# Map of steep structures in part of the southern Toquima Range and adjacent areas, Nye County, Nevada

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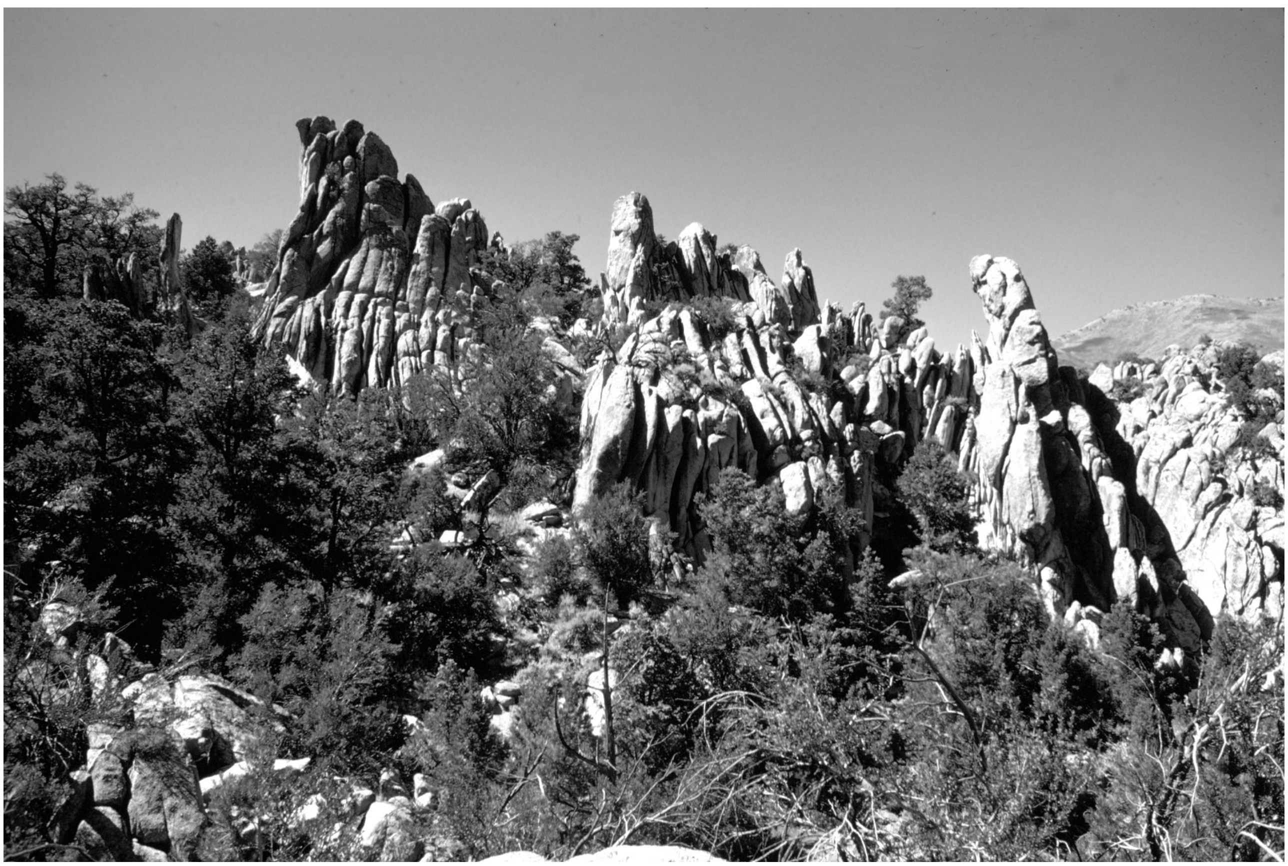
Miscellaneous Field Studies Map MF–2327–B



Northwest-striking steep joints in sparsely porphyritic granite of the Cretaceous Belmont pluton. Note slightly rolling attitudes of joints. View northwest from northwest part of pluton. Spanish Peak in the distance, at right.

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## INTRODUCTION

This special-purpose structure map is one of a series of maps depicting, at 1:48,000 scale, the geology, structure, aeromagnetic and gravity properties, and geochemistry of part of the southern Toquima Range and adjacent areas in northern Nye County, Nevada. The maps are intended to facilitate interpretation of the geology and mineral potential of the area.

The map covers an area bounded by lat 38°30' N. to lat 38°45' N., and long 116°45' W. to long 117°07'30" W., about 920 $km^2$. Geologic units shown on the map are Quaternary surficial deposits (Qs), Tertiary volcanic rocks (Tv), Cretaceous granitic rocks (Kg), and Paleozoic marine sedimentary rocks (Pz). The units are generalized from six 1:24,000-scale quadrangle maps, as follows: Round Mountain (Shawe, 1995), Manhattan (Shawe, 1999a), Belmont West (Shawe, 1998b), Jefferson (Shawe, 1999b), Belmont East (Shawe and Byers, 1999), and Corcoran Canyon (Shawe and others, 2000), and from a 1:48,000-scale map of the same area (Shawe, 2001).

An analysis of the steep structures (dips greater than about 45°) provides insight into the structural evolution of the mapped area, mechanics of fracture formation, and controls on mineralization.

High-angle structures depicted on the map are faults (black), joints (brown), dikes (green), and veins (red). Faults include all those mapped in the field on aerial photographs, many of which are not shown on the geologic maps cited above. Joints also include all those mapped in the field on aerial photographs, none of which are shown on the geologic maps. [The deleted faults and joints were eliminated on the geologic maps so as not to obscure other geologic complexities.] Dikes and veins include all those shown on the 1:24,000-scale maps cited above, but some of which are not shown on the 1:48,000-scale map cited above.

A small number of northwest-striking and steeply dipping post-metamorphic shears were mapped in the Round Mountain and Belmont plutons (Shawe, 1998b, 1999b). They are interpreted to be part of the northwest-striking structural system related to the northwest-striking Walker Lane belt to the southwest. They are not depicted on this map nor on the geologic map of part of the southern Toquima Range (Shawe, 2000).

A strain ellipse (fig. 1) illustrates the principal strain elements discussed in the following text.

Frequent reference is made herein to the maps cited above, and readers may wish to refer to them for additional information.

## FAULTS

Many faults were mapped in the field but most were mapped on the basis of lineations observed on aerial photographs. Faults were recognized in the field chiefly by geologic discontinuities between rock units. Exposed fault surfaces are uncommon relative to the great number of faults mapped. Fault attitudes, where not measured, were inferred mostly from fault traces across topography, steep attitudes being shown by relatively straight traces.

Most faults shown on the map can be grouped into northwest-, north-, and northeast-striking categories. The three categories of faults are described below, together with some minor groupings of faults.

### NORTHWEST-STRIKING FAULTS

Evidence of strike-slip displacement on the northwest-striking faults is sporadic. Right-lateral offset on the Meadow Canyon fault about 6 km north-northeast of the north tip of Ralston Valley is about 100 m, as indicated by offset of a Tertiary (26 Ma) rhyolite plug, or possibly more than 200 m, as suggested by offset of a contact separating Cambrian and Tertiary rocks (Shawe, 1999b). The Hunts Ranch fault in the southeast part of the map, east of Ralston Valley, has a right-lateral offset of about 4 km, based on an inference that a “flap” of Paleozoic oceanic rocks adjacent to the fault was dragged from underlying oceanic rocks that now lie about 4 km to the northwest, and emplaced upon Tertiary volcanic rocks (Shawe and Byers, 1999). A minor flap of Tertiary volcanic rocks extends a few hundred meters northeastward from the Hunts Ranch fault, and over rocks on the northeast side of the fault (Shawe and Byers, 1999). A significant amount of lateral slip on the fault is required to account for the relationship. Large horizontal mullions, several meters in amplitude, on the northwest-striking fault exposed in workings at the Fairview mine in the Round Mountain mining district indicate significant lateral slip (Shawe, unpub. data, 1969). A large fold in Cambrian rocks on the northeast side of the Manhattan fault in the east part of the Manhattan mining district is strongly discordant to less folded rocks on the southwest side of the fault, suggestive of lateral drag (Shawe, 1999a).

These direct and indirect evidences of lateral movement on the northwest-striking faults, some of the displacement being right slip, together with orientation parallel to the nearby right-lateral Walker Lane belt to the southwest, suggest a regional system of predominantly right-slip structures.

Two northwest-striking faults, the Jefferson Canyon in the northwest part of the map area, and the Manhattan, form parts of the southwest margins of the 27-Ma Mount Jefferson and 25-Ma Manhattan calderas, respectively. They controlled the local margins of those calderas (see also, Mills and others, 1988), and are therefore older than the calderas. Other northwest-striking faults are the Corcoran Canyon graben and subparallel faults in the northeast part of the map area, and minor northwest-striking grabens farther west and directly south of Mount Jefferson. These faults all indicate syn-caldera and post-caldera deformation.

Some of the northwest-striking faults were major controls of mineralization. The Jefferson Canyon fault localized alteration and gold-silver mineralization in the Jefferson mining district (at about 25 Ma?). That fault may also have controlled emplacement of eruptive megabreccia in a dike and in pipes (also about 25 Ma) that are aligned along its southeast projection. Alteration and mineralization locally are associated with the megabreccia intrusions. The Manhattan fault, where it forms the southwest structural margin of the Manhattan caldera, probably served as a main channelway for mineralizing solutions that deposited gold ores in the west part of the Manhattan mining district at about 16 Ma. The fault parallels an alignment of ore deposits in the east part of the Manhattan mining district. These ores formed in limestone layers in the Cambrian Gold Hill Formation (Ferguson, 1924), again at about 16 Ma and possibly in part as early as 35–40 Ma (Shawe, 1988). Bedding in the limestone projects in the subsurface to intersections with the Jefferson Canyon fault, leading to the inference that the fault was the principal feeder structure that controlled localization of the ores. The Automatic fault at the Round Mountain gold mine bisects the area of gold mineralization and is considered to be the principal feeder structure for introduction of mineralizing fluids. Mills and others (1988) also described control of mineralization by northwest-striking faults in the southern Toquima Range.

## NORTHEAST-STRIKING FAULTS

Northeast-striking faults are abundant within and bordering Monitor Valley in the east part of the map area. They include the range-bounding faults at the southeast base of the Toquima Range (fig. 2), the principal element of Basin-range structure in the area. Range-bounding faults southwest and northeast of the Belmont pluton do not extend through the pluton, as though the granite provided a bulwark impervious to fracturing. A swarm of faults and fault traces, mostly in alluvium, is located southeast of the main range-bounding faults. These form a structural step outward into Monitor Valley.

In the northeast part of the map area, the range-bounding fault defines an arc concentric with and outward of the southeast structural margin of the Mount Jefferson caldera (Shawe and others, 2000). In this area, the shape of the range-bounding fault probably was influenced by structure related to the preexisting, 27-Ma caldera.

Swarms of northeast-trending faults in Monitor Valley in the southeast part of the map area offset alluvial deposits of different ages, demonstrating that the swarms resulted from recurring deformation (Shawe and Byers, 1999). These fault traces are not marked by significant scarps. They are conjugate to the northwest-striking right-lateral faults described above, suggesting a relation to northeast-striking left-lateral faults elsewhere in the region (for example, Shawe, 1965).

A zone of northeast-striking faults at least 6 km long within the Manhattan caldera north of the Manhattan mining district, and perhaps extending southwestward into Paleozoic rocks, is nearly parallel to the range-bounding faults to the east. The faults have dropped a large segment of volcanic rocks down to the northwest. Because these faults have no consistent topographic expression, they predate the present cycle of Basin-range deformation, and they may represent an early deformation of Basin-range style. Subsequent uplift of the west side of the Toquima Range resulted from Basin-range faulting on northeast trends at the east edge of Big Smoky Valley, about 5 km west of the northeast-striking faults.

## NORTH-STRIKING FAULTS

North-striking faults are by far the most abundant structures in the southern Toquima

Range. Most of them were mapped photogeologically, by tree alignments. Subsequent field checking showed many to be faults. In some places tree alignments were perceived on the ground, but more commonly, abundance of trees in the pinyon-juniper forest that covers much of the mapped area, and irregularities in topography, prevented discerning alignments. Many faults, positions of which were established on the ground, were projected through alluviated areas along conspicuous tree alignments. Many faults mapped in treeless tracts of Quaternary alluvium were evidenced by lineaments on aerial photographs; presumably the lineaments represent alignments of vegetation such as low shrubs (sagebrush and other plants). In most places such lineaments were not visible on the ground. However, some faults mapped in bedrock projected into alluvium as lineaments visible on photographs, corroborating the interpretation of such lineaments as faults. Several faults mapped in alluvium were evident as low scarps under stereoscopic view of paired aerial photographs. A few were discernible on the ground.

The densest concentration of north-striking faults is in the Round Mountain and Belmont plutons. Few faults were mapped in the high parts of the Round Mountain pluton, probably because of the scarcity of trees at higher altitudes. Fewer mapped faults may not mean, however, that the actual number of faults is less than at lower altitudes. In areas of Tertiary volcanic rocks and Paleozoic marine sedimentary rocks, fewer mapped faults may reflect variations in vegetation cover, or softer character of the rocks resulting in subdued visibility. Varied degrees or kinds of alteration of the rocks also may have affected visibility of faults. The actual frequency of north-striking faults throughout the southern Toquima Range in general may be nearly uniform.

North-striking faults mapped from evidence of offset of geologic units (fig. 3) form groups that consist of either a series of stepped blocks from east to west, or from west to east, and some groups define sets of small horsts and grabens. Only a few show evidence of strike-slip movement, such as low-angle grooves on fault surfaces or offset of high-angle contacts.

Ages of the north-striking faults are inferred from their relations to dated rocks or deposits. Possibly the oldest fractures are filled with 80-Ma aplite dikes that are intruded into the west and south parts of the Belmont pluton (fig. 5). Aplite dikes also were emplaced about 75 Ma in the Pipe Spring pluton. A few north-striking fractures in the west part of the Round Mountain pluton were intruded by 36-Ma rhyolite dikes. Many north-striking faults cut Tertiary ash-flow tuffs, ranging in age from about 27 Ma to about 23 Ma. North-striking faults in the Belmont mining district controlled deposition of silver ores that are probably about 80 Ma. North-striking faults in the Manhattan mining district provided local controls on gold mineralization that occurred about 16 Ma (possibly also as much as 35–40 Ma). Finally, faults of this set cut Quaternary alluvium, suggesting continuing deformation. It seems evident, therefore, that the north-striking faults have been active, probably sporadically, from Cretaceous time to the present.

### OTHER FAULTS

East-trending faults are most abundant in the east part of the Manhattan caldera, and in granitic rocks of the Belmont pluton farther east. They do not appear to constitute a significant structural element. Some isolated faults of diverse orientations are not associated with fault sets, and may consist of radial or concentric faults related to collapse or resurgence of the Manhattan and Mount Jefferson calderas, or to doming of the Round Mountain and Belmont plutons. The Soldier Spring fault is a slightly arcuate, north-northwest- to north- to north-northeast-trending fault in the Manhattan caldera that marks a conspicuous topographic break within the Toquima Range and at the east base of the main part of the range.

## JOINTS

Structures mapped as joints probably grade into faults. However, where joints were mapped on the ground, evidence of significant movement was absent.

Joints that represent the dominant joint sets in the southern Toquima Range were mapped photogeologically. They are most abundant, by far, in the Cretaceous Round Mountain and Belmont granitic plutons (fig. 4, and pamphlet cover). Most are part of a well-developed northeast-striking set. Less abundant northwest-striking joints form a set in the Belmont pluton and in the southeast end of the Round Mountain pluton. Northeast-striking fractures, probably both joints and faults, controlled emplacement of the 36-Ma dike swarm in the Round Mountain pluton as well as the localization of numerous quartz veins in the granite, some of which have been dated at about 80 Ma.

In the Round Mountain quadrangle, joints were mapped on the ground also, verifying the dominant joint sets, but also showing other joint orientations. An evaluation of 326 joint measurements in the Round Mountain pluton indicated a dominant north-northeast strike and steep east-southeast dip (Shawe, unpub. data, 1973, 1998). Also, no significant variations in joint orientation that could be related to doming of the pluton were observed, suggesting that the jointing was a post-doming phenomenon and therefore younger than the inferred 80-Ma date of doming. Subordinate joints mapped on the ground are variably oriented, possibly reflecting local inhomogeneities in the rocks; moreover, joints mapped on aerial photographs do not reflect the inconsistent orientations of those mapped on the ground. The subordinate joints are not considered further here.

Mapped joints outside the plutons are sparse. They are numerous only in the north mapped part of the Manhattan caldera, where north-striking, east-striking, and northeast-striking sets are evident, and in the Mount Jefferson caldera north of the Round Mountain pluton, where east-striking and northeast-striking sets are evident. Probably, joints in soft poorly exposed rocks are abundant elsewhere in the southern Toquima Range, but they are not evident on aerial photographs. Some of the joints in volcanic rocks near the Cretaceous plutons, particularly the northeast-striking set, may have propagated upward from underlying granite as a result of reactivation of earlier-formed joints in the granite. Northeast-striking joints, formed as early as about 80 Ma, also were forming as late as about 26–25 Ma, following emplacement of the volcanic rocks.

## DIKES

Eighty-million-year-old dikes consist of aplite intruded along north-striking fractures in the west and south parts of the Belmont pluton (fig. 5). A few aplite dikes of this age strike more nearly northwest, northeast, or east in the Round Mountain pluton. Aplite dikes that are about 75 Ma in the Pipe Spring pluton strike mostly north. Most aplite dikes of this age in Paleozoic rocks between the Pipe Spring pluton and the Manhattan fault were intruded along fractures that strike northwest, subparallel with the Manhattan fault. Rhyolite and andesite dikes intruded into the northwest part of the Round Mountain pluton that are 36 Ma strike mostly northeast. A few of these dikes strike north, and rhyolite dikes of this age in Paleozoic rocks west of the Round Mountain pluton strike north. Andesite dikes that are about 25 Ma in the south part of the Manhattan caldera (fig. 6) strike mostly northwest, subparallel with the Manhattan fault. Breccia dikes near the southeast end of the Manhattan caldera that are likely about 25 Ma were emplaced in steep north-striking fractures.

Dikes emplaced in the southern Toquima Range during the period 80–25 Ma predominantly strike north, but others strike northeast and northwest as well.

## VEINS

Dated veins (about 80 Ma) in the Round Mountain pluton are mostly northeast striking (fig. 7). A few strike more northerly. Veins in Paleozoic rocks in the Belmont mining district, mostly north striking, are inferred to be related to the episode of doming, metamorphism, and mineralization that affected the Belmont pluton at about 80 Ma. Veins in the Pipe Spring pluton, probably about 75 Ma, are north striking. Veins in the Tertiary volcanic rocks, near the Jefferson Canyon fault in the south part of the Mount Jefferson caldera, in the Round Mountain gold district, and near the Manhattan fault in the south part of the Manhattan caldera, some of them dated at about 25 Ma, are mostly northwest striking. A few veins (probably about 25 Ma) near the Manhattan fault, in both Tertiary volcanic rocks and Paleozoic rocks, are north striking. Three veins in volcanic rocks near the southeast margin of the Mount Jefferson caldera and probably about 25 or 26 Ma strike north, northeast, and northwest, respectively.

As a whole, ages and orientations of the veins mimic the ages and orientations of the faults, joints, and dikes, again suggesting persistent, similarly oriented stress throughout the period from 80 to 25 Ma.

## SUMMARY

The southern Toquima Range, a horst in the central part of the Basin-range structural province, is characterized by several fault associations or systems, namely (1) range-bounding faults, generally northeast striking (Basin-range faults), (2) transverse (northwest-striking) faults that reflect right-slip wrenching possibly related to the nearby Walker Lane belt of right-lateral deformation, and (3) north-striking faults of enigmatic origin. Other faults of diverse orientations are radial and concentric faults related to collapse and resurgence of the Manhattan and Mount Jefferson calderas, and to doming of the Round Mountain and Belmont plutons. The Soldier Spring fault probably was initiated before deposition of ash-flow tuffs ranging in age from about 25 Ma to 22 Ma (Shawe and others, 2000). This normal fault is suggestive of extensional deformation predating initiation of Basin-range deformation (17 Ma, Stewart, 1978). The Soldier Spring fault may have been reactivated during Basin-range deformation, however, as it marks a pronounced topographic break east of the summit of the Toquima Range. The northeast-striking fault zone in the west part of the Manhattan caldera north of Manhattan may be a similar structure. Its age is not known, but it lies within the Toquima Range and shows no evidence of activity during Basin-range deformation.

Northeast-striking faults are best exemplified by the range-bounding zone that extends along the east front of the Toquima Range. This zone of faults clearly defines the principal element of block faulting in the area. Faceted spurs, an abrupt topographic discontinuity, and extension of some faults into Quaternary alluvium attest to the youthfulness of this deformation. To some extent the location and form of the range-bounding faults have been influenced locally by older structures, such as the Belmont pluton and faults related to the margin of the Mount Jefferson caldera. Swarms of northeast-striking faults in alluvium near the south end of Monitor Valley may represent left-lateral strike-slip deformation, conjugate to the northwest-striking zone of right-slip faults, consistent with a regional system of such strike-slip structures proposed by Shawe (1965) and Stewart (1978).

Northwest-striking faults commonly cut or bound the Tertiary volcanic rocks, indicating that they are generally younger than the Tertiary rocks, about 27–25 Ma. However, the Jefferson Canyon and Manhattan faults bound calderas, which suggests that they influenced location of the calderas and are thus older than the calderas. Also, the Manhattan fault appears to be interrupted (intruded?) by the Pipe Spring pluton, suggesting that the fault existed before about 80 Ma.

The numerous north-striking faults, although mostly of only small displacement, are characterized by a system of horsts and grabens, or they are disposed in groups showing stepwise, normal offsets. They reflect extensional deformation as old as about 80 Ma; they continued to control dike emplacements that are about 36 Ma and 25 Ma; they localized mineral deposits about 16 Ma (possibly as old as 40–35 Ma); and they form scarps and lineaments in Quaternary alluvium. Their orientation diverges significantly from that of the present Great Basin range in which they occur.

The most numerous joints in the southern Toquima Range are northeast striking, and they are widely distributed in the Round Mountain and Belmont plutons. Within the Round Mountain pluton, northeast-striking joints (and faults?) localized quartz veins that are about 80 Ma. They also controlled emplacement of 36-Ma dikes. They are subparallel to the dominant Basin-range faults at the east front of the Toquima Range.

Northwest-striking joints are most prevalent in the Belmont pluton (pamphlet cover) where they parallel post-metamorphic (post-80-Ma) shear foliation thought to be related to wrench deformation of the Walker Lane belt. Northwest-striking joints (or faults) also localized 75-Ma dikes in Paleozoic rocks south of the Manhattan fault, 26-Ma veins in volcanic rocks at Round Mountain, and 25-Ma(?) dikes and veins in the Manhattan caldera north of the Manhattan fault.

North-striking joints (or faults) localized 80-Ma dikes in the west and south parts of the Belmont pluton, 80-Ma(?) veins in Paleozoic rocks in the Belmont mining district, 75-Ma veins in the Pipe Spring pluton, 36-Ma dikes in the Round Mountain pluton, and 16-Ma (possibly also 40-Ma to 35-Ma?) ore deposits in the Manhattan mining district.

Altogether, faults, joints, dikes, and veins suggest an integrated system of strain continuing, probably sporadically, from about 80 Ma to the present. At any one time in this sporadic deformation, one element may have dominated over others, yet the whole system appears to have persisted intact throughout.

## DISCUSSION AND CONCLUSIONS

Northwest-striking faults are thought to be related to the northwest-striking Walker Lane belt of dominant right-lateral shear deformation, directly to the southwest. Some of the faults appear to have a component of strike-slip displacement, probably right lateral and in part significant. The Manhattan and Jefferson Canyon faults partly controlled locations of the Manhattan and Mount Jefferson calderas, showing that they are older than about 25 and 27 Ma, respectively. The Manhattan fault appears to be interrupted by the Pipe Spring pluton, suggesting that the fault is older than about 80 Ma.

The Corcoran Canyon graben and subparallel faults in the northeast part of the map area, and minor northwest-striking grabens farther west and directly south of Mount

Jefferson, may also reflect right-lateral wrenching of the Walker Lane belt. Strike-slip faulting commonly results in formation of grabens oriented at low angles to the strike-slip faults (for example, Grindley, 1960), and experimental work (Tanner, 1962) bears out the relation The cited faults within the Mount Jefferson caldera indicate syn-caldera and post-caldera deformation.

Inasmuch as most of the northwest-striking faults are no more than a few kilometers in length, they are considered to be en echelon(?), near-surface (brittle crustal regime) expressions of deeper-seated (brittle-ductile and ductile crustal regimes) throughgoing flaws.

Most northeast-striking faults, especially in and bordering Monitor Valley, are related to development of Basin-range structure. Parts of the major range-bounding faults are thought to have been localized by preexisting structural grain in the region (Shawe, 1965; Stewart, 1978).

North-striking faults, the most populous category shown throughout the map area, are enigmatic, and of uncertain genesis. They are enigmatic because they appear to have developed through a long period of time, dating from perhaps the Late Cretaceous to the present, yet they are not clearly related to the known structural systems in the region, such as Basin-range deformation, or strike-slip deformation associated with the Walker Lane belt. However, right-lateral slip on northwest-striking wrench faults and extension on Basin-range faults probably are related (Shawe, 1965). Both have been active for a long time and are active presently. The numerous north-striking faults, being of minor displacement and commonly confined within individual rock units and hence within a more-or-less homogeneous medium, broke as north-striking normal faults in response to the generally prevailing east-west tension. I examine such a hypothesis below, recognizing that some aspects are speculative.

The structural pattern may reflect persistent, more or less consistently oriented stress. I think that a particular structure, for example a northeast-striking dike or fault, does not necessarily indicate extension normal to strike. Any preexisting structure that strikes northeast may open as a result of east-west extension. A system of northwest-, northeast-, and north-striking fractures could be susceptible to dilation as a result of east-west extension. Sporadic activity on any of the structures could be related to gross local or regional inhomogeneities of rock type, such as rheologic variations, or to minor reorientations of regional stress. An example of such recurring sporadic activity is reflected in the consistent northerly orientation of structures in the south-central part of the map area, including 80-Ma dikes in the Belmont pluton, 75-Ma dikes in the Pipe Spring pluton, 25-Ma dikes in the Manhattan caldera, and fault lineaments in Quaternary alluvium in the nearby Ralston Valley.

The strain system described here can be considered as resulting from east-west tension (or north-south compression) that formed northwest-striking right-slip faults, northeast-striking left-slip faults, and north-striking extensional (normal) faults. Greatest strain is normal to the extensional faults, indicating a general east-west extension of the region (fig. 1). Because of persistence through time of structural deformation, it seems likely that the strain system also persisted through time, and was not related to a changing regimen of subduction and transform faulting at the continent margin (for example, Atwater, 1970).

The Walker Lane belt has been active since the Mesozoic (for example, Albers, 1964), and deformation of the zone continues. Basin-range deformation in the region commonly is interpreted to have started about 17 Ma (Stewart, 1980), and it continues today. However, propagation of the north-striking faults likely commenced long before the assumed onset of Basin-range deformation in the region, suggesting that the faults may not be related to Basin-range structure. But if extensional deformation was associated with right-lateral slip deformation in the Walker Lane belt, and it caused development of the large normal fault set in the west part of the Manhattan caldera and the Soldier Spring fault (see below) in the north-central part of the map area, then the north-striking faults may have been related to an early phase of block faulting.

The Soldier Spring fault in the north-central part of the map area is believed to have formed as a result of right-lateral slip on a deep-seated structure manifested at the surface by the Jefferson Canyon and Meadow Canyon faults. Near-surface tension northeast of the deep-seated fault resulted in sagging of a basin subsequently filled with younger volcanic units, and a break away from the present high terrane of the Mount Jefferson massif along the Soldier Spring fault (Shawe, 1999b).

Stewart (1978) has discussed four principal theories of the origin of Basin-range structure: (1) oblique tensional fragmentation resulting from collision of the East Pacific Rise with the North American Plate (formation of the San Andreas transform fault system); (2) upwelling of mantle behind an active subduction zone (back-arc spreading); (3) spreading that resulted from subduction; and (4) plate motion caused by deep-mantle convection in the form of narrow mantle plumes. Stewart (1978) concluded that a combination of anomalous upper mantle, thin crust, high heat flow, regional uplift, and extension that characterizes the Basin-range province is best explained by back-arc spreading. He rejected the oblique tensional theory on grounds that it could not produce the regional uplift that characterizes the province. I have suggested (Shawe, 1998a) that subduction was not an important aspect of the geologic history of the Western United States except at the west margin of the continent (for example, the generation of the Sierra Nevada batholith and associated phenomena). I propose here an alternative to Stewart's (1978) proposal: that uplift and extension took place in the Basin-range province long before 17 Ma.

Meyerhoff and others (1992) suggested a tectonic mechanism they termed "surge tectonics" that incorporates upwelling of mantle beneath an extending terrane, and strike-slip and normal faulting, without requiring subduction of the East Pacific Rise beneath western North America. Such a model could account for the simultaneous strike-slip, normal fault, and uplift deformation of the region, and timing that seems not to accord with a back-arc spreading model. The model also satisfactorily explains the fracture relations mapped in the southern Toquima Range.

The surge tectonics theory (Meyerhoff and others, 1992) proposes that a magma-filled "surge channel" underlies all tectonically active regions of Earth, including the Basin-range province. Magma is derived from hot (low seismic velocity) regions of the upper mantle, and upon rising induces uplift and bilateral extension of the crust away from the axis of uplift. During tectogenic phases of magmatic activity, magma rise is relatively rapid, causing folding and thrust faulting of crustal rocks as they are pushed laterally from the axis of the surge channel. During taphrogenic phases of magmatic activity, injection of magma into the surge channel is relatively slow, and rift (extensional) faulting occurs above the surge channel. Characteristic linear fractures paralleling the axis of the channel are interpreted to reflect horizontal, longitudinal flow of magma in the surge channel.

As applied to the southern Toquima Range, this theory suggests that the abundant north-striking fractures are a consequence of horizontal, longitudinal (north-directed?) flow in the surge channel during an early phase of tectogenesis. During later taphrogenesis (the present phase) the fractures reactivated as normal faults, many propagating upward from older rocks (Paleozoic and Mesozoic) into overlying younger rocks (Tertiary and Quaternary). If the north-striking fault grain had not been established before normal (extensional) faulting, the tension-caused faults should display irregular, tension-crack traces (for example, virtually all Basin-range faults in detail). Northwest- and northeast-striking slip faults formed to accommodate east-west extension, and were active probably during earlier tectogenesis as well as during recent taphrogenesis.

Formation of mineral deposits in the southern Toquima Range, during the Late Cretaceous and at various times during the Tertiary, are readily related to high heat flow, faulting, and magmatic and hydrothermal activity associated with surge tectonics.

## ACKNOWLEDGMENTS

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