoning, An 30-40). Potassium feldspar makes up from 10-15% of the rock. Quartz is anhedral, often strained, and comprises about 20% of the rock. Biotite and hornblende in about equal amounts make up 15% of the crystals. Accessory minerals
include traces of magnetite, apatite and zircon.

Granite aplites are conspicuous along many of the ridges and are intruded into the granodiorite. The aplite is light pink and has a sugary texture. It is commonly more resistant to weathering than the granodiorite and often makes up the ridge lines. The aplite was not studied petrographically (descriptions occur in McJannett, 1957) nor were they mapped as a distinct unit.

The intrusions on Dogskin Mountain are presumed to be Mesozoic in age and intrude the Triassic and Jurassic Peavine sequence (Bonham, 1969). Plutons in the Granite Range, about forty-five miles north of Dogskin Mountain, have been dated between 88.8 and 91.2 m.y. (Smith et al., 1971; Bonham, 1969). These dates are similar to those dates which one would expect for the intrusions of Sierran granodiorite on Dogskin Mountain and correspond with dates attained in the Sierran batholith to the south (Everden and Kistler, 1970). The ages of the aplite must be slightly younger or contemporaneous with the batholithic intrusions.

**MIDDLE TERTIARY ASH-FLOW TUFFS**

**General**

The middle Tertiary ash-flow tuffs in the northern part of Dogskin Mountain, heretofore assigned to the Hartford Hill Rhyolite Tuff by Bonham (1969) were subdivided and mapped as eight distinctive cooling units. Division into cooling units was based on changes in composition, phenocryst mineralogy (ratio and abundance), welding and
stratigraphic parameters of superposition, age and disconformities. Such division is based on the classic studies of ash-flow tuffs of Smith (1960) and Ross and Smith (1961). The eight cooling units were deposited between 28 to 23 million years ago. The tuffs include from oldest to youngest: the tuffs of the McKisnick Springs group (an informal group composed of four distinct cooling units); tuff of Dogskin Mountain; tuff of Jackass Springs; the Nine Hill Tuff (Bingler, 1978); and the tuff of Chimney Springs.

Correlation of these tuffs with the units of Wallace (1975) and Bingler (1978) is represented in Figure 4. Graphic representation of phenocryst mineralogy of each unit is shown in Figure 5. A complete stratigraphic section of all the tuffs on Dogskin Mountain is shown in Figure 6 and a partial section is represented in the photo in Figure 7.

Tuffs of the McKisnick Springs Group

The tuffs of the McKisnick Springs group are herein named for a group of mineralogically similar cooling units exposed in and around McKisnick Springs in the northern part of Dogskin Mountain. The type section of this group is in the SW 1/4 of sec. 15, T.24N., R.19E. At the type section, the McKisnick Springs group disconformably overlies Triassic to Jurassic metavolcanics. The group is disconformably overlain by the tuff of Dogskin Mountain.

Four mappable cooling units have been included in the McKisnick Springs group. These cooling units have been combined into a group because of their similar mineralogy and lithology (fig. 4). Each
Figure 4. Correlation chart for the middle Tertiary ash-flow tuffs of Bingler (1977), Wallace (1975), Bonham (1969), and the present study.
Figure 5. Histograms of phenocryst mineralogy of ash-flow cooling units of the middle Tertiary tuffs in the northern part of Dogskin Mountain, Nevada.
Figure 6. Stratigraphic section of ash-flow cooling units present in the northern part of Dogskin Mountain, Nevada. (%pheno/%plag/%san/%qtz/%bio)
Figure 7. Photo and schematic drawing of the type sections of the McKisnick Springs group and the tuff of Dogskin Mountain. At this location there is no Nine Hill Tuff present.

Tc - tuff of Chimney Springs
Td. - tuff of Dogskin Mountain

McKisnick Springs group
Tmd - Cooling Unit D
Tmc - Cooling Unit C
Tmb - Cooling Unit B
Tma - Cooling Unit A

Mesozoic metavolcanics - Mmv
cooling unit represents a complete cooling break and was mapped as an individual unit. From oldest to youngest the units are designated: Cooling Unit A; Cooling Unit B; Cooling Unit C; and Cooling Unit D. A complete discussion of each cooling unit follows.

Cooling Unit A

The lowest cooling unit of the McKisnick Springs group herein is informally named Cooling Unit A (Tma, Plate 1). This unit is exposed at one isolated location at the base of the type section of the McKisnick Springs group. At this locality the metavolcanics of the Peavine sequence are disconformably overlain by the light brownish gray, rhyolite vitric crystal tuff of Cooling Unit A. No sediments or other volcanics are present along the disconformity. Cooling Unit A is overlain disconformably by a thin bed (approximately 50 cm thick) of poorly outcropping pebble conglomerate, which is overlain by a light greenish gray vitric-crystal tuff.

Cooling Unit A is a simple cooling unit composed of two distinct zones of welding: a basal densely welded zone; and an upper partially welded zone. The densely welded zone forms a light brownish gray cliff six meters high. The cliff has a rugged outcrop pattern but lacks distinct columnar structure. In hand specimen, the tuff is composed of about 20% phenocrysts, about three-quarters of which are milky white plagioclase (0.5-1.0 mm long), and about 20% are sanidine, which can be distinguished from the plagioclase by its glassy appearance. Overlying the densely welded zone is three meters of light gray slope-forming tuff which comprises the partially welded zone.
Phenocrysts make up about 15% of the rock and resemble in composition and appearance those of the subjacent densely welded zone. Trace amounts of pumice (less than 1 cm long) and dark green metavolcanic lithic fragments are present throughout the cooling unit.

In thin section, the tuff appears strongly devitrified. Phenocrysts comprise about 20% of the tuff in the densely welded zone and include 74% plagioclase, 19% sanidine, 2% quartz and 5% biotite. The plagioclase is strongly altered to calcite and sericite. Secondary devitrification, as indicated by the presence of light green zeolites and clay, has affected the uppermost part of the partially welded zone.

Cooling Unit B

Cooling Unit A is disconformably overlain by as much as 70 meters of pale greenish gray to medium gray, pumice bearing, rhyolitic vitric-crystal tuff, here informally called Cooling Unit B (Tmb, Plate 1). The type exposures are located at the type section of the McKisnick Springs group. At this location, the base of Cooling Unit B overlies a thin bed of pebble conglomerate comprised of dark green to black metavolcanics set in a yellowish brown well indurated matrix. These sediments disconformably overlie the moderately to weakly welded top of Cooling Unit A. Elsewhere, as at the upper part of McKisnick Springs Canyon, Cooling Unit B nonconformably overlies Mesozoic granodiorite. At several other locations, the base of Cooling Unit B is not exposed due to faulting. Cooling Unit B is overlain by a very thin (2-5 cm) discontinuous bed of air fall tuff which is overlain by a densely welded, medium brownish red,
cliff forming vitric tuff.

Cooling Unit B is a compound cooling unit which varies from weakly to densely welded. A slight cooling break is observed at the type section of the McKisnick Springs group. This break occurs about 20 meters above the base and is denoted by a thin bed (5 cm) of tuffaceous sediments. Along the upper portions of McKisnick Springs Canyon no such break in Unit B is observed. The base of Cooling Unit B is made up of approximately 45 meters of partially welded tuff. The partially welded zone is overlain by roughly 5 meters of densely welded tuff, which is overlain by a 10 meter zone of partially welded tuff. This apparent reversal of the upper and lower zones of partial welding (the reverse of that shown in Figure 3) is thought by Smith (1960) to be an indication of a compound cooling unit.

The outcrops of Cooling Unit B are often platy and rarely appear massive. The cooling unit varies in color from pale greenish gray in the basal secondarily devitrified zone to moderate gray in the primarily devitrified zone (fig. 7). Pumice and lithic fragments are conspicuous throughout the unit. Flattened pumice "eyes" (0.5-3.0 cm long) occur where the pumice has been completely weathered out of the rock. The phenocrysts are very hard to distinguish in the field. The plagioclase varies in appearance from very glassy to milky white. Sanidine is glassy and about the same size as the plagioclase (0.5-1.5 mm long).

Cooling Unit B is composed of two slightly different tuffs separated by a discontinuous cooling break. The lower tuff is composed of about 18% phenocrysts: 57% plagioclase, 35% sanidine,
5% quartz and 3% biotite. The groundmass is thoroughly devitrified and secondary devitrification has affected the pumice and much of the groundmass. The upper tuff is composed of about 24% phenocrysts: 60% plagioclase (An 30-40), 33% sanidine, 2% quartz and 5% biotite. Secondary devitrification has affected only the lower 3 meters of the upper tuff. Above the secondarily devitrified zone, the upper tuff exhibits very slight primary devitrification which is generally confined to the dusty groundmass and pumice. The shards are generally still glassy. Pumice and lithic fragment content varies from 3% and 2%, respectively, in the lower tuff to 5% pumice and 2% lithics in the upper tuff. The lithics are comprised of dark green metavolcanics, black shale and black hornfels.

The exposed thickness of Cooling Unit B is constant throughout the mapped area. Very little lateral variation in the lithology of Cooling Unit B was observed.

Cooling Unit C

Cooling Unit B is disconformably overlain by 30 meters of reddish brown rhyolite vitric tuff, here named Cooling Unit C (Tmc, Plate 1). The type locality is the same as the type section of the McKisnick Springs group. At this location, Cooling Unit C overlies a very thin bed (2-5 cm) of tuffaceous sediments, which disconformably overlies the partially welded top of Cooling Unit B. Elsewhere the disconformity is not marked by tuffaceous sediments; instead, the top of Cooling Unit B is directly overlain by the base of Cooling Unit C. Cooling Unit C is overlain disconformably by 1-3 meters of volcaniclastic
Figure 8. The massive cliff zone of Cooling Unit C of the McKisnick Springs group. The contact between Cooling Unit C and Cooling Unit B is located at the base of the cliff. The man in the photo is approximately six feet tall.
sediments. These sediments are overlain by a light greenish gray, biotitic, vitric-crystal tuff.

Cooling Unit C is a simple cooling unit. It is densely welded at the base and weakly welded at the top. The lower two-thirds of the cooling unit boldly crops out as a massive cliff with moderately well developed columnar jointing (figs. 7 and 8). Rock in this zone is densely welded and is composed of about 10% phenocrysts. Pumice, lithic fragments and biotite comprise a small part of the total rock, or are completely lacking. Plagioclase and less often sanidine have been weathered out of the outcrops and have left euhedral casts in the rock which are sometimes filled with clay.

Overlying the densely welded zone is a zone of partial welding. The partially welded zone forms a slope which varies in color from bright brownish orange to light gray. Phenocrysts in this zone are somewhat better preserved than those in the lower zone. Biotite may comprise 2 to 3% of the phenocrysts.

The cliff forming tuff is composed of 10% phenocrysts, of which 40% are plagioclase and 60% sanidine. The plagioclase and, in places, the sanidine have been strongly altered to calcite, sericite and clays (?). Devitrification in the densely welded zone consists of intergrowths of cristobalite and alkaline feldspar, sometimes in spheroidal intergrowths. The upper partially welded zone exhibits a slight increase in total phenocrysts (up to 15%) and a slight increase in biotite (up to 2 to 3% of the phenocrysts). The most distinctive changes in the zone of partial welding are those of welding and crystallization. The tuff varies in a normal progression
from moderately to weakly welded. Vapor phase crystallization has affected the dusty groundmass while the pumice and shards are axiolithically devitrified.

Cooling Unit C is generally of constant thickness across the mapped area. One notable exception is the upper part of McKisnick Springs Canyon (NE 1/4, SE 1/4, sec. 22, T.24N., R.19E.) where Cooling Unit C changes southward in thickness from 20 meters to 0 meters at the springs and then to 15 meters further south.

Cooling Unit D

Cooling Unit C is disconformably overlain by 30 meters of repeated lithology of the basal zone of Cooling Unit B. This lithology is here informally named Cooling Unit D (Tmd, Plate 1). The type section of Cooling Unit D is designated as the same location as the type section of the McKisnick Springs group. An additional reference locality is on the slope to the west of McKisnick Springs (NW 1/4, sec. 22, T.24N., R.19E.). At most locations, the tuff of Unit D overlies a distinctive volcaniclastic bed (0-5 m thick) which also includes minor air fall ash. The volcaniclastic sediments vary from 50 to 80% plagioclase crystals cemented in a silica and iron oxide matrix. Lithics of underlying tuffs and propylitized lavas of intermediate composition make up from 3-10% of the rock. The bed of volcaniclastic sediments disconformably overlie the partially welded zone of Cooling Unit C. At McKisnick Springs, Unit D directly overlies the medium gray top of Unit B. The top of Cooling Unit D is marked by a thin reddish brown oxidized zone which is overlain by the
biotite rich crystal-vitric tuff of Dogskin Mountain.

Cooling Unit D is a simple cooling unit composed of a rhyolite vitric-crystal tuff. Unit D forms a prominent pale greenish gray to pale gray slope which distinctly overlies the reddish brown cliffs of Cooling Unit C (fig. 7). Cooling Unit D is slightly to moderately welded and forms platy outcrops which are conspicuously rich in pale green pumice and multi-colored lithics. The phenocrysts, as in Unit B, are hard to distinguish in hand specimens.

In thin section, Cooling Unit D is composed of approximately 15% phenocrysts, of which about 80% are plagioclase (sodic andesine), 14% sanidine and 6% are biotite. There are trace amounts of quartz and opaques found in the groundmass. Plagioclase and sanidine grains vary in length from 0.25-1.0 mm and from 0.5-1.5 mm, respectively. Primary devitrification is present throughout the unit. The intensity of devitrification varies from slight at the base to moderate at the top of the unit. Secondary devitrification has overlapped the zones of primary devitrification both at the base and top of the cooling unit.

Cooling Unit D varies in thickness from 20 to 30 meters. It is thickest near McKisnick Springs where Cooling Unit C pinches out. The composition of Cooling Unit D appears to be constant over the entire mapped area.

Emplacement of the McKisnick Springs Group

The McKisnick Springs group is composed of four ash-flow cooling units which comprise the base of the middle Tertiary ash-flow
tuff section present on Dogskin Mountain. However, these cooling units probably do not represent the base of the group. Cooling Unit A is of limited exposure, both in its distribution, and in the fact that only the upper part of the cooling unit is seen. The part of Cooling Unit A which is exposed suggests that the tuff is onlapping a basement high. In addition, the nonconformity between Cooling Unit B and the Mesozoic granodiorite further suggests onlap and indicates that highs of moderate relief of Mesozoic basement did exist. It can be surmised that if these highs existed, so did topographic troughs. No tuffs of the McKisnick Springs group have been identified in association with these troughs.

Other workers (Bonham, oral communication; Deino, oral communication) have identified in their areas both correlative and different tuffs in the basal group of tuffs of middle Tertiary age. Some of the different units should correspond to tuffs which probably underlie Cooling Unit A (Tml, Plate 1). These tuffs would be limited in their distribution in the direction of their width, but, because they fill topographic lows, would extend in the direction of their length over large distances. These basal tuffs tend to smooth out the topography and by the time Cooling Unit A and the overlying tuffs were emplaced, the surface expression was relatively flat, protruded only by isolated Mesozoic highs.

The genetic relationship of the four cooling units of the McKisnick Springs group is fairly clear. There is strong evidence, both megascopic and microscopic, that the tuffs of Cooling Unit B and D are closely related. Both tuffs have very similar outcrop appearances
and thicknesses. Their phenocryst composition and ratios are nearly identical. Microscopically the two units are nearly impossible to distinguish. There is slight indication that Cooling Unit A is genetically related to Cooling Unit C. In both of these tuffs the plagioclase and sometimes the sanidine are altered to calcite, sericite and clays. This suggests propylitic alteration. However, the alteration is confined to the respective units and is not regional. This seems to indicate a relation to the cooling history. If, as noted earlier, there are vapor phases associated with the cooling history, then there may also be associated fluid phases. Such a phase consisting of warm fluids may cause this type of alteration. The fact that this type of alteration is present in both Cooling Units A and C suggests that both units may have had similar cooling histories. Dense welding is present in each unit and indicates that they may have been emplaced at temperatures as high as 850°C (Ross and Smith, 1961). The ensuing cooling of each unit would first develop a vapor phase which would be followed by a fluid phase.

The source areas for the McKisnick Springs group do not lie within the mapped area. Bonham (oral communication) believes that the sources may be in the vicinity of the Pah Rah Range because of the thick section of basal units of the middle Tertiary ash-flow tuffs located in that range.

The cooling units of the McKisnick Springs group indicate that either a single magma source or at the most, two sources were tapped at the time of the eruption of the tuffs. The idea of a single magma source is consistent with the fact that the phenocryst composition is
essentially the same in the four units. However, a mechanism must be derived to explain the low phenocryst ratio and the relatively high emplacement temperature of Cooling Units A and C. Without such a mechanism, these factors seem to indicate the existence of a second magma source. One possible mechanism is that the vent or center of Cooling Units A and C tapped the magma chamber at a greater depth than the centers of the other cooling units. The deeper parts of the magma chamber should contain hotter and less crystallized magma as compared to magma at shallower depths. An indication of such a process, which is poorly illustrated in thin sections of Cooling Unit C, would be resorption of the phenocrysts. Because of the lack of conclusive evidence, it is impossible to determine how many magma sources were tapped.

Age correlations are tentative for the tuffs in the McKisnick Springs group. No cooling unit in the group has been radiometrically dated. However, dates are pending for correlative units in the Pah Rah Range (Bonham and Silberman, oral communication) and for units in Seven Lakes Mountain (Deino, oral communication). The only published date for the lower tuffs in one obtained by Wallace (1975) for the base of his Cooling Unit 1. This zone of Cooling Unit 1 probably correlates with Cooling Unit D of this report and yields an age of 28 m.y. before present. This date corresponds well with other dates obtained for the basal section of middle Tertiary ash-flow tuffs (Bingler, 1978; Proffett and Proffett, 1976; Silberman, oral communication). All the tuffs of the McKisnick Springs group seem to have been erupted in rather quick succession. This is
indicated by the lack of channels and sediments along the disconformities between the cooling units. It is possible to conclude that the McKisnick Springs group could very easily have been emplaced in a time period of less than one million years and that all the tuffs were emplaced about 28 m.y. ago.

The tuffs of the McKisnick Springs group have not been recognized in the section of tuffs south of the Truckee River. Bonham (oral communication) is mapping the basal group of the middle Tertiary ash-flow tuffs in the Pah Rah Range and has assigned them the field name of the tuffs of Whiskey Springs. Deino (oral communication) is mapping this group in Seven Lakes Mountain and has adopted Bonham's field name of the tuffs of Whiskey Springs.

**Tuff of Dogskin Mountain**

The tuffs of the McKisnick Springs group are disconformably overlain by as much as 50 meters of gray, biotitic, rhyolite crystal-vitric tuff, here informally named the tuff of Dogskin Mountain (Td, Plate 1) for its good exposures in the northern and northwestern parts of Dogskin Mountain. The type section lies on the northern slopes of the unnamed canyon just north of McKisnick Springs Canyon (SW 1/4 of sec. 15, T.24N., R.19E.). A principal reference section is designated along the northwestern face of McKisnick Springs Canyon in the N 1/2, SE 1/4 of sec. 22, T.24N., R.19E. The tuff of Dogskin Mountain is usually observed to overlie Cooling Unit D of the McKisnick Springs group. At most locations, this contact can be distinguished by a thin oxidized soil horizon which causes a thin reddish
brown band (0-1 meters thick) at the top of Cooling Unit D. At one location along the southern boundary of the tuffs, the tuff of Dogskin Mountain nonconformably overlies Mesozoic granitic rocks. The tuffs of Dogskin Mountain are disconformably overlain by channel controlled deposits of either densely welded vitric tuff or a crystal-vitric tuff.

The tuff of Dogskin Mountain is a compound cooling unit which varies from weakly to moderately welded. A discontinuous cooling break of tuffaceous sediments (5-10 cm thick) is observed at the base of the cliff which occurs in the moderately welded tuff. This cooling break occurs about 20 meters above the base of the cooling unit. On the west side of Dogskin Mountain no sediments were observed below the cliff. The tuff of Dogskin Mountain shows a reversal of the weakly and moderately welded tuffs. The significance of such a reversal has been noted earlier.

The tuff of Dogskin Mountain is almost entirely partially welded. The welding within the partially welded zone varies from weak to moderate. This zone generally forms a light gray slope with very platy outcrops. There is, however, a distinctive cliff which also forms in the partially welded zone. The welding of the cliff approaches dense welding, but, in the strict sense of the definition (see Appendix I), is moderately welded. This cliff is light gray and exhibits poorly developed columnar structure which forms wide vertical blocky outcrops with rounded tops. Within the partially welded zone are two slightly different tuffs separated by a discontinuous cooling break. The lower tuff, which always forms a slope, has approximately
27% phenocrysts, a few percent of which are quartz. The upper tuff, which forms the discontinuous cliff as well as an overlying slope, contains nearly 33% phenocrysts and rarely has any quartz present. The basic mineralogy of the two tuffs is about 90% plagioclase and 10% biotite. The distinctive decrease in sanidine percentage and the high plagioclase and biotite content make the tuff of Dogskin Mountain petrographically distinctive. However, for the untrained eye, distinguishing this decrease of sanidine in the field may be very difficult. In addition, the plagioclase is often very glassy in appearance and may exhibit a pseudo-conchoidal fracture which may cause it to be mistaken for quartz. Both lithic fragments and pumice lapilli are very abundant throughout the cooling unit. Pumice "eyes" are present throughout, but become particularly conspicuous in the moderately welded cliff. The lithic fragments and pumice are present in amounts which vary from 3-6% and 5-9%, respectively. The lithics are generally fragments of metavolcanics and occasionally shales and hornfels. The pumice varies in length from 1 to 4 cm and is generally light greenish gray in color.

The tuff of Dogskin Mountain contains 27-33% phenocrysts. Plagioclase accounts for about 90% of the phenocrysts and varies in composition from An20 to An43. Normal zoning is present in some of the plagioclase. The phenocrysts vary in size from 0.25 to 2.5 mm; however, they have an average length of 0.75 mm. Biotite grains are generally about 0.75 mm long. Primary devitrification is present throughout the cooling unit. The devitrification varies from moderate to weak. Glassy shards and pumice are usually observed in the middle
regions of the cooling unit. The top and bottom of the cooling unit exhibit the strongest devitrification. Secondary devitrification has occurred at the very top of the cooling unit.

Emplacement of the Tuff of Dogskin Mountain

The tuff of Dogskin Mountain is composed of two slightly different but genetically related tuffs. No volcanic centers or vents for these tuffs have been identified. However, the abundance of lithic fragments seems to indicate a relatively close proximity (less than 25 miles) to the source. The base of the tuff of Dogskin Mountain was emplaced over the flat upper surface of Cooling Unit D and onlapped Mesozoic granitics along the southern part of the mapped area. No channel features were observed over the disconformity of Cooling Unit D. The thin oxidized zone which overlies the disconformity is probably a weathered soil horizon. The thinness of this horizon, and the lack of sediments, indicates that a relatively short span of time elapsed between the cooling of Unit D and the emplacement of the tuff of Dogskin Mountain. It is tentatively concluded, on the basis of this disconformity, that the tuff of Dogskin Mountain was emplaced no less than 27 m.y. ago. No radiometric dates have been obtained for this tuff.

The tuff of Dogskin Mountain appears to be correlative with lithologically similar tuffs in the Pah Rah Range and in Seven Lakes Mountain. A tentative correlation may be established with a very mineralogically similar tuff in the Gillis and Gabbs Valley Ranges called the Petrified Springs Tuff (Bingler, oral communication).
Zone of Disconformity

Three different lithologic types disconformably overlie the tuff of Dogskin Mountain. These include sediments, volcanic flows and lahars of intermediate composition, and ash-flow tuffs. Neither the sediments nor intermediate volcanics attain great enough stratigraphic thickness or regional extent to be mapped as individual units. Reference localities of the thickest sequence of sediments, volcanic flows and lahars are as follows: SW 1/4, NW 1/4, SE 1/4 of sec. 22, T.24N., R.19E.; and the NW 1/4, SW 1/4, SW 1/5 of sec. 16, T.24N., R.19E. At these locations, two to three meters of coarse grained feldspathic sediments are overlain by slightly porphyritic volcanic flows of intermediate composition. No petrographic studies were conducted on any of these rocks. At many locations, small amounts of volcanics and/or sediments occur as float at the top of the tuff of Dogskin Mountain but do not form prominent outcrops. Three ash-flow tuffs comprising the upper sequence of the middle Tertiary ash-flow tuff assemblage overlie the tuff of Dogskin Mountain. However, their stratigraphic sequence can be clearly identified at locations where these tuffs are in direct contact with each other. From base to top, these tuffs include: the tuff of Jackass Springs; The Nine Hill Tuff; and the tuff of Chimney Springs.

Tuff of Jackass Springs

The tuff of Dogskin Mountain is disconformably overlain by a
poorly exposed densely welded biotitic, vitric-crystal tuff of rhyolitic composition. This tuff is here informally named the tuff of Jackass Springs (Tj, Plate 1). The only mapped occurrence of this tuff is located in the prominent canyon just east of Jackass Springs in the SE 1/4 of sec. 17, T.24N., R.19E. At this location, the tuff of Jackass Springs rests on about 8 meters of sediments and volcanic flows which disconformably overlie the moderately welded tuff of Dogskin Mountain. The tuff of Jackass Springs is disconformably overlain by the very densely welded, vitric Nine Hill Tuff.

The tuff of Jackass Springs is a simple cooling unit and is the oldest cooling unit of the middle Tertiary ash-flow tuffs that contains an appreciable amount of quartz phenocrysts. The cooling unit is about 18 meters thick and is composed to two distinct zones: a basal light tan to brown densely welded zone (only observed at the type section); and an upper gray to light greenish gray, partially welded zone. The basal zone forms a distinct cliff approximately 12 meters high at the base of the unnamed canyon in section 17. The partially welded zone forms a six meter slope which is often covered with talus of overlying tuffs.

The phenocryst content of the tuff of Jackass Springs ranges from 13 to 18% and is comprised of approximately equal amounts of plagioclase (An 37-42) and sanidine, 6 to 14% quartz and about 6% biotite. Lithic fragments are generally absent; however, 2 to 4 percent of the rock may be comprised of pumice. The quartz is generally resorbed and has a wormy appearance in hand specimen. The rock is entirely primarily devitrified. Devitrification is
strongest in the partially welded zone where it consists of axiolitic and spherulitic intergrowths.

The upper partially welded zone of the tuff of Jackass Springs had been identified in the early phases of mapping at a few isolated locations along the western and southwestern parts of the mapped area. However, this lithology was not mapped as a distinct unit, rather it was included as the top of the tuff of Dogskin Mountain. At such locations, no distinct sediments or volcanic flows mark the contact between the two tuffs.

Emplacement of the Tuff of Jackass Springs

The emplacement of the tuff of Jackass Springs was probably controlled by a channel which developed along the top of the tuff of Dogskin Mountain. The deepest part of this channel exposed on Dogskin Mountain is located at the type section of the tuff of Jackass Springs. The other occurrences of this tuff (which were mapped as the upper part of the tuff of Dogskin Mountain) represent onlap of the tuff of Jackass Springs over the tuff of Dogskin Mountain.

The age of the tuff of Jackass Springs is uncertain. It seems likely that it was emplaced sometime between 27 to 25 million years ago.

The tuff of Jackass Springs reaches distinct and mappable dimensions on Seven Lakes Mountain (Deino, oral communication). Deino has tentatively named this tuff the Last Day Canyon Tuff. It is unknown how extensive the tuff of Jackass Springs is in the Pah Rah Range. Initial observations indicate that it is very limited in this
The Nine Hill Tuff

The Nine Hill Tuff (Tn, Plate 1) is one of the most lithologically distinct cooling units present in the middle Tertiary ash-flow tuff assemblage. It was named for exposures in and around Nine Hill in the Virginia Range near Virginia City, Nevada (Bingler, 1978). At the type locality it is a compound cooling unit which includes three distinct rock types: a basal densely welded vitric tuff; overlain, through normal progression of decrease in welding, by a non-welded pumice-poor vitric tuff; overlain in turn by a very densely welded crystal-rich vitric tuff. Bingler (1978) also describes a fourth rock type, a non-welded, pumic lapilli, vitric tuff, which appears to comprise the entire unit at some locations. In Dogskin Mountain, the densely welded vitric tuff which disconformable overlies the tuff of Jackass Springs and the tuff of Dogskin Mountain is directly correlative with the Nine Hill Tuff. Reference localities on Dogskin Mountain are designated in the NE 1/4, SE 1/4 of sec. 14, T.24N., R.19E., and in the SW 1/4 of sec. 17, T.24N., R.19E. At the location in section 14, the Nine Hill Tuff consists of one lithology, a densely welded pumice-rich, vitric tuff. This lithology is the dominant rock type of the Nine Hill Tuff exposed on Dogskin Mountain. However, in section 17, a more lithologically diverse section of Nine Hill is present. This section resembles the compound nature of the Nine Hill Tuff described by Bingler (1978).

The limited lateral distribution of the Nine Hill Tuff indicates

area (Bonham, oral communication).
that the tuff's emplacement was controlled by channels which developed within the upper portions of the tuff of Dogskin Mountain (fig. 9). The base of the Nine Hill Tuff directly overlies coarse-grained sediment which collected in these channels. The sediments disconformably overlie the tuff of Dogskin Mountain. Along the flanks of these channels this disconformity is not marked by sediments, instead, the two tuffs are in direct contact with each other. In section 17, the Nine Hill Tuff disconformably overlies the tuff of Jackass Springs. No sediments are associated with this contact. The Nine Hill Tuff is overlain by either a light green crystal-vitric tuff or a red vapor phase crystal-vitric tuff.

The base of the Nine Hill Tuff is exposed at the reference locality in section 14. There it overlies a cobble conglomerate consisting of clasts of the tuff of Dogskin Mountain and a coarse grained feldspatic sandstone. At this location, the basal 3-5 meters of the Nine Hill Tuff is brecciated. The breccia clasts are 2 to 10 millimeters in length and consist of a moderately welded vitric tuff approximately 75% sanidine and 25% plagioclase. The matrix of the breccia is almost entirely converted to iron oxide and is very well indurated. This thin zone outcrops sporadically along the eastern side of Dogskin Mountain. The breccia zone is overlain by 40 meters of very densely welded (length to thickness ratio of the pumice about 20:1) to moderately densely welded pumiceous vitric tuff. The rock varies in color from pale reddish orange to dark reddish purple. At this location, the Nine Hill Tuff typically consists of 7-12% phenocrysts: sanidine 75%; plagioclase (Na-andesine) 20%; and about
5% quartz. Biotite is conspicuously absent. The rock contains from 10 to 15 percent strongly flattened, gray to black pumice lapilli. The length of the pumice fragments is generally less than 5 cm, but an occasional lapilli up to 15 cm is not uncommon. Lithic fragments are generally absent. Lithophase parting and/or weathered pumice hollows form a distinct flattened "eye" appearance in the outcrop. The cliffs are blocky and exhibit moderately developed columnar structure. Vapor phase crystals resembling "desert varnish" are well developed on faces of the columns. In addition, coarse grained vapor phase crystals are apparent in open space fractures and as recrystallization products after pumice. Microscopically, the extent of vapor phase crystallization is confined to fractures and pumice lapilli. The matrix and shards exhibit strong primary devitrification.

The lithology described above is typical for most of the Nine Hill Tuff in the mapped area. However, in section 17, this basal lithology is overlain by a gray partially welded vitric tuff. This tuff contains less pumice (about 5% of the rock) than the subjacent underlying tuff, and it contains from 1 to 2% biotite. The sanidine to plagioclase ratio is about 3:2. Quartz comprises about 5% of the phenocrysts. The zone of partial welding is about 15 meters thick; it is overlain by a light yellowish brown vitrophyre about one meter thick (17/10/28/2/-). The vitrophyre is overlain by a zone of densely welded biotitic, crystal-rich, vitric tuff. The basic phenocryst ratio and mineralogy is unchanged except for the presence of 3 to 6 percent biotite. This uppermost densely welded zone is about
15 meters thick.

In section 17, the outcrop pattern of the middle partially welded zone and the overlying densely welded zone is complicated by the fact that the rocks are exposed on a dip slope. The complex relationship of this dip slope to the exposures in section 17 is not apparent on Plate 1 since the units were not individually mapped.

Emplacement of the Nine Hill Tuff

The distribution of the Nine Hill Tuff was restricted to topographic troughs and channels developed within the tuff of Dogskin Mountain. Most of these troughs and channels had fairly gentle profiles. In the base of the channels, the Nine Hill Tuff rests on sediments; however, most of the contacts indicate onlap of the Nine Hill Tuff over the tuff of Dogskin Mountain. It appears possible that belts of the upper non-welded tuff of Dogskin Mountain existed as highs protruding the surrounding surfaces of the Nine Hill Tuff (fig. 9). The emplacement of the Nine Hill Tuff along at least one of the channels which existed on the east side of Dogskin Mountain was over wet, saturated sediments. The effects of the vaporization of the moisture within the sediments probably caused the brecciation of the lower zone of the Nine Hill Tuff in this area.

The Nine Hill Tuff is a normally zoned cooling unit: the quartz content decreases upward while the biotite increases. This suggests that the vent area tapped the magma chamber near its top. The very densely welded nature of zones of the cooling unit suggest very high emplacement temperatures.
Figure 9. Schematic drawing representing the emplacement of the Nine Hill Tuff over the tuff of Dogskin Mountain.

A) Approximately two million years elapsed after the cooling of the tuff of Dogskin Mountain before the Nine Hill Tuff was emplaced. During this time moderately deep canyons were cut into the partially welded top of the tuff of Dogskin Mountain.

B) The Nine Hill Tuff was erupted from a source about 45 miles south of the study area. By the time the Nine Hill Tuff reached the study area its distribution was controlled by channels in the top of the tuff of Dogskin Mountain.
No radiometric dates are available for the Nine Hill Tuff. Bingler (1978) considers the Nine Hill Tuff to be approximately 25 \(25.22 \pm 0.03\) million years old. He arrives at this date from a sandwich of radiometric dates of underlying and overlying cooling units. An age of 25 million years for the Nine Hill Tuff indicates that approximately two million years elapsed between the cooling of the tuff of Dogskin Mountain and the emplacement of the Nine Hill Tuff.

Bingler's (1978) mapping of the Nine Hill Tuff in the vicinity around Virginia City, Nevada, designates a region that he suggests might be a cauldron source for the Nine Hill Tuff. The existence of this tuff as far north as Dogskin Mountain (some 45 miles from its source) suggests the large areal extent that the tuff covers. In addition to Dogskin Mountain, the Nine Hill Tuff has been identified on Seven Lakes Mountain (Deino, oral communication), and in the Pah Rah Range (Bonham, oral communication). Wallace (1975) mapped a correlative tuff in Rainbow and Mine Canyons and called it Cooling Unit #2. Bingler (1973; oral communication) has identified the lithology of the Nine Hill Tuff as far south as the Singatse and Wassuk Ranges and as far east as the Gillis Range.

Tuff of Chimney Springs

Disconformably overlying the Nine Hill Tuff is a very distinctive quartz-rich, crystal-vitric tuff. Bonham (oral communication) has informally assigned the name the tuff of Chimney Springs (Tc, Plate 1) to this tuff in the Pah Rah Range (type locality, SE 1/4 of sec. 20, T.22N., R.22E.). In this report, the name tuff of
Chimney Springs is adopted for rocks of this lithology which overlie the Nine Hill Tuff on Dogskin Mountain. Reference locations for the tuff of Chimney Springs in Dogskin Mountain are as follows: SE 1/4, NW 1/4 of sec. 14 and the EW 1/4, SW 1/4 of sec. 29, T.19N., R.24E. The tuff of Chimney Springs overlies either the tuff of Dogskin Mountain or the Nine Hill Tuff. The contact between the tuff of Chimney Springs and the tuff of Dogskin Mountain is sometimes marked by sediments and/or volcanic rocks of intermediate composition. No sediments or volcanics are associated with the contact between the tuff of Chimney Springs and the Nine Hill Tuff. No tuffs have been observed to overlie the tuff of Chimney Springs in the mapped area.

The tuff of Chimney Springs is a simple cooling unit of weakly to moderately welded, often brightly colored, vapor phase, crystal-vitric tuff. At many locations, the tuff of Chimney Springs consists of two distinct zones: a light green to greenish gray, basal secondarily devitrified zone; and an overlying brick red, vapor phase zone.

The basal zone is a weakly welded, poorly outcropping slope former which varies in its thickness from 0 to 15 meters. Typical samples from this zone are light green to light greenish gray. White blotches of pumice lapilli are common in this zone. The phenocryst content may vary from about 18% at the base to about 28% at the top of the zone. The phenocrysts are comprised of about equal amounts of sanidine (often brilliantly chatoyant) and quartz (slightly wormy at the base), with about 10 to 15% plagioclase. Biotite is conspicuously absent. The pumice content varies from about 5 to 12 percent of the rock.
Microscopically, the phenocrysts of quartz and sometimes sanidine are resorbed. The plagioclase is Ca-oligoclase to Na-andesine in composition. Quartz and sanidine phenocrysts are about 1 to 2 millimeters in length. The plagioclase is generally somewhat smaller. No strong axiolitic intergrowths are present in the shards. This indicates that the rock is only moderately primarily divitrified. The pervasive light green color of the rock and the presence of low birefringent minerals in the matrix indicates that the rock is also secondarily devitrified.

Overlying the light green secondarily devitrified zone is the very distinctive vapor phase zone (0-60 m thick). This zone is marked by a red to reddish brown cliff which exhibits poorly developed columnar structure. Phenocryst content in this zone is generally about 30 to 35 percent and consists of the same ratio of minerals as present in the lower zone. Biotite may be present in trace amounts. The quartz generally occurs as euhedral bipyramids and is not resorbed. Sanidine is generally more chatoyant in this zone. The outcrops of the vapor phase zone are usually well indurated; however, friable (siliar) portions have been observed.

In thin section, disseminated iron oxide tends to mask much of the groundmass. Where the groundmass is observed, the devitrification intergrowths are coarse grained and indicate vapor phase crystallization. The vapor phase nature is also apparent by the coarse crystallization products which develop in the pumice. Fibrous overgrowths, resulting from the dissemination of iron oxide, occasionally cover the phenocrysts.
Along the lower margins of the northeastern side of Dogskin Mountain, the tuff of Chimney Springs consists solely of the upper vapor phase zone. Some parts of this zone occur as a light gray color and exhibit only weak vapor phase crystallization.

Emplacement of the Tuff of Chimney Springs

The emplacement of the tuff of Chimney Springs was controlled by channels in the Nine Hill Tuff and the tuff of Dogskin Mountain. It appears that the primary control to the development of these channels was the degree of welding of the underlying rocks. The channels did not cut deeply into the densely welded portion of the Nine Hill Tuff, instead, they developed along the margin of onlap between the Nine Hill and the tuff of Dogskin Mountain. This relationship suggests that the channels developed with a steep cliff face of the resistant Nine Hill Tuff on one side, and a gentle slope of the tuff of Dogskin Mountain on the other. When the tuff of Chimney Springs was emplaced in these channels, it would form a sharp, near vertical contact with the Nine Hill Tuff. (Such contacts may be confused with faults.)

On the other side of the channel, the tuff of Chimney Springs onlapped the smooth slope of the tuff of Dogskin Mountain (fig. 10). Evidence of this relationship can be seen at several locations in the mapped area. A typical example is the contact between the tuff of Chimney Springs and the Nine Hill Tuff on the knoll just south of Hill 6827 (Plate 1).

No prospective sources have been identified in the field area. It appears that the tuff of Chimney Springs was erupted from a single
Figure 10. Schematic drawing representing the emplacement of the tuff of Chimney Springs (see also Figure 9).

A) Approximately 1 to 2 million years elapsed between the cooling of the Nine Hill Tuff and the emplacement of the tuff of Chimney Springs. During this time channels developed in the partially welded top of the tuff of Dogskin Mountain. Channels generally did not develop on the densely welded Nine Hill Tuff.

B) The tuff of Chimney Springs was erupted from a source to the south of the study area. Its distribution in the mapped area was initially controlled by the channels which had formed on the top of the tuff of Dogskin Mountain. However, in later stages the tuff of Chimney Springs overflowed its banks and onlapped the two lower tuffs.
source. The marked increase in the phenocryst content from the base to the top of the unit may be a reflection of increased water pressure towards the margin of the magma chamber. Green (1973) has suggested that increased water pressures along the margins of a chamber would retard crystal growth. Therefore, when the chamber is initially tapped, the rapid decrease in water pressure would cause resorption of the phenocrysts along the margin of the chamber and the subsequent emplacement of a relatively crystal-poor tuff. The upper crystal-rich zone resulted as the vent tapped the interior of the chamber where the water pressure was low and crystallization more advanced.

No radiometric dates are available for the tuff of Chimney Springs. Trexler (1977), in his mapping of the Carson City quadrangle, interprets the stratigraphic position of the tuff of Chimney Springs to overlie the Eureka Canyon Tuff and underlie the Santiago Canyon Tuff. Bingler (1978) has attained dates of 25.0 ± 1.0 and 22.2 ± 0.8 m.y.B.P., respectively, for these two tuffs. The extent of erosion along the disconformity between the Nine Hill/tuff of Dogskin Mountain and the tuff of Chimney Springs indicates that about the same amount of time elapsed between the emplacement of the tuff of Chimney Springs over the Nine Hill as had elapsed between the emplacement of the Nine Hill Tuff over the tuff of Dogskin Mountain. It can be concluded that from one to two million years of erosion took place between the cooling of the Nine Hill Tuff and the emplacement of the tuff of Chimney Springs. This yields a tentative age of 23 to 24 million years for the tuff of Chimney Springs.
The tuff of Chimney Springs is a regionally extensive tuff. It corresponds to Wallace's Cooling Unit 3 in Mine and Rainbow Canyons and is present on Seven Lakes Mountain (Deino, oral communication). The tuff of Chimney Springs is also present in the Pah Rah Range (Bonham, oral communication). Trexler (1977) has mapped occurrences of this tuff as far south as the southern end of Washoe Lake.

Summary of the Middle Tertiary Ash-Flow Tuffs

The northern part of Dogskin Mountain was a site of deposition of Oligocene ash-flow tuffs. During this period more than 225 meters of tuff accumulated. These tuffs can be separated into two sequences on the basis of their eruptive history. The lower sequence consists of five cooling units (A through D of the McKisnick Springs group and the tuff of Dogskin Mountain) which were erupted in quick succession between 28 and 27 million years ago. This sequence consists of mineralogically similar tuffs that were erupted from at least two separate sources. These sources were near enough to Dogskin Mountain to permit each tuff sheet to have a blanketing effect over the surrounding topography. The upper sequence includes the tuff of Jackass Springs, the Nine Hill Tuff and the tuff of Chimney Springs. These cooling units are separated from each other by time gaps of from one to two million years. None of the upper tuffs blanketed the area, instead, their distribution was controlled by channels which developed on the tuff of Dogskin Mountain. This relation suggests that the sources of the upper sequence of tuffs were further away (probably to the south) than the sources of the lower tuffs.
No ash-flow tuffs were observed to overlie the tuff of Chimney Springs. In most locations north of the Truckee River, this relation is true. However, Wallace (1975) identified three cooling units overlying the tuff of Chimney Springs in Rainbow and Mine Canyons. Because these cooling units have not been observed in any other region, they are considered the exception and not the norm. It seems reasonable to conclude that after approximately 23 million years ago, the northern part of Dogskin Mountain became a site of erosion and not deposition.

QUATERNARY DEPOSITS

The western and eastern margins of the northern part of Dogskin Mountain are covered with Quaternary deposits. Two types of alluvium were mapped: rock pediments (Qp, Plate 1); and undifferentiated alluvium (Qa). In addition, landslide deposits (Qls) were also mapped.

The pediments are confined to the northwestern side of Dogskin Mountain. They consist of a thin veneer of gravel and cobbles (0-3 meters thick) which overlie the tuff of Dogskin Mountain. The cobbles of the pediments are mostly derived from the Nine Hill Tuff and the tuff of Chimney Springs.

The undifferentiated alluvium consists primarily of alluvial fans, eolian sands and undifferentiated Quaternary surficial deposits. No Lake Lahontan sediments are present. This is consistent with the fact that the Warm Springs Basin was covered by Lake Lahontan only to an elevation of 4,400 feet (Glenn, 1968) and that minimum elevations in the mapped area are 4,800 feet.
The regional structure in the area around Dogskin Mountain is dominated by strike-slip faults related to the Walker Lane, and by Basin and Range normal faults (fig. 11). This faulting results in northwest trending horsts and grabens.

The en echelon series of right lateral strike-slip faults which form the Walker Lane extend from Honey Lake, California, south through western Nevada to fault zones in the Death Valley and Las Vegas areas. Bonham (1969) presented evidence for right lateral faulting on the Walker Lane in Winnemucca Valley. The Walker Lane zone near Winnemucca Valley probably includes a strand fault on the east side of Virginia Mountain (Slemmons, oral communication) and additional strand faults on the west and east sides of Dogskin Mountain (see fig. 11). This indicates a total width of the Walker Lane fault zone in excess of 30 kilometers in this region. The trends of the right lateral slip faults in southern Washoe County average N.40°W. to N.45°W. This is essentially the same orientation as the San Andreas fault in California. The orientation corresponds to first order right lateral wrench fault and results from an approximate north-south compression axis (Wright, 1976). Movement on the Walker Lane may date as early as late Mesozoic as is suggested by recent mapping by the U.S. Geological Survey in the Gillis-Gabbs Valley Ranges (Bingler, oral communication).
Figure 11. Skylab photograph showing the regional structure in the vicinity of Dogskin Mountain.

#1) Northern part of Reno and Sparks, Nevada.

#2) Pyramid Lake. Longest dimension of the lake is approximately 30 miles.

#3) "Circular feature".

#4) Inferred location of Walker Lane fault traces.

#5) The area of study, located in the northern part of Dogskin Mountain, Nevada.
Movement on the Walker Lane continues through today. Historical faulting along or near the Walker Lane includes possible historic offset south of Pyramid Lake (Bell and Slemmons, 1978), in the Cedar Mountain area (Gianella and Callaghan, 1934) and at Fort Sage Mountain (Gianella, 1957).

Basin and Range extensional faulting also affects this region. Normal faults are usually controlled by preexisting splays of strike-slip faults and generally follow a northwest trend. Movement resulting from Basin and Range extensional faulting is normal to oblique slip. A general inception date of Basin and Range faulting in Nevada is placed at approximately 17 m.y. (McKee, 1971).

Dogskin Mountain forms the east side of a large circular feature which was first observed by Sales (1974) on E.R.T.S. photographs (fig. 11). This feature is about 50 kilometers in diameter and encompasses bed rock of Sierran granitics. The flanks of the feature are composed of Tertiary volcanics (Bonham, 1969). Sales (1974) suggests three possible origins for the feature: (1) meteor impact; (2) volcanotectonic events such as caldera formation; and (3) the intersection of structural zones involving the Walker Lane. Wallace (1975) discounts meteor impact due to the lack of impact features. Cupp et al. (1977) suggests that the feature fits Smith and Bailey's (1968) model of a resurgent caldera. However, such a large caldera, which has undergone resurgence to the degree of bringing up granitic bedrock, would surely have erupted a tremendous volume of compositionally similar volcanic rocks. The sequence of compositionally different middle Tertiary ash-flow tuffs in this area does not fit this relationship.
The tuffs on Dogskin Mountain were erupted from at least five different sources. The only compositionally similar tuffs are those of the McKisnick Springs group and their combined volume does not justify the degree of resurgence proposed by Cupp et al. (1977). The outcrop pattern within the circular feature suggests a structural positive region. Such a region may have resulted from compression and wrenching associated with intersecting structural trends.

STRUCTURAL GEOLOGY OF DOGSKIN MOUNTAIN

General

The oldest known structural activity in Dogskin Mountain involved deformation of the Peavine Sequence. Interpretation of this structure is impossible due to the lack of outcrops. Sierran intrusion may have further deformed the Peavine Sequence in the late Mesozoic. No field evidence of this was observed.

Early Tertiary tectonic activity is suggested by the degree of relief present on Dogskin Mountain prior to the emplacement of the McKisnicks Springs group. Relief in the southern part of Dogskin Mountain was greater than 425 meters and is indicated by the onlap of the Nine Hill Tuff over the granitic highs at the Divide Prospects (Plate 1). This tectonic activity predates Basin and Range faulting by more than 10 million years and probably is related to compression resulting from strike-slip movement within the Walker Lane fault zone. Active compressional forces do not appear to have continued during the Oligocene as indicated by the lack of folding or faulting occurring
contemporaneously to the emplacement of the tuffs. Movement on some of the recent faults in this area suggest that compressional forces, probably related to strike-slip activity, may have been rejuvenated in post-Oligocene time.

Basin and Range faulting did not begin on Dogskin Mountain until after the end of ash-flow activity. A general inception date of 17 m.y.B.P. (McKee, 1971) seems reasonable. Field evidence suggests that normal faulting continues through the present.

The Faults

Dogskin Mountain is a tilted horst with larger offsets on the normal faults on the east side of the range. This differential uplift has tilted the ash-flow tuff beds 15° to 20° to the west. There is at least 730 meters of displacement associated with the faults along the east side of the northern part of Dogskin Mountain. The displacement on the west side is about 100 meters.

Most of the displacement along the east side of the range is along two unnamed faults (Plate 1). The larger of the two is at the base of the McKisnick Springs type section (see fig. 7) and is an arcuate fault whose strike is roughly northwest. This fault is the northern continuation of one of the major frontal faults of the southern part of Dogskin Mountain. At the McKisnick Spring's type section, this fault is joined by a N.10°E. trending splay which continues northward in an arcuate direction changing its strike to roughly N.5°W. The major offset is expressed along the northern continuation of the frontal fault up to the point where it is joined
by the N.10°E. trending splay. From this point the major offset is expressed on the northern continuation of the splay. The dip of the faults varies from about 65° to 75° to the east. The second major fault on the east side of the range is just east of the one discussed above. It is also a northwesterly trending arcuate fault which appears to be a branch of the main frontal fault to the south. Displacement on this fault is about 220 meters with the unthrown block to the west. A major variation of its strike occurs just south of Whiskey Springs where a northerly striking splay joins it.

The strike of the faults on the west side of the range is a bit more complex. The main western frontal fault of the southern range, the Dogs skin Mountain Fault (McJannett, 1956), extends into the south-central part of the mapped area at Willow Springs (Plate 1). It continues on a northwest strike to Red Rock Canyon where it makes an abrupt bend to strike nearly east-west. The fault continues down the canyon for about three-quarters of a mile where it once again bends to strike northwesterly and then splits into two branches, each striking northerly. Displacement along all parts of this fault is small and varies from about 20 meters in the south to about 40 meters in the north. A second major fault on the west side of the range is located in the canyon southwest of Hill 6641. This fault strikes northwest and dips about 67° to the west. Apparent displacement along this fault probably does not exceed 60 meters.

There are several locations in the mapped area where faults appear to be reverse (Plate 1). However, these faults are probably normal faults which are displacing blocks downward at slower rates
than adjacent blocks. It is also conceivable that these faults are indeed reverse faults resulting from compressional forces associated with recent strike-slip movement along the Walker Lane.

There is evidence of recent faulting in the rock pediment near Steel Springs on the west side of the mountain. In this vicinity, a small break in slope can be observed in the pediment. In aerial photographs this break in slope appears as a lineation which is inferred to be a fault scarp. All other faults which extend into the Quaternary sediments are buried by the recent sediments.

Interpretation of the Fault Patterns

Interpretation of the fault patterns present in the northern part of Dogskin Mountain is dependent on two unknown factors: the pre-Oligocene configuration of the Walker Lane fault patterns; and the differences in basement lithology. I believe that the former is by far the most important factor controlling the strikes of the Basin and Range faults.

It seems apparent that several strike-slip faults were present in this region in the early Tertiary. These faults probably had trends of roughly N.40°W. Such a system of dextral faults would have a conjugate system of first and second order shears. The first order shears, called Riedel Shears (Tchalenko, 1970), would have a trend of roughly north-south. The second order shears, called conjugate Roedel Shears, have a trend of east-west. If such a system of faults had formed during the early Tertiary, they may well be responsible for controlling the Miocene fault patterns observed today. These
faults, even if not active during the Oligocene and Miocene, would have defined zones of weakness which the Basin and Range normal faults would follow. Figure 12 represents the basic fault patterns which may have existed in the early Tertiary. Superimposed on this fault pattern is the trend of major normal offset at the McKisnick Springs type section. The present expression of this pattern is a normal fault with a highly variable strike. One can explain the variations in strike of all the faults in this study area by application of this model or by modifications of the model which include conjugate Riedel Shears.

Structural Summary

The faults present on Dogskin Mountain are the results of a complex interaction of compressional, right-lateral Walker Lane forces...
with the tensional forces typical of Basin and Range extension. The varying amount of vertical offset is well documented throughout the study area. However, the strike-slip component associated with recent movement on the Walker Lane is poorly documented. An inferred estimate of the trend of the main faults of the Walker Lane through Winnemucca Valley is indicated on Plate 1. The positions of these faults were determined from air photos and not investigated in the field. Although field evidence contributes little to documenting right slip movement, I infer such movement exists along the frontal faults on both the east and west sides of the range.

Faults on Dogskin Mountain can be divided into two groups: first, and earliest, an en echelon series of strike-slip faults; and second, normal faults. Tchalenko (1970) has thoroughly discussed the steps of development of the former, and that discussion will not be repeated here. There is weak evidence in the mapped area that there may have been a slight southward rotation in the direction of tension which occurred during the formation of the normal faults. The first trend of normal faults to develop was northerly and was the result of east-west tension. The second trend, northwesterly, immediately followed or was perhaps in part contemporaneous to the first. This trend resulted from southwest-northeast tension. The origin of the tension has been interpreted as simple extension by various authors (Wright, 1976; Gilluly, 1970; Scholz et al., 1971; Davis and Burchfiel, 1973).
Major Element Oxide and Uranium Chemistry of the Ash-Flow Tuffs

Bulk rock chemistry and uranium content of the middle Tertiary ash-flow tuffs present on Dogskin Mountain and surrounding areas have been determined within the budget limits for this study. Ten samples from various cooling units have been analyzed for bulk rock chemistry. These ten samples, as well as seventeen others, have been analyzed for U$_{308}$. All analyses were performed by Wyoming Mineral Corporation's geochemical laboratory in Boulder, Colorado. The oxide values were determined by standard X-ray fluorescence techniques, and the uranium values were determined by standard fluorimetric procedures. Sample locations and analytical methods are listed in Table 1.

The bulk rock chemistry of the ten samples, as well as that for four additional samples supplied by H. Bonham and M. Silberman, appear in Table 1A. The average of the sum of the oxides is 95.2. Because of this low total of the analyzed oxide values, normalized oxide values (Table 1B) were determined and were used to calculate the CIPW norms (Table 1C). A major reason for the low analyzed oxide sums is that H$_2$O and CO$_2$ values were not determined, nor were any values of the weight lost by ignition. However, it is believed that the normalized values are representative of the chemistry of the rocks.

Examination of the bulk rock chemistry data substantiates conclusions already drawn that the middle Tertiary ash-flow tuffs were products of multiple magma sources. The data is in agreement with
Table 1 is divided into three tables. The first, Table 1A, lists the chemical analyses in weight percent. The second, Table 1B, lists normalized oxide values. Table 1C lists CIPW norms calculated from the normalized oxide values. The normalization of the oxide values as well as the calculations of the CIPW norms were performed by the PETCAL (Bingler et al., 1976) computer program.

Samples B-5, M-10, M-11, M-33, B-2, B-2a, B-3, B-3a, B-4, and Z-10 were analyzed by Wyoming Mineral Corporation's geochemical laboratory in Boulder, Colorado. X-ray fluorescence was used in the determination of the percent oxides. The chief analyst was Tom Benjamin. Samples #24, #25, #26, and #27 appear in this report courtesy of M. Silberman and H. Bonham. They were analyzed by the U.S.G.S. Analytical Laboratories in Menlo Park, California by M. Villarreal and B. King. The sample numbers used in the analyses are M130224, M130225, M130226 and M130226. X-ray fluorescence was used in the determinations.

List of samples:

- **B-5** McKisnick Springs (unit A?); glassy; NW^s, NW^w sec. 19, T.22 N., R.21 E.
- **M-10** McKisnick Springs (unit C); glassy; SW^w sec. 15, T.24 N., R.19 E.
- **M-11** McKisnick Springs (unit C); devit.; SW^w sec. 15, T.24 N., R.19 E.
- **#27** Whiskey Springs (written comm. H. Bonham)
- **B-2** tuff of Dogskin Mtn.; glassy; SE^w, NE^s sec. 24, T.22 N., R.21 E.
- **B-2a** tuff of Dogskin Mtn.; devit.; SE^w, NE^s sec. 24, T.22 N., R.21 E.
- **M-33** tuff of Dogskin Mtn.; slightly devit.; SW^w sec. 15, T.24 N., R.19 E.
- **Z-10** tuff of Dogskin Mtn.; glassy; NE^s, NE^e sec. 31, T.24 N., R.18 E.
- **#24** Petrified Springs (written comm. H. Bonham)
- **B-3** Nine Hill Tuff; glassy; NE^e, NE^w sec. 24, T.22 N., R.21 E.
- **B-3a** Nine Hill Tuff; devit.; NE^e, NE^w sec. 24, T.22 N., R.21 E.
- **#25** Nine Hill Tuff; (written comm. H. Bonham)
- **B-4** Chimney Springs; slightly devit.; NE^e, SW^w sec. 13, T.22 N., R.21 E.
- **#26** Chimney Springs (written comm. H. Bonham)
### Table 1A

#### Chemical analyses (weight percent)

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### Table 1B

#### Normalized oxide values

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FeO* (combined iron) and FeO determined by PETCAL.

### Table 1C

#### Quartz content

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<td>Anorthite</td>
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<td>Diopside</td>
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<td>Hornblende</td>
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<tr>
<td>Apatite</td>
<td>28.6</td>
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<td>Rutile</td>
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**TOTAL** 99.9

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**Table 1D**

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**Table 1E**

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<td>Rutile</td>
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</table>

**TOTAL** 99.9
the idea that each cooling unit originated from an independently differentiating magma. This relationship is represented in Figure 13 on the crystallization index variation diagram (Poldervaart and Parker, 1964) and in Figure 14 on the silica variation diagram. The crystallization index (C.I.) given in Figure 13 is a theoretical representation of igneous differentiation. The C.I. is defined as the sum (weight percent) of normative anorthite, normative magnesian diopside, normative forsterite plus normative enstatite converted to forsterite, and magnesian spinel. This represents an expression of the primitive system anorthite-diopside-forsterite which decreases with increased differentiation of the magma. Therefore, lower values of the C.I. represent an increase in the degree of crystallization and differentiation of a magma. A normal differentiation series, representing cooling units originating from a single crystallizing magma, would be represented on this diagram by the oldest tuff having the highest C.I. value and the youngest tuff having the lowest value. A quick inspection of Figure 15 shows that this is not the case with the tuffs present on Dogskin Mountain. The tuff of Dogskin Mountain has higher C.I.'s than those of the oldest tuffs, the McKisnick Springs group. In addition, the youngest tuff, the tuff of Chimney Springs, has greater C.I. values than all other tuffs except the tuff of Dogskin Mountain. This diagram is strong evidence that each tuff represents a lithology which originated from separate magma sources and not by differentiation of a single magma.

The silica variation diagram (fig. 14) is included in this report because in addition to indicating differentiation from multiple
TABLE 2
Uranium Analytical Results

All samples except #24, #25, #26, and #27, were analyzed by Wyoming Mineral Corporation's geochemical laboratory in Boulder, Colorado. The uranium content was analyzed by standard fluorimetric procedures. The chief analyst was Tom Benjamin. Sample #24, #25, #26, and #27 appear in this report courtesy of M. Silberman and H. Bonham. They were analyzed by the U.S.G.S. Analytical Laboratories in Menlo Park, California by M. Villarreal and B. King. The uranium content was analyzed by delayed neutron activation. Locations of some of these samples appear in TABLE 1.
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<tr>
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<td>McKisnick Springs, Unit C; devitrified</td>
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<tr>
<td>M-7</td>
<td>McKisnick Springs, Unit B; devitrified</td>
<td>8.3</td>
</tr>
<tr>
<td>M-9</td>
<td>McKisnick Springs, Unit B; devitrified</td>
<td>3.3</td>
</tr>
<tr>
<td>M-21</td>
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<tr>
<td>M-17</td>
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<td>6.5</td>
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<td>M-29</td>
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magmas, the diagram can also be used to plot uranium variations with respect to silica (see page 78). The silica variation diagram indicates that the silica values have not increased through a normal progression with the decreasing ages of the tuffs. This relationship also supports the conclusion of multiple magma sources.

Interpretation of the chemical trends which should be represented in these diagrams (figs. 13 and 14) is not possible due to the limited number of data points for each cooling unit, and the small range of variation of silica and C.I. for the respective diagrams. In addition, interpretation of the magmatic differentiation of each magma by use of C.I.P.W. norms plotted on various triangular diagrams is not possible because of the lack of data points for each cooling unit. However, the limited data does not permit interpretation of differentiation trends of each magma.

The uranium contents of the ash-flow tuffs on Dogskin Mountain are listed in Table 2 and shown in Figures 14 and 15. The majority of the tuffs present in this thesis are devitrified and have uranium values which range from 2 to 172 ppm, with most of the tuffs containing from 5 to 10 ppm uranium. It was not possible to compare the uranium content of the glassy and devitrified zones of each cooling unit because only Cooling Unit C of the McKisnick Springs group contained a prominent glassy zone. However, samples of glassy and devitrified tuffs were collected for two correlative cooling units in the nearby Pah Rah Range. (Samples from this location are designated by the letter B preceding the sample number.) Therefore, sample pairs of glassy and devitrified tuffs are represented in this study.
Figure 13. Crystallization Index diagram. Sample descriptions and locations appear in TABLE 1. See text for discussion of diagram.
Figure 34. Silica variation diagram. Sample descriptions and locations appear in TABLE 1. See text for discussion of diagram.
Figure 15. Graphical representation of uranium values in ppm plotted with respect to cooling units.
for three cooling units: Cooling Unit C (M-11 & M-12); the tuff of Dogskin Mountain (B-2 & B-2a); and the Nine Hill Tuff (B-3 & B-3a).

The uranium values of these sample pairs as well as other devitrified tuffs are shown in Figure 15. This figure shows that the devitrified tuffs generally contain greater amounts of uranium than the glassy tuffs. This is particularly evident in the three paired samples. Such results are in direct disagreement with published results of several authors who have found that uranium values decrease substantially as the tuffs devitrify (Welke et al., 1968; Shatkov et al., 1970; Rosholt et al., 1971).

There are probably two basic reasons why the uranium content of the devitrified tuffs are greater than the contents of the glassy tuffs. The first is that the results are based on a very small amount of analytical data which may not be representative. However, even more important is the apparent redistribution of uranium by the groundwater system. Figure 15 indicates that about 20% of the analyzed samples contain greater than 30 ppm uranium and represent anomalously high values for their respective units. These high uranium values probably represent concentration of uranium by remobilization in the groundwater system. In addition, the uranium values plotted on the silica variation diagram (fig. 14) do not represent a normal trend which should increase with increased silica content. Instead, the diagram shows a wide degree of scatter and a slight decrease of uranium with increase in silica within any single magma system. The reason for the inverse relation of uranium to silica is not fully understood; however, the degree of scatter
suggests that it may be related to redistribution of uranium by groundwater.

The original uranium content of each cooling unit was not possible to determine from the limited amount of data presented in this report. However, the voluminous amount of data presented by other authors indicates that such values are best represented in the glassy zones of each cooling unit (Welke et al., 1968; Shatkov et al., 1970; Rosholt et al., 1971). This suggests that the high uranium values of the devitrified tuffs on Dogskin Mountain are the results of the redistribution of uranium by groundwater after the initial devitrification of the tuffs. The initial uranium concentrations of each tuff was probably between 7 and 15 ppm and is best represented by analyses done on the glassy tuffs (M-10, Z-10, B-5, B-3 and B-2).
URANIUM, ITS ACCUMULATION AND MIGRATION IN ASH-FLOW TUFFS

Silicic ash-flow tuffs were erupted over much of northwestern Nevada in late Oligocene time. Most of these ash-flow tuffs are highly differentiated calcalkaline rhyolites with silica contents of 70-77 weight percent and very low MgO and CaO contents. In addition to concentrating silica, these differentiates also concentrated alkalies (Na$_2$O and K$_2$O) and various volatile elements. The pyroclastic nature of the emplacement of the ash-flows indicates that the concentration of water in the magma was sufficiently high to exsolve and aqueous phase. In addition, the high water content is an indication of a high degree of fractional crystallization of the magma (Noble, 1972). The high degree of fractional crystallization of the magma is in agreement with low strontium isotopic ratios represented by McKee et al. (1972) which they interpret to indicate that the rhyolitic magmas are differentiates of mafic magmas. It can be concluded that ash-flow tuffs are the eruptive products of highly differentiated mafic magmas which should be enriched in volatiles.

Uranium is a common volatile element that is concentrated in silicic differentiates (Larsen et al., 1958). Its degree of accumulation depends on the original content of uranium in the source magma and the rate of crystallization of that magma (Shatkov et al., 1970). Only limited substitution of uranium in common rock forming minerals occurs in magmatic processes because of its large ionic radius.
(0.97 Å) and large charge (+4 or +6). However, in late stages of differentiation, uranium may have a tendency to be associated with accessory minerals. This tendency is probably offset in volcanic processes by the enrichment of fluorine and the formation of large uranyl-fluorine complexes (Shatkov et al., 1970).

The sudden and violent eruption of the partially crystallized viscous rhyolitic melt traps the majority of the uranium within the rapidly solidifying glass (Rogers, 1958). A very small portion of the uranium may be lost at the time of emplacement by its partial escape with the gaseous component. However, because of the very high viscosity of the basal flow of nuee ardente eruptions, much of this gas will be trapped as bubbles within the glass. The uranium within the trapped gas will probably electrostatically bond to the margins of the surrounding glass (Hsu, oral communication). The amount of uranium electrostatically bonded to the interior margins of bubbles enclosed by the glass is negligible when compared to the 7 to 15 ppm uranium initially trapped within the glass.

The post depositional mobility of the uranium associated within the glass is dependent upon chemical changes affecting that glass. Following deposition, glassy pyroclastic deposits are readily altered because of their high porosity, large size of particles and inherently unstable character of the glassy fragments. The volcanic glass will tend to undergo two types of chemical change: hydration and devitrification.

Hydration of volcanic glass is a chemical modification initiated during cooling by the addition of water to the glass. Rhyolitic
glasses containing more than a few tenths of a percent water have been hydrated (Ross and Smith, 1955). Once hydrated, the glasses are subject to leaching and ion exchange by groundwater (Lipman, 1965; Noble, 1967; Lipman et al., 1969). These authors have found that the effects of hydration may be accompanied by a loss of Na₂O and an increase in K₂O. No change of the uranium values has been detected in hydrated compared to non-hydrated glasses (Rosholt, 1971). Thus, it appears that during hydration and leaching, uranium is not mobile in glassy phases of ash-flow tuffs. However, the very small quantity of uranium electrostatically bonded to the margins of the glass shards (bubbles) would quickly be leached by the groundwater.

The second alteration that affects natural glasses if devitrification. The effects that volcanic glass devitrification has on uranium has been studied by several authors (Welke et al., 1968; Shatkov et al., 1970; Rosholt et al., 1971). These authors have found that the uranium content of glassy tuffs is twenty to seventy percent greater than devitrified tuffs. Rosholt (1971) concludes that devitrification, accompanied by leaching, will oxidize the uranium and allow it to escape into solution as a UO₂⁺⁺ complex. This results in the devitrified tuffs releasing from 30 to 80 percent of their original uranium to the groundwater system (Shatkov et al., 1970; Rosholt et al., 1971).

Once the uranium is released, the oxidized uranium (UO₂⁺⁺) is transported through permeable parts of the ash-flows. This movement generally results in the uranium bearing solutions gradually being percolated downward to the porous basal zone of each cooling unit and
to the sediment zone which may lie between cooling units. At this point, the solutions may be transported out of the tuffs to surrounding sediments or they may become trapped between cooling units in reactive zones or in permeability barriers.

Migration of oxidized uranium may go on indefinitely in the groundwater system. In fact, the $\text{UO}_2^{++}$ ion is so soluble that once it is leached from the tuffs and placed in solution, it may easily travel down the paleochannels and be removed from the vicinity around its source. The high solubility and stability of the $\text{UO}_2^{++}$ ion does not necessarily preclude its ability to be fixed in a less soluble form. In fact, uranium can, and often is, fixed in relatively stable compounds either within the ash-flow tuffs or within the surrounding sediments. Uranium may be fixed in three ways: (1) as a $\text{UO}_2^{++}$ compound with either As, V or P; (2) adsorbed on clays or zeolites; or (3) in a reduced state as an oxide ($\text{UO}_2$).

There are only a few insoluble compounds which $\text{UO}_2^{++}$ may form. It may react to form compounds with As, V and P. Such elements are considered uncommon in natural groundwater systems (Holmes, 1972), but may be fairly common in hydrothermal waters. The Oligocene ash-flow tuffs present on Dogskin Mountain pre-date the Miocene to Recent (Wallace, 1975) hydrothermal activity. Therefore, the majority of the uranium released during cooling and devitrification would have moved through the groundwater system before the start of regional hydrothermal activity.

Adsorption of uranium on clay minerals and zeolites probably accounts for only minor amounts of uranium found in ash-flow tuffs.
The same time-sequential argument may be used in this discussion as was used in the previous paragraph. The clay zones in the ash-flow tuffs on Dogskin Mountain are related to tectonic (Basin and Range faulting, late Miocene to Recent), or hydrothermal activity. The development of zeolites is associated with secondary devitrification which occurs after primary devitrification and the initial release of uranium. Neither the development of clays or the development of zeolites is in the proper time relation to the earlier time of major release of uranium to the groundwater system. Therefore, neither clays or zeolites should be expected to host large deposits of uranium on Dogskin Mountain.

The process of reduction can stabilize uranium in a reduced environment in two states: either as an oxide (uraninite); or as a hydroxy-silicate (coffinite). Carbonaceous matter has long been considered a classic reductant. Consequently, carbonaceous matter both in older sedimentary material and along disconformities between cooling units can be considered uranium precipitators. The carbon in the organic material acts as a reducing agent which causes the soluble $\text{UO}_2^{++}$ complex to reduce to the less soluble $\text{UO}_2$ compound. This causes oxidation of the organic material and the subsequent replacement of carbonized matter by uraninite. Carbonaceous matter has been observed in the sediments between cooling units on Dogskin Mountain. The cooling unit immediately overlying such a zone of sediments would have released uranium which would eventually migrate through these sediments. There is a high potential that this uranium will be fixed in a reduced state in carbon rich zones in these sediments.
URANIUM OCCURRENCES

GENERAL

Uranium deposits have been known in the ash-flow tuffs on Dogskin Mountain since the early 1950's. The deposits are either stratigraphically controlled between cooling units or are structurally controlled by faults. All the uranium deposits located on Dogskin Mountain (Plate 1) are small. A concise history of each uranium prospect appears in a report by Garside (1973).

Most large prospects on Dogskin Mountain are associated with organic matter in sediments which lie above disconformities. Deposits in this area have been described as infiltration uranium deposits by Holmes (1972). Basically, these deposits represent an oxidation-reduction reaction in which the uranium is reduced from a soluble $\text{UO}_2^{++}$ complex to a relatively stable $\text{UO}_2$ compound. The important factor controlling the formation of infiltration uranium deposits is not which tuff overlies the disconformity, but rather, the existence of sediments above the disconformity. The two major stratigraphic positions where sediments occur in the tuff section of the present study area are: at the very base of the middle Tertiary ash-flow tuff assemblage; and in channels which developed above the tuff of Dogskin Mountain. In addition, sediments are sometimes observed where tuffs onlap basement highs. Overlying the sediments may be any one of the eight cooling units described in this report.
The uranium content of each of these devitrified units is generally between 5 and 10 ppm. The works of Shatkov et al. (1970) and Rosholt et al. (1971) suggest that at the time of their emplacement and before devitrification, each unit may have had uranium contents between 30 and 80% greater than their present values. Therefore, it appears possible that the uranium released during devitrification of any cooling unit which overlies a zone of sediments would contribute sufficient uranium to form infiltration deposits in those sediments.

The second control of the formation of uranium ore deposits in ash-flow tuffs is structural. Shear zones, formed by Basin and Range faulting, are zones of reduced permeability and high clay content. Fluids are easily trapped in these zones, and if the fluids are uraniferous, the uranium may be adsorbed on the clays. The formation of these structural traps started about 6 million years after the last ash-flow tuff was emplaced. Any uranium liberated from the tuffs through primary devitrification had, during this time, passed through the sediments and had the opportunity to form infiltration uranium deposits. The uranium which mineralizes the structural traps originated in two ways: (1) it may have been remobilized from pre-existing infiltration deposits; or (2) the uranium may be liberated from the devitrified tuffs by erosion and decomposition of that tuff.

POTENTIAL FOR ORE DEPOSITS

This study suggests that two factors contribute to reducing the likelihood for the localization of uranium ore deposits in the
ash-flow tuffs on Dogskin Mountain. These are the lack of sedimentary traps and the lack of structural traps in the tuffs at the time of primary devitrification. Neither has to do with the lack of uranium in the tuffs; there appears to be sufficient uranium present today to justify the conclusion that large quantities of uranium were released upon the tuffs' devitrification.

The major reason uranium ore deposits are uncommon in the tuffs is the lack of sediments associated with the disconformities. The sedimentary material is necessary to the formation of uranium deposits because it often contains carbonaceous matter which reduces the uranium to a relatively stable form. In addition, the sediments provide a conduit for groundwater percolation which permits the mobilization of uranium necessary to form ore.

Thick accumulations of sediments are not observed in the mapped area. They are apparently lacking because: (1) the base of the tuff section is not exposed; and (2) the fluvial systems which developed on the tuff of Dogskin Mountain appear to have been moderately high energy systems. These systems cut deep canyons and did relatively little lateral cutting. Hence, there was very little deposition of sediments associated with the streams.

The pre-ash-flow tuff fluvial sediments which were developing on the basement topography at the time of the first pyroclastic eruptions hold the best potential for localizing uranium in ore concentrations. These sediments underlie the entire middle Tertiary ash-flow tuff assemblage and may have received uranium from the devitrifying tuffs. These sediments are only locally preserved
in Washoe County and were not observed in the mapped area. However, these sediments are likely to be present at depth in this area and would underlie the lower tuffs of the McKisnick Springs group (Tml, structural section AA', Plate 1).

Recently, there has been renewed interest in the uranium ore potential in the area around Dogskin Mountain. This interest is based on the realization that the ash-flow tuffs are favorable source rocks but less than favorable host rocks of uranium. Exploration targets therefore have been the basins adjacent to topographic highs of ash-flow tuffs. The conceptual model of ore formation generally states that the middle Tertiary ash-flow tuffs provide uranium to the younger, but topographically lower sedimentary deposits. It is by the process of erosion and decomposition of the devitrified tuffs that uranium is released to the groundwater system. The released uranium will percolate in the groundwater system through the basin sediments and collect in zones of favorable permeability and reactivity.

The base of the Truckee Formation (Axelrod, 1957) appears to be a favorable zone for ore accumulation. At its base, the Truckee Formation is composed of a conglomeratic sand, rich in carbonaceous matter. I believe that most of the uranium found in this basal zone was probably introduced to the sediments shortly after their deposition. At that time major movements were occurring along Basin and Range frontal faults. This movement is likely to have caused the basal beds of the Truckee Formation to be up-turned towards the faults as a result of drag. Uranium laden solutions then could
have percolated down the aquifer composed of these up-turned beds of the basal Truckee Formation and migrated through the sediments. As the solutions migrated through the basal sands they may have reacted with carbonaceous matter to oxidize and precipitate uranium in the form of uraninite. These small deposits of uraninite may have been remobilized into ore deposits through processes of multiple migrations.

Exploration for targets in the basal Truckee Formation will involve extensive drilling. Such drilling has been started by several firms and it is reported that Rocky Mountain Energy has delineated ore reserves in Long Valley on the northwest side of Petersen Mountain. Further drilling will probably follow. The valley deposits on the northwest side of Dogskin Mountain should be considered prime targets for drilling exploration.
The oldest rocks exposed in the study area are the Peavine Sequence of Late Paleozoic to early Mesozoic age. These rocks were deposited in a volcanic arc environment and have long been considered a eugeosynclinal assemblage. The entire assemblage underwent regional metamorphism sometime prior to the late Mesozoic. In the late Mesozoic, rocks of the Peavine Sequence were orogenically uplifted and intruded by granitic batholiths of Sierran affinity. Between the late Mesozoic and middle Tertiary, the rocks of the orogenic belt were eroded and reduced to a relatively flat plane. Drainage of meandering fluvial systems were entirely to the west. The Walker Lane strike-slip fault zone probably became active during this period. By the beginning of the middle Tertiary, strike-slip faulting along the Walker Lane had formed isolated basement highs. These highs formed in response to compression associated with the intersection of fault branches or the intersection of Riedel Sheras with right lateral, strike-slip faults. Stream sediments collected in topographic depressions of the basement topography.

The onset of pyroclastic ash-flow tuff eruptions began in the middle Tertiary. The oldest and basal ash-flow tuffs in this region were erupted about 28 to 29 million years ago. The first of these tuffs represented in the mapped area are 28 million years old and are called the tuffs of the McKisnick Springs group. The eruptions of
this group of tuffs occurred sporadically over a period of about a million years. During this time at least four cooling units were deposited. Immediately following the emplacement of the McKisnick Springs group, the tuff of Dogskin Mountain was erupted. Roughly two million years elapsed after the cooling of the tuff of Dogskin Mountain and the eruption of the Nine Hill Tuff. During this period, the upper partially welded part of the tuff of Dogskin Mountain was subjected to erosion. Channels, some as deep as 50 meters, developed on the tuff of Dogskin Mountain. Stream sediments and organic matter collected along the floors of the channels. Minor volcanic flows of intermediate composition were erupted from unidentified vents and traveled down these channels. Relatively small ash-flow cooling units were also erupted during this period. The Nine Hill Tuff was erupted about 25 million years ago from a caldron source about 45 miles south of the mapped area. This tuff flowed into the study area controlled by the channels in the tuff of Dogskin Mountain. In most locations of this thesis area, the Nine Hill Tuff is confined to these channels. A second period of erosion occurred after the cooling of the Nine Hill Tuff. Channels were cut once again into the partially welded top of the tuff of Dogskin Mountain in preference to the densely welded top of the Nine Hill Tuff. The tuff of Chimney Springs was erupted about one to two million years after the cooling of the Nine Hill Tuff. The emplacement of the tuff of Chimney Springs was initially controlled by the channels in the tuff of Dogskin Mountain; however, the ash eventually overflowed its erosional channels and onlapped the Nine Hill Tuff and the upper zone of the tuff of Dogskin Mountain.
Silicic ash-flow tuff eruptions ended in this area about 23 m.y. B.P. Since that time, the area has been the site of erosion.

Basin and Range faulting began about 17 m.y.B.P. The strikes of the normal faults in this area appear to be controlled by pre-existing strike-slip features associated with the Walker Lane. The present topographic expression of Dogskin Mountain is the result of normal faulting. Both normal and strike-slip faulting continues today.

Since Miocene time, sediments derived from the erosion of ash-flow tuffs have been collecting in basins which surround Dogskin Mountain. Recent sediments form alluvial deposits in the basins.
CONCLUSIONS AND RECOMMENDATIONS

This study has identified middle Tertiary ash-flow tuff cooling units in the northern part of Dogskin Mountain. Each cooling unit represents a unique and mappable formation and may be discriminated on the basis of its mineral ratios, variations of welding and crystallization, and on the presence of bounding disconformities.

Eight cooling units were identified on Dogskin Mountain and described in this report. The lower five cooling units were erupted over a period of a little more than one million years from at least two separate sources which tapped independently differentiating magmas. These cooling units represent the lower sequence of tuffs present on Dogskin Mountain. Overlying the lower sequence of tuffs are three additional cooling units, each of which originated from a different magma and source. Time gaps of one to two million years existed between the emplacement of each of these three cooling units. During these time gaps, channels developed in the upper cooling unit of the lower sequence of tuffs. The emplacement, in this study area, of each of the three upper tuffs was controlled by these channels. This suggests that the source areas of the youngest tuffs were further away from the thesis area than the sources of the tuffs of the lower sequence.

The area mapped is structurally complex. The present expression of Dogskin Mountain is that of a fault tilted horst typical of Basin
and Range extension. In addition to tensional forces, the area studied lies in the zone of strike-slip faulting associated with the Walker Lane. This indicates that compressional forces have been active in the area since the early Tertiary. The strike-slip system of faults probably controlled the formation and distribution of basement highs which existed before the onset of pyroclastic ash-flow tuff activity. These faults also delineate zones of weakness which the Miocene normal faults followed.

The ash-flow tuffs on Dogskin Mountain have long been known to be the host of small deposits of uranium. Deposits are located either at the very base of the middle Tertiary ash-flow tuff section, or in sediments overlying the disconformity between the lower and upper sequence of tuffs. Uranium was introduced into the sediments immediately following the cooling and devitrification of the overlying cooling units. Any cooling unit which overlies sediments should be considered the source of the uranium deposits within those sediments. Therefore, any and all cooling units present on Dogskin Mountain have the potential of being source rocks for uranium.

Uranium ore deposits may exist in sediments within the basins which surround the northern part of Dogskin Mountain. The most favorable sediments in the area are the basal conglomeratic carbonaceous sands of the Truckee Formation. Uranium in these deposits originated from the erosion and decomposition of the structurally higher, middle Tertiary ash-flow tuffs.

This study should be the beginning of a series of mapping projects which will link the areas of middle Tertiary ash-flow tuffs
located north of the Truckee River with published accounts of areas south of the river. Each study should include new bulk rock chemical data, and possibly uranium data. However, these studies should not be expected to fully interpret the chemical data. Detailed chemical studies of a cooling unit should not be expected until after the full distribution of that cooling unit has been mapped.

The only way to fully understand the complex structural interactions of the Walker Lane and Basin and Range normal faulting will be by detailed mapping of the ash-flow tuffs and overlying volcanics in the area within the Walker Lane fault zone. A key area for making this interpretation probably lies just northwest of this study area (and in part inclusive of the eastern side of this thesis area). Such a study can only be made by a person who fully understands the stratigraphy of the area.

In summary, the base of the Tertiary section in northwestern Nevada is often represented by middle Tertiary ash-flow tuffs. These tuffs represent a time span of roughly six million years and may hold the key in interpreting the late Mesozoic and early Tertiary structural and environmental histories of the area. Understanding the chemistry of these rocks may unravel their relation to subduction as well as clarify their relation to later andesitic and basaltic volcanic activity. The middle Tertiary ash-flow tuffs should be mapped as individual cooling units and not lumped into assemblages like the Hartford Hill.


Bonham H.S., 1969, Geology and mineral deposits of Washoe and Storey County, Nevada: Nevada Bureau of Mines Bull. 70.


Sales, J.K., 1974, Simulate "true color" images from ERTS data: Comment: Geology, v. 2, p. 496.


APPENDIX I

TERMINOLOGY*

Pyroclastic: to be used as an adjective applying to rocks produced by explosive eruptions (either aerial or flow) from a volcanic center or vent, or as a noun to apply as a general term for volcanic material emplaced from an explosive eruption, and including volcanic and conglomerates, agglomerates, tuffs and ashes.

Pyroclastic materials:

Block: greater than 32 mm
Lapilli: 4-32 mm
Coarse ash: 1/4-4 mm
Ash (or fine ash): less than 1/4 mm
Volcanic dust: less than 1/4 mm

Nuee ardente: violent eruptions of pyroclastic material composed of a dense basal flow and an overriding dust cloud.

Ash-flow: a turbulent mixture of gas and pyroclastic materials (ash) ejected explosively at high temperatures and covering vast regional extent. The flows travel by the principle of fluidization.

*Taken in part from Ross and Smith (1961) and Smith (1960).
Tuff: an indurated pyroclastic rock of ash size.

Ash-flow tuff: consolidated deposits of ash whose mechanism of emplacement was an ash-flow.

Ignimbrite: essentially synonymous with ash-flow tuff.

Cooling unit: a single unit (map unit) which forms as the result of the simultaneous cooling of one or more ash-flows. Usually exhibits zones of welding and crystallization.

Zones of cooling units: referring to variations in welding and/or crystallization. Not referring to color or outcrop variations.

Welding: a process which promotes the union or cohesion of glassy fragments. The degree of welding varies from incipient stages marked by the sticking together (touching) of glass shards at only one or two points, to the complete welding marked by the flattening of glass shards so that their entire surfaces are in contact.

Non-welded: a zone of an ash-flow in which no welding has taken place. As a field term, this zone may include part of tuff in which incipient welding has occurred.

Partial welded: includes all material which shows incipient welding up to material which has lost virtually all its pore space. This zone has been further subdivided into two additional zones: that of weakly and moderately welded tuff. Weakly welded material will show compaction
of the pumice lapilli but will not show any deformation of the groundmass. Moderately welded material will show deformation of both the pumice lapilli and the groundmass.

Crystallized tuffs: tuffs whose glass has devitrified, generally to cristobalite and alkalic feldspar.

Slightly devitrified: tuffs which show crystallization of the groundmass but not the pumice or shards.

Moderately devitrified: tuffs which show crystallization of the groundmass as well as crystallization of the pumice lapilli and shards. This crystallization takes place without strong development of axiolitic or spherulitic intergrowths.

Strongly devitrified: complete devitrification of groundmass, shards and pumice lapilli accompanied by strong development of axiolitic and spherulitic intergrowths.

Vapor phase tuffs: tuffs in which devitrification is caused by vapor action. This phase generally takes place in non-welded or slightly welded tuffs. The prime mineral phase is tridymite, alkalic feldspar and cristobalite (crystals are coarser grained than crystals of devitrification).

Sillar: non-welded tuffs which have been indurated by vapor phase crystallization.
Secondary devitrification: occurring after cooling, this type of devitrification is caused by the migration of groundwater through the porous zones of the cooling unit. The crystal phases are zeolites and clays and are often accompanied by iron oxide crystals.

Textures:

**Eutaxitic:** parallel banded pyroclastic material whose structure originated from compaction.

**Fiamme:** dark glass lenticles resulting from complete collapse of pumice lapilli.

**Lithophysae:** cavities caused by entrapped or exsolved gas.

In welded tuffs, these cavities may take on the appearance of "eyes."

**Pumice "eyes":** "eye" in the outcrop which probably formed by differential weathering of pumice lapilli, or in some instances may have formed from lithophysae.

**Axiolitic:** devitrification structures resulting from the intergrowth of cristobalite and alkalic feldspar.

**Spherulitic:** devitrification structure resulting in radial aggregates of alkalic feldspar and cristobalite.