University of Nevada

Reno

Structural Geomorphic Analysis of the Virginia Mountains Washoe County, Nevada

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Geology

by

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ABSTRACT

The Virginia Mountains of Washoe County, Nevada, is an uplifted and collapsed anticlinal structure having a N-S trend but bending toward the southeast at the southern end of the range. NW and NNW fault trends in Winnemucca Valley and within the low hills on the eastern range front are believed to be a part of the Walker Lane lineament. Topographic, structural, and geologic evidence yields confidently a first-order, right-lateral, strike-slip fault interpretation. Also indicated are second-order left-lateral, strike-slip movements along the eastern mountain front. The structurally very complex southern one-fifth of the range together with the northern portion of the Pah Rah Range suggest distributive branching of the Walker Lane lineament in the brittle Hartford Hill rhyolite as the lineament nears termination in southern Washoe County.

The present topography of the Virginia Mountains is the result of bending of layers of volcanic rocks, high-angle and strike-slip faulting, and erosion in an arid to semi-arid climate. Major and minor drainage is controlled almost exclusively by the structure. Fault valleys are characteristic of the entire range and are the principal topographic forms, but many other types of drainage are present. The higher elevations are representative of old erosion surfaces.

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Mullen Gap Looking Towards Warm Springs Valley

INTRODUCTION

Purpose and Approach

The Virginia Mountains, Washoe County, Nevada, is a geologically complex and imperfectly mapped range in the Basin and Range Province of the Western United States.

My interest in geomorphology led me to investigate the nature of the Virginia Mountains using morphological techniques rather than by the usual investigations by geologic mapping. The work was done by interpretation of aerial photographs. Faults, folds, and rock formations were mapped on the photographs and the geomorphology was described and analyzed. Field investigation supplemented the photo interpretations and final data was mapped on topographic maps. Stream profiles were also done.

The approach I have used in my investigation of the range was suggested by N. Dasarathi. He advised the separation of the range into three levels: high, intermediate, and low; and to systematically describe the geomorphology, evaluate the causes, and finally synthesize a total geomorphic and structural picture of the area.

Separation into levels was done on the basis of distinct changes in topography that took place over a large area. The high level was separated from the intermediate level by a change from very steep slopes to more gentle slopes. The low and intermediate levels were divided roughly at the change from steep canyons to low hills. At many places the line demarcking the levels was arbitrarily chosen but especially between the bottom two levels. With levels separated by changes in topography, it was hoped that areas with similar characteristics, geomorphic, structural, and geologic, could be described and mapped with a certain level.

Location and Accessibility

The Virginia Mountains are located about 24 miles (39 km) north of Reno, Washoe County, Nevada. (Refer to the location map on the following page.) The thesis area is about four-fifths of the total area of the Virginia Mountains, excluding the lands west of Black and Cottonwood Creek Canyons, hereafter referred to as the Western Virginia Mountains.

The Virginia Mountains are bounded by Warm Springs and Winnemucca Valleys, Black Canyon, Cottonwood Canyon, and Honey Lake Valley on the west; by Astor Pass on the north; by Pyramid Lake on the east; and by Mullen Gap on the south. The total area is about 160 square miles (415 sq. km).

Access to the area is provided by State Highway 33 which is paved as far as Sutcliffe. A gravel road extends from there around the perimeter of the range as far as Cottonwood Canyon. The Milk Ranch Road provides access to Winnemucca Valley. It is a wide well-kept dirt road. All access to the interior is by jeep trail and four-wheel drive is required.

Much of the Virginia Mountains is restricted by ranchers and permission must be obtained to travel on many jeep trails. Much of the eastern front of the Virginia Mountains lies within the Pyramid Lake Indian Reservation.

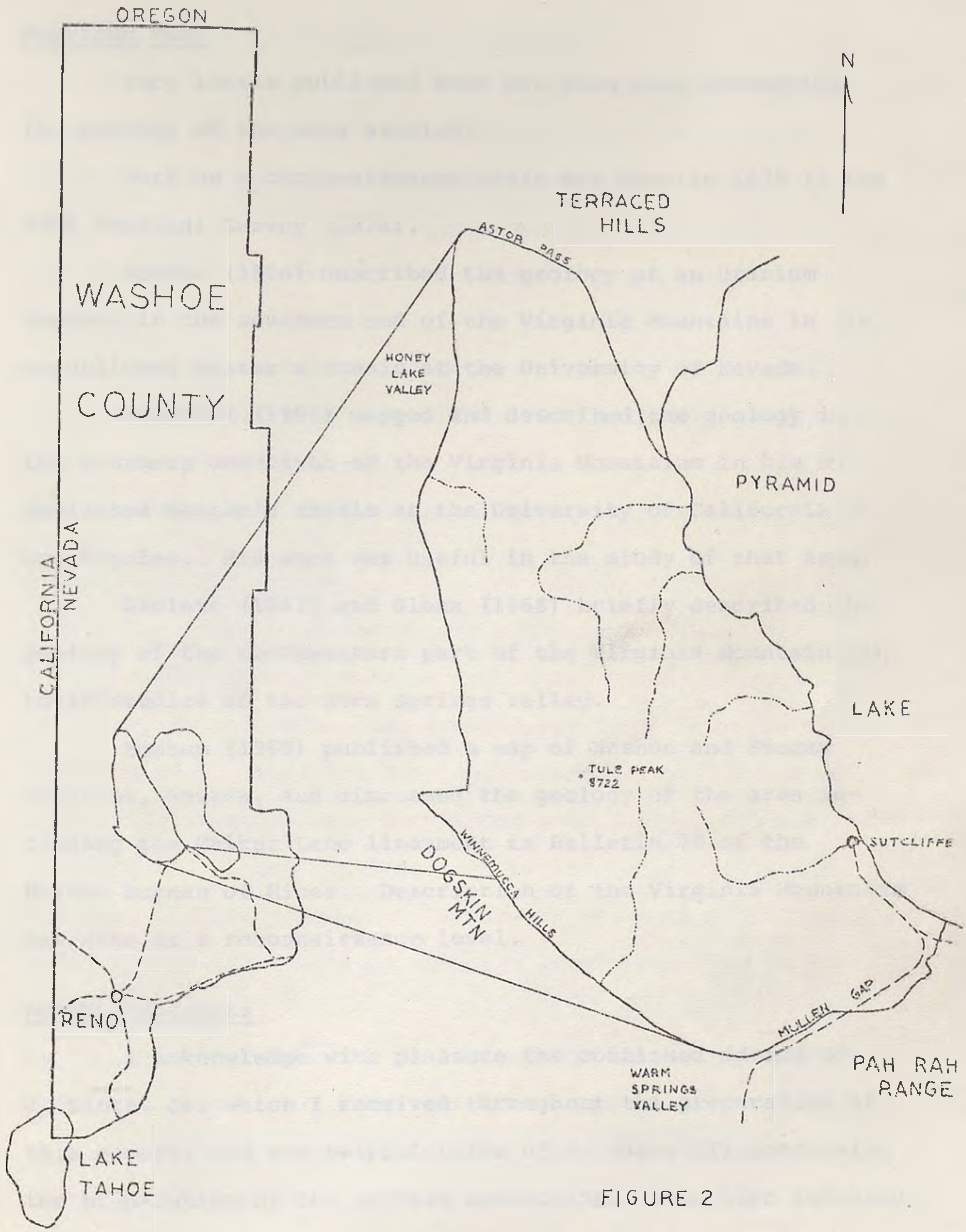


FIGURE 2

VIRGINIA MOUNTAINS

SCALE 1:250,000

Previous Work

Very little published work has been done concerning the geology of the area studied.

Work on a reconnaissance scale was done in 1878 in the 40th Parallel Survey (1878).

Brooks (1956) described the geology of an uranium deposit in the southern end of the Virginia Mountains in his unpublished Master's thesis at the University of Nevada.

McJannet (1957) mapped and described the geology in the southern one-sixth of the Virginia Mountains in his unpublished Master's thesis at the University of California at Los Angeles. His work was useful in the study of that area.

Gimlett (1967) and Glenn (1968) briefly described the geology of the southwestern part of the Virginia Mountains in their studies of the Warm Springs Valley.

Bonham (1969) published a map of Washoe and Storey Counties, Nevada, and discussed the geology of the area including the Walker Lane lineament in Bulletin 70 of the Nevada Bureau of Mines. Description of the Virginia Mountains was done at a reconnaissance level.

Acknowledgements

I acknowledge with pleasure the continued advice of J. Lintz, Jr. which I received throughout the preparation of this report, and the helpful talks of A. Baker III concerning the preparation of the written manuscript. I am also indebted to N. Dasarathi for his many valuable suggestions concerning methodology and analytical technique.

Topographic Maps and Aerial Photography

The Virginia Mountains is covered by two 15 minute quadrangle maps south of the 40th parallel: the Dogskin Mountain and Sutcliffe maps. North of the 40th parallel four 7.5 minute quadrangle maps cover the rest of the area: the Spanish Flat, Pyramid SW, Astor Pass, and Needle Rocks quadrangles.

Aerial photographs used were flown by the U. S. Geological Survey in 1954 south of the 40th parallel at 1:40,000 scale and in 1962 north of the 40th parallel at 1:38,000 scale. These are VEU and VAMV projects respectively.

Climate and Vegetation

The climate of the Virginia Mountains is typical of the northwest Basin and Range Province. Climate varies with increases in altitude. The lower 4,000 foot (1,200 m) basin level is arid, receiving less than eight inches (20 cm) of precipitation annually. Elevations over 7,000-8,000 feet (2,100-2,400 m) receive more than twice the precipitation annually of the lower basin levels and are semi-arid. Daily temperatures are cooler in the high level area than in the lower elevations.

The climate is hot in summer, the temperatures often exceeding 100° F. (37.8° C) and cold in winter, the readings dipping below 0° F. (-17.8° C). It is common to have diurnal variation of over 50° F. (28° C).

Most of the total precipitation in the northwest Basin and Range Province is snow. Snowfall is not uncommon in summer. Winter and spring snow may persist as snowbanks on northeastern slopes until late spring or early summer. Thunderstorms occur occasionally in summer.

Vegetation in general reflects the change in altitude; thus the climatic variation. Sagebrush, other desert shrubs, and grass are common at low elevations. Lowlands are generally treeless except for cottonwoods and willows present along some streams and springs. In higher terrain, junipers and pinons are found in response to the greater precipitation. Vegetation shows preference to certain lithological units in some areas and at high elevations the highest percentage of growth occurs on northeastern slopes. The canyon slopes and lower hills to the north of the Tule Ridge area show significant plant growth, especially of trees, only on the southern-facing slopes. The cause of this apparently anomalous occurrence of vegetation is not discernible from the photographs.

The relative thickness of soil also causes variations in plant growth with steep canyon walls having the least soil mantle and therefore a smaller amount of vegetation.

Physiography and Drainage

Although the physiography and drainage are main concerns of this paper, an introduction will be given here to discuss the gross features of the range.

The Virginia Mountains is a NW trending range in the Basin and Range. The range has a high "plateau" area with steep slopes on all sides. The highest peak is Tule Peak at an altitude of 8,722 feet (2,660 m) at the southern end of a long, north trending ridge, Tule Ridge. Major drainage at high elevations is predominantly N-S. Major drainage along the middle and lower elevations is predominantly N-S and E-W, but many ENE channels are present on the eastern mountain front. A semi-rectangular pattern of drainage is present in the northernmost segment of the range. Drainage varies in the southern one-sixth of the range.

The arid to semi-arid climate indicates little running water except during summer storms and when snow is melting. The many springs issue too small a quantity of water to maintain permanent streams.

The Virginia Mountains drains into several different basins. To the northwest, drainage is into Honey Lake Valley and the small basin between Never Sweat Hills and the northern Virginia Mountains. To the north, drainage is into Astor Pass, which, although connected to the Pyramid Lake Basin, seldom receives enough run-off to reach Pyramid Lake. The major eastern stream run-off drains into Pyramid Lake. Streams on the southwest and south sides of the range drain into Winnemucca Valley, Warm Springs Valley, and Mullen Gap, then subsequently into Pyramid Lake. A fairly large portion of the western Virginia Mountains drains through Dry Valley Creek and into Dry Valley. Basin levels are below 4,000 feet (1,300 m).

CENOZOIC ROCKS

The rock formations that are present are geomorphologically significant because each possesses its own characteristics of fracturing and faulting and of weathering. They also are important in evaluating movement along faults, and are especially important as the Walker Lane lineament passes through this area.

The geologic map, Plate I, is based partly on the work of Bonham (1969) and McJannet (1957), but many of the contacts are modified on the basis of the more detailed field and photographic work of the writer. Fault patterns, unless otherwise noted, are the responsibility of the writer.

Hartford Hill rhyolite and Pyramid sequence rocks are present in the thesis area and compose most of the rocks in the Virginia Mountains. A basalt formation, called the Terraced Hills basalt in this report, is believed by the writer to also occur in the range. Bonham (1969) has mapped outcrops of the Kate Peak Formation and the Washington Hill rhyolite in the study area. All these formations, including Quaternary deposits, have been differentiated in this paper.

There are no rocks exposed in the Virginia Mountains older than Tertiary age known to this or any other writer. Cretaceous granodiorite, however, supposedly unconformably underlies the superficial rocks of the range.

Hartford Hill Rhyolite

Hartford Hill rhyolite is the oldest rock exposed in the thesis area and is Early or Middle Miocene in age (Bonham, 1969). Its type locality was described by Gianella (1936) in the Comstock and Silver City districts. McJannet (1957) described the Hartford Hill rhyolite as his Tule Peak formation with a member by member study of that formation in the Virginia Mountains.

The Hartford Hill rhyolite in the Virginia Mountains is a thick series of vari-colored, welded ash-fall and ash-flow tuffs. Thin lenses of breccias and conglomerates are found locally within the formation. Bonham (1969) has noted that other sediments occur sporadically within the Hartford Hill rhyolite.

The formation consists of alternating light and dark members, the light members non-resistant units which are overlain by darker resistant cliff-forming units. The formation shows bright hues of red, orange, yellow, cream, green, white, pink, grey, and varying colors of brown.

In the Virginia Mountains, the Hartford Hill rhyolite is present in the southern part of the range and comprises about one-sixth of the total rock exposure in the range. Another large exposure is located west of Winnemucca Valley, but only a small portion of those rocks extend into the Virginia Mountains--in the Dry Valley area. Another occurrence of what this writer believes to be Hartford Hill rhyolite is present in Water Hole Canyon on the east side of the Virginia Mountains.

The thickness of the Hartford Hill rhyolite in this area reaches a maximum of nearly 2,300 feet (700 m) with individual thicknesses of units ranging from five feet (1.5 m) to several hundred feet (over 100 m) (McJannet, 1957). The best exposures of Hartford Hill rhyolite are in Rainbow and Box Canyons.

Pyramid Sequence

Bonham (1969) has grouped the Chloropagus Formation, the Pyramid Formation of McJannet (1957), the Old Gregory Formation of Rose (1969), and an unnamed formation in the Virginia Mountains, the Lake Range, and the Fox Range as the Pyramid sequence.

In the Virginia Mountains, the basal portion of the Pyramid sequence, McJannet's Pyramid Formation, lies unconformably over the Hartford Hill rhyolite. The Chloropagus Formation lies unconformably on the Pyramid Formation. The unnamed formation occurs in the unmapped northern part of the Virginia Mountains. The relationship of the unnamed formation with the overlying Pyramid and Chloropagus Formations is not known, although Bonham believes that this unit is at least in part correlative with the Chloropagus Formation.

Nearly five-sixths of the Virginia Mountains is mapped by Bonham on a reconnaissance level as Pyramid sequence.

The Pyramid Formation consists chiefly of a sequence of basaltic rocks and lacustrine sediments. Pyroxene andesite and rhyolite units are present. The uppermost unit of the Pyramid Formation is a hard columnar-jointed pyroxene andesite that caps many individual mountains and ridges. Buttes and small flows of this formation are found in the Mullen Gap area and underlying the Chloropagus Formation to the north.

The Chloropagus Formation consists of basalt and andesite flows and breccias. Lenses of dacite and rhyolite tuff occur as well as some thin sedimentary units. This formation and the Pyramid Formation are more resistant to erosion than the Hartford Hill rhyolite.

The unnamed formation consists of, according to Bonham, (concurs with field observations) intermediate to mafic volcanic rocks. The formation is nearly homogenous in its resistance to weathering and is less resistant than either the Chloropagus or Pyramid Formations.

Total thickness of the Pyramid sequence is estimated to be about 4,000 feet (1,200 m) in the Virginia Mountains (Bonham 1969). The age of the rocks has been dated as Late Miocene (Bonham 1969).

Kate Peak Formation

Bonham (1969) has mapped as Kate Peak Formation several plugs in the Mullen Gap area. These plugs are mostly dacites. They stand as small resistant peaks within and adjoining the Hartford Hill rhyolite. The Kate Peak Formation overlies the Chloropagus Formation in the Pah Rah and Virginia Ranges, and because of this stratigraphic data, the Kate Peak Formation is believed to be Mio-Pliocene to Early Pliocene in age.

Terraced Hills Basalt

Rocks in the Never Sweat Hills, a short ridge just to the west of the northern tip of the Virginia Mountains, and the Terraced Hills north of the Virginia Mountains, have been mapped by Bonham (1969) as a basalt of Late Miocene and Pliocene in age. The formation, for convenience, is called the Terraced Hills basalt in this report.

The basalt was also found by this writer in the northern segment of the Virginia Mountains and along the northeastern flank of the range. Its exact contact with the Pyramid sequence, while being fault-bounded at most places, is greatly obscured by lake and reef deposits, but it may overlie the Pyramid sequence.

The basalt is a little more resistant to weathering than the unnamed formation of the Pyramid sequence which is in contact with it.

Washington Hill Rhyolite

The Pliocene Washington Hill rhyolite consists of several large and small intrusive and extrusive rhyolite formations. Bonham (1969) has mapped one such area in the northern Virginia Mountains, although its correlation with the Washington Hill rhyolite is not certain. The rhyolite making up this exposure is very light in color, pumiceous, shows a distinct, nearly horizontal layering of units, and weathers homogenously to smooth colluvial slopes.

Pre-Lake Lahontan Deposits and Quaternary Rocks

Pre-Lake Lahontan terrace, pediment and alluvial fan gravels crop out as faulted and tilted ridges in Winnemucca Valley.

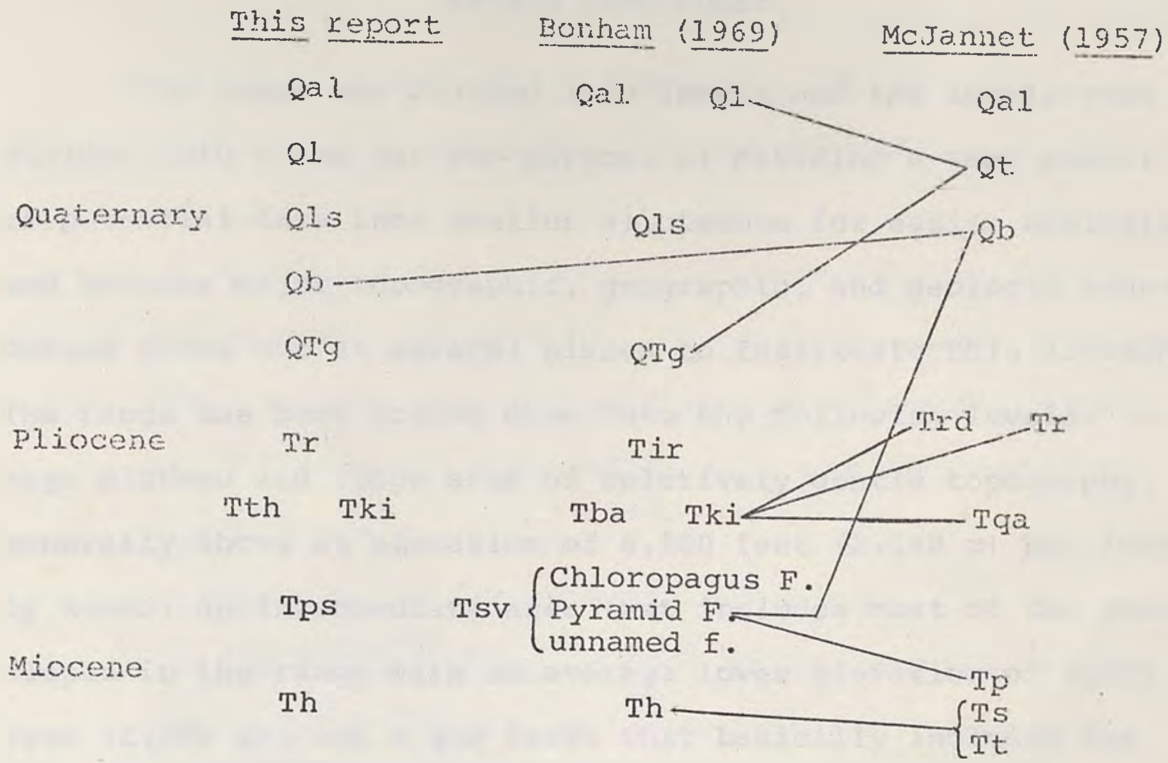
Several old landslides and mudflows have occurred within the Virginia Mountains and according to Bonham (1969) are older than Late Pleistocene lake deposits that overlie them.

Pleistocene Lake Lahontan deposits occur along the edge of the Virginia Mountains in Mullen Gap, in the Pyramid Lake basin, Astor Pass, and in Honey Lake Valley. The maximum level of the lake was 4,360 feet (1,330 m). The extent of the lake deposits can be easily seen on the aerial photographs in Astor Pass and along the eastern slopes of the Virginia Mountains. Tufa deposits are present to the maximum level of the lake on the eastern and northern parts of the range.

Quaternary alluvium is present in the mouths and as fans of most large canyons that drain the Virginia Mountains. Alluvium is the thickest at the mouth of Cottonwood Canyon, along the Hartford Hill rhyolite and especially on the eastern flank of Winnemucca Valley. Spanish Flat, at an elevation of 6,700 feet (2,040 m), is a small alluvium-filled basin formed by faulting high in the Virginia Mountains. Overall, the alluvium present in the Virginia Mountains is very thin.

Quaternary basalt flows, some several tens of feet (several meters) thick and some very thin, overlie Pre-Lake Lahontan deposits in the Winnemucca Valley and Mullen Gap areas.

STRATIGRAPHIC CORRELATION CHART



EXPLANATION

Qal -- alluvium

Ql -- Pleistocene lake deposits

Qls -- landslides and mudflows

Qb -- basalt flows

QTg -- Pre-Lake Lahontan deposits

Tr, Tir -- Washington Hill rhyolite

Tth, Tba -- Terraced Hills basalt

Tki -- Kate Peak Formation

Tps, Tsv -- Pyramid sequence

Th -- Hartford Hill rhyolite

Qt -- Lahontan terrace deposits

Trd, Tr -- rhyolite dikes and flows

Tqa -- Quartz andesite plugs

Tp -- Pyramid Formation

Ts -- Sutcliffe Formation (Wildcat Ridge)

Tt -- Tule Peak Formation

SEPARATION OF LEVELS AND DIVISION OF LEVELS INTO ZONES

The range was divided into levels and the levels were divided into zones for the purpose of dividing a vast amount of potential data into smaller allotments for easier analysis and because major topographic, geographic, and geologic boundaries stood out at several places to facilitate this dividing. The range has been broken down into the following levels: a high plateau and ridge area of relatively gentle topography, generally above an elevation of 6,800 feet (2,100 m) but locally lower; an intermediate area that includes most of the steep slopes in the range with an average lower elevation of 5,200 feet (1,600 m); and a low level that basically includes the lower mountains and hills and the Basin-Range interface. Each level was divided into three zones for systematic analysis and a tenth zone was differentiated to study the Hartford Hill rhyolite area of the southern part of the range. (Zones outlined in brown on geologic map and indexed on smaller inset map.)

Division into Zones

The three zones in the High Level are:

(1) The Northwestern Zone of moderately sloping relief. This area is bounded on the west by Cottonwood Creek and the Intermediate Level, to the east by the east side of Spanish Flat, and to the north and south by steep canyons.

(2) The Central Zone of N-S trending ridges and

valleys. This area is bounded on the west by Spanish Flat and the Intermediate Level, to the east by Little Valley Ridge and Piute Canyon, to the north by steep canyons and to the south by the Hartford Hill Rhyolite Zone.

(3) The Southeastern Zone that has been disconnected from the Central Zone by N-S trending canyons and bordered to the north and east by the Intermediate Level and to the south and southeast by the Hartford Hill Rhyolite Zone.

The three zones in the Intermediate Level are:

(1) The Northern Zone bounded by Cottonwood Creek to the west and Big Canyon to the east and between the High and Low Levels.

(2) The Pyramid Zone of steep canyons bounded by Big Canyon to the north and an unnamed canyon to the south and between the High and Low Levels.

(3) The Western Zone bounded by Black Canyon, Dry Valley, and the High Level to the north and east, and alluvial fans in Winnemucca Valley to the south.

The three zones in the Low Level are:

(1) The Northern Zone bounded by Cottonwood Creek to the southwest and Big Canyon to the southeast and below the Intermediate Level. It includes nearly the entire northern end of the Virginia Mountains.

(2) The Pyramid Zone bounded by Big Canyon to the north and the Hartford Hill Rhyolite Zone to the south

and below the Intermediate Level.

(3) The Winnemucca Valley Zone which includes most of the fans and uplifted ridges of Winnemucca Valley.

The tenth zone, the Hartford Hill Rhyolite Zone, was delineated to study as a unit the rocks included in the southern one-fifth of the range where the Hartford Hill rhyolite is the major rock type.

CHARACTER OF THE HIGH LEVEL

The Northwestern Zone of moderately sloping relief.

An old erosion surface is present in the northeastern leg of this zone. The surface has moderately sloping relief with steep canyons existing on nearly all sides. The Virginia fault crosses the ancient erosion surface but with very little effect on topography. Recognizable evidence of faults exists in only a few places.

Although the dip of the beds cannot be seen in this area, it is presumed from neighboring rock units to be very gentle. A smooth slope exists over rocks of varying resistances and no dissection occurs because of faulting, so it is therefore believed that the old erosion surface resembles the surface present before mountain building.

The NE trending Salt Cabin fault is responsible for a moderately sloping symmetrical valley that separated the old erosion surface from the rest of the Northwestern Zone. The nature of the fault is undeterminable from the photographs.

Three major N-S trending faults with upthrown walls to the west are occupied by three stream valleys in the major part of this zone, the longest fault being the East Cottonwood Canyon fault. The second longest fault is named the Spanish Flat fault and lies east of and is tributary to the East Cottonwood Canyon fault. The third fault, still further east, is called the Divide fault.

The rocks west of East Cottonwood Canyon to Salt Spring Valley and Spanish Flat strike north and dip about 25° west.

Topographic surfaces are dip slopes facing to the west and escarpment slopes to the east. Differential weathering has taken place on the escarpment slopes so resistant and non-resistant units are visible. There are some small cross-faults that variously affect the otherwise poorly developed drainage on the east and west slopes. Springs are present in East Cottonwood Canyon, and vegetation is located in abundance on the north-facing sides of the small tributary valleys. Additionally, some vegetational differences in the individual beds occur.

The geomorphology of the East Cottonwood Canyon fault area further southward is similar except the drainage on the eastern-facing slopes is more regular and on the western slopes the surface is smooth. The surface manifestation of the fault is a long, shallow and narrow valley. The narrow valley ends west of Spanish Flat reservoir but the fault can be seen to continue on the west flank of the mountain but with no topographic expression. Further south the fault valley picks up again and the fault can be traced to the 40th parallel before it can no longer be seen.

The Spanish Flat fault crosses the N-S drainage divide and is lost under the alluvium of Spanish Flat. Surface features indicate that the fault divides into two branches on either side of Spanish Flat. Alignment of vegetation suggests the western fault while a linear truncation of beds definitely indicates the presence of the eastern fault. Spanish Flat, therefore is probably a graben structure.

Dip of the beds west of Spanish Flat is about 25° west.

The canyon occupied by the Divide fault is better described as a N-S lineament rather than a canyon. Runoff drains to either side of the Virginia Mountains divide. To the north the Divide fault runs nearly along the crest of the divide forming an indentation in the ridge top. Further southward, the fault has no apparent effect on the topography except to bring more resistant rock units to the east against less resistant rock units to the west. The fault is perfectly vertical, the west side having moved up. Beds dip gently westward on the west wall. Dip of beds on the east side is not discernible.

On the divide, once erosion has "broken through" the uppermost resistant beds, downcutting has proceeded to a small degree where there is no faulting. Where there is one cross-fault downcutting has proceeded a great deal farther.

The slopes to the west of the Virginia Mountains divide are smooth and covered with colluvium. The slopes to the east are very steep and moderately dissected. Vegetation is heavier on the east side of the divide on the northern slopes, the sites for heavy snowbanking for much of the year.

The Divide fault extends southward into a resistant rock and shows a north trending joint pattern crossed in some places by small E-W faults and E-W joints. The north trending joints parallel the major N-S fault that terminated Tule Ridge. In addition, some NNE trending joints parallel some small NNE faults in the Intermediate Level below. This suggests that similar forces are responsible for both faults and joints.

Within the entire Northwestern Zone, the broad, gentle, undissected surfaces present that mostly conform to dip slopes are representative of an old erosion surfaces whose character has been altered by faulting and Quaternary erosion. Figure 3 shows one such surface.

Figure 3

Old erosion surface, looking west on ridge between East Cottonwood Canyon fault and Spanish Flat fault southwest of Spanish Flat

Summary of the High Level Northwestern Zone

Three major faults trending N-S comprise the major structure in this area. The faults are vertical or near vertical and the upthrown walls are to the west. Spanish Flat is a possible graben structure. Joint patterns trend with the faults. Dips of beds are gentle on the eastern part of this zone and about 25° west at the western edge.

Major drainage is N-S with secondary streams consequent parallel. An old erosion surface is present in the northeastern corner of this zone.

The High Level Central Zone of N-S trending ridges and valleys.

At the northernmost end of the Central Zone, Tule Ridge is abruptly terminated by Right Hand Canyon. Responsible for the truncation is the E-W Right Hand Canyon fault. The area north of and including the Right Hand Canyon area is part of the Intermediate Level Pyramid Zone and will be discussed with that zone.

Tule Ridge itself is about 5 miles (8 km) long and trends just west of north. The ridge, which is primarily resistant rock units, forms the E-W drainage divide. Two small faults are located about a mile from the north end. The topographic surface of the ridge dips at this point, low enough so that this is where the only transridge jeep trail was built. Beds dip gently east or NE about 10°. At one spot they appear to dip west.

A long N-S trending fault, which the writer has named the Scott Springs fault, parallels the ridge on the west. Beds along this upthrown side are horizontal or dipping or west. This long fault gives rise to a N-S valley lineament the length of the fault.

The ridge west of the Scott Springs fault is roughly the axis of what is discerned to be an anticlinal structure. Beds to the west of the ridge dip west; beds to the east of the ridge dip east. The anticlinal structure, which will be termed the Virginia Mountains anticline in this paper, is shown by dips to be roughly N-S and somewhat symmetrical.

Topographically below the Scott Springs fault and to the west occur one and probably two more N-S trending faults with upthrown sides to the west that create the same effect of valley lineaments.

Subsidiary drainage is not well developed on the western slopes. Where no structural features appear, a drainage pattern is almost entirely lacking except for small consequent "streamlets." The N-S trending valley lineament on the west side of Tule Ridge drains where there are cross-faults at two places at the northern end, and in five small canyons at the southern end where possible faulting exists.

A curious feature is present on the slope between the ridges caused by the topographically lowermost N-S faults. A perfectly symmetrical fan is formed as the stream issuing from the area of the Scott Springs fault flows through a breach in the N-S ridge. On the photographs, it is noted that the northern half of this fan was dark-colored, the southern half light-colored. Although the fan's northern half could not be seen in the field, it is the conclusion of this writer that a micro-climatic factor allows a darker, meadowlike vegetation to grow on the northern slopes, while sagebrush grows on the south. In the Spanish Flat area the presence of darker vegetation on slightly north-facing slopes is quite common.

The sparse vegetation on the west side of Tule Ridge grows mostly on the small NE-facing slopes and more heavily in preferred beds.

East of Tule Ridge is another long N-S trending fault, the Little Valley fault, that creates the long, deep N-S Little Valley Ridge.

On the east slope of Tule Ridge is a large hummocky surface five miles (8 km) long and nearly a mile (1.6 km) wide. Both rock type and vegetation are vari-colored giving the surface a motley texture. As this area could not be approached in the field because of terrain and land ownership problems, and since photographic evidence is not clear, a satisfactory explanation for the hummocky surface cannot be given. Possibilities include faulting, landslide, and possible sedimentary rocks overlying the Pyramid sequence unconformably.

Differences in vegetation occur because of the microclimatic factor already described and probably aided by the increased water supply from snowbanks on the northern side of the hummocks.

Little Valley Ridge is infrequently affected by cross-faulting. A NE cross-fault on the northern tip and a fault in the central part of the ridge have little topographic effect. On the southern half of the ridge transverse faulting does control drainage.

Drainage on western slopes is poorly developed; drainage on the eastern slopes is consequent parallel with some drainage fault controlled.

Peculiar, nearly flat, unfaulted undissected deposits are located over some former valleys that were the result of some cross-faults. These surfaces are not closed basin deposits nor are they old erosion surfaces. There is no adequate explanation for their nature, and they cannot be approached in the field.

Two similar blocks, both the result of faulting, both small, N-S trending, with the east blocks moved up, are present to the east of Little Valley Ridge. Both form fault valleys.

To the south of Tule Peak, the slope is very steep; the elevation dropping 2,000 feet (600 m) in less than a mile (1.6 km). The Hartford Hill rhyolite is exposed below the Pyramid sequence. The Scott Springs fault is the western border of the Hartford Hill rhyolite and a NW striking fault is the eastern border.

A characteristic of the Hartford Hill rhyolite is that it is densely faulted. In this case, faulting is present both upslope and cross-slope. This faulting has caused deep gully and stream erosion, and the cross-faulting has produced fairly deep saddles in the ridges between streams. As a whole, the Hartford Hill rhyolite here forms as a huge amphitheater of over a square mile (2.6 sq. km) in area containing several "aisles"--the ridges between gullies. The amphitheater is well-dissected and steep. A landslide is located down the mid-part of the amphitheater but has been eroded away at the sides by the streams.

East of the amphitheater is northern Piute Canyon, a N-S fault valley that lies directly in line with Jigger Bob Canyon to the north. Upthrow is to the east.

Beds in this area dip about 25° east. Dissection of these east dipping slopes is mostly consequent, but there is one N-S trending secondary stream that appears to have cut into the bedding behind a resistant bed to form a hogback.

A dark resistant rock caps the ridge at one place west of Piute Canyon; then the topography slopes down into lower levels.

To the south of this capped ridge is a spoon-shaped valley with one and possibly more faults running through it. The one fault, N-S to NNE in trend, has formed a fault valley, with the upthrown block to the east, and what may be one or two transverse faults have probably helped form the spoon-shape.

A volcanic plug may be present at the southern end of the central zone of the ridge of Piute Canyon. It may be the cause of the transverse faulting that crosses the spoon-shaped valley plus other supposed structures that cause certain gullies.

<u>Summary</u> of the High Level Central Zone

The main topographic feature of this zone is the long N-S trending Tule Ridge. It is flanked by parallel faults and corresponding valleys, and valley lineaments to either side. Upthrown sides are to the west west of Tule Ridge, to the east east of Tule Ridge. This type of faulting indicates the presence of a collapsed anticlinal structure.

The main axis of the Virginia Mountains anticline is located approximately at the ridge west of Tule Ridge. The anticline is N-S trending and symmetrical.

Hartford Hill rhyolite crops out south of Tule Peak and forms a topographic low, mainly due to extensive faulting and the rhyolite's low resistance to weathering.

The Central Zone continues south as a resistant ridge of variable topography west of upper Piute Canyon.

<u>The High Level Southeastern Zone</u> of varied high elevation topography.

Jigger Bob Canyon is another N-S trending fault valley feature with the eastern block upthrown. The small part of the eastern ridge that is in the High Level is faulted itself, the fault cutting obliquely across the ridge. The eastern side is upthrown once again. The faulting gives a very symmetrical valley with very smooth slopes. Beneath these two blocks Hartford Hill rhyolite is exposed.

South of these fault blocks, the heads of Jigger Bob and Piute Canyon meet on either side of a small, nearly flat area that has the appearance of an old erosion surface. Two sets of faults join over the plateau, a NNW set and a NE set. It is indeed possible that more faults exist in the "plateau" area as vegetation is well aligned. The number of faults present suggests that a principal stress area may have been located here.

Faults within the plateau have little effect on the topography. The faults have set some resistant beds above other non-resistant beds, but the only effect on drainage has been to afford underground water movement along the faults as shown by springs downslope. Along the sides of the plateau the faults are mainly responsible for some steep-walled canyons.

The plateau is linked to a smaller round-top mountain to the east by a short ridge. A long NNW fault has probably been responsible for the narrowing of the plateau into a ridge at this point. The rounded mountain appears to be another former old erosion surface as it is not dissected by youthful gullies or streams and is connected to the aforementioned erosion surface. It is at the northern end of another fault block canyon, the Hardscrabble Creek Canyon, which like Piute Canyon, has beds on either side dipping approximately 25° east, has a gentle western wall relatively speaking, and has a steep eastern escarpment slope serrated by small parallel gullies.

A high angle reverse fault exists midway down the east slope of the canyon which raises the beds over 500 feet (150 m) higher to the north.

Between Piute and Hardscrabble Creek Canyons is another large ridge which takes up most of the area in the Southeastern Zone. The escarpment slope of this ridge shows remarkably well the series of resistant and non-resistant beds of the Pyramid sequence. This escarpment slope is fairly well benched, the resistant rocks forming steep bench walls and the non-resistant beds the more moderately sloped surfaces.

Large and small gullies exist down the sides of the slope; the small gullies follow an ENE joint pattern. The large gullies and small canyons are the result of both definite and probable faults.

On the eastern slope, the topography is gentler than that on the western escarpment slope and very irregular. A NW fault valley traverses the area. Other possible faults of similar trend may be responsible for the irregular nature of the slope, but a large mudflow is responsible for a great deal of the irregularity. Springs occur in several places near the bottom of the mudflow.

Farther south, an E-W fault crosses the ridge. The fault is found in two valleys on either side of the ridge. The top of the ridge is the intersection area of several faults bringing together a mixture of different rock types. The N-S Piute Canyon takes a sudden E-W jag west of this intersection of faults. Faults on the west side of the ridge are in NW and NE directions resulting in drainage in those directions. The minor drainage, into the bigger canyons, follows small faults or flows consequent to the land surface formed by the bigger canyons. At the bottom of this area (out of the High Level) exposed Hartford Hill rhyolite shows a much more dissected drainage pattern. On the east side of the ridge, drainage follows possible faults, follows the bedding structure to some degree, and in some places is consequent as small gullies. Where the Hartford Hill rhyolite is exposed in the Intermediate Level, greater dissection is present.

Summary of the Southeastern Zone

The northern area of this zone is a plateau-like surface, probably an old erosion surface. It is separated from the Central Zone by Jigger Bob and Piute Canyons.

NE and NNW faults traverse the plateau. The plateau and a linked rounded mountain are the northernmost parts of two ridges, one between Piute and Hardscrabble Creek Canyons and the other east of Hardscrabble Creek Canyon. These ridges are of fault block origin with the eastern blocks having moved up. The escarpment slopes are steep with drainage essentially straight into the canyons. The east-facing slopes are irregular in drainage due to faults, bedding, and mass movement processes.

A high angle reverse fault is located on the ridge east of Hardscrabble Creek Canyon, denoting possible compression forces.

Summary of the High Level

All of the High Level is composed of Pyramid sequence rocks with the exceptions of the Hartford Hill rhyolite in the southern part of the Central Zone, Quaternary deposits, and possibly two oddities in the Central Zone--the hummocky surface on the east side of Tule Ridge, and the flat, undissected deposits near the head of Little Valley.

All three zones in the High Level are characterized by vertical or nearly vertical N-S trending faults that parallel the Virginia Mountains anticline. The upthrown blocks along the major N-S faults are almost always away from the anticlinal axis indicating that the Virginia Mountains in the High Level is a collapsed anticlinal structure.

The axial trace of the Virginia Mountains anticline is about a mile west of and parallel to Tule Ridge.

The main structural pattern of N-S faulting within the High Level does not vary greatly. The Spanish Flat graben in the Northwestern Zone, the occurrence of the Hartford Hill rhyolite "amphitheater" with its many faults in the Central Zone, and the relative abundance of cross-faults and transverse faults, and an E-W reverse fault in the Southeastern Zone, are the only significant departures from the N-S pattern.

Topographically, the characteristic and largest features are fault valleys created by the N-S faults. Tule Ridge is the outstanding topographic feature as it stands well above all other parts of the range. Dissection of the High Level is not great, but the Southeastern Zone is a little more dissected than the other two zones. Most of the gently sloping area of the High Level represents the pre-Basin and Range erosion surface. The principal drainage is N-S as a result of the N-S fault valleys. Most minor drainage is perpendicular to the main drainage channels. Almost all significant drainage channels, i.e., stream channels and major gullies, are structurally controlled, either by faults, by joints, or by tilt of the beds.

Minor topographic features are old erosion surfaces, Spanish Flat, the alluvial fan east of Spanish Flat, the hummocky surface on the east side of Tule Ridge, the flat undissected surfaces in Little Valley, the "amphitheater" south of Tule Ridge, and a large mudflow.

CHARACTER OF THE INTERMEDIATE LEVEL

The Intermediate Level Northern Zone of very steep but including relatively gentle transitional topography.

The westernmost part of this zone is the west dipping beds between Cottonwood and East Cottonwood Creeks. As partially described in the High Level, these beds are dipping west 30°, the western sloping surface being the top of the uppermost beds; therefore, this slope is about 30° and the bedding is the main control, streams being mostly consequent and parallel with the presence of faults controlling the drainage for a small area.

East Cottonwood Creek flows north, then curves east into Cottonwood Creek at the base of the mountain range. On the slopes south and southwest of East Cottonwood Creek, drainage is parallel on the steep canyon wall, but the main tributaries are all fault controlled, medium-size tributaries are fault and joint controlled, and the very small gullies are the result of joints and straight run-off.

A volcanic plug and a N-S dike control the drainage at the bend of East Cottonwood Creek. The long NW Virginia fault controls the tributary that circles the plug to the east. Joints control a drainage that is all parallel. On the slope south of the plug, joints and/or faults control a drainage that is all parallel. Some faults and joints appear related to the plug.

On the north wall of the E-W section of East Cottonwood Creek and on the steep western wall abutting Honey Lake Valley, there is a differing rock type than on the southern and eastern walls of East Cottonwood Canyon. It is a soft, light-colored, semi-homogenous appearing rock that is overlain by the resistant rock of the Pyramid sequence described at High Level. This is the unnamed formation Bonham (1969) has included in his Pyramid sequence.

In this area, although evidence is obscured, the dip of the beds appears to be gently north. The northern-facing colluvial-covered dip slopes and shallow valleys on the dip slopes are all very smooth and generally with sparse vegetation. Fine gullies occur on the south-facing escarpment slopes. Numerous pinon pines grow here. Only the south-facing slopes support trees, the reason not apparent on the photographs. Pinon trees cease abruptly along a distinct line to the north of this area where the unnamed formation contacts the Terraced Hills basalt.

To the east of this area in the Intermediate Level, the soft rock is capped by the resistant rock typical of the High Level. East of the Virginia fault, the elevation increases sharply as the eastern fault block is all resistant cap rock. Beds dip slightly to the east in what can be described as a lobe sloping away from the High Level.

On the western slope of the "lobe," the main drainage flows down the valley of the Virginia fault. Shallow gullies form the minor drainage, the gullies perhaps following small faults or joints. The joint trends are NNW or NNE; therefore, the joints are a doubtful control unless an additional E-W joint set is present. Small faults, on the other hand, do appear possible forces in controlling drainage. Lineations of rock and vegetation are E-W and coincide with gullies for the most part.

The main drainage channels on the north-facing slopes are likewise controlled by faults or probable faults. Apparent faults of a NNW trend control drainage channels of the same direction, which is about 90° from the overall slope of the land including both upper resistant and lower non-resistant rocks. The change between the two rocks types affects the drainage pattern only by the steepening of the slope in the resistant rocks.

Drainage to the east flows into two canyons. In the bigger canyon, there is a fault, the east side upthrown; in the smaller, which branches into two canyons, fault control can not be definitely established. One of those two canyons may be correlated with a possible fault on the East Cottonwood Creek side of this zone. Another possible control for the two canyons is zones of fracturing that may have existed at the areas of the canyons between non-fractured peaks to the north and south.

Minor drainage is not controlled by any visible joint pattern. Minor drainage trends E-W and joints north to NE. Except for where the gullies are forced to circumvent resistant rock, the minor drainage looks to be entirely consequent except for control by a possible E-W fault.

The old erosion surface in the High Level Northwestern Zone tops a second "lobe" east of the large canyon just described. It can be seen here that one reason for the undissected nature of the old land surface is the highly resistant nature of the rock.

The east side of the large canyon has drainage similar to the west side. Over the ridge on the east side, however, the exposure of rock is much more extensive. Scree material is restricted to the north-facing slope.

On the north-facing slope, two small canyons join to drain the highest elevations. A NNE fault is present in one of the canyons and in the larger canyon formed by the two. This fault then appears to be terminated by the possible E-W fault that strikes across the ridge there. At one point, the upthrown side of the NNE fault forms a steep resistant wall.

Other canyons, two "medium-size," and one small, drain the rest of the lobe to the north. A spring suggests faulting in one of the canyons. The spring may be the result of a NW transverse fault that does not otherwise affect the drainage.

The lower two-thirds of the north slope is in the soft rock below the hard cap of the higher elevations. Discontinuous capping by the hard rock is present along ridges down into lower elevations. It is quite probable that cross-faults have not much affected drainage. It can be seen at lower levels that small cross-faults do seem to occur without appreciably affecting drainage.

On the east side of the lobe, there is a smooth, nearly vertical wall about one-third mile (one-half km) long. This may be a fault wall, but scree so obscures what should be the downthrown block that it cannot be definitely assured. To either side of the wall there does not appear to be any continuance of a fault; therefore, this wall may be the result of joint control and rockfall.

The major drainage in the amphitheater on the east side of the ridge looks to be fault controlled, but definite criteria for defining the faults beyond doubt are absent. Cross-faults in the amphitheater appear to affect the drainage and shape of the features within although there is only one definite fault. Minor control of drainage is by NNW joints.

Surrounding the old erosion surface and to the northwest side of Big Canyon, the structure and geomorphology is much the same: faulted and questionably faulted main canyons in the resistant rock of the Pyramid sequence; north to NNW joint control and probable cross-faults affecting minor drainage; SE dipping beds, dipping approximately 25^{o}; and steep slopes. Distinction between canyon faults and cross-faults depends on the canyon's trend. The two major canyon trends, and thus faults, are NNE to NNW and NE. Upthrown sides are toward the lower elevations. Springs occur at many places where faults are suspected.

Faults cannot be seen to extend through the old erosion surface although fault canyons trend toward it. A hypothetical explanation for the lack of faulting in the old erosion surface is that many NE canyons may be controlled by the SE dipping beds in hogback fashion. Of course, some faulting may be older than the old land surface, and thus may not be detected.

The last segment of the Northern Zone of the Intermediate Level is the slope east of the N-S Divide fault. Here major drainage is fault controlled. Dip of beds cannot be told from the photos; although it is probably gently east or SE. The divide has nearly horizontal beds cut by the Divide fault and to the west beds dip gently west. It is concluded with some reservations concerning tilt, that the Virginia Mountains anticlinal structure passes roughly through the top of the divide in this area as dip of beds changes from east to west.

In this area in the shadows of Tule Ridge, trees grow only on south-facing slopes, an oddity without any adequate explanation.

Control of two or three small canyons cannot be definitely established. Minor drainage is consequent on smooth slopes and on others is controlled by NNE joints.

<u>Summary</u> of the Intermediate Level Northern Zone

West dipping beds on the west side of this zone and south of East Cottonwood Creek control the drainage patterns. A small plug, faulting, joints, and beds control drainage in much of the East Cottonwood Canyon area.

North of East Cottonwood Canyon, the dip of beds is inferred to be north. Slopes are smooth to the north, gullied to the south, without vegetation to the south. A distinct line separates the wooded area from a northern low level treeless area which is believed to be the contact of the Terraced Hills basalt.

Hard resistant rock crops out over the rest of the area. Faults, joints, and beds control the drainage over this steep area. Most large faults are NNW or NNE, but faults in other directions, particularly E-W, exist.

The High Level old land surface is almost unscathed by faults and is capped by hard resistant rock which greatly attributes to its lack of dissection. Why faults are not visible passing through the surface is unsolved.

<u>The Intermediate Level Pyramid Zone</u> of very steep slopes and deep canyons.

The northern area of this zone, roughly between Big Canyon and Right Hand Canyon, is well faulted. Faceted spurs attest to the drop of a northern block north of Big Canyon along an E-W fault. Right Hand Canyon is similarly faulted by an E-W fault. Several odd-shaped blocks to the southwest of Big Canyon and east of the Divide fault are surrounded by faults with fault trends basically NNW and NE to east.

A N-S fault bisects the block between the E-W faults, the east side moving up. The E-W fault in Big Canyon is younger than the N-S fault as the spurs are still in the same plane. Three or four other NNW to N-S trending faults also cut this block but have not had near the geomorphic effect of the bisecting fault, perhaps because there was little movement along the faults or because they are of older age than the present land surfaces and any topographic differences were removed by erosion before the present uplift of the Virginia Mountains.

One of the NNW faults creates an offset in the western side of the block, but its direction of movement is undeterminable. The fault scarp on part of the western face of the western side of the block is an even plane with small, jagged outcrops of resistant rock covering the entire face. Since the joint trend is parallel to the face, there is very little minor control of drainage, and thus the slope is a plane.

A nearly north-trending fault cuts or is cut by the E-W Right Hand Canyon fault. Along the northern side of the block, this fault is parallelled by a large gully. Four springs are located along the fault near the bottom of Big Canyon. The upthrown side of the fault is to the east. The fault can be traced over into Right Hand Canyon.

It appears probable that Right Hand Canyon has pirated Left Hand Canyon's Little Valley source area. It seems the Right Hand Canyon fault occurred after the Left Hand Canyon fault had already formed a valley draining the Little Valley area. The Right Hand Canyon fault, with a great displacement between blocks, formed a deep fault canyon that robbed Left Hand Canyon of its source area.

Tracing any of the faults that are north of Right Hand Canyon south into Tule Ridge is difficult. There are lineations on the Tule Ridge side that occur with all of the faults on the Right Hand Canyon side. Those lineations may all or partly be coincidental. Only one of the five faults appears as if it may be a fault on the Tule Ridge side, a NNW one, although it has no effect on the Tule Ridge drainage except to the east side of the lineation there is much more vegetation.

In this area, almost all vegetation grows on the southern slopes.

The big block just described has been so downdropped that the canyon in the center of the block forms a negative feature where Tule Ridge would be had not the faulting occurred. This block seems to be a center where N-S, NNW and E-W trending faults meet, the N-S and NNW faults with upthrown blocks to the east, the E-W faults with downthrown blocks to the north.

Joints in this area are N-S and help to define some very minor drainage where the resistant rocks crop out. Gullies exist in number only on the west side of the bisecting canyon. A possible NE fault may cause one of the gullies, but the cause of the rest are unknown. Most other slopes on the block are covered smoothly with colluvium with some outcrops present on escarpment slopes.

To the northwest of the block between Right Hand and Left Hand Canyons is another similar "block." It has a N-S canyon caused by a fault bisecting the block, the east side upthrown. An E-W fault exists along the bottom of the east side of the block and possibly extends west. There is gullying extensively only on the west side of the bisecting canyon but not definitely of fault origin. All the other slopes are relatively smooth just as on the first block. Resistant outcrops are found on the slope bordering Big Canyon and Left Hand Canyon. It can be concluded that the structures and their causes and the landforms resulting are probably of the same origin as the first block.

Vegetation and trees on the second block are heavier than in the area of the first block.

The west ridge of the second block merges with Little Valley Ridge.

South of Poison Canyon is another block. It, though, has been bisected by an E-W fault, the upthrown side to the south. The E-W fault has formed a large center canyon. A N-S fault is present along the bottom of the block and is responsible for diverting the bisecting canyon's stream to the north. It is likely that another N-S fault exists at the top of the block. E-W faults are present on both sides of the block. Thus, the E-W, N-S trend of faults continues in this area.

Minor drainage on this eastern-sloping block, of course, is different from that on the first two blocks. Beds are exposed both north and south with a dip of about 20° east, and thus the minor drainage is affected by joints on escarpment slopes. The dip of the beds east makes east-facing slopes somewhat smoother.

Vegetation becomes much heavier on all slopes, especially on the south sides.

Between the north fork of Jigger Bob Canyon and Hornet Spring Canyon is an area that slopes east from Little Valley Ridge. It is not cut by any visible fault, although the canyons to either side are cut by faults, and a small segment of the bottom most part of the area is cut by the N-S fault that cut the block north of it.

The top and side of the slope of Little Valley Ridge in this area shows the same hummocky nature as the east side of Tule Ridge. This is evidence that the hummocky slope of Tule Ridge existed before formation of Little Valley.

On the steeper slopes below the hummocks, craggy outcrops of east-dipping beds appear. The drainage of this area is similar to that of the block north of it.

Jigger Bob Canyon is caused by a basically N-S fault block that moved up to the east. Drainage and structure to the west of the canyon are all similar permitting this four mile long, one mile wide (6.4 km long, 1.6 km wide) canyon slope to be described as one feature.

The dozen or so canyons tributary to Jigger Bob Canyon on the west side all trend in a ENE direction. Faulting appears to be the cause of three or four of the canyons, some can be said not to be faulted and the rest are indeterminate. The lower parts of the ridges, between canyons on the northern side of Jigger Bob Canyon, are cut by the N-S Jigger Bob fault. That is to say, that the Jigger Bob fault is not in Jigger Bob Canyon but runs west of it. Strong downcutting into the eastern ridge has probably forced the stream valley to migrate eastward away from the fault. Where the tributary streams enter Jigger Bob Canyon, the canyon bends toward the east because of the extra erosional power of the high gradient, eastward flowing water cutting into the N-S ridge. Where there are no tributary streams, Jigger Bob Canyon bends back to the west or north because the eastward power has dissipated, and the water no longer laterally cuts but downcuts instead so the bends to the west remain.

At the top of Little Valley Ridge and facing Jigger Bob Canyon is more of the hummocky surface found on the east slope of Tule Ridge. Springs and heavy patches of vegetation occur on this hummocky surface.

Hornet Spring Canyon exists because Little Valley Ridge has been faulted near the top of its eastern slope, the east side moving up. This fault may be responsible for some of the springs.

Jigger Bob Canyon heads as one of several NE-facing canyons. The features in these canyons are similar to others in this area that have been described.

Drainage into the tributary canyons of Jigger Bob Canyon is almost all on slopes with very few gullies or joint controlled drainage. The smoothness is a function of the eastward inclined dip slopes.

The ridge to the east of Jigger Bob Canyon is similar to other N-S ridges that are formed as fault blocks. The western side of the ridge shows beds cropping out, major drainage controlled by probable faults, minor by joints. The eastern slopes are smooth although canyons present at the Low Level have cut deeply in places. Some ridge top areas are suggestive of old erosion surfaces.

A possible small intrusive domes up some of the beds about half way up Jigger Bob Canyon. Additional effects are a forced bend in the stream and joints at a NW to west trend in addition to the normal N-S joint trend. The intrusion itself is less than a quarter mile (0.4 km) in diameter.

Hartford Hill rhyolite, as mentioned in the High Level, crops out further south below the top of the ridge at the ridge's highest point of elevation.

Between Wood and Water Hole Canyons and east of Jigger Bob Canyon is another block with canyons to either side and cut by a NW fault through the middle. The fault through the middle has caused canyons on both the north and south sides of the block. Another NW fault terminates the block to the east. The eastern part of the block has moved down in relation to the western part, a state contrary to upward movement of other "eastern" blocks. The nature of the whole block to the ridge east of Jigger Bob Canyon is uncertain except in the northern canyon where the block appears to have moved down.

An old erosion surface exists on top of the western part of this block. The southern part of the old erosion surface is steeply inclined toward the north while the northern part is gently inclined. There is a sharp break in slope in between. The old erosion surface could have had this topography before formation of the present Virginia Mountains, or the northern part is perhaps another downthrown block, or possibly the old erosion surface was bent during uplift or faulting. Colluvium has covered any suggestion of a fault trace.

Again, minor drainage is typical of previously described blocks.

South of this block is Water Hole Canyon, a very deep canyon due to the presence of easily eroded Hartford Hill rhyolite in the lower portion. Both the Pyramid sequence cap and the Hartford Hill rhyolite are very steep. The Hartford Hill rhyolite, as usual, is much more gullied and more dissected than the Pyramid sequence. Drainage is thus a combination of the two kinds found in the two individual rock types.

There appears to be three or four faults in the small individual canyons in Water Hole Canyon in the Hartford Hill rhyolite. Rockfall and small landslides may partially conceal possible cross-faults although at least one exists.

At first glance it would appear the Hartford Hill rhyolite has moved up in relation to the Pyramid sequence as the Pyramid sequence around Water Hole Canyon appears to be the same as that found at the top level of the formation, but no evidence of faulting of this nature is apparent. More likely Pyramid sequence volcanics were deposited directly on a large "hump" or mountain of Hartford Hill rhyolite that was present in late Miocene. A very curious flat area exits within the canyon but cannot be explained either. The causes of drainage within Water Hole Canyon are likewise unknown.

South of the area of Water Hole Canyon, it appears that there are NW trending faults, possibly with upthrown sides to the east. Faults probably traverse the plateau-ridge of the High Level Southwestern Zone. Drainage in this area appears to be typical of the type already described for adjacent areas.

<u>Summary</u> of the Intermediate Level Pyramid Zone

The Pyramid Zone is typified by N-S trending faults that have produced the main canyons. Two northern blocks have similar shapes, and it is assumed they were caused by the same forces. Upthrown blocks are almost always east.

E-W faults are also typical of this zone. These faults have formed both major and tributary canyons. The E-W faults north of the High Level Central Zone have down-thrown blocks to the north. Blocks to the east of the High Level Central Zone may be more varied in direction of movement.

Joints trend N-S. Joints and dip of beds eastward determine the gully drainage into the canyons. Gullying is principally a phenomenon occurring on the escarpment slopes as is cropping out of the resistant beds. Eastern-facing dip slopes are gentler and smoother than the escarpment slopes, with canyons generally the only type of drainage channels.

A small intrusion domes up the rock units at one point in Jigger Bob Canyon.

An old land surface exists near Water Hole Canyon.

Hartford Hill rhyolite crops out in Water Hole Canyon.

Heavy vegetation grows on the southern slopes in the Right Hand Canyon area; elsewhere, heavy vegetation grows everywhere unless there is some type of local control.

<u>The Intermediate Level Western Zone</u> of varied topography.

Below the 40th parallel, beds are dipping west along rather smooth 25° slopes east of Black Canyon. Secondary drainage is controlled by beds. No definite faults can be seen.

To the east of Black Canyon is the northern segment of the Dry Valley Creek Canyon. Its western slope is short, steep, and an escarpment slope. The eastern slope is again a dip slope with several NE trending canyons tributary to Dry Valley Creek. Fault control seems likely for the biggest of the tributary canyons. A good first conclusion would be that this area is structurally and geomorphologically similar to the Cottonwood Canyon-East Cottonwood Canyon area, its counterpart to the north.

Northwest of Little Valley (Little Valley in Winnemucca Valley), five to six NW trending faults traverse the area creating low NW trending hills. These faults are believed to be part of the Walker Lane lineament although only dip-slip movement is apparent here. The rock type is Hartford Hill rhyolite. The faults affect drainage to various degrees, but major drainage from the hills, as would be expected, is NW trending with minor drainage perpendicular to this. Some dips of beds in the fault slices can be seen to be approaching vertical while others dip 25° to 30°. Escarpment slopes are gullied and rough while dip slopes are gullied and smooth.

In Little Valley itself there are many springs, some or all attributable to the fault slices. Three faults running NW and one E-W seem to cause some of the springs. The motley appearance of this area (alternating rock types) probably means that there are many more faults but small in comparison to the NW trending faults.

To the west of this motley, hummocky, spring-lined area is a smooth, flat, NW trending, uplifted slice of Tertiary and Pleistocene gravel (Bonham, 1969) with a NW fault-bounded slice of Hartford Hill rhyolite present within it. Only one large gully has cut through the slice.

About a mile (1.6 km) up the slope of the Virginia Mountains from the spring-lined area is a N-S to NNW fault, the upthrown side to the west. While the upthrown wall may have been a barrier to drainage in the past, streams have created gaps through it. The streams are draining into Little Valley and Winnemucca Valley. The streams probably all are fault controlled to some extent. Only the positive faults have been mapped, however.

Above the N-S to NNW fault is a smooth dip slope and several canyons that have been described in the High Level.

Segments of the canyons appear faulted, but it is difficult to tell. Secondary drainage into those canyons is very weak.

South of the Intermediate Level Western Zone is an alluvial fan of the Low Level Winnemucca Valley Zone to be described later.

Summary of the Intermediate Level Western Zone

Three structurally and morphologically different areas are present in this zone. The Black Canyon area is similar to the Cottonwood-East Cottonwood Canyon area to the north: N-S trends of canyons and faults, smooth west-facing dip slopes, rough eastern escarpment slopes.

NW faults slice through the Little Valley area in Hartford Hill rhyolite and other rocks and probably are part of the Walker Lane lineament. (See Fig. 4.) Many spring-lines and individual springs occur along faults.

Figure 4

Northwest trending fault bounded ridges in Hartford Hill rhyolite in Little Valley area, looking southeast

West-facing canyons drain the steep, southwestern slopes of Tule Ridge with some parts of the canyons showing faulting. Channels pass through a N-S to NNW trending fault block that acted as a barrier before streams had breached it. The upthrown side of the fault that caused the barrier is to the west.

Summary of the Intermediate Level

The Intermediate Level is composed mostly of Pyramid sequence volcanics with outcrops of Hartford Hill rhyolite present in Water Hole Canyon and in the Winnemucca Valley Zone. Tertiary and Quaternary deposits are present in the Winnemucca Valley Zone and possibly as the hummocky surface on the east side of Little Valley Ridge.

Structurally, the three zones in the Intermediate Level are not similar for the most part. The Northern Zone is characterized by joints and vertical or nearly vertical faults occurring in a variety of trends: N-S, NW, NNW, NNE and E-W. Different forces acting at different times are probably responsible for the structural patterns. Beds dip west in the western part of the zone, north in the northern part, and east in the eastern part, which suggests that the Virginia Mountains anticline passes through the zone and perhaps plunges north.

"Blocks" faulted mainly in N-S and E-W trends characterize the northern part of the Pyramid Zone. The large N-S trending Jigger Bob fault valley and its tributary faults of ENE to E-W trends are the major features in the central part of this zone. The nature of the faulting in Water Hole Canyon of this zone is not well understood, but it appears a variety of trends exist there. As might be concluded after discussion of the Low Level, the variety of faulting may be due in part to the Walker Lane lineament although no definite conclusions can be made. Beds in the Pyramid Zone, which is on the east limb of the Virginia Mountains anticline, dip in an easterly direction.

In the Winnemucca Valley Zone, which is varied in structure, the Black Canyon area structure is essentially like that of the High Level: a N-S fault and its fault valley (Black Canyon) and little other faulting. Beds dip west on this, the western side of the Virginia Mountains anticline. Walker Lane type faulting is exhibited in the Little Valley and Winnemucca Valley area as NW trending slices cut through the Hartford Hill rhyolite present there. Springs are numerous along the faults. Dip of beds is basically west, but dips vary in individual fault slices. On the steep slopes west of Tule Peak, there is a N-S to NNW block with upthrow to the west.

Although geomorphologically the Intermediate Level is characterized by valleys formed as the result of faulting and very steep slopes, the Intermediate Level Zones are not similar in topography. The western part of the Northern Zone is a smooth dip slope but most of the zone's drainage is greatly influenced by a resistant cap rock covering a softer formation beneath it. In the Big Canyon, Right Hand Canyon area, drainage is almost all the result of the extensive structure, most particularly the faulting. Major drainage channels in the rest of the Pyramid Zone also follow structure with Jigger Bob Canyon being the longest channel, but structural control is not as great as in the Big Canyon--Right Hand Canyon area because faults are fewer. Drainage in the Winnemucca Valley Zone is generally controlled by the N-S faulting and the NW Walker Lane lineament faulting.

A problem is posed by the growth of trees on southern slopes, rather than on the northern, in most of the northern part of the Intermediate Level. Trees do not grow in the Terraced Hills basalt and the contact between that formation and the Pyramid sequence is roughly the line where trees no longer exist.

CHARACTER OF THE LOW LEVEL

The Low Level Northern Zone of low hills and ridges.

A youthful Cottonwood Canyon stream and a mature East Cottonwood Canyon stream converge on an alluvial valley that narrows between the Virginia Mountains and the Western Virginia Mountains before fanning out on Honey Lake Valley.

Springs occur near the south side of East Cottonwood Canyon where the wall of the canyon and the alluvium meet. The cause of the springs is not readily identifiable.

The Cottonwood Canyon fault continues north as the fault separating the Honey Lake Valley basin and the Virginia Mountains.

The west slope of the Northern Zone south of Never Sweat Hills is a steep, faceted, fault scarp wall. It rises from ridge bottom to ridge top an average of 1,000 feet (300 m) one-third to one-half mile (0.5 to 0.8 km) on a 30° slope. The only significant canyon on the scarp wall is Telephone Pole Canyon near the south end and which drains only about one square mile (2.5 sq. km) of area. Nearly all the other canyons drain only the steep west wall. The drainage of all canyons flows out onto the many small fans that have coalesced on top of Honey Lake Valley lake sediments.

Most of the canyons on the west slope were formed along what seem to be E-W trending faults. Several small faults can also be seen in the field along the west slope, and they greatly affect the minor drainage by having helped form very small canyons along the mountain front. Along the wall some rocks crop out boldly, while in other places the wall is covered by colluvium.

A large outcrop of Washington Hill rhyolite in the Pyramid sequence southwest of Never Sweat Hills. The block is seen to be layered in the field, but the nature of its contact is not known. There may be fault contacts. Slopes on the rhyolite are quite different from slopes on the surrounding hills. Except for the needle-like outcrops on the very top, the mountain is very smooth. There are no outcroppings of individual beds on the entire west slope. Except for a slight color variation of the layers, the rhyolite mountain appears to be homogenous in its weathering characteristics: an easily fractured rock with individual particles not bigger than hand specimen size. The lack of gullies is probably due to the high permeability and homogeneity of the rhyolite. The only significant force for downward movement is probably creep.

The Never Sweat Hills is a low ridge composed of Terraced Hills basalt. It is separated from the Virginia Mountains by the Cottonwood Canyon fault and Pleistocene bar deposits at either end surround an old lagoon.

Opposite the Never Sweat Hills, the steep west wall abruptly transcends into low hills, a few of which are over 1,000 feet (330 m) high. These hills are Terraced Hills basalt. The west slope here was apparently faulted extensively enough so that there was enough movement of blocks and enough erosion to lower the relief of the area. This conclusion is reinforced by the fact that these events took place at the northern tip of the Virginia Mountains, and this west slope is just a continuation of that tip.

The low hills of the northern tip of the Virginia Mountains are terminated by Astor Pass, a WNW trending graben structure. Bonham (1969) has mapped the rock type north of Astor Pass in the Terrace Hills as Upper Miocene to Pliocene basalt (Terraced Hills basalt). South of Astor Pass, he has mapped the rock type as Pyramid sequence of Miocene age. It appears from the aerial photographs and in the field, however, that the same formation is found on both sides of the Astor Pass. What appears to be Terraced Hills basalt, although greatly obscured by lake and reef deposits, is present over ten square miles (26 sq. km) of area in the northern Virginia Mountains. Figure 5, p. 59, shows much of the Astor Pass area.

The northern tip area's highest elevation expresses itself as a N-S ridge situated in the center of the mountains. The ridge and the slopes to the east and west are highly faulted by a semi-rectangular fault pattern of N-S, NNW and NE faults. Dips of beds vary from nearly horizontal to gently north or east. No west-dipping beds were recognized.

Escarpment slopes and outcropping rocks occur on western-facing slopes and on the steep north-facing cliffs of Astor Pass. Smooth dip slopes exist on the gentle northern slopes and on eastern slopes. As would be expected, most of the rock outcrops would be to the west of the central ridge.

There is a E-W joint pattern and a NNE joint pattern.

Most of the north to NW faults have the upthrown wall to the east whether to the west or east side of the central ridge. Combined with the recognition of the north and east dipping beds, the indication is that this northern area can be correlated with the east limb of the Virginia Mountains anticline.

Observations of the NE trending faults show varied types of movement, dip-slip and strike-slip and no pattern can be established for the NE faults except in the northwest corner where two small faults show a right-lateral movement.

Drainage tends to follow the trends of the faults. Nearly all major canyons are either NW or NE, but they are not always straight. The number of fault blocks, possible strike-slip displacements, and the varying resistance of rocks help produce many small bends in the canyons. Very small gullies are found over the entire area, but few large gullies exist there.

Canyons to the west of the central ridge bring sediment into the Never Sweat Hills basin and the Astor Pass graben; canyons to the east empty into Astor Pass and onto the Pyramid Lake beds.

NNW and NW trending ridge-like hills are located on the eastern side of the northern tip and in the Terraced Hills. It appears possible that Walker Lane faulting manifests itself here as a large number of NNW and NW faults. (Fig. 5 on p. 59 shows the various trends in this area.) All these hills appear to have been moved along right-lateral faults that are part of the Walker Lane. The ridge-like hills are of the basalt rock-type of the Terraced Hills to the north. Eastern blocks have moved SSE and SE. At this point, if it is assumed the ridges once were in or near Astor Pass, the suggestive displacement may be about one or two miles (1.6 to 3.2 km) although there is relative movement between more than two blocks and, typical of the Walker Lane, there is no conclusive evidence of movement present at all. It appears, though, that some stream channels might have been offset due to lateral displacement.

The NNW and NW trending faults have formed small horsts and grabens. One NNW fault here is also the predominant Basin and Range fault for the east side of the Virginia Mountains; therefore, dip-slip movement is also very important along these apparent Walker Lane structures. The height of tufa deposits on the ridges and hills of the northern part of the range varies greatly from ridge to ridge and hill to hill, perhaps indicating movement in a dip-slip direction (the ridges generally moving down in relation to the rest of the northern tip) after the recession of Lake Lahontan. An old Pleistocene bar and lagoon are present at the end of one graben.

South of the northern tip, but still in the low elevation hills, the central ridge connects with the ridge that forms the steep west slope. The faulting in the area to the east of the ridge has combined in such a way as to form a nearly circular pattern of drainage around a circle of hills.

Figure 5
Northern tip of the Virginia Mountains, Astor Pass, and part of the Terraced Hills, showing NNW, NW, and NE lineations

The pattern closes the circle about 60%, the "unclosed" portion facing the northeast. The northern segment of the circle drains out into Astor Pass after encountering one of the NNW hills on the northeast end of the northern tip. The southern segment drains into the Shallow Springs area west of Pyramid Lake. The small canyons in the center of the circle drain out through the "unclosed" portion of the circle as a converging semi-radial pattern, then drain to the east about a mile (1.6 km) north of Shallow Springs. Gullying is very heavy on these south-facing slopes.

Beds within the circle dip ENE and NE. Beds outside the circle on the north dip in the same directions; beds outside the south of the circle appear to dip in that same general direction.

The formation of the circle may be coincidental or as the result of some subterraneous force. There are no surface features on the photographs to indicate the latter, although this does not mean there could not be an other than coincidental reason for the circle's existence. However, most of the faults that make up the formation of the circle are each part of the trends already found in the area, NE, NNW, NW. A WNW trend that has not as yet been mentioned also exists.

The WNW faults are short, averaging about one-half mile (0.8 km) in length, have a small dip-slip displacement with the downthrown blocks to the north, and generally do not have any great significance in forming the topography.

A round mountain, about a one-half mile (0.8 km) in diameter, and a few small hills border the open end of the circle. They are darker in color than the rocks on the interior of the circle, as they do not have deposits covering these flanks as high as those hills of the interior, meaning they have downdropped some since recession of Lake Lahontan. The hills are resistant and almost without gullies.

Dark-colored rock that is suggested to be the Terraced Hills basalt is present down the east side of the Virginia Mountains. NNW trending faults, separating those darker rocks and the western lighter rocks defined as part of the Pyramid sequence, can be mapped almost continuously down the mountain front till just south of Big Canyon. This anomaly appears to the writer to be part of the Walker Lane lineament and hereafter will be referred to as part of the Walker Lane.

Southwest of the southern arc of the circle, the area has been described in the Intermediate Level Northern Zone.

South of the circle, the steep canyons of the northern part of the Intermediate Level drain into the southern segment of the circle. The cross-faults noted in the Intermediate Level are of the same trend as the WNW faults that are present in the circle area.

Except for the steeper canyons, the morphology of the area below the resistant cap of the Intermediate Level is the same as for the rest of the northern area.

Thin alluvial fans partially cover old Lake Lahontan lake beds which in turn cover old pediment surfaces along the

Pyramid shore area. Faulting in or bordering the fans, pediments, and lake beds has occurred in the recent past. Deep gullies have been cut along the traces of the faults. One block of lake bed material about one-fourth of a square mile (0.6 sq. km) in area has been raised several tens of feet (several meters).

The contact between the Terraced Hills basalt and the Pyramid sequence is covered by scree, lake, and tufa deposits until just north of Big Canyon. Small hills and ridge tops of Terraced Hills basalt are visible above the cover. NW trending and other faults are present.

Just north of Big Canyon, the Terraced Hills basalt rock type forms a group of hills that is circular in nature and have smooth, rounded surfaces. There is one E-W fault in a canyon and three NNW faults, one of which is probably one of the faults that runs down the mountain front separating the basin and range. A NNW fault separates these hills from the Pyramid sequence to the west. (Refer to Figure 6, p. 66.)

Big Canyon is an alluvium-filled canyon with a mature stream at its lower level. The stream drains the longest and biggest drainage basin in the range. It also drains the area of heaviest snowpack so it has running water much of the year.

In its lower section, Big Canyon's walls all have smooth facets. It is presumed that the entire course of the lower part of the stream is due to faulting, E-W, NE, and N-S.

At its mouth, the stream flows out onto a fan situated on lake beds covering a pediment surface where bedrock is exposed and where two terraces have formed, indicating a recent rejuvenation. A deep gully from the circular hills to the north onto the fan, lake beds, and pediment also indicate rejuvenation. Rejuvenation can probably be accounted for by both the drop in the water level in Pyramid Lake and recent uplift as indicated by faulting.

Summary of the Low Level Northern Zone

From Cottonwood Creek to a rhyolite "mountain" in the north there is a steep west wall with small drainage basins, canyons and gullies formed by predominantly short E-W faults. The east-facing side of the mountain is wide and not as steep.

In the northern tip, there is a mass of fault blocks cut by NNW, N-S and NE faults that have occurred in the Terraced Hills basalt. Dip of the beds in this area ranges from near horizontal to gently north and east.

Walker Lane type faulting, with right-lateral displacement which appears to be in the order of one or two miles (1.6 to 3.2 km), is present on the eastern part of the northern tip and continues south to Big Canyon.

Faulting trends in between the northern tip and Big Canyon are NNW, WNW, and NE. At Big Canyon there is an additional E-W trend. Drainage follows all these trends.

Faulting and rejuvenation along fans, pediment, and lake beds has occurred.

The Low Level Pyramid Zone of low hills, canyon mouths, alluvium and lake beds.

Immediately south of the mouth of Big Canyon is a jagged peak of Terraced Hills basalt. West of it there appears to be a small slice of the Terraced Hills basalt. West and south of that the Pyramid sequence volcanics are present. (Refer to Figure 6, p. 66.)

Springs occur in each of the next four canyons south of Big Canyon along faults or apparent faults of NNW and nearly ENE trends. The NNW faults are very probably part of the Walker Lane faulting. On the west sides of many NNW faults, a rock of different color from that of the dark Pyramid sequence is present. This may be part of the unnamed formation of the Pyramid sequence with small caps of the darker, overlying hard rock. Along the faults left-lateral strike-slip movement with displacement in hundreds of feet (hundreds of km) is present. Very small ENE en echelon faults have a left-lateral strike-slip on a small mountain along Nine Mile Bay. The ENE faults so far described in the Pyramid Zone are younger in age than the NNW trending faults as the NNW faults are broken by the ENE faults.

Dip of beds is from 5^{o} to 25^{o} ENE to NE.

There is no occurrence of springs south of Jigger Bob Canyon in the Low Level.

Three blocks along Nine Mile Bay are tilted to the north. The NE to ENE faults have produced wide fault canyons; the widest is through a steep-walled very resistant rock along the south side of the southern most block. The block south of it has not been tilted north, and so presumably the wide canyon is the result of a wide split after the one block tilted north.

The big block--or group of blocks--between Wood and Water Hole Canyons has east dipping beds. It is cut by several NNW faults and at least two or three but probably more ENE faults. In addition, the entire block is faulted by many small faults, ENE and NNW, with a small net slip. Both Wood and Water Hole Canyons show streams offset along faulting with a right-lateral movement. (Refer to p. 68.)

Two small hills of light colored rock type, differing from the regular dark Pyramid sequence rocks of the interior, are located here.

Small Pleistocene lagoons and bars are displayed at two or three canyon mouths.

To the south side of Water Hole Canyon the NNW and ENE trends are still present. It is difficult to tell what rock type is being dealt with: regular Pyramid sequence rocks or a different type as characteristic of hills to the north (the unnamed formation). Very poor aerial photographs make discrimination between rock types impossible, but several recognizable faults of NNW and ENE trends have been mapped in spite of this problem.

Just north of Hardscrabble Creek (actually in the Hartford Hill Rhyolite Zone) NW faults and a few NE faults can be seen. A long NW fault separates Hartford Hill rhyolite

Figure 6
Fault trends in the Big Canyon area of the Low Level

from several hills of a different unknown rock type.

Dip of beds is about 25° NE.

Drainage along the entire Pyramid Zone has been dominated by canyons following the ENE trending faults. Minor canyons and saddles in ridges are present along the NNW trending faults.

Gullies have formed on escarpment slopes in greater number than on dip slopes. However, gullying is more extensive on the exterior rock type than on the Pyramid sequence exposed to the interior. In the south, Hartford Hill rhyolite has the densest gullying, and what appears to be an ENE joint pattern contributes only very slightly to minor drainage control.

Large NE trending canyons contain alluvium, most smaller ones are without. The streams in all the ENE canyons cut down into the fans, pediment, and lake beds to form entrenched gullies just as they did north of Big Canyon in the Low Level Northern Zone.

Faceted spurs are present on many of the hills along the mountain border where major Basin and Range dip-slip movement has occurred.

<u>Summary</u> of the Low Level Pyramid Zone

The Low Level mountains bordering the shoreline are all the result of what appears to be Walker Lane-type faulting with faults trending NNW. What was stated about the Walker Lane region north of Big Canyon can be said of this zone concerning faulting and geomorphological features. A

Figure 7

Fault trends in the Water Hole Canyon area of the Low Level possibly unidentified rock type exists on the east side of many NNW faults. A great part of it is probably the unnamed formation of the Pyramid sequence.

In this zone, a trend of ENE left-lateral faults was recognized. The ENE faulting is younger than the NNW faulting.

The Low Level Winnemucca Valley Zone of alluvium and low uplifted ridges.

This zone is comprised of only two important features; a large alluvial fan and upfaulted Pre-Lake Lahontan gravels that form NW trending ridges, some covered by thin Quaternary basalt flows.

The large fan drains the spring-line area to the north, the high elevation Tule Peak cliffs to the northeast, and the western side of the ridge west of upper Piute Canyon. Braided patterns exist on the fan but most of the stream run-off is through a few large gullies. No bedrock, indicating a pediment surface, is seen underlying the fan.

According to Bonham (1969), the uplifted pre-lake Lahontan sediments are old alluvial fan, pediment and terrace gravels, but some Hartford Hill rhyolite is present and thin Quaternary basalt flows cover the ridges in much of the southern half of this zone. The deposits have been uplifted along NW faults and tilted to the SW. One block appears tilted NE. NE trending cross-faults are present in several places and the gullies that run off the fan cross through what appears to be water gaps. Stream offset may have occurred. There may be more NW and NE faults than mapped. Additional gullying has dissected much of the area on the uplifted sediments.

Winnemucca Valley is an alluvium filled valley with a mature stream between the uplifted gravel and Dogskin Mountain.

Summary of the Low Level

The following rocks are present in the Virginia Mountains in the Low Level: the Pyramid sequence including the unnamed formation, the Terraced Hills basalt, the Washington Hill rhyolite, the Hartford Hill rhyolite, gravels, alluvium, lake beds and Quaternary basalt.

The Walker Lane lineament is characteristic of all three zones in the Low Level. One branch of the lineament extends through the Northern and Pyramid Zones and another through the Winnemucca Valley Zone. The first of the two branches is characterized by NNW trending right-lateral faults cut by second-order ENE trending left-lateral faults. The evidence that suggests lateral movement is the differing rock types on either side of the faults and the stream offsets present in some canyons along faults.

The Pyramid Zone is characterized basically by NNW and ENE fault trends. The Northern Zone, however, shows faults trending in several more directions, NW, NE and E-W, and N-S, indicating that more than just the NNW branching of the Walker Lane lineament was responsible for the fault trends. The position of the linear Never Sweat Hills west of the steep western wall of the Northern Zone might possibly be due to left-lateral movement, with some small faults suggesting the presence of second-order right-lateral movement. Astor Pass graben and possibly the "circle" fault pattern additionally indicate the complexity of the fault system.

Tilt of beds suggests the Northern Zone to be on the eastern limb of the Virginia Mountains anticline. The Pyramid Zone is definitely on the east limb of the anticline.

The Winnemucca Valley Zone is part of the branch of the Walker Lane lineament discussed in the Intermediate Level Western Zone. The presence of the NW trend itself and possible stream offsets help to demonstrate the presence of the lineament. Rock type is not definitive in discerning the Walker Lane in this zone.

The streams in all three zones are controlled mostly by Walker Lane faulting, although the direction of flow of major streams may differ. Major and minor channels trend NNW, ENE, or NW, except in the Northern Zone where drainage follows the many trends. Ridges and saddles are controlled by the faulting trends present. Low hills and ridges and some steep canyons are the main topographic forms in the Low Level with the exception of the steep west wall and the Astor Pass graben of the Northern Zone. Pediment surfaces underlying alluvial fans and lake beds are the typical basin features of the Low Level eastern mountain front. Upfaulted pediment surfaces, fans and lake beds, and entrenched stream channels and gullies indicate rejuvenation of the entire eastern mountain front and the Winnemucca Valley Zone. Old

Pleistocene bars and lagoons are present at several places in the Low Level Northern and Pyramid Zones.

THE HARTFORD HILL RHYOLITE ZONE

Isolated from the main body of Hartford Hill rhyolite is the amphitheater south of Tule Ridge. It has been described in the High Level, but a very brief summary will be given here: The Hartford Hill rhyolite in this small area is faulted by NNE faults crossed by smaller NW to WNW faults. The major canyons follow the NNE faults. Gullying is extensive.

Hartford Hill rhyolite crops out in a narrow strip, but not very distinctly, along the western slopes south of the amphitheater to the mouth of Piute Canyon. This area is cut up by NW, NNE and several other trends of faults. It also appears as if a block of Pyramid sequence has been faulted down in front of the Hartford Hill rhyolite to the west.

The NW faults occupy small canyons or gullies that help form hogbacks parallel to Winnemucca Valley. The NNE and other faults are in slightly larger canyons.

Most beds dip WSW to SW, but one small hogback shows beds dipping east, a phenomena for which rifting and tilting is the only visible explanation.

Gullying is not nearly as extensive here as it is for most Hartford Hill rhyolite. Important in this respect is the fact that most slopes are dip slopes.

Springs occur along the faults in a small number of places.

The ridge between Piute Canyon and this western slope is capped by a thin cover of Pyramid sequence. The cap has smooth dip slopes with a few small canyons.

Hartford Hill rhyolite begins to crop out in Piute Canyon about two miles (3.2 km) north of the canyon's mouth. The exact contact between rock formations is difficult to trace because the Pyramid sequence colluvium covers nearly everything except the southern exposure of Hartford Hill rhyolite.

The western canyon wall of Piute Canyon is an escarpment slope but is fairly smooth due to the heavy cover of colluvium. Very minor gullying has taken place along faults (springs also occur) and there is only one large tributary canyon that drains the spoon-shaped canyon north of its mouth. Exact dip of the beds is difficult to measure, but they dip in a westerly direction perhaps 20° to 30°.

The faults along the escarpment are E-W to NW trending in surface expression although the strike is generally NW. Vegetation is very useful in fault detection.

(It will be noted here that trees in the Hartford Hill rhyolite grow almost exclusively above 5,000 feet (1,500 m) and that while trees grow everywhere, there is some preference for individual rock units.)

The whole block between Piute Canyon and Winnemucca Valley is chopped up by faults. Many have not been mapped because the surface is so chopped and covered with different shades of colluvium that it is difficult to tell exactly where a fault is present.

Piute Canyon itself is a fault valley with the west side apparently the upthrown side. The valley in the canyon is alluvium filled and has a mature stream. The stream spreads over a fan which is dark because of the heavy amount of dark composition material it carries from the higher elevation Pyramid sequence rocks. It spreads its dark sediment over the light-colored rhyolite fans of other canyons. No pediment is seen in this area.

Pyramid sequence caps the ridge east of Piute Canyon. This ridge is extensively faulted but few faults have been mapped as shattering and colluvial cover make it very difficult to tell what is faulted and what is not. Recognizable faults form minor canyons trending ENE. Inferred faults have occurred in so many different directions they might be considered random. Minor canyons and gullies are extensive in this area; escarpment slopes are more often exposed than they were on the west side of Piute Canyon. Beds dip SW to south. Jointing is extensive, but many of the joints present may be of the columnar variety.

Some faults in the Hartford Hill rhyolite do not continue into the overlying Pyramid sequence, thus, the Pyramid sequence is younger than some of the faulting in the Hartford Hill rhyolite.

The highly faulted trend continues over into the next ridge, north of Mine Canyon. More faults are shown on the map than on the previous ridge because the faults are more distinct and because of the help afforded by McJannet's thesis (1957). It should be noted, however, that even more small faults can be seen in the field. The faults show two trends, one semi-parallel to the NW Winnemucca Valley and the other NE.

Some faults are located in canyons but most are in large and small gullies. Some fault segments do not manifest themselves in any geomorphic way.

Although the exact nature of most faults is not easily identifiable, normal faults with the downthrown wall toward the lower elevations appear to be the rule.

As typical of the Hartford Hill rhyolite, individual members cropping out on the ridge north of Mine Canyon show their individual resistivities to weathering. The Pyramid sequence cover is absent and the more resistant of the rhyolite units cap this ridge. The ridge is well dissected. Dips of beds are nearly horizontal.

NW and NS faults traverse small low hills of Quaternary basalt between the mouths of Piute and Chukkar Canyons.

Mine Canyon itself is a fairly deep canyon. Its upper length is faulted, and its midsection shows what appears to be an offset of a few tens of feet (several meters). In some segments no offset is seen. Nevertheless, the stream valley is downcutting deeply into the resistant rock exposed at the bottom of the canyon, indicating some sort of fracture control. Mine Canyon continues along faulted segments until its mouth reaches the alluvial fan of Winnemucca Valley.

In the upper reaches of Mine Canyon only four faults are mapped. Other small offsets may exist but none are clearly identifiable.

On the southern side of Mine Canyon five long, NW trending, nearly vertical, faults have been identified. Extensions of only two of them are seen on the north side of Mine Canyon. Four of the faults continue into the Box Canyon-Rainbow Canyon area. It is in Box and Rainbow Canyons where several of the Hartford Hill rhyolite units are spectacularly displayed as colorful alternating resistant and non-resistant rock units. Figure 8 shows the Hartford Hill rhyolite units present in Rainbow Canyon. All downthrown blocks are to the west.

The other faults in the Box and Rainbow Canyons consist of two branch faults of the Box Canyon fault and the Chukkar Canyon fault which is upthrown to the north.

Except over ridge tops, these long, NW trending faults are seen only in moderate size canyons, generally less than a mile (1.6 km) long.

The axis of the Virginia Mountains anticline passes through this area west of Rainbow Canyon as dip of beds changes to gently SW west of the axis. Beds dip from 5° to 18° E to ESE to the east of the axis.

The Hartford Hill rhyolite has a little smoother texture on these slopes. Dip slopes are quite smooth. Escarpment slopes are mostly covered with colluvium with outcrops of resistant rock present on Mine Canyon's south ridge. The outcrops of resistant rock show columnar jointing and the presence of "wind caves," geomorphic features initially formed by sandblast, then further hollowed out by moisture within the protected recesses.

Figure 8

Rainbow Canyon, looking northeast

Former old erosion surfaces appear to exist along the ridges between Mine and Chukkar Canyons which would indicate this area was a topographic high during formation of the Pyramid sequence. According to McJannet (1957), there were periods of erosion before and after formation of the Pyramid sequence.

Chukkar Ridge, according to McJannet, is composed of the less resistant members of the Hartford Hill rhyolite; and thus, there are few resistant rock outcrops, and the ridge is almost totally colluvium covered.

Chukkar Ridge is faulted by many minor faults each with only a small amount of displacement. The faults are found in very small canyons and gullies. Gullying is very extensive on Chukkar Ridge as dip slopes are small and escarpment slopes are large.

At the southwest tip of Chukkar Ridge there are volcanic plugs. These plugs also are present in the Bald Ridge mountains south of Chukkar Ridge. According to Bonham (1969), these are dacite plugs of the Kate Peak Formation.

Faults in this area are ENE to NNE trending. Plugs are both younger and older than the various faults. The plugs appear to have had only small effects on the fault pattern, and they have intruded along already existing faults. Some faults separate the plugs from Hartford Hill rhyolite.

There is no set dip of beds. Beds dip in nearly every given general direction. They do not as a rule dip toward or away from the plugs; therefore, it is probably the extensive faulting and tilting of blocks that caused the varying dips. Although plugs are not seen to have caused many faults, they may have had, along with NW faulting, some effect on tilting.

Gullying is as extensive on Bald Ridge as it was on Chukkar Ridge. The larger canyons in this small area do not follow faults according to McJannet (1957). But even though McJannet has not mapped faults in the larger canyons, they may still exist there. Small canyons, gullies and saddles follow faults.

All the alluvium from Piute Canyon to the Bald Ridge area is spread over Warm Springs Valley in the form of fans. The fans have moved up the canyon mouths to fill part of the stream valleys. Bedrock surfaces under the fans are not seen.

A fault slice, called Winnemucca Hills, has exposed Pleistocene gravel at the mouth of Winnemucca Valley. The fault responsible is probably the same fault that separates the Virginia Mountains from Dogskin Mountain and upon which Dogskin Mountain has been uplifted relative to the Virginia Mountains.

McCray Ridge separates Box Canyon from Painted Canyon. The ridge itself is only clearly faulted by a branch of the Box Canyon fault and a fault that separates the ridge from Fox Butte in the Mullen Gap area. Beds along McCray Ridge dip 10° east. Only the very top of the ridge qualifies as a dip slope. The rest of the ridge, on both sides, is a many jointed and gullied pair of escarpment slopes. Lack of faulting accounts for its relatively high elevation as compared to the surrounding hills.

Painted Canyon is another spectacularly colored fault canyon. The fault is the continuation of the NW trending fault in Mine Canyon. The upthrown wall is to the north. Several small faults exist on the northern side of the canyon but very little faulting has occurred on the McCray side of the canyon. The small faults are trending basically NNE and are in tributary canyons. Minor drainage is typical of the type found in the Hartford Hill rhyolite.

Toward the mouth of Painted Canyon, the plugs of Mullen Gap form small, jagged mountains that force the stream channel to curve around them.

Resistant rocks cap the tops of ridges and small peaks within the Painted Canyon drainage basin except at the canyon's head where more resistant capping has been worn away.

The canyon over the ridge east of Painted Canyon that drains into Mullen Gap is the result of what McJannet (1957) calls the Quail Canyon fault. The fault strikes WNW. McJannet links the fault that runs through Quail Canyon in the Pah Rah Range with this fault in the Virginia Mountains. McJannet has mapped two parallel, closely spaced faults within the canyon but only one has been detected in this study.

Beds on the ridge between Painted Canyon and this canyon have been tilted SW with an average dip of about 15°. Beds of Pulgas Ridge, the ridge to the north of the canyon, dip 10° NW, either due to tilting or what McJannet terms the Pulgas syncline.

The Washoe Peak fault strikes across Washoe Peak on the northern ridge but has no effect on the topography.

Drainage is typical Hartford Hill rhyolite type on the southern wall of the canyon. On the northern wall, slopes are quite smooth: smooth blankets of colluvium cover the entire ridge and there are only a few small outcrops of resistant rock.

Plugs of Kate Peak Formation and buttes of Pyramid sequence protrude through the Mullen Gap alluvial fans. (McJannet, 1957, and Bonham, 1969, disagree as to some of the rock units involved.) These plugs and buttes are only slightly faulted. Beds of buttes dip 10° or less SE. Reservation

Peak is a jagged plug in this area.

Drainage is mostly consequent on the plugs and buttes and forms small gullies.

An interesting feature is a straight, narrow, symmetrical canyon that separates Pulgas Ridge from Reservation Peak. Whether it is the result of a fault is difficult to determine because there appears to be no offset; yet, a canyon as deep as this one with so little area to drain is usually the result of some structural feature.

To the northeast of Reservation Peak and Lizard Mesa is the last major canyon that opens onto Mullen Gap. This canyon is most likely the result of another WNW fault. The ridge to the northwest, Wildcat Ridge, is cut by four NW trending faults. McJannet (1957) has mapped four distinct faults, two of which are easily located, the other two of which only segments can be located.

The faults to the southwest side of this ridge are traced along valleys and saddles. One fault on the Pyramid Lake-facing side is traced mostly by outcrop patterns. Dip of beds on Wildcat Ridge ranges from 10^{o} to 20^{o} ENE.

Dark Pyramid sequence (Bonham, 1969) and Quaternary basalt flows are found in the Mullen Gap area at Wildcat Ridge, the Quaternary basalt being partially covered by a landslide. The rest of Wildcat Ridge Bonham has mapped as Hartford Hill rhyolite, although it differs from the Hartford Hill rhyolite that so far has been discussed. McJannet (1957) refers to this as his Sutcliffe Formation.

At the most southeasterly point of the Virginia Mountains, Mullen Creek separates the Virginia Mountains from the Pah Rah Range. At this point Mullen Creek has deepened and widened as it passes between the two ranges to flow into Pyramid Lake. Large terraces have been created along the sides of Mullen Creek in this area.

Major drainage along Wildcat Ridge is controlled by the NW faults. Minor drainage is controlled by the bedding of the flow rocks. Very small gullies heavily dissect some slopes while other slopes are nearly smooth. Outcrops are relatively few.

All the canyons in the Mullen Gap area are choked at least at their lower ends with alluvium that spreads over the north side of the gap as fans. Some pediments may be present around the buttes in Mullen Gap.

On the Pyramid Lake side of Wildcat Ridge, many gullies drain the escarpment slope created by the major Basin and Range fault. A NW trending fault near the crest and on the Pyramid Lake side is a reverse fault that has only barely modified the drainage. An E-W fault is present in the largest gully.

Two canyons, one rather short and one long, form a drainage basin between the Hardscrabble Creek Canyon and Mullen Gap. The head of the long canyon, Wildcat Canyon, adjoins the head of Mine Canyon, and a saddle is formed between the two canyons where a fault common to both passes through the ridge. The fault is the Wildcat Canyon fault.

It is E-W trending with the upthrown side to the south. At places, the fault seems to leave the canyon bottom and continue along the canyon's walls.

At the upper end of the Wildcat Canyon at least two faults meet the Wildcat Canyon fault as they pass over the southern ridge. The resultant geomorphic effect in only two large gullies; however, other faults may occur here but are not visible on the photos.

A plug of Kate Peak Formation (Bonham, 1969) is present in the upper part of the canyon and forms Washoe Peak.

In the mid-part of the canyon the NE trending Washoe Peak fault intersects the Wildcat Canyon fault and several NW faults from canyons on the northern canyon wall. Small cross-faults may be present along the ridges of the mid-part of the Wildcat Canyon.

Determining the dip of beds in this area is difficult, but McJannet (1957) shows beds dipping 5° east. Except for very small outcrops of beds of resistant rock, the outcrops are confined to needles that jut out in and around Washoe Peak. These may be volcanic vents.

Drainage in the upper and mid-part of Wildcat Canyon is typical of Hartford Hill rhyolite type, major drainage being in fault canyons and minor drainage as gullies.

In the lower part of Wildcat Canyon; the NW faults of Wildcat Ridge seemingly end. Small faults with NW to N-S trends are present on the northern side of the canyon in this area. The canyon itself is the result of one or more NE trending faults.

The small canyon to the north of Wildcat Canyon is the result of an E-W fault. Its branches at the upper end are all the result of faults. NW to N-S trending faults form saddles in the ridge between the two branches.

Dip of beds is from 10° to 20° east. Drainage is typical of the Hartford Hill rhyolite except that some slopes are very smooth.

The last section of the Hartford Hill Rhyolite Zone to be discussed is the Hardscrabble Creek area.

Hartford Hill rhyolite crops out at the most westerly part of the Hardscrabble Creek drainage basin on the mountains southwest of the 90° bend of Hardscrabble Creek. Pyramid sequence caps the Hartford Hill rhyolite at the High Level on a ridge separating the western and eastern drainage. Faults are found in the canyons below the top of the mountain ridge. Slopes into the canyons are very steep and gullied but smooth on one wall. Resistant rock crops out locally on the slopes. A landslide covers part of one slope.

The southern wall of Hardscrabble Canyon is dissected by eight large tributary canyons. Five of them have been mapped as being fault originated. Evidence of faults is not present in the others, but they are probably faulted also. The predominant tributary canyon trend is NNE. It appears that cross-faults are present across the tributary canyon ridges to form saddles. More cross-faults probably exist than are mapped.

Beds dip gently eastward.

On the slopes north of Hardscrabble Canyon Hartford Hill rhyolite underlies the Pyramid sequence. The exact contact is distinguishable only in places because of the Pyramid sequence colluvium covering much of the Hartford Hill rhyolite. An obscured NNW fault marks one northern most boundary.

"Meander-like" youthful streams have cut into the relatively smooth, gentle slopes of some pediment surfaces. The streams follow what appear to be NNW trending faults in the bedrock. The "meanders" show definite WNW and NNE trends so the meanders are probably following joints. Further east along the northern slope there are definite WNW joints present. This area has apparently been rejuvenated entrenching the stream channels within the joints in the pediments.

The slope to the north of Hardscrabble Creek narrows out into a ridge further east. One and maybe more NW faults strike obliquely across the ridge. The faults have caused small canyons and saddles.

On the other side of the narrow ridge, entrenched meander-like streams drain the northern side of the ridge and other hills within their drainage basin(s). The meanders also show distinctive NNW and NE trends. Faults and gullies in the vicinity confirm the structural control of the trends. More faults probably exist in this area than shown.

Beds, where they are identifiable, dip gently east.

Except for the "meandering" streams and gentle slopes, which are thinly alluviated pediment surfaces with rejuvenated streams, drainage is typical of Hartford Hill rhyolite terrain.

Hardscrabble Creek is a mature stream. Alluvium fills the canyon up to the point where the canyon turns north. Lower Hardscrabble Creek Canyon is probably of fault origin, its upthrown wall to the south.

The geomorphic features along the eastern mountain front are about the same as for those described along Pyramid Lake in the Low Level: youthful rejuvenated streams cutting into the pediments fans and lake beds. Small outcrops of Pyramid sequence appear as low hills on the lake beds just northwest of Sutcliffe.

Summary of the Hartford Hill Rhyolite Zone

The predominant fault trends throughout the Hartford Hill rhyolite are NW to E-W. The small faults in the area follow diverse directions. There are many more faults present in the Hartford Hill rhyolite than mapped. Some faulting is older than the Pyramid sequence but most appears younger. Faulting is the most extensive on the western slopes of the Virginia Mountains facing Winnemucca and Warm Springs Valleys. Almost all canyons follow visible faults. Saddles and gullies have formed where faults cross ridges.

Best exposures of the Hartford Hill rhyolite rock units are in Box, Rainbow, and Painted Canyons.

Other rock units outcrop in and around the Hartford Hill rhyolite, but there is still some doubt as to what formational names they should carry. Volcanic plugs are located in the Mullen Gap area (Bonham, 1969: Kate Peak Formation). Buttes and flows of Pyramid sequence also are present in Mullen Gap. The fault pattern in Mullen Gap is apparently not influenced by the plugs, but the plugs probably intruded along the faults that were already present. Quaternary basalt flows also are present.

Gradation of Hartford Hill Rhyolite Zone fault patterns into the zones bordering it is only slight. The trends within the Hartford Hill rhyolite die out in the Pyramid sequence usually within a mile of the zone's border. For the most part, the amount of faults present changes from a great many in the Hartford Hill rhyolite to much fewer in the Pyramid sequence except where the Pyramid sequence forms a relatively thin cap. The NNW Walker Lane trend along the eastern mountain front also is seen in this zone.

The predominant dip of the beds is east 5^{o} to 20^{o} although beds dip in all directions according to McJannet (1957). The axis of the Virginia Mountains anticline passes through the Hartford Hill Rhyolite Zone just west of Rainbow Canyon and trends SW.

Gullying is more extensive in the Hartford Hill rhyolite than in other rock units. Even so, many slopes are very smooth, even on escarpment slopes. It has been noticed that a light-colored unit of the Hartford Hill rhyolite has the most extensive gullying.

Canyons in the Hartford Hill rhyolite are more choked with alluvium than the canyons of the northern Virginia Mountains and, since there is a greater amount of erosive material in the softer Hartford Hill rhyolite, that would be expected. Fans covering pediments and lake beds are in many cases larger in the Hartford Hill rhyolite.

GEOLOGIC STRUCTURE

The Virginia Mountains was divided into levels and zones at the outset of this study with the hope that there would be some degree of uniformity in the geological structure and geomorphology within subdivisions as the breaks were based mainly on natural topographic and geographic boundaries, and in the case of the Hartford Hill Rhyolite Zone, on geologic boundaries. But what information really would be found was not known, with the exclusion of the most obvious features and that information provided by earlier writers. With the conclusion of the detailed study of the range, more distinct regions where structure was generally the same throughout could be outlined. In addition, the total interrelationships of the structure within the entire mountain range could be better viewed. This chapter will therefore briefly deal with eight "sectors" as interpreted from the structure presented in the last chapter. Fault patterns and their possible or probable superficial causes and other structure will be discussed.

The sectors that the range has been divided into on the basis of structure are:

1. The "Highlands" Sector
2. The Northern Sector
3. The "Walker Lane" Sector
4. The "Block" Sector
5. The Jigger Bob Sector

6. The Piute-Hardscrabble Sector
7. The Winnemucca Valley Sector
8. The Hartford Hill Rhyolite Sector.

A reference map showing these divisions is given on the following page.

The "Highlands" Sector

The Virginia Mountains is a large, uplifted and collapsed, N-S trending anticline and this is best shown in the "Highlands" region. The sector is characterized by long, vertical or nearly vertical, N-S faults with upthrown sides almost always away from N-S trending Tule Ridge.

The Spanish Flat graben is the only major variation from the basic structure of the collapsed anticline. Faults that are not N-S are small and have little significance in studying the area.

The Northern Sector

This region is a mixture of several fault trends.

The major Basin and Range fault that separates the Never Sweat Hills from the Virginia Mountains of the western side of this sector has been hypothesized in this report to possibly be a left-lateral strike-slip fault, the Never Sweat Hills having moved south in relation to the Virginia Mountains. Two small faults, and possibly others, which would be second-order faults, seem to show right-lateral movement in accordance with Moody and Hill's (1956) system of wrench-faults (see diagram). E-W or nearly E-W faulting along the

1. The "Highlands" Sector
2. The Northern Sector
3. The "Walker Lane" Sector
4. The "Block" Sector
5. The Jigger Bob Sector
6. The Piute-Hardscrabble Sector
7. The Winnemucca Valley Sector
8. The Hartford Hill Rhyolite Sector

FIGURE 9

STRUCTURAL SECTORS

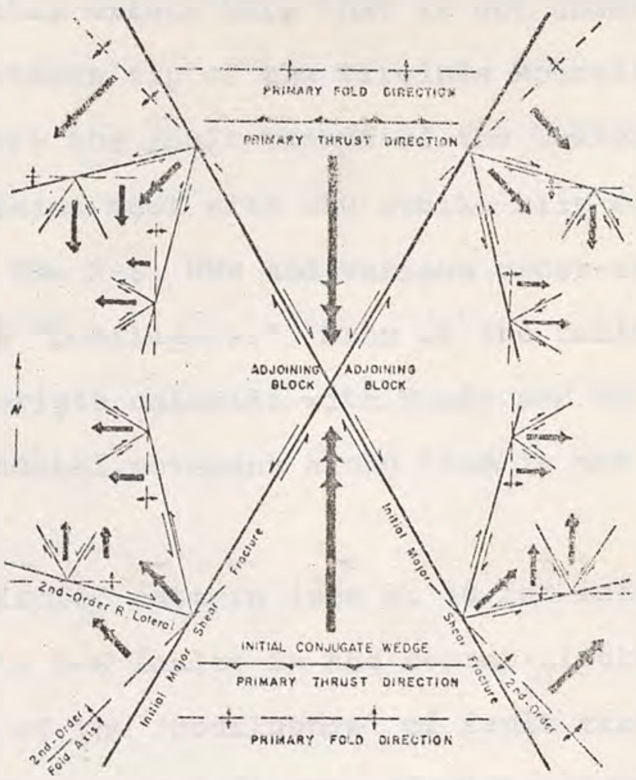


Figure 10

Wrench-fault system of Moody and Hill, 1956.

steep western fault scarp of the Northern Sector may or may not be related to the proposed strike-slip fault as type of movement along these faults is unknown. Difficulty does exist in linking the possible left-lateral fault to the NNW trending right-lateral Walker Lane faults; therefore, it is believed some relationship exists here that is not understood.

The northern tip of the Virginia Mountains appears to be an area where the fault trends of the western side of the Virginia Mountains meet with the strike-slip movement of the Walker Lane. The N-S, NNW and various cross-faults are the result of this "confluence." Many of the faults of proposed second-order origin coincide with Moody and Hill's diagram although horizontal movement along them is not definitely established.

The "circle" pattern (see p. 58 for reference) of NNW, NNE, and ENE to E-W faults in the center of this sector could be the result of the "confluence" of fault trends or the result of subterranean influence (doming and/or collapsing) although there is no direct evidence for the second theory other than the faults themselves.

Some lateral movement appears to have occurred along one NE trending fault on the "circle's" perimeter, but evidence is contradictory as to the direction of movement.

The faults mapped in the steep resistant rock on the northern side of the Pyramid sequence follow the same trends as those in the "circle" area; NNW, NNE, and ENE, and they are probably related in origin.

The long, NW trending Virginia Fault follows the Walker Lane trend, (see "Walker Lane" Sector), but there is no substantial evidence to link it to its NW trending eastern neighbors. Any statements concerning the origin of the Virginia Mountains fault would be purely hypothetical.

The east-dipping beds of the eastern part of this sector may be the result of the Virginia Mountains anticline or a large tilt block with the dip slope to the east and escarpment slope being the steep western wall. Northern dipping beds may be explained as part of the "doming" of the Virginia Mountains anticline or as tilting north of part of the Northern Sector. The northernmost blocks along Astor Pass may have been tilted with the formation of the Astor Pass Graben.

The "Walker Lane" Sector

A continuous anomalous strip of rock was mapped down the eastern mountain front--a long, narrow length of NNW and ENE trending faults and varying rock types. This strip is suggested to be part of the Walker Lane lineament. (A map showing that trend is given on Fig. 11, p. 96.)

The Terraced Hills basalt seems to manifest itself in the "Walker Lane" Sector as NNW ridges bordering the eastern side of the northern part of the Virginia Mountains. Farther south either the soft rock of the unnamed formation of the Pyramid sequence or the harder rock of the Pyramid sequence could be the rock type that forms the anomalous strip in the "Walker Lane" Sector. Right-lateral movement along the NNW trending faults, typical of the Walker Lane lineament, does

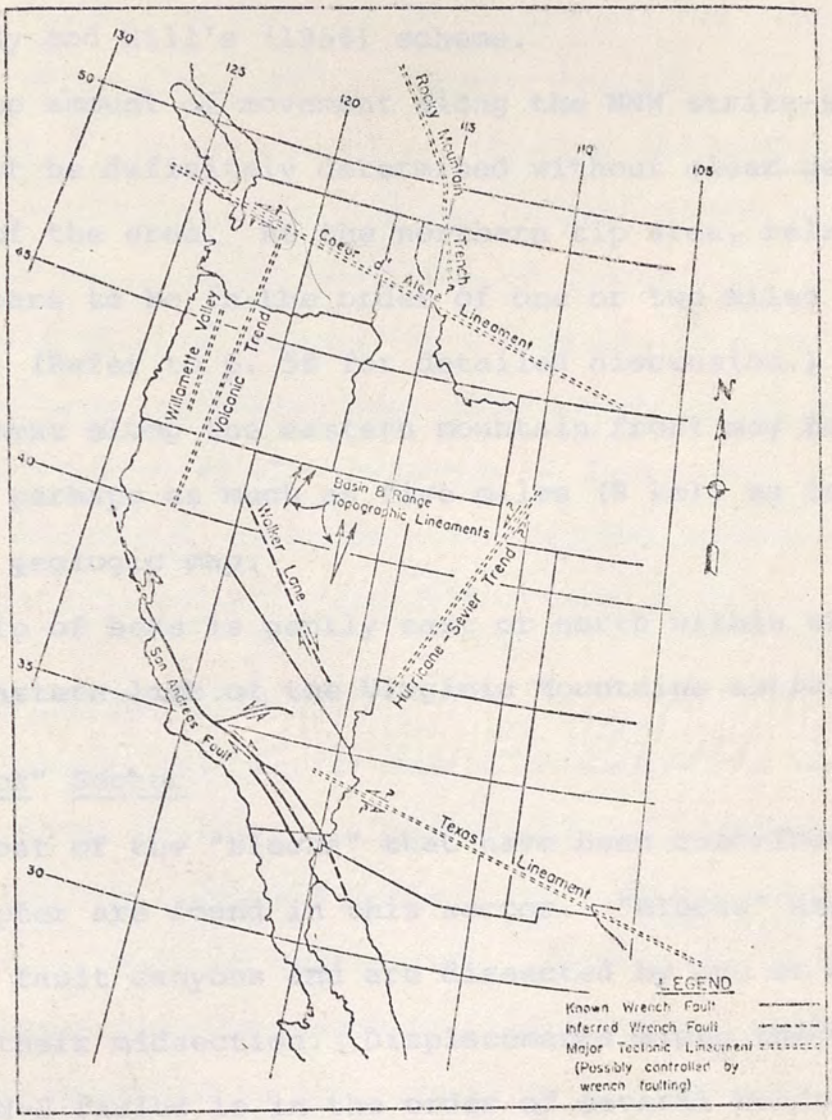


Figure 11

Major Lineaments of Western United States. After Moody and Hill, 1956.

appear to exist with the "strip" rocks having moved SSE. Left-lateral faulting would be expected along the E-W to NE faults and this type of faulting appears to be present. Moreover, the angles of the second-order left-lateral faulting fits Moody and Hill's (1956) scheme.

The amount of movement along the NNW strike-slip faulting cannot be definitely determined without clear geologic mapping of the area. At the northern tip area, relative movement appears to be in the order of one or two miles (1.6 to 3.2 km). (Refer to p. 58 for detailed discussion.) Horizontal movement along the eastern mountain front may be greater, however, perhaps as much as five miles (8 km), as interpreted from the geologic map.

Dip of beds is gently east or north within this sector on the eastern limb of the Virginia Mountains anticline.

The "Block" Sector

Most of the "blocks" that have been described in the last chapter are found in this sector. "Blocks" are outlined by large fault canyons and are dissected by one or more faults through their midsection. Displacements along the tensional E-W and N-S faults is in the order of several hundreds of feet to over a 1,000 feet (100 to 300 m). Downthrown blocks along N-S faults are to the west and on E-W blocks to the north. E-W faults cut N-S faults and probably postdated the collapse of the Virginia Mountains anticline. The reason for the sudden occurrence of E-W tensioned faults in this area is not known, but the Walker Lane lineament does at least partly overlap this sector, and there certainly may be a connection.

The Jigger Bob Sector

The N-S Jigger Bob fault is located in the steeply sloping area of the Virginia Mountains and ENE tributary faults terminate against it. Jigger Bob fault is considered to be part of the anticlinal collapse of the range. The ENE faults appear to be older and may be part of the Walker Lane.

The small canyon northwest of Jigger Bob Canyon, with a ENE fault cutting through the N-S fault, is more suspect to Walker Lane influence, and, although the fault pattern in Water Hole Canyon to the southwest of Jigger Bob Canyon is somewhat different, it appears that it may be explained by both anticlinal collapse and Walker Lane influence.

The Piute-Hardscrabble Sector

Although this sector may be considered to be part of the anticlinal collapse, it has its unique complexities. Besides the two large N-S faults, many other faults traverse this sector. Part of this sector is underlain by Hartford Hill rhyolite that is capped by Pyramid sequence and many of these faults should be analyzed along with the Hartford Hill Rhyolite Sector.

A reverse fault exists along the escarpment slope of Hardscrabble Canyon with over 500 feet (150 m) displacement. If the reverse fault is the result of N-S compressional forces, it would fit well into the Walker Lane scheme as may be seen on Moody and Hill's (1956) wrench-fault diagram.

Other faults may be caused by the presence of the Walker Lane lineament as branches are present on either side of this sector in Winnemucca Valley and on the east side of the mountain range.

This sector is on the eastern limb of the Virginia Mountains anticline.

The Winnemucca Valley Sector

The Winnemucca Valley area has been recognized by Bonham as part of the Walker Lane fault system. Faults trend NW, and NW linear ridges extend the length of the valley. Bonham (1969) and this writer believe this is a right-lateral strike-slip area, but no direct evidence has been found. The NW trend continues to the northwest of this area as mapped by Bonham.

The Hartford Hill Rhyolite Sector

This sector is much more densely faulted than any other part of the range. Possible reasons for this are; 1) the collapse of the Virginia Mountains anticline, which caused some faulting, 2) some faults are older than the Pyramid sequence volcanics, and, thus there would be more faults in the rhyolite, 3) Hartford Hill rhyolite fractures more easily, 4) a major zone of faulting passes through this sector, and 5) the plugs at Mullen Gap, however small the contribution, may have caused some faulting to take place.

The major zone of faulting which passes through the Hartford Hill rhyolite this writer believes may be a branching of the Walker Lane lineament, i.e., the Walker Lane branches across the Hartford Hill rhyolite of the Virginia Mountains and the Pah Rah Range and up through Winnemucca Valley. The branching from the Pyramid Lake area could cause the E-W to WNW trending faults across the Hartford Hill rhyolite before they shifted back to NW trends through Winnemucca Valley.

The Pah Rah Range has not been thoroughly mapped but what mapping that has been done by McJannet (1957) and students at the Mackay School of Mines, plus photographic and topographic evidence, shows the same trends south of Mullen Gap.

The chopped up nature of the rhyolite in the Virginia Mountains makes it very hard to detect any lateral displacement. McJannet has noted some horizontal component of slip on the Quail Canyon fault in the Pah Rah Range. A NW trending fault zone in the Pah Rah Range within this possible zone of branching was mapped by this and other students at the Mackay School of Mines as having horizontal slickensides at all places where slickensides were seen, but almost invariably the only displacement detectable in the Virginia Mountains and Pah Rah Range is dip-slip.

The faults that trend in directions other than NW to E-W, predominantly N-S to NE, may be part of the Walker Lane influence, may be part of the collapse of the Virginia Mountains anticline, or they may be caused by some other phase of structural activity. In any event, their origin is not positively certain.

Beds dipping east are to be expected as this is part of the eastern limb of the Virginia Mountains anticline, which at this point trends SE. Extensive faulting, tilting, rotation of blocks, and in some cases folding of beds and intrusion of plugs has caused the great variety of eastern and other dips.

Normal faults dominate the area. The trace of the faults over varying topography and the slopes of eroded fault scarps indicates that the faults are all steep and that a majority dip toward the lower elevations.

Some faulting is older than the Late Miocene Pyramid sequence rocks. Most faulting, however, appears to have occurred after the accumulation of the Pyramid sequence as faults cut through that formation as well as the Hartford Hill rhyolite. Plugs of Mio-Pliocene to early Pliocene age (Bonham, 1969) are present in the Mullen Gap area, but the plugs exhibit no visible control over the major faults and some volcanics have probably been intruded along some of those faults. Thus, the evidence indicates that most faulting has taken place since Late Miocene.

Mullen Gap itself is an ENE trending graben-like structural feature that is controlled to some degree by the same faults along which the plugs were intruded. Its ENE trend suggests its origin may be in great deal due to Walker Lane movement.

The main Basin and Range fault on the southwestern side of the range may be the Winnemucca Valley fault which apparently is the main fault in Winnemucca Valley and forms a Pleistocene to Recent fault scarp on the east side of the Winnemucca Hills.

General statement about the structural origin of the Virginia Mountains

The Virginia Mountains are part of the Basin and Range system of fault block mountains. The origin of the Basin and Range-type faulting and the Walker Lane lineament is beyond the scope of this paper except to say that the NW strike-slip fault system is believed by many to be directly connected with the formation of the N-S Basin and Ranges. The right-lateral strike-slip fault system of the Walker Lane appears to pass through the Virginia Mountains, very probably as a branching of the Walker Lane lineament, before it dies out or is covered in the area immediately north of the Virginia Mountains.

Briefly, the Virginia Mountains is an uplifted and collapsed anticlinal structure of N-S trend, greatly modified by two right-lateral strike-slip fault zones to either side, by second-order left-lateral faults, and by perhaps a left-lateral strike-slip fault and its possible branches and second-order faults in the range's northern tip.

GEOMORPHOLOGY

General Character

The area of study has rugged, youthful mountains bordered by alluviated, intermontane valleys, such as is typical of the Basin and Range topography. The present topography is the result of bending of layers of volcanics, high angle and strike-slip faulting, and erosion in an arid to semi-arid climate. Aside from few generalized statements that can be made, the Virginia Mountains is not like typical block mountain areas described in textbooks because this area does not have simple border faults controlling the majority of the topography. Instead, there are high angle faults forming fault valleys parallel and transverse to the main Basin and Range trend.

Responsible for the irregular and sinuous contact between older rocks and Quaternary deposits at the edge of the range is the multitude of blocks and the fact the Virginia Mountains were forming earlier than the more typical basins and ranges of late Pliocene to Pleistocene and thus have been under the influence of erosion for a longer time. Many parts of the range fronts are without truncated spurs or narrow "bottlenecks" at the points of dispersion of streams onto fans. All traces of many spurs have been wiped away and many streams have wide mouths. Pediments can be seen under thinly alluviated surfaces.

Even though faults play the predominant role in the formation of the landscape, varying lithologies control much of the ruggedness of the mountain range. Due to the presence of resistant layers and caps, there are many imposing cliffs, such as those of the Big Canyon area or the Rainbow Canyon-Box Canyon area. Where less resistant rocks are present, such as compose much of the northern Virginia Mountains or some areas in the Hartford Hill rhyolite, there are mostly only colluvium-covered slopes.

Dip slopes of volcanics are relatively smooth and escarpment slopes jagged and rough. Large escarpment slopes are present throughout the range and thus contribute to the ruggedness of the country. Some rock units are so resistant that reverse profiles exist along the escarpment slopes.

Fault Valleys

One of the greatest distinguishing features of the Virginia Mountains geomorphologically is the origin of its canyons. Nearly every canyon in the Virginia Mountains is directly or indirectly the result of faulting. In the central interior, topography has been greatly preserved by the lack of all but N-S trending faults and is much like it was before uplift. Nearer to and at the margin of the range, many complementary faults have greatly modified and reduced the topography. Many canyons, especially those of N-S trend, are not primarily the result of stream erosion but were formed as fault valleys when the Virginia Mountains anticline collapsed or when other structural events occurred to give V-shaped, fault-formed valleys. The upthrown walls in the majority of the cases were uplifted faster than consequent stream erosion taking place on the slopes of the higher levels could cut through them.

Many appear to be uplifted very fast, such as is the case with Jigger Bob Canyon and Hardscrabble Creek Canyon. Stream erosion has subsequently downcut and modified those valleys, as is most easily seen in Jigger Bob Canyon where tributary streams have created a sinuous stream pattern as lateral cutting has moved the canyon bottom towards the east at the apices of the tributaries with the main canyon as downcutting has lowered the course of the stream. The fault trace thus appears on the western slopes of the canyon.

Other Forms of Drainage

The fault valleys just described are the most frequent major drainage form in the Virginia Mountains. Canyons that are present because a fault zone has been subject to more intense erosion than the more resistant rock walls to either side are the second most important form. Some of the tributaries of Jigger Bob Canyon and many of the canyons in the Hartford Hill rhyolite exist because of the presence of fault zones susceptible to erosion.

Alluvial fans, valley fills, pediments and erosion by flash floods usually mask Walker Lane strike-slip faulting that may be present in most regions, but an above average quality exposure of Walker Lane faults are found in the Virginia Mountains. Although the strike-slip faults are present along the mountain front and in many places are buried, enough of the morphology can be seen to make a statement as to their geomorphic effect. The long NNW faults, where the fault trace is actually seen, are exposed in many places in very small canyons and in saddles over the low mountain front ridges. This is expected because very little erosion occurs, comparatively speaking, transverse to the direction of stream flow from the higher elevations. The effect of downcutting is small near base level and in the very small basins of the NNW faults.

The presence of resistant rock blocks moved against softer rock by strike-slip movement has modified the drainage of the Virginia Mountains. Instead of the normal Basin and Range triangular facets with the major canyon streams disgorging perpendicular to the mountain front faults have caused the barriers of resistant rock in the topographic form of ridges, to offset the final path of the streams so they must follow a course sub-parallel to the mountain front along the fault traces. Water Hole Canyon and several other small canyons demonstrate this point.

The second-order left-lateral ENE trending faults and possibly related tension faults, such as those in Big Canyon, are present in larger canyons than the first-order NNW faults. Any such faults to the east of the main Basin and Range faults are, of course, buried, but those to the west are perpendicular to the mountain front and are found in slightly higher elevations; thus, downcutting along these zones of weakness is much greater. In places, tilting of blocks away from each other along a ENE fault has greatly benefitted the larger canyon effect.

Due to the great density of faults both parallel and perpendicular to the mountain fronts, purely consequent drainage is not well developed in the Virginia Mountains. There are few large canyons present in the range that do not show at least some fault control. Some of the tributary canyons in Jigger Bob Canyon and Hardscrabble Creek Canyon and along the western slope of Tule Ridge are perhaps of purely consequent origin. Truly consequent drainage occurs along the slopes of Cottonwood Creek and Black Canyons, but the valleys formed are so small they cannot compare in size with the fault canyons. Even along both escarpment and dip slopes, gully drainage is controlled in great part by structural features including faults, joints and beds. In a given area the larger gullies in a related set of gullies will be structurally controlled. Drainage in the East Cottonwood canyon is an example.

The most extensive consequent gullying occurs in the softer rocks as would be expected. Therefore, the greatest amount of consequent drainage is present in the Hartford Hill rhyolite and in the soft rock in the northern Virginia Mountains.

Gullying of any kind is more extensive on escarpment slopes than dip slopes. The Telephone Pole Canyon area is the most clear demonstration of this point. While dissection is very heavy on escarpment slopes, almost no dissection has occurred on dip slopes. Rock breakage is irregular on escarpment slopes, and thus, water may concentrate at various low resistance areas or local topographic lows. Dip slopes, in contrast, are usually smooth, homogeneous planes of beds and, therefore, erosion along the surface of the slope has fewer and less discrete places to localize itself in the form of downcutting gullies.

Other exotic types of drainage are present in the Virginia Mountains. The "circle" of the north Virginia Mountains is an example although the exact cause for the circular pattern of faults is not identified.

Stream piracy may have occurred in several places, but the most dramatic example of stream piracy is the thievery of N-S trending Left Hand Canyon by E-W Right Hand Canyon. Supposedly, the rapidity of erosion along the E-W fault was great enough to capture the Little Valley headwaters of Left Hand Canyon. The case may be, however, that the occurrence of faulting itself may have directly affected the capture.

Hummocks on the east side of Tule Ridge cause an irregular drainage pattern.

Combination joint and fault controlled streams that resemble ordinary meandering streams are present on the gentle slopes north of lower Hardscrabble Creek. On those pediment surfaces, the streams follow two patterns of joints. The gentleness of the slopes is probably responsible for the stream's ability to "meander" although the meanders are somewhat entrenched.

Antecedent-type drainage is found at many places but most notably on the NW trending ridges in Winnemucca Valley.

The faulting and uplift, part of the Walker Lane trend, have not kept pace with the erosion of certain streams that cross the active zone. A few minor cross-faults supplement the erosion of the ridges, but truly antecedent streams are present. In the same area, however, many streams have either failed to keep pace with the formation of the ridges and are thus diverted along the ridge flanks or have been offset by right-lateral movement between fault blocks.

Springs and spring-lines are very common in the Virginia Mountains in spite of the arid-semi arid environment. The reason for this unusual abundance of springs, although many are dry during much of the year, is the great number of faults. Other reasons for springs are the emergence of water from under alluvium and from under landslides and mudflows.

Pediments, fans and lake beds on the Pyramid Lake basin are rejuvenated and, therefore, one or two major gullies are entrenched on each fan or pediment. There are two obvious causes for the rejuvenation, 1) the uplift in certain areas of the pediments, lake beds, and fans, and 2) the drop in lake level since Pleistocene. With the uplift of the lake beds and fans, two changes are being affected on the streams as they approach and enter Pyramid Lake: 1) new, very small fans are being produced on the edges of old fans or on the Pyramid Lake shoreline, and 2) the water that enters Pyramid Lake does so in the form of small falls and "rapids."

Old Erosion Surfaces

Old erosion surfaces are located at spots around a large old erosion surface present in the High Level Northwestern and Central Zones. These small, individual surfaces were found: 1) at the northeastern end of the High Level Northwestern Zone; 2) north of Water Hole Canyon; 3) as an area roughly separating Piute and Jigger Bob Canyons; and 4) in the Rainbow Canyon area.

The large High Level surface has been greatly disturbed and partly erased due to faulting and recent erosion, but the surface probably still resembles very closely the topography of the old Tertiary erosion surface. Tertiary relief displayed on the other old erosion surfaces varies from gentle to fairly steeply inclined hills and slopes. However, both the Northwestern Zone and Water Hole Canyon occurrences could be either warped or accurately representing hilly topography of the Tertiary.

The faulting in each area of old erosion surfaces is different. In the Northwestern Zone faulting is present on some of the slopes surrounding the surface but the surface itself is apparently a hard cap rock that may have postdated the faulting of the rocks below it; or it may be faulted but with soil cover masking the evidence, which is doubtful because some offset or lineation of vegetation should be seen; or there may be no significant faulting across the cap rock.

The Water Hole Canyon surface is surrounded by ENE and NNW faults. The fault block is possibly bent but it remains fairly well preserved. Probably a hard cap and lack of structure within the block have kept the surface from being destroyed by erosion.

The Jigger Bob-Piute Canyon occurrence consists of rounded mountains and ridges with many faults traversing over the surface itself. Despite the faults, erosion has not as yet greatly affected this surface. Some faults may be sealed with dikes.

The Rainbow Canyon old erosion surface is preserved as small slivers that have been separated by WNW faults. They lie for the most part on the resistant rocks of the Hartford Hill rhyolite. This old erosion surface on the Hartford Hill rhyolite together with the thinning of the Pyramid sequence indicates that the southern end of the Virginia Mountains was a topographic high during the formation of the Pyramid sequence volcanics during Late Miocene. This surface was then raised a lesser distance during the major uplift of the range.

If all of the erosion surfaces within the range were restored to their original positions before faulting and uplift they would be correlative with the large High Level surface (although the Rainbow Canyon surface would have been in existence longer). They would also roughly lie on the limbs of the Virginia Mountains anticline before it reached its present angle of bending. A shallow depositional environment may have been present at the hummocky surface on the eastern side of Tule Ridge resting unconformably on the eroded volcanics.

Stream Profiles

As part of the geomorphic study of the Virginia Mountains, stream profiles were drawn of the five major streams in an attempt to learn about the number and nature of uplifts the range has undergone. Results, however, gave little indication of what has occurred in the range.

Diagrams (refer to Figures 12-16, pp. 114-116) exhibit no uniformity to the profiles. The obvious reasons for this are the faulting both along and transverse to each stream channel and the changing resistivities of the bedrock.

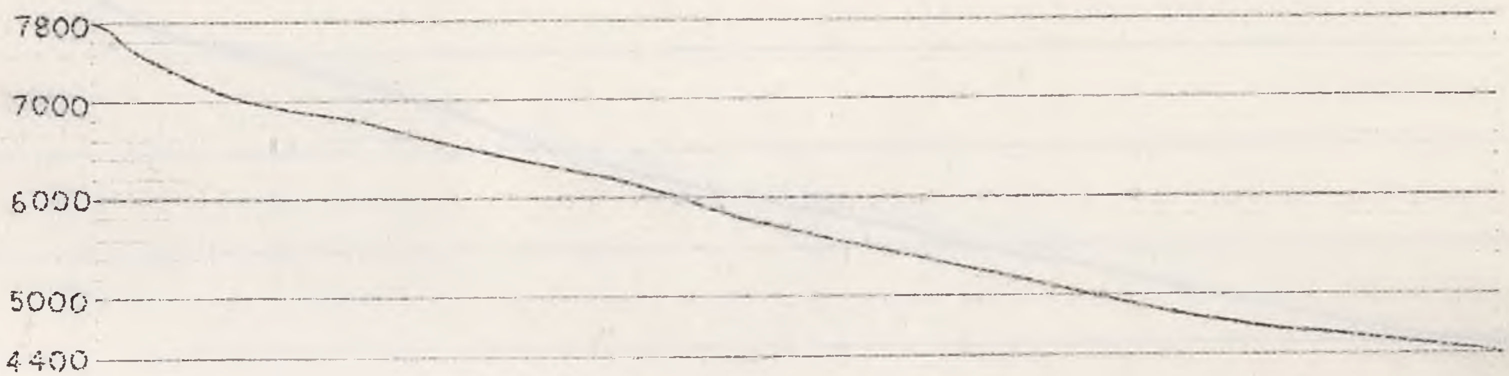
The scale of available topographic maps does not permit a sufficiently detailed treatment of the Piute and Hardscrabble Creeks but nevertheless Piute Creek can be seen to be slightly irregular and Hardscrabble Creek fairly smooth in profile. Faults and resistant beds seem to cause the irregularity of Piute Canyon. Hardscrabble Creek may be fairly close to gradation but the map scale, faults, large mudflows that probably once dammed the stream, and alluvium over half the way up the valley bottom chaotically confuse the possibility of analysis. The steep gradients just below the highest level of the streams show that the drainage region is still in youth, with rejuvenation indicated.

Modification by faults and the existence of resistant bedrock over long stretches of the stream channels cause the irregularity along Jigger Bob Canyon. Once again youthful terrain at the highest elevation is implied by the gentle slope at the top of the profile.

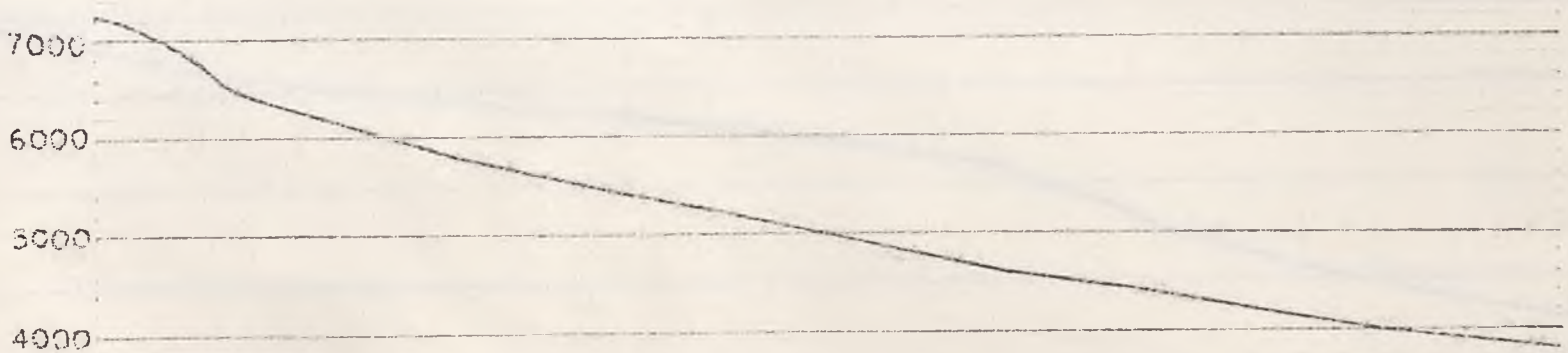
The long, gentle slope of Little Valley fault valley shows clearly on the next profile. Then, the many faults of Right Hand and Big Canyons cause the abrupt drop off into lower elevations.

The Cottonwood Canyon stream profile, uncut by cross-faults could possibly indicate changes in gradient due to uplift. At least seven "humps" may be counted along the profile. Some, however, are due to resistant bedrock and this makes the profile so complex as to not afford ready conclusions as to uplift.

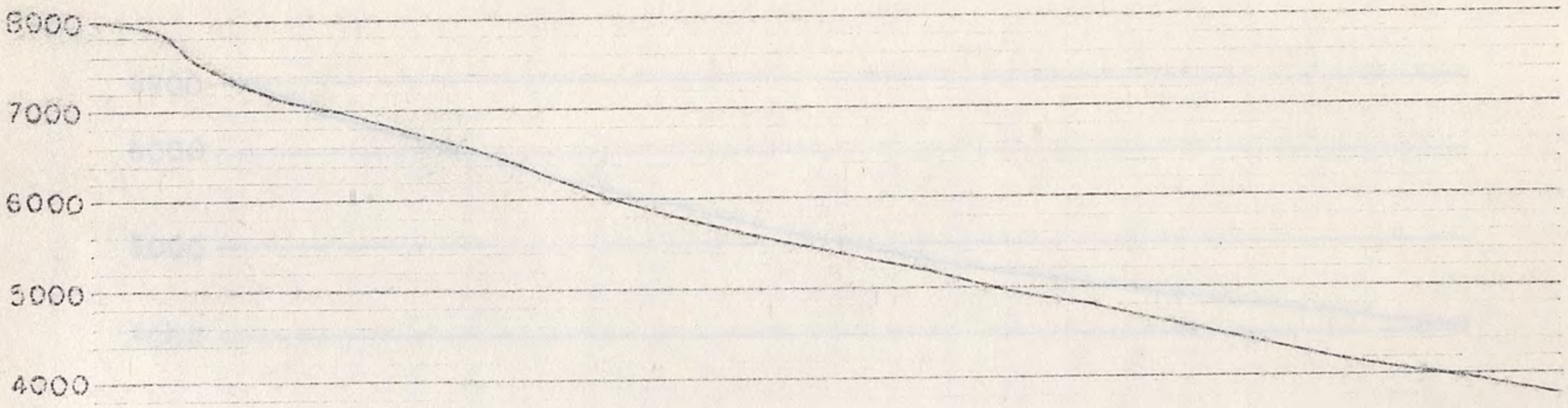
STREAM PROFILES



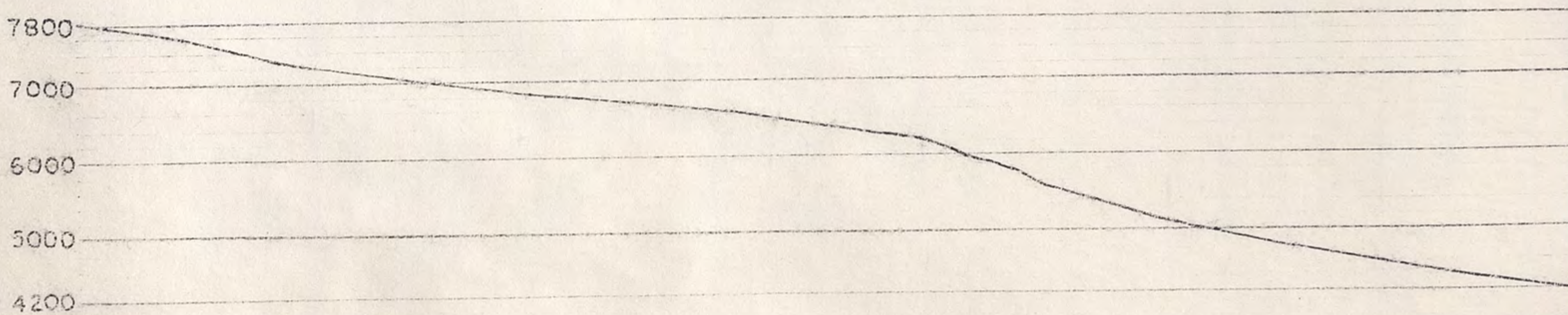
PIUTE CANYON



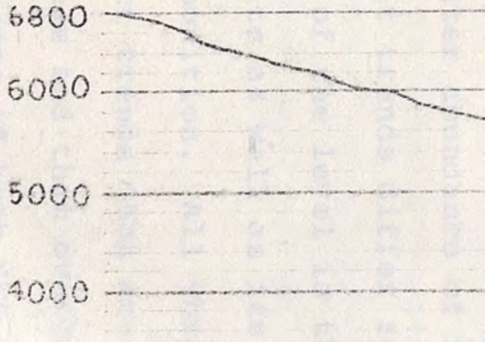
HARDSCRABBLE CREEK CANYON

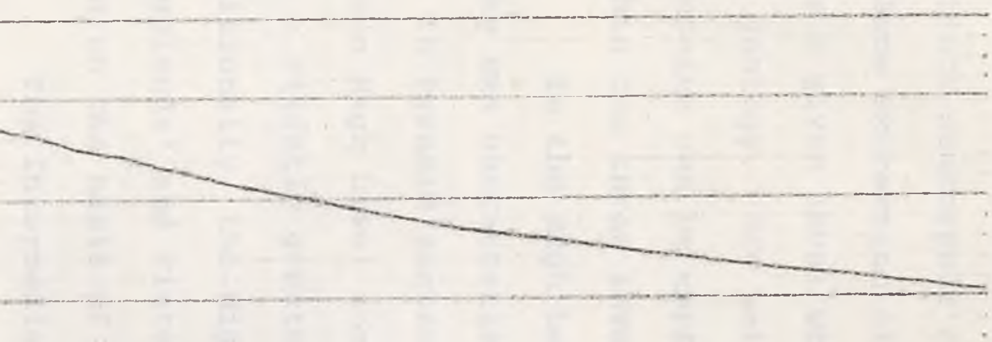


JIGGER BOB CANYON



LITTLE VALLEY—RIGHT HAND CANYON—BIG CANYON


6800
6000
5000
4000



COTTONWOOD CANYON

CONCLUSIONS CONCERNING TYPE OF ANALYSIS

Division and study of the geologically complex Virginia Mountains were performed under the hypothesis that broad, distinct geomorphic characteristics would essentially be the surface expression of the structure and geology present and thus a given level would have a somewhat similar structure and geology. How well this technique worked in the Virginia Mountains can be appreciated by contrasting the fault patterns within the three levels.

In the High Level the relatively gently sloping topography was characterized by basically widely spaced N-S faults all in Pyramid sequence volcanics. This is true for all three of the High Level zones with only the Southeastern Zone showing a slightly greater degree of faulting over the region. Additionally, the High Level zones correspond closely to the "Highlands" and Piute-Hardscrabble Sectors, which were delineated on the basis of great structural similarity.

The Intermediate Level of steep topography shows a greater abundance of faulting than the High Level. While fault trends differ somewhat in different areas, the morphology of the level is the result of the increased number of faults as well as its being the prime area of degradation due to position. All three zones in the Intermediate Level possess fault trends that are characteristic of either the High or Low Levels and that overlap in some areas. Usually this means the presence of both N-S and Walker Lane trends. Comparison of the Intermediate Level zones with the structural sectors shows that the Intermediate Level roughly coincides with the Jigger Bob and "Block" Sectors showing there is some kind of structural conformity in the level.

In the Low Level of low hills, Walker Lane fault trends are present in all zones. The expression of the Walker Lane in different areas is basically all that varies and the differences in what are dominantly Walker Lane trends are shown by delineation of the Northern, "Walker Lane," and Winnemucca Valley Sectors.

The technique of dividing up a segment of land into levels based on widely spaced and distinct topographic changes and differences in rock type, and then proceeding to find and analyze similar structural patterns within each of the divisions, and then further, to interpret the landscape from the geology and structure, has been found to be satisfactory for the Virginia Mountains. However, it would be well to remember that such will not always be the case as one is not likely to find too many areas similar to the Virginia Mountains in origin of structure or topography. Yet, with a geologically complex area of land with different rock types and/or several broad and topographically different areas, the approach used in this paper may be adequate for a systematic geomorphic analysis.

BIBLIOGRAPHY

Badgley, P. C., 1965, Structural Geology and tectonic principles: Harper and Row, New York.

Billingsley, P. R., and Locke, Augustus, 1939, Structure of ore districts in the continental framework: New York, Am. Inst. Mining Metall. Engineers; also Trans., v. 144, p. 9-59, 1941.

Bonham, H. F., 1969, Geology and mineral resources of Washoe and Storey Counties, Nevada: Nevada Bur. of Mines Bull. 70.

Brooks, Howard, 1956, Geology of an uranium deposit in the Virginia Mountains, Washoe County, Nevada: unpublished M.S. thesis, Univ. of Nevada.

Cotton, C. A., 1949, Landscape: Wiley and Sons, Inc., New York.

Fenneman, N. M., 1931, Physiography of the Western United States: McGraw-Hill, New York, p. 326-395.

Gianella, V. P., 1936, Geology of the Silver City district and the southern portion of the Comstock Lode, Nevada: Nevada Univ. Bull. v. 30, no. 9.

Gimlett, J. I., 1967, Gravity study of the Warm Springs Valley, Washoe County, Nevada: Nevada Bur. of Mines Rept. 15.

Glenn, R. J., 1968, Water resources of the Warm Springs Valley, Washoe County, Nevada: Prof. Geol. thesis, Univ. of Nevada.

King, Clarence, 1878, Systematic Geology: U. S. Geol. Explor. 40th Parallel, v. 7.

Louderback, G. D., 1923, Basin Range structure in the Great Basin: California Univ., Dept. Geol. Sci. Bull. v. 14, no. 10, p. 329-376.

McJannet, G. S., 1957, Geology of the Pyramid Lake-Red Rock Canyon area, Washoe County, Nevada: unpublished M.S. thesis, U C.L.A., 125 p.

Moody, J. D., and Hill, M. J., 1956, Wrench-fault tectonics: Geol. Soc. America Bull. 67, p. 1207-1248.

Nielson, R. L., 1965, Right-lateral strike slip faulting in the Walker Lane, west-central Nevada: Geol. Soc. America Bull., v. 76, p. 1301-1308.

Overton, T. D., 1947, Mineral resources of Douglas, Ormsby, and Washoe Counties: Nevada Univ. Bull., Vol. 46, no. 9.

Rose, R. L., 1969, Geology of parts of the Wadsworth and Churchill Butte quadrangles, Nevada: Nevada Bur. of Mines Bull. 71.

Sales, J. K., 1966, Structural analysis of the Basin Range Province in terms of wrench faulting: Ph.D. thesis, Univ. of Nevada.

Thornbury, W. D., 1965, Principles of Geomorphology: Wiley and Sons, New York.