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Thin Skin Distension in Tertiary Rocks of Southeastern Nevada

ABSTRACT

Volcanic rocks of late Tertiary age, aggregating about 17,000 ft, accumulated on a surface of low relief cut on Precambrian rocks in the Basin and Range province south of Lake Mead, in Nevada and Arizona. They consist mostly of lava and flow breccia of intermediate composition with minor ash-flow tuff, bedded tuff, and lava of rhyolitic composition.

The last of three main phases of volcanism was accompanied by widespread epizonal plutonism and intense faulting. All or parts of six similarly but separately fault-deformed structural units are recognized in a 92-sq-mi mapped area. The structural units are highly distended by a system of closely spaced north- to northwest-striking shingling normal faults (many of which are low angle) that displace younger over older rocks in a west to west-southwest direction. Cumulative amounts of distension approximate the breadth of the structural units and are as much as 20,000 ft, whereas cumulative vertical displacements are much less and in some places are minimal. The structural units are floored at or near the present level of exposure by complex low-angle zones of detachment or décollement into which the numerous shingling normal faults merge. Where the units abut along their strike, they are separated by complex zones of transcurrent faults that appear to merge with the detachment structures and thus mark the ultimate limits of the structural units. Displacement on the detachment structures has the same sense as, but in some places is much greater than, that of the cumulative offset on the shingling faults, thus indicating low-angle movement of the structural units as platelike or lobate masses. These relationships indicate remarkably thin-skinned, large-scale, fault-related tectonism of a type which is present in a broad belt south of Lake Mead and in numerous other areas in the Basin and Range province.

The best exposed structural units exhibit a serial eastward progression from broad areas of steeply dipping strata, low-angle faults, and deep denudation to gently dipping strata, high-angle faults, and little denudation. Reverse-drag flexing, a volume-compensating mechanism for movement on concave-upward faults, is inferred to have produced the gentle to moderate dips of the strata, whereas the nearly vertical dips in the western parts of the units probably resulted from a combination of reverse-drag flexing and rotation related to uplift. Evidence of compression-related folding is absent.

The extreme distension is viewed as a surficial feature of a crustal belt that was subjected to a brief episode of tensional rifting. Rifting at subjacent levels along the belt was compensated for by emplacement of plutons. The surficial rocks were stretched and thinned over the plutons.

INTRODUCTION

Recent geologic mapping in southern Nevada has revealed numerous examples of steeply tilted strata of Tertiary age displaced by low-angle normal faults. The deformed strata form structural plates within which the strike is generally uniform. Several examples of this type of low-angle faulting and steep tilting of Tertiary rocks occur in the Black and Eldorado Mountains between Kingman, Arizona, and Las Vegas, Nevada; others occur in the San Antonio Mountains and Cactus range near Tonopah, Nevada (Fig. 1), in the northern Pahroc Range in Lincoln County, Nevada, and in the vicinity of Beatty, Nevada (W. J. Carr, 1969, written commun.).

This report describes the geology of a 92-sq-mi area located in the Eldorado Mountains about 12 mi south of Boulder City, Nevada (Fig. 2). Structural geology is emphasized in an effort to explain the relationships between tilting and faulting. In reading the geologic

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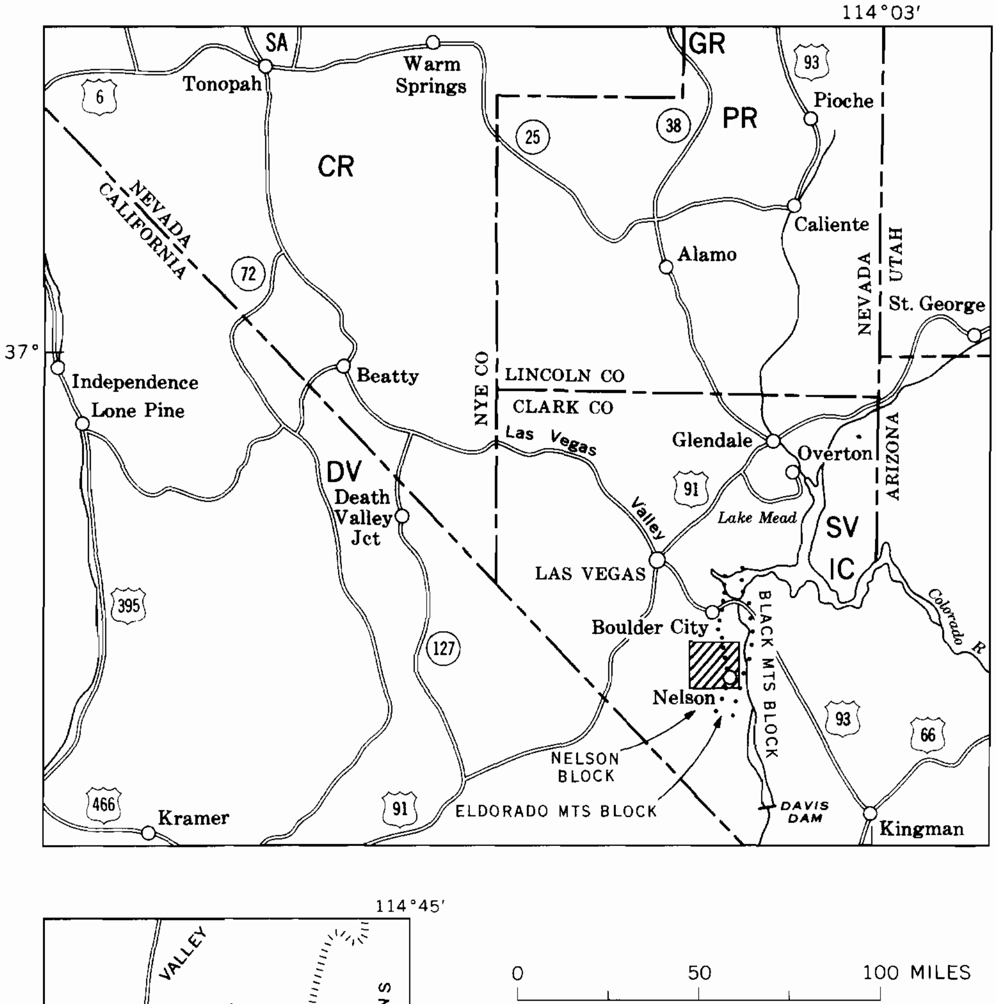


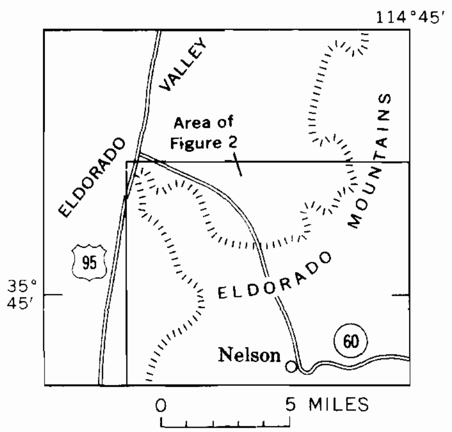


Figure 1. Index map. SA, San Antonio Mountains; GR, Grant Range; CR, Cactus Range; PR, Pahroc Range; DV, Death Valley; SV, South Virgin Mountains; IC, Iceberg Canyon.

map, special attention should be given to the attitudes of fault and bedding surfaces.

The area was mapped (at a scale of 1:125,000) by Longwell (1963), who also described it, and by Hansen (1962) at a scale of approximately 1:35,900. It lies within a distinctive part of the Basin and Range structural province where bedrock consists mainly of crystalline rocks of Precambrian age and volcanic and intrusive rocks of Tertiary age (Longwell and others, 1965; Wilson and Moore, 1959). The center of the area shown on Figure 2 is situated about

20 mi south and east of the limit of exposures of thick Paleozoic and Mesozoic sedimentary rocks of large areal extent (Longwell and others, 1965).

The structures described herein are very similar to those reported from (1) the mountain ranges north of Las Vegas Valley and the Iceberg Canyon area (Longwell, 1945), (2) the south Virgin Mountains (Morgan, 1968), (3) the Death Valley area, California (Hunt and Mabey, 1966; Wright and Troxel, 1969), and (4) the Grant and Horse ranges of east-central Nevada (Moores and others, 1968). Although there is no agreement among these reports as to the origin and significance of the structures, all are known to be, or it can reasonably be inferred that they are Tertiary in age. This structural style is common to large parts of the Basin and Range province and seems, on the basis of published and unpublished evidence, to be a major factor in the Cenozoic tectonics of the province.

STRATIGRAPHY

The oldest rocks in the mapped area (Fig. 2) are mainly garnetiferous gneiss, granite gneiss, schist, and granite pegmatite of Precambrian age. They were mapped and described by Hansen (1962). Rocks of this general type comprise the cores of numerous ranges and structural blocks in southeastern Nevada and northwestern Arizona (Longwell and others, 1965; Wilson and Moore, 1959).

The Precambrian rocks are almost everywhere separated from overlying volcanic rocks by a few tens of feet of conglomerate, conglomeratic limestone, and sandstone composed of angular detritus derived from the underlying crystalline rocks. The sedimentary rocks are of unknown age. They are moderately well sorted but poorly bedded and remarkably widespread, as indicated by their presence in sections as much as 30 mi from the mapped area. The prevolcanic sedimentary rocks are mapped, as they were by Longwell (1963, p. E20), with the overlying Patsy Mine Volcanics.

Volcanic Rocks

Longwell (1963, p. E18) recognized five distinct episodes of volcanism in the area between Lake Mead and Davis Dam, Nevada-Arizona, and mapped rocks representing four of those episodes in the area shown on Figure 2. In order of decreasing age, the units represented by Longwell are the Patsy Mine Volcanics, Golden Door Volcanics, Mount Davis Volcanics, and the Fortification Basalt Member of the Muddy Creek Formation. This succession of strata was mapped and described in greater detail by Hansen (1962). The general distribution of strata shown on Figure 2 is similar to that shown on the earlier maps, but the name Golden Door Volcanics is not used because recent mapping between Lake Mead and Davis Dam has shown that the rocks mapped by Longwell (1963) as Golden Door Volcanics in the type locality at the Golden Door mine in Arizona correlate with the Patsy Mine Volcanics. The name Golden Door Volcanics is hereby abandoned. Strata mapped as Golden Door in the area shown on Figure 2 by Longwell (1963) and Hansen (1962) are informally designated tuff of Bridge Spring and are described below.

TABLE 1. AGE RANGE OF TERTIARY IGNEOUS ROCKS DETERMINED ON THE BASIS OF K-AR DATES*

	Number of analyses	Range m.y.	Mean m.y.
Mount Davis Volcanics	13	10.9–14.6	12.3
Tuff of Bridge Spring	2	15.3–15.5	15.4
Patsy Mine Volcanics	5	15.2–22.8	18.3
Intrusive rocks	13	12.5–16.9	14.2

* *From* Armstrong (1964), Damon and others (1965), and *from* files of the U.S. Geological Survey, Denver, Colorado.

Fifty K-Ar age dates of Tertiary rocks from the Lake Mead area are available from various sources.[1] These data establish the approximate age range of each major volcanic unit and also indicate the age of intrusive activity as shown in Table 1.

A basalt lava mapped by Longwell (1963) as the Fortification Basalt Member of the Muddy Creek Formation 5 mi north-northeast of Nelson gave a whole-rock K-Ar age of 13.8 m.y. This age is older than the median age of 12.5 m.y. for 12 K-Ar ages of lavas of the Mount Davis Volcanics. The rocks mapped by Longwell (1963) as Fortification are accordingly included with the Mount Davis on Figure 2. Thus, three major volcanic units are mapped and described herein: (1) Patsy Mine Volcanics, (2) tuff of Bridge Spring, and (3) Mount Davis Volcanics.

[1] The stratigraphic and structural significance of these dates is evaluated in a report being prepared by the author in co-operation with C. R. Longwell and R. L. Armstrong.

Patsy Mine Volcanics. The type locality of the Patsy Mine Volcanics is near the south boundary of T. 25 S. within the area shown on Figure 2 (Longwell, 1963, p. E19). The strata there are displaced by several faults and therefore no continuous section is available. Longwell (1963, Pl. 1) showed the base of the Patsy Mine sequence to be displaced from view by a large north-trending normal fault, but no evidence for this fault was found in the present study. The base of the Patsy Mine is exposed in many places in the western part of the area of Figure 2, thus a composite section of the Patsy Mine can be measured in the type locality. Although the thickness of this section varies laterally, because of abrupt lateral thinning of all viscous lava flows, the gross lithologic characteristics of the unit persist over a wide area. The thickest known section of Patsy Mine Volcanics, which totals 13,200 ± 500 ft, occurs in the type locality where the breadth of outcrop is about 3.5 mi (Fig. 2). The Patsy Mine is divided into three informal parts —lower, middle, and upper; the lower and upper parts are predominantly andesite, and the middle part is mostly rhyolite.

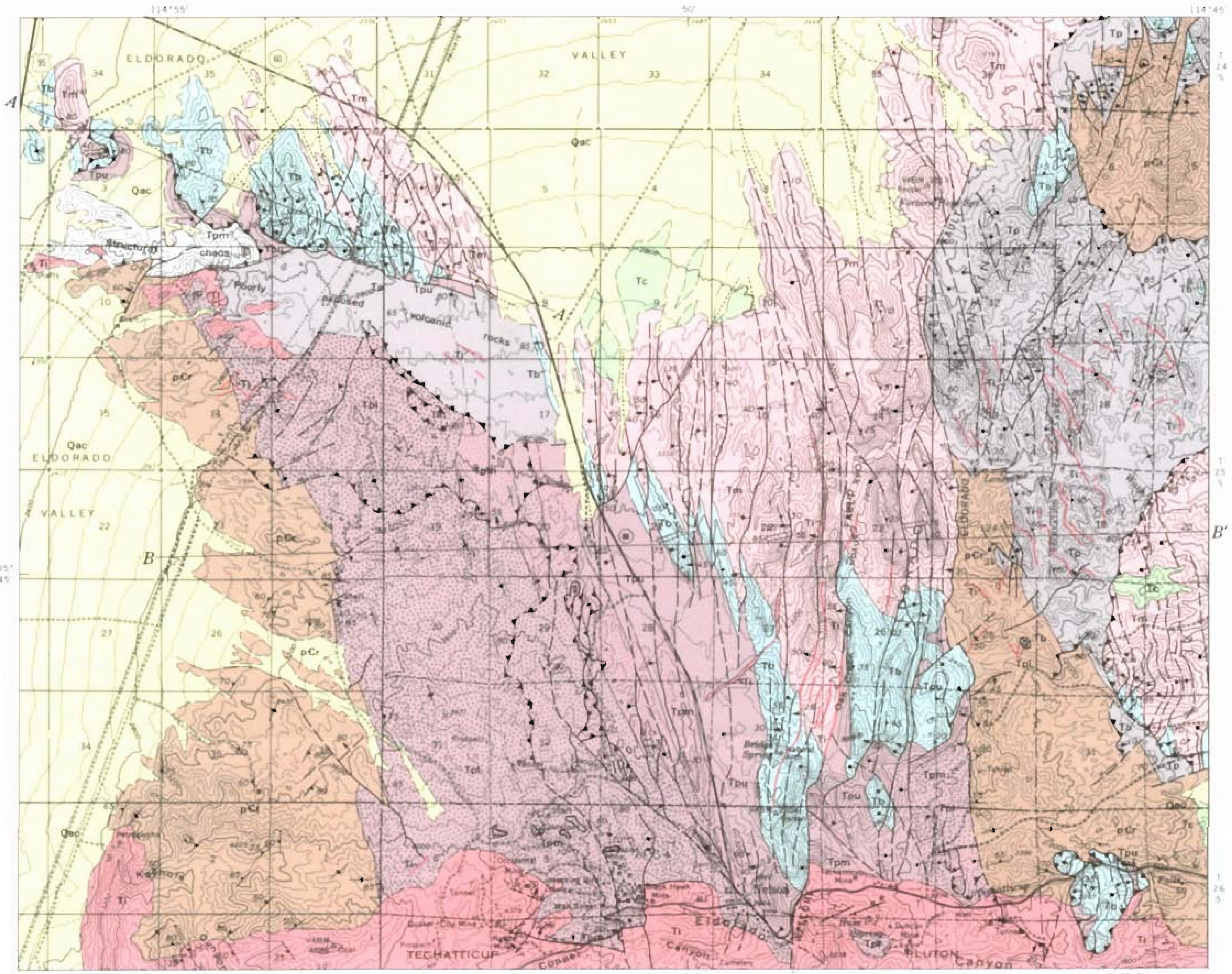
The thin sequence of prevolcanic sedimentary rocks of unknown age is included with, but is not considered to be part of, the lower part of the Patsy Mine Volcanics. These are generally overlain by a few thin dark-green to black, basaltic andesite flows less than 50 ft thick. The next highest volcanic rock is a light-gray to pale-reddish-gray, densely welded rhyolitic ash-flow tuff. Although this welded tuff is discontinuous, it is found in widely spaced localities. Its consistent thickness (about 50 ft) and wide distribution indicate that it was extruded onto a surface of low relief. Locally the tuff rests with apparent conformity on the prevolcanic sedimentary rocks.

The ash-flow tuff is overlain by a monotonous succession of perhaps 40 conformable deposits of andesite and basaltic andesite lavas, flow breccias, and explosion breccias totaling approximately 9000 ft in thickness. Rocks in the lower 1000 to 2000 ft are commonly dark-greenish-gray propylites. The upper several thousand feet of the lower part of the Patsy Mine consists mostly of reddish-brown pyroxene-olivine andesite that is conspicuously less altered than the rocks below. Lavas tend to be thin in contrast to the flow and explosion breccias, which are as much as 2200 ft thick with no apparent depositional break. Lithic fragments in the breccias are exclusively volcanic rocks with mineral compositions and textures similar to those of the faintly porphyritic dacitic to andesitic matrix. The fragments are generally angular and range in length from a few inches to 15 ft. Lavas are dense and massive, and they contain only indistinct, if any, flow layering and sparse vesicular structure. Although some flows are lobate in cross section, most are tabular and extend for as much as 3 mi. A remarkably small percentage of the total sequence of extrusive rocks consists of thin, discontinuous beds of interstratified thin-bedded tuffaceous sedimentary rocks. Coarse clastic rocks are unknown.

The middle part of the Patsy Mine Volcanics in the type locality consists predominantly of light-gray to pink rhyolite lava with local brown, dark-greenish-gray, or black basal vitrophyres. Phenocryst content ranges from almost 0 to about 30 percent and consists mostly of plagioclase, sanidine, pyroxene, biotite, hornblende, magnetite, and sphene. Much of the rhyolite is spherulitic. These light-colored rocks form a conspicuous north-northwest–trending faulted ridge that parallels the road north of Nelson (Fig. 2). The rhyolite lavas are interstratified with yellow zeolitized tuffaceous sedimentary rocks and dark-reddish-brown andesite lava. No more than three separate rhyolite flows were observed in any section. The rhyolite flows tend to be distinctly lobate, and successively younger rhyolite flows, bedded tuffs, and andesite flows lap onto the margins of individual lava masses. Because of the lobate flows and onlapping relationships, the middle part of the Patsy Mine ranges in thickness from about 1000 to 2700 ft.

The upper part of the Patsy Mine Volcanics consists of 1500 ± 300 ft of massive dark basaltic andesite lava very similar to the upper flows of the lower part of the Patsy Mine and to the flows interstratified with the rhyolites of the middle part of the Patsy Mine. These lavas are magnificently exposed east of State Route 60 (Fig. 2). The rocks contain 20 to 40 percent conspicuous phenocrysts of plagioclase, pyroxene, olivine, and magnetite in a dense dark-brown aphanitic matrix.

Tuff of Bridge Spring. The tuff of Bridge Spring is named for excellent exposures in the vicinity of Bridge Spring, 1.5 mi north-northeast of Nelson. The tuff there forms a conspicuous, light-colored, north-trending faulted ridge that contrasts sharply with the surrounding dark lavas of the Patsy Mine and Mount Davis Volcanics. The tuff near Bridge Spring



Base from U.S. Geological Survey, Boulder City and Nelson, 1958

SCALE 1:62 500

1 ½ 0 1 2 3 4 MILES

1 .5 0 1 2 3 4 KILOMETERS

CONTOUR INTERVAL 80 FEET

Geology by R. Ernest Anderson, 1968–69

EXPLANATION

QUATERNARY

Qac — Alluvium and colluvium

TERTIARY

Tc — Muddy Creek Formation

Tm — Mount Davis Volcanics

Tb — Tuff of Bridge Spring

Tp, Tpu, Tpm, Tpl — Patsy Mine Volcanics
Tpu, *upper part*
Tpm, *middle part*
Tpl, *lower part; includes sedimentary rocks of unknown age*

Ti — Intrusive rocks
Includes aphanitic rocks ranging from rhyodacite to andesite and phaneritic rocks ranging from granite to granodiorite. Line indicates dike

PRECAMBRIAN

pCr — Gneiss, schist, and pegmatite

Contact
Dashed where approximately located

25

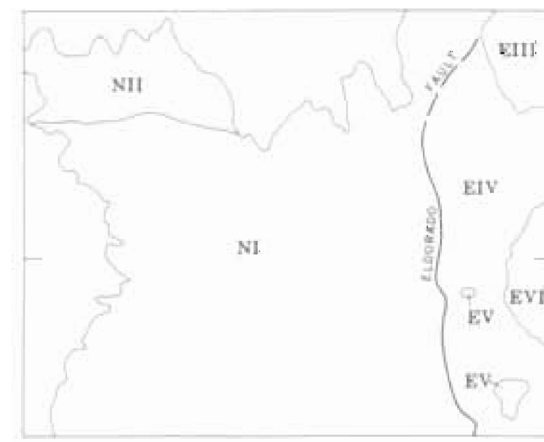
Fault with steep to moderate dip
Dashed where approximately located, dotted where concealed. Bar and ball on downthrown side; arrows indicate direction of relative lateral movement

Fault with low dip
Dashed where approximately located. Sawteeth on upper plate

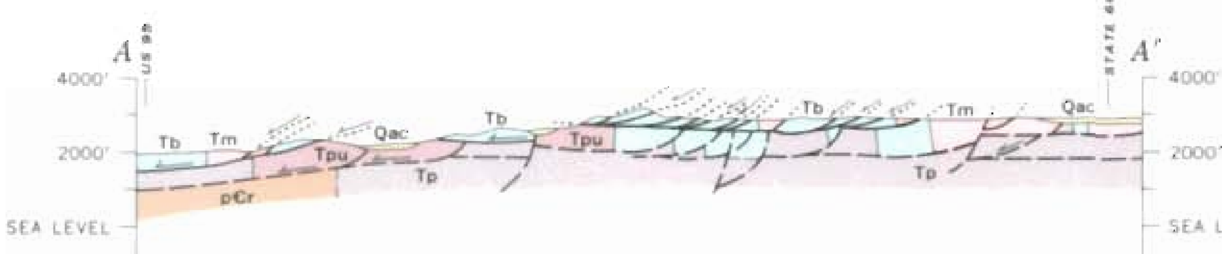
65 — 80
Inclined Vertical Overturned
Strike and dip of bedding

70 — 80
Inclined Vertical Overturned
Strike and dip of flow layering, compaction foliation, or gneissic foliation

30
Bearing and plunge of maximum compressive stress (σ_1) at ground surface



INDEX MAP OF MAJOR STRUCTURAL UNITS



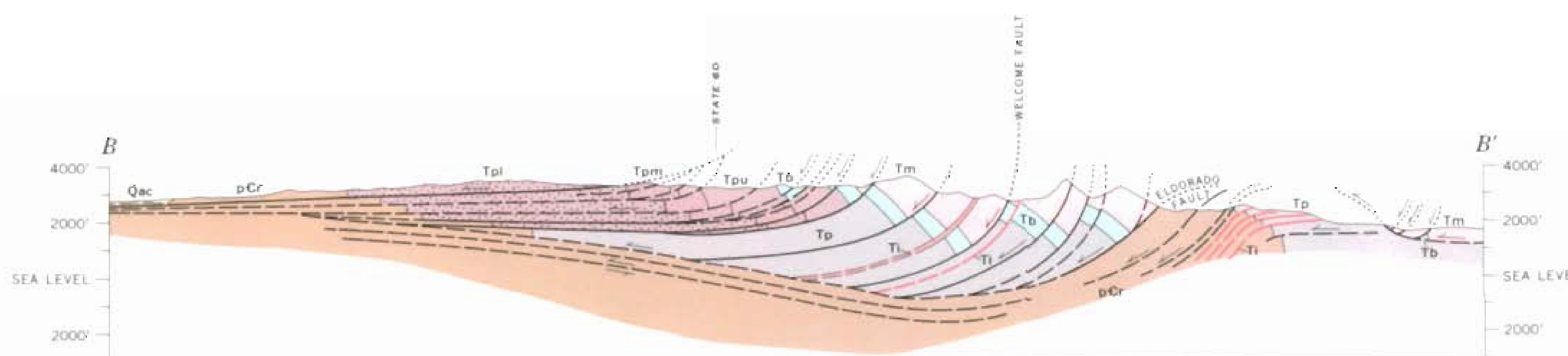


FIGURE 2.—Geologic map and sections of parts of the Boulder City and Nelson quadrangles, southern Nevada.

forms a typical ash-flow tuff cooling unit about 800 ft thick. The cooling unit consists of a pale-gray to pink nonwelded lithic-bearing base separated from a brown welded interior by a dark-gray vitrophyre. A thin nonwelded top is preserved locally. Features formed by vapor phase crystallization are common in the upper half or third of the unit. The tuff is rhyolitic and generally contains about 20 percent phenocrysts consisting of plagioclase, sanidine, pyroxene, biotite, magnetite, and sphene.

Mount Davis Volcanics. In the area between Lake Mead and Davis Dam, the Mount Davis Volcanics include a variety of volcanic and clastic rocks ranging in composition from rhyolite to basalt, together with beds of tuff and thick coarse rubble and landslide debris (Longwell, 1963, p. E24–E29). In the area shown on Figure 2, the unit consists almost entirely of lavas ranging from rhyolite to basalt with dark-gray to black andesite predominant in the lower part, light-gray to moderate-reddish-gray rhyodacite in the middle part, and dark-gray basalt in the upper part. The lavas are almost 2000 ft thick between the Welcome and Eldorado faults. Longwell (1963, p. E24) cited several lines of evidence indicating severe crustal unrest before, during, and after the Mount Davis eruptions. Mild downfaulting or downwarping is indicated east of State Route 60 by a thickening of the lava section (especially the rhyodacite and basalt lavas) eastward toward the Eldorado fault. In that area, however, there is no suggestion of a basal unconformity or of the severe tectonism that is indicated by the thick coarse rubble and landslide deposits found in the unit to the east near the Colorado River.

Clastic Rocks

Topographically low areas shown in Figure 2 are underlain by basin-fill deposits of alluvium and colluvium that consist of unconsolidated to weakly lithified, poorly sorted to unsorted coarse and fine detritus derived from the adjacent bedrock highlands. They are divided into two units: (1) the sedimentary rocks of the Tertiary Muddy Creek Formation in which most of the material is lithified, and (2) alluvium and colluvium of Quaternary age.

STRUCTURE

The mapped area is near the north limit of a broad region of widely scattered exposures of Precambrian crystalline rocks and Tertiary igneous rocks in the Basin and Range province. It is structurally higher than the region to the north where the crystalline basement is buried beneath thick Paleozoic and Mesozoic sedimentary rocks. The mapped area is part of an approximately 30-mi-wide belt of highly deformed Tertiary and Precambrian rocks. The belt extends south-southeast from Lake Mead and embraces the valley of the Colorado River. Its northern part includes the Eldorado Mountains in Nevada and northern Black Mountains in Arizona. Longwell (1963) divided the Eldorado Mountains into two structural blocks, parts of which are shown in Figure 2. The area west of the Eldorado fault spans the Nelson block; the area east of the fault is part of what he termed the northern Eldorado Mountains block. The author recognized (unpub. mapping) structures similar to those described herein from the Nelson and northern Eldorado Mountains blocks in the Black Mountains block. Thus, three parallel structural blocks that consist of similarly deformed Tertiary rocks comprise the northern part of the deformed belt (Fig. 1).

Regional Structural Trends

The general trend of the mountain ranges within the deformed belt is north, and thus the area superficially resembles many areas of block-faulted ranges in the Basin and Range province. In the area between Lake Mead and Davis Dam (Longwell, 1963), faults that bound the ranges and displace the youngest of the volcanic units tend to strike north, whereas structural patterns within the ranges and blocks trend northwest. This relationship is seen in the mapped area (Fig. 2) where the main fault that separates the two structural blocks (the Eldorado fault) and several smaller faults that cut young volcanic units adjacent to it trend north, whereas the structural grain to the east and west is conspicuously northwest.

Structural Units

As shown in the inset of Figure 2, two main structural units (NI and NII) are recognized in the Nelson block part of the mapped area, and all or parts of four units (EIII, EIV, EV, and EVI) are recognized in the northern Eldorado Mountains part. The intrusive mass along the south margin of the area spans both structural blocks. The structure within unit EIII is not essential to the structural interpretations made herein and is therefore omitted from discussion. Structural features common to some or all of the other units are described in the following paragraphs.

The predominant strike of volcanic rocks throughout the area ranges from north to northwest. Stratigraphic tops are to the east. The Precambrian-Tertiary depositional contact in NI and EIV strikes northwest and is generally nearly vertical or steeply overturned. These nearly vertical and locally overturned attitudes prevail in the volcanic rocks over broad areas in the western parts of units NI, EIV, and EVI. The steep attitudes grade to lesser east dips in the eastern parts of the structural units. For EIV and EVI, this eastward lessening of dips is based on geologic mapping east of the area of Figure 2. Dips of bedding surfaces in structural unit NII are steep throughout.

The rocks in each structural unit are cut by numerous shingling normal faults that displace younger rocks down and to the west over older rocks. The faults have low dips where the strata dip steeply, and grade to steep dips where the strata dip gently. Stated differently, the angle between fault and stratification surfaces is approximately 90° for almost all major faults encountered in any cross section drawn normal to the strike of the strata. Although at many intersections, angles greater or less than 90° were observed, hundreds of near 90° intersections and very few as low as 60° were observed. Where the shingling faults dip steeply, their surface trace tends to strike north to northwest, but where they have low angles of dip, they tend to have irregular traces that respond to topographic irregularities. A few northeast-trending normal faults that may have a component of lateral displacement occur in NI, NII, and EIV.

Locally, as near the center of NI, low-angle normal faults appear to pass laterally into "transcurrent" faults. This feature may simply reflect a local tendency for the low-angle faults to shoal along lines normal to their strike. That such shoaling does occur is suggested by a tendency for these transcurrentlike faults to have moderate dips.

Most of the normal faults are simple clean breaks devoid of drag folds or breccia zones but commonly marked by thin (as much as 2 ft) zones of resistant silicified gouge. Many surfaces have well-developed slickensides or corrugations. These lineations were not systematically analyzed, but about 30 orientations (mostly from NI) measured on variously striking principal fault surfaces show a very strong preference for a S. 70° W. trend. This trend indicates dip slip on the north-northwest–trending normal faults, oblique slip on the northeast-trending normal faults, and S. 70° W. translation of successively higher plates in the areas of low-angle faults. Slickensides on the apparent "transcurrent" faults have little or no plunge, thus indicating strike-slip displacement.

Sheetlike dacitic intrusive masses occur along many of the faults that cut NI and EIV. They are not shown on the geologic map of western NI; they dip gently there as in western EIV (section B-B′, Fig. 2).

Fault Displacements within the Structural Units

The direction of downthrow on the shingling normal faults that cut each structural unit is generally toward the structurally elevated part of the unit and is opposed to the dip direction of the strata. If the tilting of the strata resulted from compression-related folding and the horizontal component of displacement on the faults resulted from extension, the two opposed horizontal components of strain would tend to cancel one another. Thompson (1956, p. 64) and Thompson and White (1964, p. A40) evaluated this relationship for somewhat similar structures in the Virginia City, Nevada, area. As discussed below, the author proposes that most of the tilting is related to displacements on the faults and not to folding. As such, the cumulative horizontal strains estimated in the following paragraphs are far in excess of those that would result from estimates made in a manner similar to that of Thompson and White (1964).

Individual low-angle faults that cut the vertical Patsy Mine Volcanics in NI have horizontal components of displacement as much as 2000 ft. The cumulative horizontal separation on the shingling faults, measured at the 2000-ft level across NI, is about 11,500 ft. The component of vertical displacement is difficult to assess because of the complicating effects of probable postfaulting uplift of western NI. Western NI is structurally higher than eastern NI, although all major faults displace rocks down to the west.

The caps of several hills west and northwest of Nelson consist of light-colored, resistant silicified rhyolite and tuffaceous sedimentary rocks that are probably equivalent to the middle part of the Patsy Mine Volcanics (Fig. 2). These rocks, although intensely altered and fractured, show a consistent pattern of steep dips and northwest strikes. Low-angle faults marked by zones of brecciated rock and gouge gird several of these hills and separate the steeply dipping silicified caprock from similarly colored less resistant argillized and bleached andesite(?) lavas. On some hills, the intensity of bleaching decreases downward and dark lavas can be seen low on the hillsides. The resistant caps of rhyolite and tuff are interpreted as erosional remnants of a once-continuous highly distended plate of middle Patsy Mine and younger(?) strata that moved southwestward over the lower Patsy Mine rocks. Prior to removal of most of the plate by erosion, it may have looked much like the NII structural unit. Indeed, if the NII unit were eroded to about the 2000-ft level, the geology as depicted in section A-A′ (Fig. 2) could produce a pattern of hills of resistant tuff of Bridge Spring separated structurally from surrounding lowlands fashioned on weaker lavas. The pattern might be very similar to that observed at the present level of erosion northwest of Nelson. In any case, the distribution of the faulted, steeply dipping middle Patsy Mine rocks suggests more than 15,000 ft of cumulative horizontal separation across the southern part of NI.

Unit NII is composed mostly of thick, massive, welded tuff of Bridge Spring and the overlying lavas of the Mount Davis Volcanics. These nearly vertical strata form thin highly distended structural plates that are separated from underlying highly contorted and sheared Patsy Mine Volcanics by low-angle normal faults (section A-A′, Fig. 2). The base of the tuff of Bridge Spring in NII is a dark-gray to black vitrophyre that serves as an excellent marker horizon. The minimum cumulative horizontal separation of the vitrophyre on the shingling faults (measured normal to the strike of the strata) is 20,000 ft across the NII unit. The vertical component of separation is near zero.

Distension-type structures are well displayed along the southwest margin of the small part of EIV that is included in the area of Figure 2. There the steeply dipping contact between the tuff of Bridge Spring and Mount Davis Volcanics is repeated numerous times by closely spaced shingling faults. The cumulative horizontal separation is about 4000 ft. No trace of these faults was found in the adjacent parts of EIV, and so they appear to be restricted to EVI. A paradoxical relationship is observed when this area is viewed from the south at a distance of a mile or so. The Mount Davis

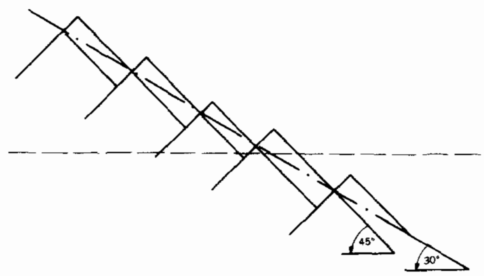


Figure 3. Diagram illustrating difference between actual dip (45°) and effective dip (30°) in a series of fault blocks; *from* Hunt and Mabey (1966, Fig. 111).

rocks are dark basaltic lavas that are continuously exposed along the topographically high part of the area. The contrastingly light tuff of Bridge Spring is discontinuously (and more poorly) exposed at lower elevations. This relationship creates the definite impression of a gently east-dipping contact between the two units. This is an extreme manifestation of the relationship between actual and effective dip in highly faulted areas as described by Hunt and Mabey (1966) and reproduced in Figure 3.

Fault Displacements between the Structural Units

The part of structural unit EVI included in the mapped area (Fig. 2) is structurally and stratigraphically exotic and must have been transported westward to its present position by faulting. That it was deformed separate from the underlying EIV mass is indicated by the fact that the numerous shingling faults do not extend beyond its boundaries. Also, bedding and fault attitudes within it are more northerly than in the surrounding EIV unit. The minimum displacement is at least as much as the 5000-ft breadth of outcrop shown. The actual displacement is probably much more. Most of the movement is probably a result of merging of the numerous shingling faults into a single detachment fault.

The fault that separates NII from NI is complex. The east and west parts have different strikes, and the relationship between the two is unclear. Both parts of the fault show drag features that suggest lateral displacements. Where the tuff of Bridge Spring abuts the NII-NI boundary fault, the basal vitrophyre of the tuff tends to be dragged parallel to the fault, suggesting left-lateral separation. The volcanic rocks within the area designated as a structural chaos on Figure 2 are highly fractured and contorted. Although the stratigraphic succession in that area is largely unknown and the structures are chaotic, there is a tendency for planar features in the rocks to be dragged parallel to the NII-NI boundary fault in a manner further suggesting left-lateral separation. The tuff of Bridge Spring is about 10 times thicker in structural unit NII than in northern NI. Also, the area of structural chaos in NII contains rocks not recognized in NI. These stratigraphic differences suggest that parts of NII may not have been coextensive with NI prior to the left-lateral shifting of NII relative to NI. If this is so, the amount of left-lateral separation may be considerably greater than the 20,000 ft judged from horizontal separation *within* NII.

Structural units EIV and NI are dimensionally and structurally very similar (EIV extends 3 mi east to the Colorado River). Both are intruded by and, in part, faulted against the Techatticup pluton on the south. Part of the base of EIV is exposed in the northeast corner of the mapped area where a low-angle fault transects steeply dipping Patsy Mine Volcanics normal to their strike and separates the volcanic rocks from the underlying Precambrian rocks of EIII. The faulted lavas are several thousand feet stratigraphically above the base of the Patsy Mine. Unit EIV must have been shifted westward an equivalent distance relative to EIII, because no reasonable amount of dip-slip displacement on the fault could produce the observed offset relationships.

Structural units NI and EIV are separated by the Eldorado fault, a complex break that dips from 5° to 60° west. The low dips are found along its southern trace, and the fault steepens, horsetails, and becomes partly buried toward the northern boundary of the mapped area. The low west dips indicate that EIV extends westward beneath NI, thus making the subsurface distinction between the two structural units arbitrary (B-B′, Fig. 2). The displacement on the Eldorado fault apparently is very great as indicated by the following: (1) The fault juxtaposes the upper units of a very thick sequence of volcanic rocks in NI against older Tertiary volcanic and Precambrian crystalline rocks of EIV. (2) Equivalent strata in the steeply dipping lower part of the Patsy Mine Volcanics show a west-southwest lateral separation of about 6 mi between NI and EIV. Considering the fact that they are lavas and flow breccias, there is a remarkable lithologic and stratigraphic similarity between these rocks in the two structural units, suggesting that they were once much closer together and were separated structurally. (3) Slices of middle and upper parts of the Patsy Mine Volcanics occur along the fault where it juxtaposes Mount Davis Volcanics and Precambrian rocks (not shown on Fig. 2). (4) The two small masses that comprise EV are structurally detached from the underlying Precambrian rocks of EIV. Considering that the Eldorado fault to the west is complex and dips very gently, the detachment faults that underlie the EV masses may well be eastward extensions of the Eldorado fault. Presumably the fault slices, and possibly the EV masses, were eroded tectonically from the base of the westward-shifted NI structural unit. In addition to indicating large displacement, their presence supports the inferred décollement or transgressive character of the Eldorado fault as is suggested in cross section by the absence of a complete thickness of volcanic rocks in the eastern part of NI (B-B′, Fig. 2). Displacement on the Eldorado fault along the line of section could be as much as 15,000 ft. It is probably greater to the south and less to the north.

The Precambrian-Tertiary contact is exposed about 2 mi southeast of Nelson beyond the area included in Figure 2 (Hansen, 1962). The contact and the overlying lavas strike northwest and are steeply overturned, as they are 3.2 mi west of Nelson (Fig. 2). Stratigraphic tops are to the east at both locations. Hansen concluded, and the author concurs, that these two contacts were displaced by left-lateral faulting of large magnitude. At least 20,000 ft of left-lateral separation is indicated. The inferred fault or fault zone is occupied by the Techatticup pluton, but the relationship between faulting and emplacement of that mass is uncertain. Some of the faulting postdates the pluton, but the generally unsheared and transgressive character of the pluton seems to indicate that the major displacement either accompanied or preceded intrusion.

Age of Faulting

As noted by Longwell (1963), there are several localities in the area between Lake Mead and Davis Dam where abundant coarse debris is intercalated with Mount Davis lavas, suggesting that tectonism accompanied volcanism. In eastern NI, displacements on some faults decrease in successively younger Mount Davis flows thus providing evidence of faulting simultaneous with eruption. Of the 13 available K-Ar age dates of Mount Davis lavas, one is from a lava that rests on beveled steeply tilted Patsy Mine Volcanics in the Black Mountains and a second is from a young Mount Davis lava that appears to postdate steep tilting of earlier Mount Davis lavas in NI. Whereas the 13 age dates indicate that Mount Davis eruptions ranged from about 15 to 11 m.y. (Table 1), stratigraphic and structural relationships such as those for the sample from NI indicate more restricted intervals of severe tectonism of about 1.5 m.y. locally. Undoubtedly tectonism accompanied most, if not all, volcanic activity, but the Mount Davis interval seems to have been a time of widespread wholesale disruption of large magnitude.

Subsurface Interpretation

Fault and bedding attitudes at the surface along the lines of section (Fig. 2) are well known. Section B-B′ clearly depicts the serial gradation in magnitude of dip of fault and stratification surfaces observed at the surface across NI. In making subsurface projections, it was necessary to integrate the surface data into a model that would ultimately be capable of explaining the seemingly paradoxical development of very steep dips in an area where fault relationships argue strongly for intense distension.

Special features incorporated into the subsurface construction include (1) decrease of dip with depth of fault surfaces, (2) reverse drag flexing of faulted strata, and (3) merging of faults at depth. The first two special features are closely related.

Indirect evidence of decrease of fault dips with depth is found at the surface, where it is seen that areas of greatest denudation exhibit faults with lower dips than do areas of lesser denudation.

Volume increases produced by extension on faults that decrease in dip with depth are compensated for by either antithetic faulting or reverse drag flexing (Hamblin, 1965). In the area under consideration, only one of the two theoretically predictable systems of concave-upward faults is developed. That is, antithetic faults are either absent or uncommon (if they exist they would nearly parallel the bedding surfaces and would be difficult to detect). The pattern of reverse drag flexure shown in the block-faulted area west of the Eldorado fault (upward curvature of beds in section B-B′) results from geometric demands related to displacements on concave-upward faults. A discussion of the origin of reverse drag associated with concave-upward faults and a review of examples of this type of structure are given by Hamblin (1965). Hamblin based much of his analysis on direct observation of reverse drag flexures and decrease of fault dips with depth in the western part of the Colorado Plateau as little as 50 mi northeast of the mapped area. The faults there are widely spaced, and the strata in the downthrown block are flexed only near the faults. In contrast, the faults in the eastern part of the Nelson block are so closely spaced that the intervening blocks are inferred to be flexed throughout their breadth. The flexed nature of any particular downthrown block as shown in section B-B′ is, however, very similar to that of the analogous area adjacent to the Hurricane fault as illustrated by Hamblin (1965, fig. 9). It is important to note that, except for the prescription of the abruptness of curvature on the fault, the similarity results not from the style of the illustrator, but from the geometric demand that the angle between the fault and bedding surfaces be nearly 90°.[2]

Although it is easy to conceptualize that the mechanism of reverse drag operates along the moderately to steeply dipping part of a concave upward fault where flexing is a volume compensating response to gravity forces, it is extremely difficult to do so where the fault approaches a horizontal attitude. The difficulty is particularly acute in western NI where a broad expanse of nearly vertical beds are shown cut by low-angle normal faults (B-B′, Fig. 2). Such a configuration could not have been produced solely by reverse drag flexing. Western NI is an area of relative uplift. I

[2] If it is assumed that tilting of fault blocks was produced by rigid rotation of initially horizontal beds on inclined faults, then an approximately 60° angle between bedding and fault surfaces can be predicted from considerations of the mechanics of gravity faulting. Many geologists working in areas of similarly directed moderate tilting of blocks between parallel faults assume that the strata were rigidly rotated by displacements on inclined gravity faults. Although such rigid-block rotation may occur, the complications arising from preservation-of-volume demands are considerable and often neglected. Geologic mapping of numerous areas in the Basin and Range by the author has revealed that an approximately 90° angular relationship between bedding and fault surfaces is very common over the entire range of dips of strata. It is certainly the prevailing condition in the region considered in this report. Where near-surface horizontal or gently dipping beds are displaced by near-vertical faults, the failure seems best explained as having resulted from tension.

interpret the flat(?) low-angle faults there to be downward extensions of curved high-angle faults that have been removed by erosion. Although this interpretation is not based on direct observation, it is completely consistent with the serial gradation of fault dips observed across NI and, based on mapping east of the area of Figure 2, across EIV and EVI. A quantitatively unknown part of the steep dip of the beds must be related to tilting produced by the uplift.

Evidence for the third assumption that faults merge at depth is seen in areas of both low- and high-angle faults. In the northwest corner of the mapped area, two west-dipping low-angle faults exposed in a low hill merge westward into a single fault. The Welcome fault and other high-angle faults of the same system show mergence as they are traced southward from high to low structural levels (Fig. 2). Merging at depth of concave-upward fault surfaces will produce zones of detachment or décollement at least locally. Cross section B-B1 shows the Eldorado fault passing downward and westward into a zone of detachment that separates distended blocks of volcanic rocks above from sheared Precambrian rocks below. This subsurface interpretation is highly conjectural and probably oversimplified, although it has an apparent exposed corollary in NII to the northwest where the underlying block consists of volcanic rocks of Tertiary age (A-A′, Fig. 2) and in EVI to the east. It is possible to eliminate the detachment zone and show only the downward mergence of faults for which there is surface evidence. In doing so (Fig. 4), the nonmerging faults would be shown as concentric surfaces and the Precambrian-Tertiary contact would be displaced at least 10,000 ft west and 10,000 ft down along the Eldorado fault. Although such a subsurface configuration may be reasonable for NI, it is not for the other structural units which have their bases exposed at the present level of erosion. It is much more reasonable to assume that the distended masses are thin and bottom at décollementlike faults.

The generally nonbrecciated condition of intrusive rocks in the mapped area indicates that most of the movement on the faults along which they were intruded occurred before their emplacement. Groundmass textures of the intrusives are generally similar to those of the enclosing volcanic rocks. This condition seems to indicate similar cooling histories and possibly near-surface intrusion. No relationship between depth of denudation and granularity was noted either for the sheetlike masses or for the large intrusive mass along the south boundary of the mapped area. These observations are consistent with a thin-skin structural model that does not call for extremely large amounts of postfaulting, postintrusion uplift.

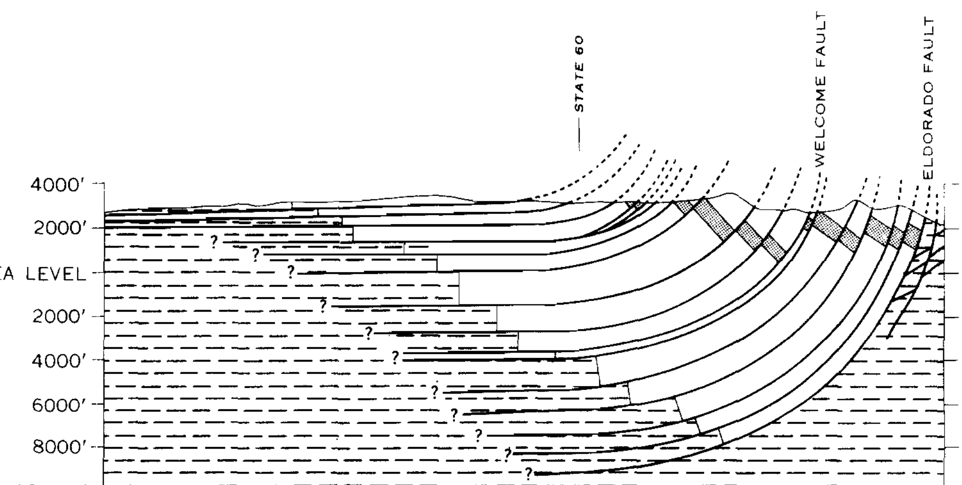


Figure 4. Sketch showing possible pattern of concentric faults that results if it is assumed that the faults do not merge at depth. Compare with more favored structural interpretation along the same line of section (*B-B′* on Fig. 2). The relative amounts of vertical and horizontal offset are considerably different between the two sections. Dashed area is Precambrian rock; stippled is tuff of Bridge Spring.

Stress Distributions

The persistent north-northwest alignment of structures within the deformed belt (Longwell, 1963; Wilson and Moore, 1959; Anderson, 1969) indicates maximum and minimum compressive stresses (σ_1 and σ_3, respectively) distributed around a north-northwest–trending horizontal axis (intermediate stress axis, σ_2) and precludes radially symmetrical (dome or circular basin) deformation. The pattern of faulting in the mapped area and to the east in Arizona indicates that the horizontal component of *a* (the principal movement direction) is similar for almost all faults. Measurements of slickensides on major fault surfaces of various strikes indicate that the modal orientation in plan of *a* is S. 70° W. This fact, together with the obvious pattern of serial structural gradations across the Nelson block and across other structural units located to the east, is considered strong evidence against a stress configuration that was first compressional with σ_1 trending S. 70° W. and subsequently reoriented so as to be tensional with σ_3 trending S. 70° W.

If a fixed angular relationship between σ_1 and fault surfaces in the σ_1-σ_3 plane is assumed, the plunge of σ_1 can be obtained at all localities where the movement direction is known from slickensides and other linear features on the fault surface. Representative σ_1 orientations obtained in this way would vary greatly from place to place as a consequence of varied fault dips. One set of possible solutions is shown on the geologic map (Fig. 2). These solutions have little real value because they reflect only the final (present) structural condition and not that which prevailed at the time of faulting. Nothing is known of the time sequences or amounts of fault and tilt displacements which might allow solutions of σ_1 orientations based on reconstructed structural conditions. Also, the possibility exists that the angle between σ_1 and the fault surface was not constant with depth at the time of faulting. As suggested by Kanizay (1962), a reasonable yield envelope could be oriented and positioned in such a way that failure near the surface is of a brittle nature and results from tensile stress in excess of compressive stress. The near-surface fractures would be oriented at 90° to the largest principal stress which is tensile. Like many, if not most, faults that displace horizontal near-surface strata in the Basin and Range, they could be expected to be vertical. With increasing depth, failure is more of a plastic nature and fractures are inclined at lower angles, approaching 45° to the largest principal stress which is compressive. The fractures in this depth region are shear fractures and could approach low angles of dip if a supplemental basal shear stress of the type analyzed by Hafner (1951) were applied at an appropriate angle. Because of the lack of knowledge of the faulting and tilting histories or of the presence or absence of lateral stress gradients, it would be futile to attempt a detailed analysis of the stress configurations that produced the mapped structures.

Possible Causes of the Observed Structures

Three possible causes of the observed structures, none of which call for stress reorientation, are considered. They are: (1) gravity sliding from a north-northwest–trending arch, (2) compression directed toward S. 70° W., causing broad folding with compensatory low-angle normal faulting on the flanks of the folds, and (3) distension of a shallow crustal block by rising and spreading magma.

Gravity Sliding. The area south of Lake Mead was structurally high before and during the main episode of volcanism and, by inference, before the episode of tectonism. Widely distributed Precambrian-Tertiary contacts are now at an almost concordant level (Longwell, 1963, Pl. 1) thus providing no evidence of strong broad arching during the period of severe tectonism. It might be possible, however, to have had an early (post-early Mount Davis Volcanics) episode of arching and gravity sliding and a subsequent (pre-late Mount Davis Volcanics) episode of collapse of the arch thus bringing the Precambrian-Tertiary marker horizon to its present semiconcordant level. Admitting this as a possibility, it becomes necessary to consider whether the observed structures could be caused by gravity sliding.

In the area south of Lake Mead, gravity slide masses several hundred feet thick and several square miles in extent and of known source have been described by Longwell (1951). He reported that the masses are composed of broken unsorted wholly chaotic megabreccia that moved downslope away from a rising mountain front. They are related to a period of post–Mount Davis Volcanics uplift of the Black Mountains block. The masses bear no resemblance to the structural uniformity exhibited throughout the mapped area. Gravity sliding away from volcanic domes in the

Bearpaw Mountains of Montana was reported by Reeves (1946) and in Java by Bemmelen (1954). In those areas not only are the structures vastly dissimilar to those of the mapped area, but the possible relative roles of gravity sliding and some other forces related to volcanism are unclear.

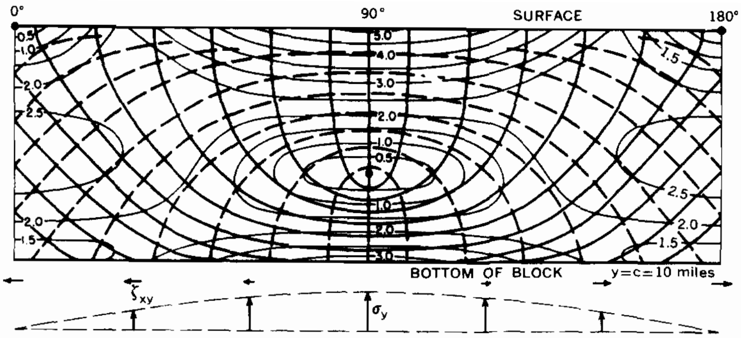
Although the role of gravity as a body force is not to be denied, gravity sliding does not appear to have produced the Nelson block-type structures that occur south of Lake Mead. Some of the principal reasons for rejecting a gravity slide hypothesis are: (1) Displacements on high- and low-angle faults did not occur parallel to any apparent prefaulting plane of weakness or potential glide plane; the rocks are broken the "hard way." (2) No evidence exists that faults broke to the surface in their downdip direction; that is, no features suggest a toe. (3) All movement was in one direction rather than being axially symmetrical as would seem to be required by gravity sliding from an arch. (4) Within blocks having the scale of the Nelson block, the areas of relative structural uplift and depression are the reverse of what would be required to produce gravity sliding with the observed movement direction. (5) There are no obvious source areas for the detached masses.

Directed Compression Causing Broad Folding with Compensatory Low-Angle Normal Faulting on the Flanks of the Folds. Longwell (1945), concluded that low-angle normal faults in southern Nevada formed on the flanks of major rising and spreading anticlines, the cores of which were undergoing "plastic flow." He assumed that the large structures had a high confining pressure. As viewed by Longwell (1945, p. 117), the normal faults are passive features unrelated to regionally distributed tensional stress. In support of a theoretical model of a supplemental stress system consisting of variable vertical and shearing stress along the bottom of a crustal block, Hafner (1951, p. 394) cited Longwell's model as a naturally occurring example of the resultant fault patterns. Longwell's dimensionless physical model is reproduced in Figure 5 together with the related portion of Hafner's graphic illustration of the mathematical model.

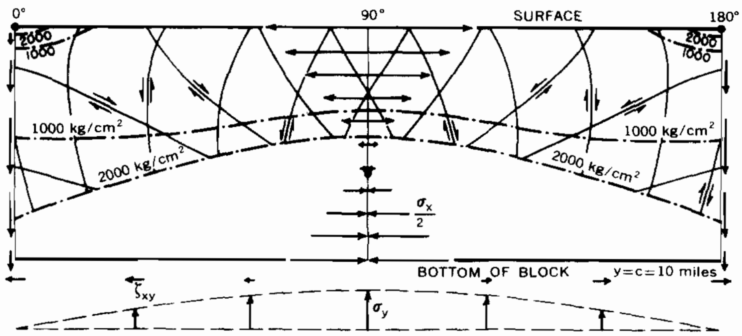
The geologic relationships described by Longwell (1945) are so similar to those described herein that a similar genesis seems very likely. Although the dynamics of Longwell's model (Fig. 5) are very appealing, there is no known evidence suggesting the presence of large anticlinal structures either in the deformed belt south of Lake Mead or in the Iceberg Canyon area (Fig. 1) where Longwell (1945) postulated a large anticline in the south Virgin Mountains. The structural configurations are asymmetric in the extreme with no suggestion of two conjugate fold limbs. Stratigraphic tops are all in one direction. Horizontal displacements greatly exceed vertical displacements. To interpret these structures as faulted folds is to attach undue significance to the presence of dipping strata and to avoid explanation of the structural asymmetry and the strike and lateral faults which have many miles of cumulative horizontal and lateral separations, respectively. Reverse-drag flexing provides a means of producing steep dips in rocks that are subjected to horizontal extension. There need be little associated vertical displacement. The mechanism specifically eliminates the necessity of assuming earlier or concomitant periods of compression-related folding, which has been the preferred solution by other geologists working in southeastern Nevada (Longwell, 1945; Hansen and Proctor, 1963; Morgan, 1968) and elsewhere in the Basin and Range province (Thompson and White, 1964; Moores and others, 1968).

Distension of a Shallow Crustal Block by Rising and Spreading Magma. Granitoid and subgranitoid epizonal plutons are widely distributed within the deformed belt south of Lake Mead (Longwell, 1963; Anderson, 1969). The largest of these is a composite mass exposed over more than 50 sq mi in the northern Black Mountains (unpub. mapping by the writer). Hundreds of aphanitic dikes and irregular small intrusive masses occur in areas between the larger plutons, thus attesting to the presence of magma sources at depth.

Figure 5. Diagrams *A* and *B* are σ_1-σ_3 plots of stress trajectories and slip planes respectively for a stress system consisting of variable vertical and shearing stress along the bottom of a crustal block. Boundary stresses are indicated by double-headed arrows (*from* Hafner, 1951, to which report the reader is referred for a complete development of the theoretical basis for the diagrams). Diagram *C* is a dimensionless sketch from Longwell (1945), showing low-angle faults that extend outward from a region of plastic flow and displace a rigid shell surrounding a rising spreading anticline. The dashed line through *A* represents the reconstructed anticline, assuming no compensating faults. Note similarity between low-angle faults in *B* and *C*.



A



B

EXPLANATION

A — Trajectory of maximum principle pressure = σ_{min}

A — Trajectory of minimum principle pressure = σ_{max}

A — 2.0 — Line of equal maximum shearing stress = ζ_{max} for B = 1.0

B — Position of potential fault surface $\theta = 30°$

B — Boundary of area of stability for various values of A_{max}

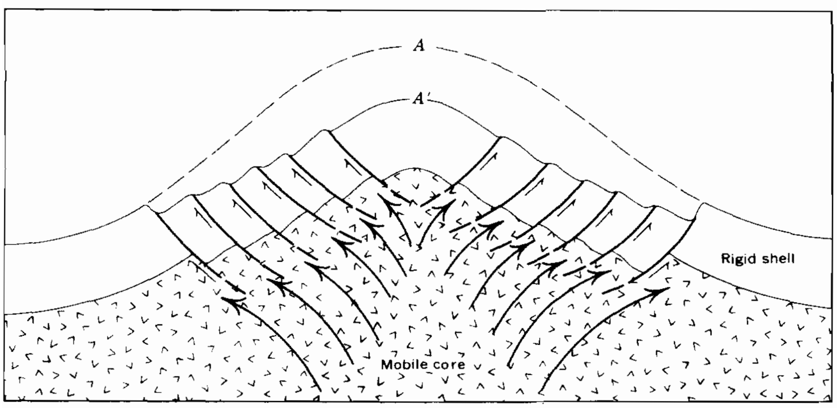
● Point of zero shearing stress

BOUNDARY STRESSES ALONG BOTTOM OF BLOCK

$\sigma_y = -A \sin \alpha x$; $\zeta_{xy} = -B \cos \alpha x$; $A = 2B$

$A_{max} = 1000$ to 2000 kg/cm

HALFWAVELENGTH 31.4 MILES, A=2B



Thirteen K-Ar age dates on 10 different intrusive masses (Table 1) show an age range of 16.9 to 12.5 m.y. Ten of the ages fall within the age range indicated for the Mount Davis Volcanics, and the other three are slightly older. The widespread distribution of intrusive rocks of roughly concordant age is considered to be strong evidence that the entire area is underlain in the shallow subsurface by a broad coeval plutonic mass. The period of eruption of the Mount Davis Volcanics was thus a period of widespread plutonism and wholesale tectonic disturbance. It seems very likely that the volcanism, plutonism, and tectonism are genetically related processes. Widespread substrata of plutonic material are indicated elsewhere in southern Nevada (Anderson and Ekren, 1968) where structural configurations similar to those of the area south of Lake Mead are spatially and temporally allied with igneous activity.

The rising, spreading, mobile anticlinal core proposed by Longwell (1945) and depicted theoretically by Hafner (1951) yields a stress distribution (Fig. 5) similar to one that might be expected in a rock mass that is being displaced by a rising, spreading pluton of the type produced experimentally by Ramberg (1963, Figs. 32, 34, and 38). In the area south of Lake Mead, a strong density contrast is indicated between the dense metamorphic rocks of Precambrian age and the less dense, felsic Tertiary intrusive rocks (Kane, 1963, and 1968, written commun.). A reasonable model of pluton emplacement might be that of material of relatively low density rising diapirically along a rift and spreading away from that rift at some shallow level in the crust. If the spreading is assumed to be asymmetric, the overlying rocks would be asymmetrically distended by drag associated with the horizontal component of tangential shear imparted by the spreading mass. The Eldorado fault and subjacent shear planes (Fig. 2) are intended to depict the results of such a tangential shear stress. The inferred pluton is at an unknown depth and therefore is not shown in the cross sections. The conjectured shear system resembles laminar underflow or underthrusting. However, the shear planes are inferred to have been rotated from an initially moderate west dip to an east dip during postfaulting uplift of the western part of the block. Therefore, the "underthrusting" is an apparent feature caused by postfaulting rotation through an estimated 15° which is equivalent to about 5000 ft of uplift.

On a province-wide scale Hamilton and Myers (1966) suggest, and I concur, that the brittle fracturing that produces the block-faulted pattern in the Basin and Range is limited to the upper part of the crust and gives way downward to horizontal laminar flow. I am suggesting that the depth at which the transition occurs is shallow in local areas of widespread plutonism and that the laminar flow condition is augmented by spreading magma. According to Kanizay (1962), a high geothermal gradient, as would be expected to be present in an area of intense igneous activity, would tend to shift the transition from brittle to perfectly plastic response closer to the surface.

SUMMARY AND CONCLUSIONS

A large stratavolcano of Tertiary age was constructed on a nearly featureless platform of Precambrian crystalline rocks that were mantled by a few tens of feet of prevolcanic clastic rocks. The volcano was constructed of andesite lavas and flow breccias and rhyolite lavas (Patsy Mine Volcanics). It may have attained a height of 13,000 ft. Although seismicity and faulting doubtlessly accompanied the volcanism, evidence of severe tectonism during the eruptions is lacking. The lava eruptions were followed by emplacement of widespread rhyolitic ash-flow tuff (tuff of Bridge Spring) from an unknown source. Eruption of the tuff was followed by accumulation in the Nelson block of an eastward-thickening wedge of andesitic and rhyodacitic lavas (Mount Davis Volanics). East of the mapped area, the lavas of the Mount Davis are interlayered with thick accumulations of clastic debris. Normal faulting appears to have occurred throughout the Bridge Spring and Mount Davis interval and to have increased in intensity with time. In the eastern Nelson block, the Mount Davis lavas probably were erupted from an extensive system of fissures that are now occupied by dikes.

The mapped area is divided into six structural units that are separated from each other by faults with large displacements. Features common to the six units are: (1) with minor exceptions, volcanic rocks strike north to northwest; (2) stratigraphic tops are to the east; (3) dips increase from east to west and are commonly near vertical in the western part of each unit; (4) faults displace younger rocks over older; and (5) an approximately 90° angular relationship between fault and bedding surfaces predominates in sections taken normal to the strike of the strata. Unpublished and published geologic mapping of widespread areas in the surrounding region indicates that these features are common to a large number of structural units that are dimensionally similar to those in the mapped area. There is an indication that where a structural unit has been penetrated by erosion, the unit is separated from underlying rocks by a complex décollementlike structure. Also, there is generally an indication of transcurrent movement in faulted areas where two structural units are juxtaposed at a high angle to the strike of the strata. The transcurrent faults, like the décollement structures, are reasonably inferred to mark the ultimate extent of the structural units. *Within* the structural units, there is a consistent pattern of large-scale west- to west-southwest–directed distension on closely spaced shingling faults.

Steep to moderate dips prevail over much of the area. It is concluded that extension movements on concave-upward faults produced volume increases that were compensated for by reverse drag flexing, and that most of the dip was produced by this flexing. Evidence of compression-related folding is generally lacking.

Deformation within a unit is similar to, but separate from and possibly simultaneous with, that of surrounding units. Serial structural gradations and consistent displacement directions over a wide range of bedding and fault dips in the Nelson block and elsewhere in southern Nevada strongly suggest that all fault systems are genetically related and formed from a single stress configuration. A distinct pattern emerges from the complex fault relationships. The pattern is one of thin highly distended lobate or platelike masses or structural units that were shifted horizontally to varying distances and possibly at varying rates. Some units moved several miles over or past one another.

Although the causal relationships are unclear, the Cenozoic tectonic history of the Basin and Range is dominated by regional extension. Thompson (1966) suggested dilation of the lower crust aided by igneous intrusion as a cause of *local* tensional rifting. Plutonism clearly accompanied the brief episode of severe local tensional rifting that is recorded in the deformed belt south of Lake Mead. The plutonism there extended to a higher level in the crust than that proposed by Thompson (1966), and the magnitude of surficial distension is far greater than that implied in his model. Pluton emplacement probably served as a volume-compensating mechanism for dilation of the upper crust. As the surficial rocks were stretched and thinned (distended) over the zones of dilation (spreading plutons), they presumably responded by brittle fracture near the surface and plastically nearer to the plutons.

The fact that similarly distended structural units moved past one another suggests laterally variable amounts and, possibly, rates of extension. There is, in addition, a clear indication of variable amounts of uplift along any line normal to the structural grain. The possibility exists that the laterally variable distension and uplift are features related to the positions of subjacent plutons. Perhaps as magma spread laterally, it did so in the form of pulses or waves rather than flat sheets.

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