Precambrian Ancestry of the Colorado Mineral Belt

Abstract: The narrow northeast-trending Colorado mineral belt, the site of most of the major mining districts of Colorado, is characterized by intrusive porphyries and associated ore deposits of Laramide age and, in some places, by fissures and faults of northeasterly trend. The belt, about 250 miles long, extends diagonally across the generally north-trending mountain ranges of Colorado, occupies several different geologic environments, and seems to be independent of the present mountain structure.

The mineral belt follows an ancient zone of weakness defined by northeast-trending shear zones of Precambrian age in a belt 10–35 miles wide. Individual shear zones or clusters of zones are spaced from a mile or less to many miles apart. In most parts of the belt, a major northeast-trending shear zone is flanked by lesser shear zones in an echelon arrangement.

Movement occurred along the belt of shear zones through most of the Precambrian time recorded in the region. During this time, deformation progressed from a deep-seated environment characterized by folding and plastic flow to a more shallow environment characterized by fracture and retrograde metamorphism. The earliest movement occurred during regional folding, when folds were oriented parallel to the shear zones or were bent where they impinged upon the shear zones. Cataclastic deformation began after the folds had formed, but the earliest products of cataclasis recrystallized as new gneisses, indicating that relatively intense metamorphic conditions either still prevailed or recurred. Later, when pressure and temperature were lower, cataclastic gneisses, pseudotachylite, mylonite, and broad granulated zones formed, and in some places small crossfolds formed in layers of incompetent gneiss between cataclasically deformed competent layers. Still later in the Precambrian, gouge and breccia formed, partly by the degradation of earlier shear products of higher rank.

During Paleozoic and Mesozoic time, minor differential movements occurred repeatedly in the regional zone of shearing, as recorded by thinning, wedgeouts, and changes in facies of several sedimentary formations along the zone.

With the onset of the Laramide orogeny, magma invaded the regional zone of shearing and imparted to it the conspicuous features that characterize the mineral belt—intrusive igneous bodies and ore deposits. Fault movement occurred along the zone at this stage also but was on a smaller scale than it had been previously.

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INTRODUCTION

Dozens of the mining districts for which Colorado is famed are clustered in a generally narrow but somewhat irregular strip of ground that extends southwestward across the state from the mountain front near Boulder to the region of the San Juan Mountains. This strip, known as the Colorado mineral belt, has been termed the Colorado mineral belt district. It is a strip less than 50 miles wide in gold, silver, lead, zinc, molybdenum, tungsten, and fluorspar. It contains all the major mining districts of Colorado except uranium districts near the western border and a few gold-silver districts localized at isolated volcanic centers, such as Cripple Creek and Silver Cliff.

The mineral belt is characterized geologically by intrusive igneous rocks and related ore deposits of Tertiary (largely Laramide) age and in some places by fissures and veins of north-easterly trend. The intrusive rocks are typically hypabyssal porphyries which occur as stocks, laccoliths, sills, and dikes. The associated ore deposits are mesothermal and epithermal veins associated with intrusive igneous rocks and related ore deposits of Tertiary (largely Laramide) age.

The Rocky Mountains extend north-south through the central part of Colorado, between the High Plains on the east and the Colorado Plateau on the west. The mineral belt as ordinarily recognized extends diagonally across the mountainous portion of the state and into the Plateau (Fig. 1).

The state of Colorado contains all the major mining districts, or a part of it, by mineral belt association that the shear zones not only cross many of the folds, but between north-easterly and northeasterly trends.

The Front Range, the easternmost part of the mountain ranges in Colorado, is divided into three structural units. The youngest of these units, the Front Range, is separated from the Middle and South parks, which are characterized by their different structural histories.

The Park Range, which is part of the southern end of the Front Range, is the most geologically complex part of the range. It contains a variety of geologic environments ranging from Precambrian crystalline rocks through Paleozoic and Mesozoic sedimentary rocks to Tertiary volcanic rocks.

In the search for a unifying structure of persistent a belt, some authors have appealed to a presumed regional north-easterly trend of the foliation in the Precambrian rocks, but actually no such trend exists. A compilation of all data on foliation trends now available shows that if any trend predominates regionally, it is a northwesterly one. Localization of the mineral belt, or a part of it, by belts of relatively incompetent rocks (schists and gneisses as contrasted to granites) has also been suggested. As the mineral belt, along the northeastern part, lies largely in meta-morphic rocks between large masses of granite, this suggestion is valid, but we now know of other factors that make this picture incomplete.

Detailed mapping in the Precambrian rocks in recent years has revealed a system of major Precambrian shear zones within the mineral belt. The purpose of this paper is to document the existence of these shear zones and the genetic relation of the mineral belt to them. We believe that the shear zones not only localized the belt but played an active part in its origin, as contrasted to the generally passive role that might be played by a simple belt of incompetent rocks. The shear zones, not all of which are yet mapped in detail, trend northwesterly and are scattered in a broad belt that is approximately coextensive with the mineral belt. Although few of the individual Laramide intrusive bodies or ore deposits are located directly on the shear zones, the system of shear zones constitutes a zone of crustal weakness that localized the deep-seated magma body that was parent to the hypabyssal intrusives that define the mineral belt. In rising toward the surface, the hypabyssal intrusives were guided by whatever local structural features were present and suitably oriented. Consequently, although the intrusives are confined to the mineral belt, many of them are closely related to structural features.

It stays in the gneisses, as noted by Lovering (1933). Within the mineral belt and defining it are Laramide intrusive rocks, fractures, and ore deposits superposed on it in origin. Some of these features are Laramide in age and some are Precambrian, and as we shall show, some that previously have been classed as Laramide are in reality Precambrian.

Eeologic SETTING

The Rocky Mountains extend north-south through the central part of Colorado, between the High Plains on the east and the Colorado Plateau on the west. The mineral belt as ordinarily recognized extends diagonally across the mountainous portion of the state and into the Plateau (Fig. 1).

The mountain province of Colorado consists of four major elongate ranges and several sub-circular mountain groups. The mineral belt crosses three of the ranges, the Front, Park, and Sawatch, but passes north of the fourth, the Sangre de Cristo Range. Southeast of the Sawatch Range, the mineral belt impinges on the Rocky mountain groups, the Elk and West Elk Mountains, and finally projects into the western part of the San Juan Mountains, a large volcanic mountain group that straddles the boundary between the mountain and plateau provinces.

Figure 1. Geologic sketch map of central Colorado. 

Front Range

The Front Range, the easternmost and largest of the mountain ranges in Colorado, is 30-60 miles wide, more than 250 miles long, and is crossed at about mid-length by the mineral belt. It consists almost entirely of Precambrian rocks, which form the core of a great steep-sided and flat-topped anticline or arch.

Sedimentary rocks on the flanks of the arch dip up abruptly, and all except the Cretaceous formations thin and wedge out against the crystalline mass, for the range is part of an area that has been intermittently or continuously since the middle Paleozoic.

The part of the Front Range occupied by the mineral belt consists of Precambrian metasedimentary and granitic rocks in roughly equal proportions (Pl. 1). The granitic rocks are in stocks and small batholiths, many of irregular shape. The metasedimentary rocks form a ragged matrix for the granite bodies and are cast into folds of various orientations. The mineral belt strikes across many of the folds and cuts through some granite bodies, but in general
is carved from the eastern flank of a huge faulted anticline, the core of which constitutes the Sawatch Range, the next range west of the Park Range. The mineral belt crosses the Park Range in the transition zone between these two dissimilar parts in the segment known as the Mosquito Range and its short northern extension, the Tennille Range. The Mosquito and Tennille ranges are bordered on the west by a major normal fault of roughly north-south trend, the Mosquito fault, which brings Paleozoic rocks on the west against Precambrian rocks that have a local thin cover of Paleozoic strata. At the northwest edge of the mineral belt, the Gore fault branches from the Mosquito fault and extends north-northwestward along the western side of the mountain unit known as the Gore Range. This fault, of variable dip, brings Paleozoic strata on the west against Precambrian rocks of the old highland on the east. The Gore and Mosquito faults are major Precambrian faults that were reactivated in the Laramide.

The area east of the Mosquito fault in the mineral belt segment of the Park Range is partly in Precambrian rocks and partly in Paleozoic sedimentary rocks on the eastern flank of the range (Fig. 1). Porphyry occurs in many sills in the sedimentary rocks, but in the Precambrian rocks it occurs only in scattered dikes and in a single stock northeast of Kokomo. The area has a pronounced geologic grain that trends northward—the direction of most of the veins, many dikes, and foliation in the Precambrian rocks (Singewald, 1951), as well as the average trend of the flanking sedimentary rocks and the Mosquito fault. West of the Mosquito fault, the mineral belt is principally in sedimentary rocks and is characterized by a remarkable display of porphyry sills and associated stocks, plugs, and dikes. Faults of many trends exist, but a prominent and persistent set trends northward, and another, less persistent set trends northeastward. The ore deposits, principally at Leadville and Kokomo, are mostly replacement deposits in carbonate rocks but include some veins, most of which trend northeast. The great Climax molybdenum deposit lies in Precambrian rocks just across the Mosquito fault from the town of Climax (Fig. 1) and just above the apex of a sharply domical Laramide stock (Wallace and others, 1960).

**Sawatch Range**

The Sawatch Range lies west of the central and southern parts of the Park Range (Fig. 1). The range consists largely of Precambrian rocks in the core of an anticline 90 miles long and 40 miles wide between bordering faults on each side. Most of the preserved sedimentary rocks on the east flank of the anticline lie in the Park Range, where they are raised to the east along the Mosquito and related faults. On the opposite side of the range near Aspen the flanking sedimentary rocks dip westward into a broad syncline, which is broken near its axis by the Castle Creek fault, a steep reverse fault of large displacement. The Sawatch Range lies largely within a basin of Paleozoic sedimentation and thus is flanked by formations of Paleozoic age except for a part of the southwestern border, which is part of the Uncompahgre-San Luis highland, a positive area of late Paleozoic age.

Almost the entire Sawatch Range lies in the mineral belt, which here flares to its greatest width (Fig. 1). A discontinuous chain of mining districts encircles the range, lying for the most part in the flanking sedimentary rocks; other districts, most of them small, lie within the range. The veins are in scattered clusters and have no consistent trend. The range contains a small batholith and several stocks of Laramide age, chiefly in its southern half.

**Elk and West Elk Mountains**

The Elk Mountains, west of the central part of the Sawatch Range, are composed of sedimentary rocks intruded by early Tertiary stocks aligned along a northwest-trending zone of tight folds and westward-directed overthrusts (Vanderwilt, 1937, p. 83-96). The West Elk Mountains, southwest of the Elk Mountains (Fig. 1), owe their relief to many large laccoliths, which lie in little-disturbed sedimentary rocks of Cretaceous and early Tertiary age. Near the Gunnison River, south of the West Elk Mountains, crystalline rocks of the old Uncompahgre-San Luis highland are overlain by erosional remnants of Jurassic and younger sedimentary rocks, and these in turn are overlain by volcanic rocks.

Ore deposits occur as veins in the eastern part of the Elk and West Elk Mountains. Most of the more productive veins and many dikes trend northeast, although one major dike swarm trends north. At outlying Treasure Mountain, veins trend north to northeast, as does the foliation in the one area of exposed Precambrian rocks, but early dikes trend northeast (Vanderwilt, 1937). Most of the
large lenticiths of the West Elk Mountains are unaffected by mineral deposits or by tectonic disturbance other than the arching of strata over the laccoliths.

**San Juan Mountains**

The San Juan Mountains and volcanic field occupy a roughly circular area nearly 100 miles in diameter that lies south and southwest of the West Elk Mountains and the southern end of the Sawatch Ranger. Volcanic rocks of middle and late Tertiary age dominate the geology of this area, but an eventful geologic history preceded them. A large part of the mountain area is on the site of the old Uncompahgre-San Luis highland, a positive area that underwent repeated vertical movements during the Paleozoic and early Mesozoic, but the southeastern part is in the sedimentary basin that lay to the southwest of the highland. During the Laramide orogeny, large-scale doming accompanied by folding, intrusion, and mineralization took place, particularly in the western part of the modern mountains, on the trend of the mineral belt (Burbank and others, 1947). Volcanic activity, with attendant intrusion, mineralization, and the formation of great calderas, began in the Miocene and continued through the Pliocene.

**EXTENT OF THE MINERAL BELT**

Although the mineral belt is a persistent and in some ways a prominent geologic entity, it is not sharply defined, and its borders can be placed in various positions, depending on the criteria used to outline it. In general, the belt is narrowest and most sharply defined in its northeastern part, and it becomes broader, more diffuse, and less precisely defined to the southwestern. Two possible outlines of the mineral belt are shown in Figure 2. The outer, dashed lines show the shape and extent of a "maximum" belt including: (1) all the Laramide intrusive bodies near the main chain of mining districts; (2) small outlying mineralized areas; and (3) the principal mining districts of the San Juan Mountains. The inner, solid lines show boundaries of the belt drawn to include only the major mineralized areas and, in the San Juan, the area containing Laramide intrusive centers. This is probably the form most often emphasized when the term "mineral belt" is used.

The mineral belt is 10-15 miles wide in the Front Range and in the Park Range widens abruptly along the Mosquito fault to about 30 miles. In the next range west, the Sawatch Range, it widens even more. Intrusive rocks are scattered over a wide area, but deposits are confined to the eastern part of the mountains. Here, the mineral belt is broad as defined by all the intrusive bodies, but much narrower if it is restricted to the mineralized zones (Fig. 2).

From Gunnison southwest across the old Uncompahgre-San Luis highland to the vicinity of Ouray, a distance of 50 miles, the mineral belt is only faintly expressed by scattered small Laramide intrusive bodies and mineralized areas. Farther southwest, the belt extends into the San Juan Mountains, where intrusive bodies and ore deposits are widespread but are principally of late Tertiary age rather than Laramide. However, Burbank and others (1947, p. 399 and pl. 27) noted, "The outer, dashed belt is broad as defined by principal mining districts of Laramide age, and mining districts of Tertiary age in the San Juan Mountains." The outer, dashed belt is broad as defined by principal mining districts of Laramide age, and mining districts of Tertiary age in the San Juan Mountains. The outer, dashed belt is broader, mineralized as a precursor to the mineral belt (Pl. 1, locs. 1-10). Present knowledge suggests a pattern in any given year of the belt of a single major northeast-trending shear zone or block, not necessarily symmetrically, by lesser shear zones in an echelon arrangement. The major shear zones are also an echelon pattern through the length of the belt. Individual shear zones or clusters of shear zones are spaced unevenly within the belt line a mile or less to many miles apart. The width of the belt of shearing ranges from about 10 miles in the Front Range to 30-35 miles in the Sawatch Range.

The shear zones of the belt do not take the same form at all places. They are expressed by poorly defined faults and mylonite zones, by granulated or cataclastic bodies, by remnants of formation, which, with other geologic evidence, suggests that movement along the shear zones continued for a long period of time. In addition, to the shear zones of northeast trend, cross faults or shear zones of north-northeast, north, and north-northwest trends...
Precambrian structure related to the mineral belt

The crossfolds that characterize the shear zone are abundant and generally closely spaced. They trend N. 55°E, parallel to the length of the shear zone, and plunge at various angles, depending upon their position on the older, primary folds. The folds are small, ranging from less than a foot to as much as 400 feet in length, and distinctly asymmetric, the steepest sides having a trend parallel to the southwest sides. The folds are remarkably straight and persistent; many can be traced for several thousand feet along strike.

History. The Idaho Springs-Ralston shear zone underwent movement at least as early as the stage of regional metamorphism and primary folding. The cataclasit and attendant crossfolding—now the most conspicuous features of the shear zone—are relatively young features superposed on folds in rocks that are typical of the high-grade metamorphic rocks of the region. As the older folds are not truncated or even markedly displaced where crossed by the zone of cataclasis, it is evident that the cataclasis was not accompanied by large-scale fault movement. Yet, the shear zone does have features that suggest repeated movement, such as a difference in the kinds of gouges on the two sides, (2) different orientations of faults on opposite sides of the shear zone, (3) fold axes or limbs that bend into crude parallelism with the shear zones, (4) the introduction of the shear zones in and near the shear zone, and (5) the pinchout of certain major lithic units within the shear zone. The movement that produced these features must have occurred at an early stage, for no evidence of it remains except the disposition of these features themselves. If faults or earlier shear zones existed, they were obliterated when the present gouges crystallized.

The nature of the movement that produced these early structural discontinuities and orientations cannot be closely specified at this time. The pattern of the distorted folds (Lovering and Goddard, 1950, Pl. 2) suggests that the horizontal component of movement was large, but the relative directions of movement along the shear zones appear to be inconsistent. Probably, movement occurred at many times and in many directions in a complex pattern.

At a later stage when the cataclasit and crossfolding occurred, movements in the shear zone were largely those indicated by the geometry of the cataclasit structures near Idaho Springs. The consistent asymmetry of the younger folds indicates that the northwest
side of the shear zone was raised relative to the southeast side. This also was the pattern of movement on northwest-dipping shear planes in competent rocks along the northwestern margin of the shear zone. Some of these shear planes pass directly into crossfolds in adjoining incompetent rocks (Mast and others, 1962).

Although the dominant rock textures in the shear zone are cataclastic, mineral recrystallization was extensive, and the occurrence of small pegmatite bodies along the axes of the younger folds suggests some rock mobilization. As the newly crystalized minerals are essentially the same as the old metamorphic minerals, shearing related to the younger deformation must have taken place under P-T conditions that were moderately high, yet different enough to yield cataclastic textures. This probably reflects deformation under a lower confining pressure than during the regional plastic deformation.

The cataclastic deformation in the Idaho Springs–Ralsdon shear zone is younger than the Silver Plume Granite, dated about 1300 m.y. by Aldrich and others (1958), and older than Pennsylvanian. Except for some faults within the shear zone, the shear zone is probably entirely Precambrian, as it is older than the Precambrian gneiss in adjoining zones. The Precambrian gneiss in adjoining zones was emplaced into the Idaho Springs–Ralsdon shear zone. This gneiss has the same orientation, as shown below, as are Precambrian gneiss.

**Other Shear Zones in the Front Range**

Many other shear zones of northeast trend are known within the mineral belt in the Front Range and more come to light yearly as mapping progresses. Shear zones in a group near Berthoud Pass (Pl. 1, no. 2) have been studied in quadrangles recently mapped by R. B. Taylor, P. K. Theobald, and W. A. Brady, but have not yet been traced beyond these quadrangles. Some shear zones of this group either branch from the northeasterly trending Berthoud Pass fault or are greatly displaced by it, and others are displaced hundreds or thousands of feet by generally northwest-trending faults. Two members of the group are broad zones of the shear zone are a mile or more wide, and in part are very old, as the shear zone can be traced back to the Precambrian gneiss. Several fault zones in the group are a few hundred feet wide, and extend for several miles to the east and west, and along with a part of one of the broad zones, contain a variety of shear products, including simple cataclastic rock, augen and faser gneisses, mylonite, and mylonite gneisses. In addition, one contains a shear of slenec black ultramylonite that verges on pseudohaloclastite. The shear zones cut in a straight line the gneisses of various orientations, but only are extend into Silver Plume Granite, which they are typically weak. Detailed studies by P. K. Theobald (oral communication, 1962) indicate that the movement along some shear zones was synchronous with emplacement of the Silver Plume Granite.

An unmapped shear zone along Leavenworth Creek southwest of Georgetown (Pl. 1, no. 2) seems to be an echelon continuation of the Idaho Springs–Ralsdon shear zone. The Precambrian gneiss on the northwest and Precambrian gneiss on the southeast contains many dikes of Silver Plume Granite that strike approximately N. 70° E. and dip about 70° S.

It is characterized by intense cataclasites and locally contains mylonite gneisses. The shear zone has the same general orientation, movement, and movement pattern as the Idaho Springs–Ralsdon shear zone.

A major northwest-trending zone of Precambrian shear in Hall Valley about 1.5 miles south-southwest of Montezuma (Pl. 1, no. 4) has been mapped in part by Walthron and Kim (1959, Pl. 4, p. 1235), who named the North Fork fault and traced it about 1 mile north of the Laramie Range. The present displacement separates rocks to the northwest that is northwestward and are largely cataclastic rocks to the southeast that strike northwestward and are mainly migmatitized biotite gneiss and granite. Walthron and Kim (1959, p. 1235) described the fault as a zone of shear, and they have recrystallized mylonite. A part of the fault examined by one of the ridge between Hall Valley and Handels Gulch, is an intensely cataclasic zone at least 500 feet wide; it gradually passes laterally to the north into rocks cut by wadges and radially sheared gneisses and granite.

The cataclastic rocks consist of interlayered flaser and augen gneisses and mylonites. Foliation resulting from the shearing is prominent in the older black gneisses and small angles, but in places shearing foliates the older foliation planes. The shear foliation strikes N. 55°–70° E., subparallel to the trend of the zone, and dips N. 55°–70° W. NW. A conspicuous lineation related to the shear, a part of the protomylonitic lineation, is everywhere developed on slickenlines, and tight, nearly recumbent folds plunge N. 10°–25° W. In places, especially along the margins of the zone of intense cataclastic crossfolds that cut older folds and lineations are well developed; the crossfolds plunge NW. Approximately parallel to the trend of the shear surfaces, Locally, shear zones transect nearly recumbent young drag folds. The shear zones of northwesterly trend are known along many places outside the mineral belt in the Front Range (Levering and Goddard, 1950), and they are small, discontinuous, and scattered. Movement that created this widespread zone is almost entirely Laramide, but in places along the fault and a major branch are remnants of mylonite that must have formed in a different environment, possibly in the Precambrian. As some northwesterly shear zones seem to end against or branch from the Berthoud Pass fault, it is possible that this fault is cognate with the shear zones. In contrast, the generally smaller north-northeast faults of the Idaho Springs–Central City area are younger than the northwest faults, which, as shown below, are younger than the Idaho Springs–Ralsdon shear zone.

Northwest-trending faults that branch from the Idaho Springs–Ralsdon shear zone, and, as they displace older features an equal amount, almost all displacement along the northwest-trending faults must be later than the cataclasts and crossfolds in the shear zone.

The question of whether the displacement is Precambrian or younger then arises.

Evidence is strong that the northwest-trending faults or breccia reefs are of Precambrian origin. (1) They have the style of Precambrian fracture zones, showing pervasive shearing and local mylonites that are products of a relatively deep-scaled environment. No steep fractures of proved Laramide origin show evidence of formation in such an environment. (2) Some northwest-trending faults coincide in position and trend with the Precambrian pegmatite and aplite, and in some places the faults are followed by dikes of undeformed Precambrian pegmatite and aplite (Levering and Tweto, 1953, Pl. 1). (3) Many of the faults are at the boundary between the sedimentary rocks and the mountain front, and even those that underwent Laramide movement apparently die out rapidly in the sedimentary rocks (Levering and Goddard, 1950, Pls. 1, 2; Boos and Boos, 1957, Figs. 3-10).

**Homestead Shear Zone, Sawatch Range**

Location and setting. A swarm of Precambrian shear zones in the northern part of the Sawatch Range defines a major shear zone 7 or 8 miles wide which is here called the Homestead
shear zone. The master shear zone lies principally in the valley of Homestake Creek, but elements of it occupy most of the area between Homestake and Cross creeks (Fig. 4). The shear zone (Pl. 1, no. 5) has been mapped in detail for about 12 miles on the eastern slope of the Sawatch Range, between the covering sedimentary rocks to the east and the crest of the range. On the western slope of the range, part of the shear zone has been traced about 8 miles farther southwest; as projected a few miles more, it would pass close to Aspen. The shear zone and most of its component members trend N. 50°-55° E., but a strong branch diverges in the valley of Homestake Creek trends N. 75° E. (Fig. 4).

For many miles south of the Homestake shear zone, the Sawatch Range consists of metasedimentary gneisses perforated by granite bodies of various sizes and kinds (Pearson and Tweto, 1958). The gneisses dip northeast at low angles and are corrugated by gently northward-plunging folds. As the Homestake shear zone is approached, the gneisses steepen and assume a northeast strike, and at the base of steepening, granite almost disappears. With the shear zone, the bedrock is principally white gneiss and migmatite, which trend northeast parallel or subparallel to the shear zone. Structurally, these gneisses are characterized over wide areas by essentially vertical foliation, lineations, and fold axes. The gneisses are cut by many small bodies of igneous and plutonic rocks, several of which are peculiar and planar, but in detail they have a complex internal structure and show many slight sinuosities. They pinch at places to a single tight fracture and swell at others to great width; typically, they consist of several strands that follow a sinuous course, splitting and reuniting around lens-shaped bodies of less deformed rock, forming an over-all braided pattern. Most of

Figure 3. Metal-mining areas and Precambrian tectonic features, central Front Range, Colorado

Figure 4. Pattern of shear zones within the Homestake shear zone. Adapted from unpublished map of the Holy Cross quadrangle, Colorado, by Ogden Tweto and R. C. Pearson

to the shear zone or are rare outside it. North of the Homestake shear zone, the exposed Precambrian rock is mainly a granite unlike any to the south. Character. The Homestake shear zone is made up of a great number of individual shear zones and faults, many of which are themselves hundreds of feet wide. Viewed broadly, the individual shear zones are remarkably straight, the shear zones dip about vertically, but some are inclined; the intersection of inclined zones with the rugged topography accounts for the sinuosities of some of the shear zones shown in Figure 4. The pattern of shear zones within the master zone and the remarkable straightness of the individual shear zones for many miles along strike suggest strike-slip movement. A small
subvertical layer of amphibolite is displaced 1–2 miles in a left-lateral sense along some shear zones. If correlation of larger belts of amphibolite on the two sides of the range is correct, the southeastern portion of the master shear zone may have a horizontal displacement of 4–6 miles. Displacement on the master zone as a whole is unknown but may be many miles, as the terranes on the two sides of it are quite different.

Shear products. The materials within the shear zones take a variety of forms, ranging from gouge and breccia at one extreme through mylonites and pseudotachylite to recrystallized and refoliated new gneisses at the other. In the most highly recrystallized shear rocks, new biotite gneisses have formed; it is fine-grained, finely banded or layered, and remarkably straight-banded. It forms thin sheets a few feet thick and is sheared or cataclized in some degree but is not completely disorganized or reorganized. Some of the recrystallized rocks show accompanying strong retrograde changes in mineralogy, but in others the change was slight. Gouge and breccia occur in some shear zones and faults, either alone or as sole products of movement, or more often as younger facies superimposed on shear products formed earlier in an environment of high pressure and temperature.

History. The Homestake shear zone coincides with a belt of vertical gneisses that had the same general trend as the shear zone. It is the transect of the fault that provided the best exposure for 20 miles to the south and to that in the granite on the northeast part of the shear zone. Movement along the Homestake shear zone must have occurred at the stage of plastic deformation when the gneisses were folded and metamorphosed. There is no special orientation of the gneisses within the zone and the parallelism with younger zones of shearing. Such movement probably accounts for the near-vertical lineations and fold axes in the gneisses of the Homestake zone. Rotation about vertical axes in a zone of horizontal differential movement could produce vertical fold axes, which are hard to avoid for any other means as a standard pattern over an extensive area.

The stage in which movement was exposed by folding and flow was eventually followed by one in which fracture could occur, but it took place before the metamorphic regime had disappeared permanently. The sequence of shear products, ranging from coarse, biotite gneiss through mylonite to gouge, is evidence of an average progressive degree in P-T conditions, from moderately intense metamorphic to near-surface environment. The stage of shearing extends through a long period of time. Reshearing of earlier shear products under different environments corroborates this evidence, as is the relation of shear zones to the several kinds of mineral a clastic rocks within the master shear zone. The gneissic rocks were deformed and recrystallized over a considerable period of time, as they are of different ages and apparently not closely related genetically, and some were affected by a stage of metamorphism, and some were not. Yet these rocks show no consistent relation to the shearing; they are sheared in some but not in others, and they do not have a characteristic foliation. Shear zones are strongly gneissic but purcly foliated, formed by refoliation of the mylonitic gneisses.

In the Quartz Creek pegmatite district, in the southwestern part of the Sawatch Range, evidence of a northeast-trending fracture system of Precambrian age is furnished by swarms of pegmatites which cut across the northwest-trending foliation of the gneisses (Staatz and Trites, 1955, p. 12-18, Pl. 1).

Shear Zones in the Park Range

In the Park Range—between the Sawatch and Front ranges—shear zones of a northeast-trending trend are subordinate to major cross-trending shear zones that are followed by the Gore and Mosquito faults. The Homestake shear zone enters the lower southwestern flank of the Gore Range segment of the Park Range as a strong and wide feature but almost immediately disappears beneath the cover of sedimentary rocks (Pl. 1). As projected across the area of sedimentary rocks, the shear zone should reappear in the Precambrian rocks to the east in an area near Vail Pass, but is instead only a very faint expression. The Homestake shear zone probably ends against the Gore fault, and its trace is taken to the northeast by smaller and more widely separated shear zones. A short segment of one such shear zone extends across the extreme northern tip of the Tenmile Range at Frisco and other smaller shear zones have been found to the south (A. H. Koschmann and M. I. Bergendahl, oral communication, 1959). About 7 miles northeast of Frisco, a prominent shear zone trends eastward across the acute angle between the Gore fault and the northward prolongation of the Mosquito fault (Pl. 1). At its western end this zone deflects the Gore fault (Lavergne and Twiner, 1944, map), and a few miles to the east, it has a prominent southwest-trending mylonitic branch. The shear zones followed by the Gore and Mosquito faults are best exposed north of the intersection of the two faults in the area between Vail Pass and Frisco (Pl. 1). The Mosquito fault is here in Precambrian rocks and is a sheared and mylonitized zone several hundred yards wide. The Precambrian and Laramide components of the fault can be distinguished by marked differences in their character or style, but the differences are far more striking along the Gore fault. The Precambrian component of
the Gore fault is a sheared and mylonitized zone as much as half a mile wide. As in the Homestake shear zone, this deformed zone has been the locus of intrusion of small bodies of old dioritic rocks, hornblendeite, and pegmatite, many of which are conspicuously less deformed than their host rocks, although all are of Precambrian character. In contrast, the Laramide component is a simple steep fault that brings coarse-grained redbeds of the Minturn Formation (Pennsylvanian) against Precambrian rocks, which tower high above the fault trace. The Minturn strata turn up almost vertically in a narrow zone along the fault but otherwise are unexposed. Immediately west of the Gore fault, the Minturn Formation abruptly overlies older Paleozoic and Precambrian rocks (Lovering and Tweto, 1944; Tweto, 1949), indicating an almost scarp-like western border of the old highland along the line of the old Gore fault. In places undeformed Minturn strata lie upon or against mylonites and cataclastic gneisses of branches and strands of the old fault, and some of the conglomerates contain abundant cobbles of the sheared Precambrian rocks.

**Shear Zones Southwest of Sawatch Range**

Precambrian rocks disappear beneath a cover of sedimentary rocks at the western edge of the Sawatch Range and, except in the small isolated uplift at Treasure Mountain in the Elk Mountains, are not exposed along the trend of the mineral belt for 60 miles to the canyon of the Gunnison River. The Precambrian rocks exposed for 70 miles along the Gunnison fall structurally into two units separated by a zone of faulting and complex structure that is at least in part Precambrian (Pl. 1, no. 8). In the eastern half of the canyon and in an extensive area to the south—mapped principally as Black Canyon biotite schist—the foliation consistently strikes west-northwest. In the western half of the canyon—mapped principally as River Portal mica schist—the foliation near the disturbed zone strikes north, and farther west, northwest. The Minturn Formation in the eastern part of the Black Canyon of the Gunnison National Monument (Pl. 1, no. 9) was examined by one of us with Wallace R. Hansen, who is currently mapping there. The characteristic River Portal schist is a fine-grained, straight-layered schist (foliation) that closely resembles some recrystallized cataclastic gneisses of the Sawatch and Front ranges. It is characterized by nearly vertical foliation and lineations, in contrast to bounding and interbedded gneiss, a schist of Black Canyon aspect, which is characterized by a lineation that plunges about to SW. Persistent diabase dikes and many pegmatite parallel the sheared or "River Portal" layers; although they are probably Precambrian, they are not visibly sheared.

Southeast of Black Canyon, near the village of Gateview, in an area mapped by J. C. Ille, and D. C. Hedlund (oral communication, 1962), is a wide northeast-trending belt of intensely sheared Precambrian rocks. A 70 miles northeast of Gateway, this shear zone is interrupted by a strong one of west-northeast trend, but farther northeast its course is marked by a northeast-trending cross-foliated and diabase dikes (Hunter, 1925, Pl. 1), still farther northeast, by sheared rocks preserved in places in an unmappe: area south-southeast of Gunnison (Pl. 1, no. 10).

Thus, in southwestern Colorado, shear evidence indicates two major northeast-trending shear zones in or along the mineral belt about 25 miles apart. The northeastern zone of Black Canyon, is approximately on the line of the shear zones in the northern Sawatch and Front ranges (Pl. 1). No evidence is known southwest of Black Canyon, where Precambrian rocks are covered for more than 10 miles. The southeastern zone, if projected to the State line, would pass through the Quilt Creek area with its dense swarm of crossing, northeast-trending pegmatites (Staats and Trites, 1955). If projected southwest of Gateway, it would pass beneath the volcanic rocks of the Ouray and Telluride areas, farther southwest, beneath sedimentary rocks. If projected to the State line, both zones would line up approximately with the boundary of a northeast-trending basement structural belt defined by magnetic and gravity anomalies adjoining Utah (Case and Joesting, 1961).

**Figure 5. Relation of shear zones to positive areas of the late Paleozoic and early Mesozoic in Colorado. Adapted from maps by Burbank (1933, Fig. 14) and Mallory (1938, Fig. 2)**

**Records in the Paleozoic and Mesozoic Rocks**

**Introduction**

In many places along the mineral belt, sedimentary rocks of Paleozoic and Mesozoic age show abrupt changes—as in thickness, character, or distribution—that suggest the belt was bordered and intersected by sheared Precambrian and Laramide time. Such features are at once indirect evidence of the sheared belt and a record of its later history. A few examples indicate that movements within the belt caused slight warping, disconformity, and changes in facies in the sedimentary rocks, but the belt was not the only site of crustal movements. The rise and fall of major crustal units as the Front Range and Uncompahgre Highlands and bordering basins extended primary sedimentation on the belt. Locally, the shear zones of the mineral belt modified the great active and negative units and served as borders of the basement structural belt.
it served as the border of the old highland (Lovering and Tweto, 1944; Tweto, 1949).

**Pando Area**

The Pando area is in the mineral belt between the Sawatch Range on the west and the southern part of the Gore Range on the east (Fig. 4). Effects of the Homestake shear zone can be seen in a few kilometers into this area, which is in the basin between the old highlands. The Upper Cambrian Sawatch Quartzite, the basin unit of the sedimentary sequence, provides a good example. Regionally, this quartzite lies on a virtually planar surface cut into Precambrian to Mississippian rocks in the area. The planar surface is exposed in outcrop and in mine workings in the Gilman area, immediately northwest of the Pando area, where the quartzite is 195 feet thick (Lovering and Tweto, 1944, p. 15-18). As the quartzite is traced toward Pando and into the central part of the Homestake shear zone, northeast-trending ridges with relief of as much as 75 feet appear on the surface on which the quartzite lies, and the quartzite shows corresponding changes in thickness. For about 100 feet across the shear zone, the quartzite rests on an uneven floor, displays many changes in thickness, and, above depressions in its floor, contains lenses of basal conglomerate and poorly sorted arkosic sandstone that contrast markedly with the well-sorted quartz sandstones of the overlying quartzite. South of the shear zone, the surface beneath the shear zone becomes planar, but the quartzite is reduced to a thickness of 120–130 feet, in contrast to the 195 feet at Gilman. Apparently, fault movement occurred along the Homestake shear zone after the planar surface or "peneplain" had formed, with the result that low ridges and a general steplike rise still existed there when the Late Cambrian sea advanced over the area.

Evidence of later warping at the site of the Homestake shear zone also exists. The Lower Ordovician Manitou Dolomite is widespread southeast of the shear zone and wedges out at the edge of the shear zone owing to erosion before deposition of the Middle Ordovician Harding Quartzite. The Harding shows similar relations but is preserved principally on the northwest side of the shear zone, where the Manitou is absent; only a few thin and discontinuous lenses exist within the area of the shear zone, and the thickness of the zone is only a few miles to the southwest (Johnston, 1949; 1953; 1956). Again, and in a suggestive way, the Parting Quartzite Member of the Upper Devonian Chaffee Formation is almost twice as thick in an elongate area overlying the shear zone as it is on each side and is much more conglomeratic. The Middle Mississippian Laramie dolomite, although irregular in thickness because of a karst erosion surface at its top, shows a change in average thickness upon entering the shear zone from about 140 feet on the northwest side to 90 or 100 feet on the southeast side. The zone, the thickness is now largely a regolith accumulated upon the karst surface, shows a complementary relation to a lumpy and hololus but essentially continuous blanket southeast of the shear zone but is restricted to crevices and underground channels in the immediate vicinity of the shear zone. Although these few evidence are little more than suggestive, they taken alone, collectively define a pattern of instability within this part of the sheet and through much of the Paleozoic. Rocks of Mesozoic age are absent.

### SUMMARY OF PRE-LARAMIDE HISTORY

The mineral belt, characterized principally by deposits and intrusions of the Laramide age, coincides with a deformed zone of Precambrian age. Crustal movements occurred within the deformed zone through most of the Cambrian time of which there is record in the region. During this span of time, the entire crustal environment of deformation changed progressively, as recorded at the levels now visible, from a deep-seated environment characterized by folding and plastic flow at one extreme to a shallow environment characterized by fracture and retrograde metamorphism at the other. During this time, the products of the deformation movement assumed a variety of forms as they fall roughly into an age sequence.

In both the Homestake shear zone of the Sawatch Range and the Idaho Springs-Ralston shear zone of the Front Range, the deformed zone, the Mesozoic units, and the north-northwest striking faults of the San Juan shear zone can be traced in the adjacent Precambrian age. And in the southeastern part of the Sawatch Range, apparently the locus of a profound period of deformation in the Triassic, a north-northwest striking fault can be traced in the adjacent Precambrian age.

In the Sawatch Range this couple appear to form in a belt a few miles wide and many miles long. In this belt the foliation is vertical and trends northeast, parallel to the deformed zone, in contrast to a pattern of open folds which are of Late Cretaceous age. The faulting took place along the northeast-trending ridges, which are the same ridges as those formed as a result of shear zones in the Precambrian age. The Sawatch Range in these areas are of Mesozoic age. The Sawatch Range in this belt the foliation is vertical and trends northeast, parallel to the deformed zone, in contrast to a pattern of open folds which are of Late Cretaceous age. The faulting took place along the northeast-trending ridges, which are the same ridges as those formed as a result of shear zones in the Precambrian age. The Sawatch Range in these areas are of Mesozoic age.

### LARAMIDE EVENTS AND PROBLEMS

**Age Relations**

As a structural zone, the mineral belt originated in the Precambrian, but the structural zone did not become a mineral belt per se until the Laramide orogeny, when intrusive bodies and related ore deposits were introduced into it. These distinguishing features of the belt formed at different times in different places, for the Laramide orogeny lasted throughout a period of time from Late Cretaceous into the Eocene, and the magmatic activity that characterizes the belt was not all synchronous. Some of the stocks in the Front Range, for example, are relatively old, as they mark volcanic centers that contributed large amounts of debris to the Middle Park and Denver formations, which are of Late Cretaceous and Paleocene (Fort Union) age. In the West Elk Mountains, in contrast, the intrusive bodies postdate the Sawatch Formation of Early Eocene age, as may the intrusions of the Elk Mountains according to D. L. Gaskill and L. H. Godwin (oral communication, 1962).

Throughout the mineral belt, the ore deposits are generally younger than the intrusive porphyries and are commonly regarded as the youngest major feature of the Laramide orogeny within the belt. Their deposition was accompanied in many places by tectonic movements, as shown by repeated brecciation of vein fillings and the presence of postore faults in some districts; but on the whole, the tectonic movements of the ore stage or later were relatively slight, and the tectonic features of the mineral belt are principally of preore age. In several mining districts, ore deposits cut by a few dikes—mostly porphyritic—or, as at Leadville, by plugs of hydritic intrusion breccia.
Laramide Events and Problems

Most of these postore intrusions have not been dated with certainty, but hypogenic rocks of probable Paleocene age in the heart of the mineral belt in the Swath Range and along the northwestern edge of the belt in the Front Range (Tweto, 1957, p. 23) show that in parts of the belt at least, magmatic activity occurred after the time that the Swath Range, the volcanic rocks are accompanied by related intrusive plugs or stocks and many dikes (Burbank and Goddard, 1935). Similarly, the late Tertiary hypolite of the Front Range may have come from the mineralized composite intrusive center at Red Mountain, southwest of Berthoud Pass, as suggested both by field relations and by petrologic relations now being investigated by P. K. Theobald.

Although many features of the mineral belt cannot be closely dated by geologic means, the available data indicate that the belt developed piecemeal through the entire Laramide orogeny and that magmatic activity, minor tectonic movements, and possibly the formation of some ore deposits (Wahlstrom, 1936) continued sporadically after the Laramide and as late as the Paleocene.

brian shear zone, rather than the shear zone localizing the magma? Many authors have classified the mineral belt, or parts of it, as a zone of transverse shear related in origin to the mountain structure as a whole, the generally north-trending mountains regarded as products of Laramide compressive forces of approximate east-west orientation. The Front Range segment of the mineral belt, which is the part generally referred to, is the only part to which this interpretation can apply. In the other mountain ranges, no system of oriented fractures comparable to the vein system of the Front Range is known. Obviously, for these ranges some other explanation for the Laramide mineral belt must be found, and we think it the old zone of weakness defined by the Precambrian shear zones. The Front Range, the suggested mechanics could have been effective, the transverse Laramide shearing being localized by the old zone of weakness, but even here, this may not be ill-prepared prediction. The Front Range is a product of vertical forces is less than that for horizontal compressive forces. The range were formed by vertical uplift. The fissionary system of the mineral belt is a secondary fracture system localized by the old zone of weakness, not a primary Laramide tectonic element.

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