U.S. DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

Preliminary geologic map of the Howardsville 7.5-minute quadrangle, San Juan and Hinsdale Counties, Colorado

by

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Introduction

The Howardsville 7.5-minute quadrangle, located in the western San Juan Mountains of southwestern Colorado (fig. 1), includes almost 59 square miles (153 km^2) of rugged mountainous terrain at altitudes ranging from about 9,500 ft (2895 m) in the Animas River valley at the west edge of the map to 13,552 ft (4130 m) on Tower Mountain near the northwest corner of the map. The Continental Divide traverses the southeastern part of the quadrangle, with the Rio Grande heading in the basin just east of Canby Mountain in the southeastern part of the map. Steep valley walls below timberline (about 11,500 ft or 3500 m), particularly some protected north-facing slopes, usually are covered with dense timber, underbrush, and soil; geologic features may be obscured by this cover and local rock debris contaminated with transported clayey material and residual products of oxidation.

The townsite of Howardsville, at the confluence of Cunningham Gulch with the Animas River, is the only village of note formerly located within the quadrangle. In its heyday during the 1880's, Howardsville had a population of about three hundred people (Ayers, 1951), most of whom were engaged in mining and related industries.

The earliest areal geologic mapping was done by Cross and others (1905) and subsequently included in a comprehensive study of the San Juan Mountains region by Larsen and Cross (1956). Detailed geologic mapping was begun by Burbank (1933) and continued by Varnes (1963) for part of the quadrangle. The accompanying geologic quadrangle map is part of a study covering the western San Juans (fig. 1); we were assisted by Rene DeHon, Phillip Burbank, Steven Maione, and Gary Galyardt.

Geologic setting

Exposed pre-Tertiary bedrock includes Proterozoic metamorphic rocks in the southern part of the quadrangle and limited patches of Paleozoic sedimentary rocks mostly in the upper part of Cunningham Gulch. The assemblage of Paleozoic and Mesozoic sedimentary rocks, which at one time covered the western San Juan Mountains region, was removed by extensive erosion in part during the Rocky Mountain orogeny at the close of the Paleozoic era and in part during the Laramide orogeny at the end of the Mesozoic era. This beveled older terrain is unconformably overlain by a thick widespread sequence of predominantly Tertiary volcanic rocks. Throughout the quadrangle the entire rock assemblage has been intruded by igneous dikes and irregular-shaped bodies of silicic to mafic composition, and locally blanketed by a variety of surficial deposits.

The metasedimentary and metavolcanic rocks in the southern part of the quadrangle are a part of the Early Proterozoic Irving

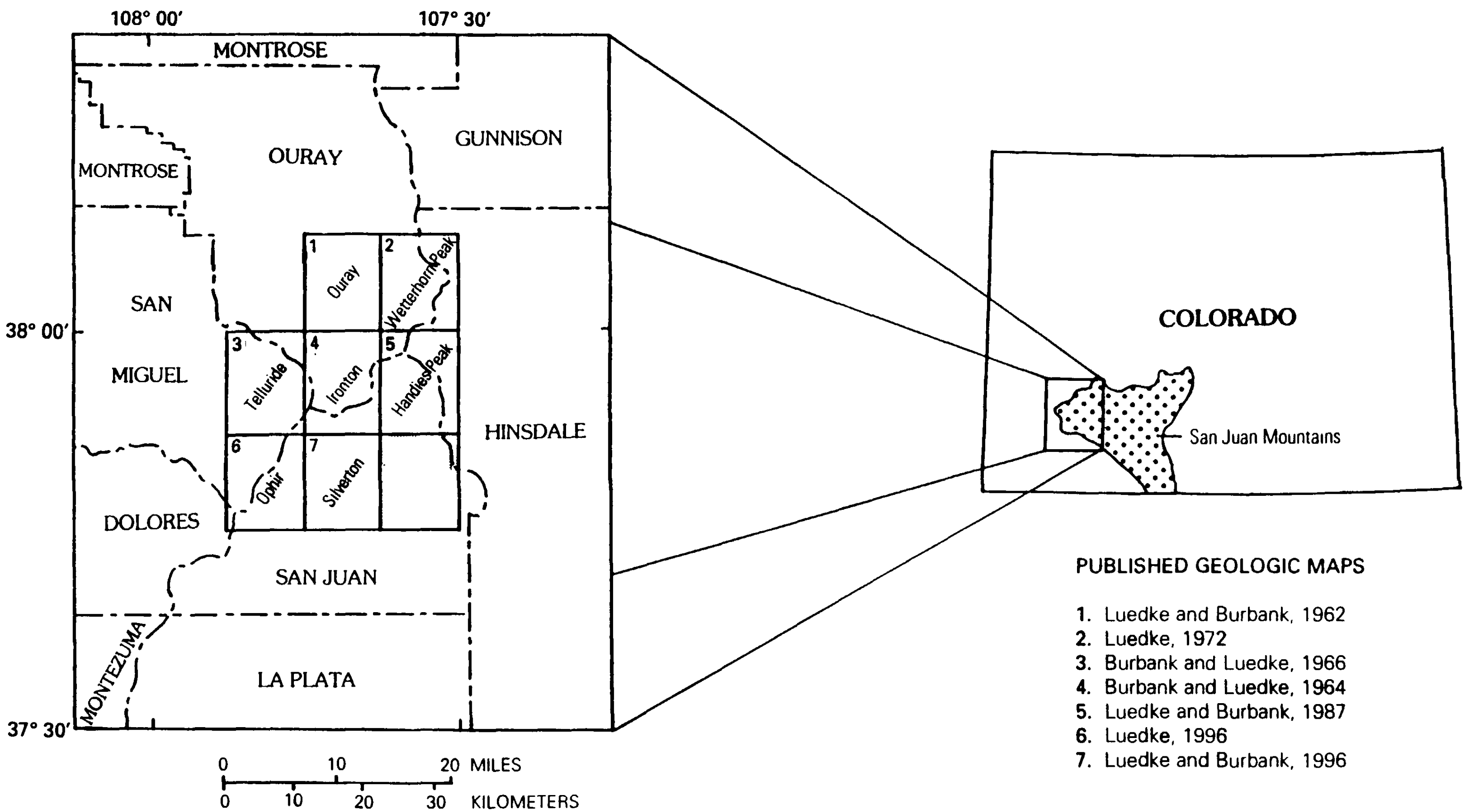

Figure 1.--Index map showing location of the Howardsville 7.5-minute quadrangle (shaded) with respect to related quadrangles studied in the western San Juan Mountains of southwestern Colorado. All published geologic maps by the U.S. Geological Survey.

Formation exposed more extensively to the south in the Needle Mountains region, and consist dominantly of gray to greenish-gray, well foliated, thin to thick bands of quartz-feldspathic gneiss and thinner bands of quartz-mica schists and almandine-bearing amphibolites. Origin of the interbedded amphibolite in the Highland Mary Lakes area is partly volcanic as indicated by pillow structure (Barker, 1969). This metamorphic rock complex has been intruded by a set of diabase dikes that generally strike northerly to northeasterly, are mostly about 3 to 4 ft (1 m) or less in thickness, and, a few, are as much as half a mile (about 1 km) in length. These dikes are shown as being of Cambro-Ordovician age, after Lipman (1976) and Hansen and Peterman (1968), but some if not all of the dikes here are suspected to be Precambrian in age. All younger rocks within the quadrangle overlie these older basement rocks with angular unconformity.

The Ignacio Quartzite of Upper Cambrian age is the basal unit of the section of Paleozoic rocks within the map area and crops out only in the upper basin of Deer Park Creek (southwest part of the map); it rests upon an erosional surface on gneiss and in turn is overlain by volcanic rocks of Tertiary age. Most of the Paleozoic sedimentary rocks in the map area consist of (1) undifferentiated carbonate rocks exposed as small isolated bodies in Stony Gulch, on both sides of Cunningham Gulch near the Pride of the West mine, and underground in both the Pride of the West and Osceola mines, and (2) a differentiated stratigraphic section in the small east-west trending graben in the upper part of the same valley.

Thin interbedded calcareous shale, siltstone, and sandstone exposed at the base of the sedimentary rock section within the small graben in the upper part of Cunningham Gulch are assigned to the Upper Devonian Elbert Formation. These beds, in turn, are overlain by light-gray, fossiliferous, thin-bedded limestone of the Upper Devonian Ouray Limestone and dark-gray thick-bedded to massive limestone of the Leadville Limestone of Mississippian age. Beds overlying the Leadville Limestone, only exposed in the northeastern corner of the small graben, consist of red shale and siltstone of the Pennsylvanian Molas Formation; included within and at the top of this thickness of redbeds are some coarse grained, pink sandstones that possibly may represent the basal part of the overlying Hermosa Formation of Pennsylvanian age.

Except for the limited outcrops of the sedimentary Telluride Conglomerate at the base, rocks of Tertiary age consist of a thick assemblage of volcaniclastic rocks of intermediate composition in the lower part, volcaniclastic rocks, lava flows and breccias, and both air-fall and welded ash-flow tuffs of mafic to silicic composition in the middle part, and welded ash-flow tuffs of silicic composition in the upper part. Sources for the volcanic rocks were the San Juan and Silverton calderas and adjacent areas in the western San Juan Mountains.

Middle to late(?) Tertiary igneous dikes and small irregular-shaped bodies of intermediate to silicic composition have intruded the bedded volcanic sequence throughout the quadrangle, but most are within or near the ring-fault zone of the Silverton caldera (fig. 2 and geologic map). Contact metamorphism of minor extent and varying intensity has occurred in the bedded volcanic rocks adjacent to the larger of the intrusive bodies.

During Pleistocene time the region was extensively glaciated resulting in typical U-shaped valleys, sharp peaks, narrow ridges, and many steep-walled, bowl-shaped basins (cirques). This alpine topography is covered locally by a variety of differentiated surficial deposits including much glacial debris along the major valley walls.

Exclusive of the profound Precambrian deformational events, the structural features within the Howardsville quadrangle are typical of the western San Juan Mountains and are characteristic of deformation associated with earlier mountain building and later caldera-related volcanic activities. The map area lies within the region affected by the ancestral San Juan Mountains domal uplift that occurred in Late Paleozoic time (Rocky Mountain orogeny) and again in Late Cretaceous-early Tertiary time (Laramide orogeny). The structural attitudes best reflecting these two orogenies are more vividly displayed by the Paleozoic and Mesozoic strata in adjacent quadrangles to the west and north (see fig. 1) where the strata were not as extensively eroded prior to the middle Tertiary volcanic activity.

Within the map area, the principal structural features are those associated with the Silverton caldera and are continuous with the same structures in the Eureka district (Burbank and Luedke, 1969) and Handies Peak quadrangle to the north (Luedke and Burbank, 1987) and the Silverton quadrangle to the west (Luedke and Burbank, 1996). The caldera outline, although locally shown as a single fault, undoubtedly consists of a broad zone of faults and fractures enclosing fault-block segments and broken and crushed rocks that provided an easily accessible route for intrusive igneous material to penetrate the country rock, such as the prominent dike parallel to the Animas River valley. The fractured and broken ground also was easily removable by glaciers resulting in the U-shaped valley of the Animas River.

Less obvious features of a second major structure are those related to the formation and development of the older San Juan caldera. The buried structural wall of this caldera is believed to trend easterly about on line with the Titusville vein, south of Kendall Peak near the west edge of the map, across Arrastra Basin, through Royal Tiger Basin, curving slightly northward to intersect Cunningham Gulch near the mouth of Dives Basin where the vertical contact of volcanic rocks against metamorphic rocks

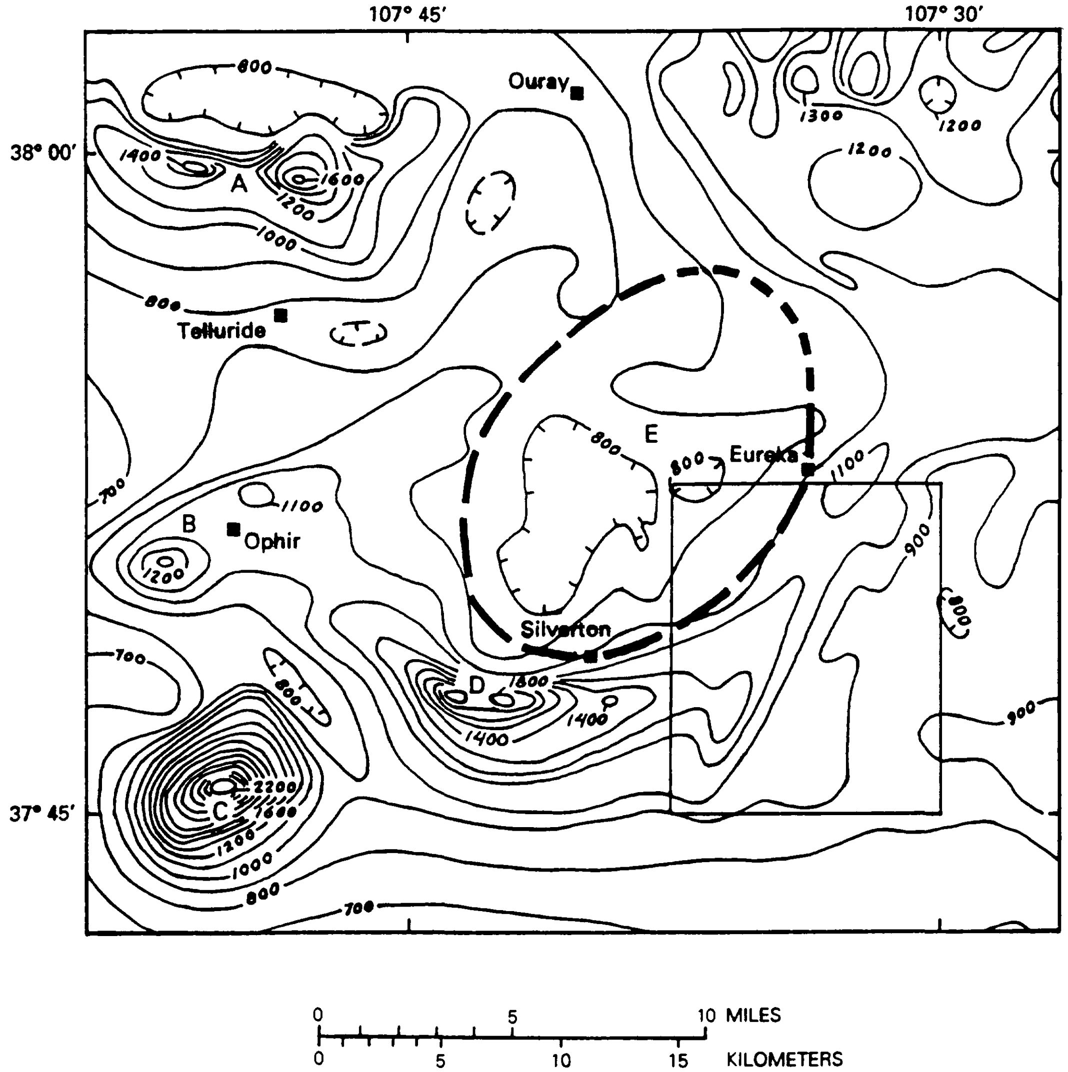

Figure 2.--Aeromagnetic map of part of the western San Juan Mountains region showing location of the Howardsville quadrangle in relation to position of major intrusive masses and the Silverton caldera. Contours show tctal intensity of magnetic field of the earth in gammas relative to an arbitrary datum; hachures indicate closed areas of lower magnetic intensity. Points cf reference: A, Mount Sneffels stock; B, Ophir stock; C, Grizzly Peak stock; D, Sultan Mountain stock; E, Silverton caldera (heavy dashed line). Map modified from U.S. Geological Survey (1972).

is exposed. Structural attitudes are vertical within the welded tuffs on one side and the schists on the other side of this contact. The presumed structural wall, very near the topographic wall, is first observed underground within the workings of the Highland Mary mine (Varnes, 1963, pl. 3). The vertical to very steeply-dipping contact between the Precambrian metamorphic rocks on one side and Tertiary volcanic rocks on the other side trends northerly parallel to the valley wall and can be traced underground within both the Green Mountain mine (Hagen, 1951) and Pride of the West mine (Cook, 1952; Varnes, 1963, pl. 5) to surface exposures in the lower parts of Stony and Rocky Gulches, and again underground in the cross-cut tunnel to the Gary Owen mine in the upper workings of the Old Hundred mine. The position of the structural wall can only be surmised northeasterly to surface exposures in Cuba Gulch just beyond the northeast corner of the quadrangle. However, it must be located about where the 10,800-foot contour line intersects the creek in Maggie Gulch, and about where flows and tuffs in the Henson and pyroxene andesite members of the Silverton Volcanics steeply dip northwest on the east side of Minnie Gulch; it also, probably is reflected by the easterly-trending mineralized fault near the Kitti Mack mine. Most of the unconformable and depositional topographic wall, overlain by the interfingering postsubsidence caldera-fill assemblage of the San Juan caldera, is as much as 1 to 3 miles outside the presumed position of the structural wall.

Numerous mostly mineralized faults and fractures with varying but usually small displacements occur throughout the quadrangle and are believed to be mostly related to formation of the younger Silverton caldera; they are principally radial and concentric to the caldera. The complex fracture systems developed in the surrounding volcanic rocks have been analyzed for two parts of the quadrangle: Varnes' (1962) discussion of a west-central area, south of the river valley and mostly west of Cunningham Gulch that includes the Arrastra Gulch area by Burbank (1933), and Schwarz's (1968) discussion for a northeastern area in the vicinity of Minnie Gulch.

Economic geology

The Howardsville 7.5-minute quadrangle area has yielded base- and precious-metal ores and was an integral part of mining activity in the western San Juan Mountains metal-mining region. The area encompassed by this quadrangle figured very early in the history of prospecting and then mining and milling. Following upstream to the headwaters of the Rio Grande provided an arduous yet accessible route into the area; it also was one of the early routes, by the way of Howardsville, up Cunningham Gulch, and over Stony Pass, for tansporting ore out to the nearest railhead. It was quickly established that mining was the method for obtaining mineral wealth of the area with the Little Giant mine (1870 or 1871) on the northeast side of Arrastra Gulch reported as being the first (Raymond, 1877; Ransome, 1901, p. 19); the district's first shipment of gold ore, treated in arrastres, were from this mine. Insignificant amounts of gold had been obtained by placer mining. The greater part of the area's production undoubtedly has been from silver-bearing lead ores.

A few of the many mines opened within the map area developed into major mines for the region as a whole; this was possible in part through consolidation of properties, improvements in mining and milling methods, and a reduction in transportation costs with the building of roads and the coming of the railroad in the early 1880's. The area's rugged topography was conducive to mine development mostly of adit and tunnel-type construction, and for gravity tram lines to transport ore from those mines high on the slopes to the mills below. Of major importance to the entire western San Juan metal-mining region, the Silver Lake mine was one of two in the region where milling methods were successfully developed in 1890 to concentrate and amalgamate lower-grade ores. The approximate $50 million in ore production from 1901 through 1957 (Varnes, 1963, table 6), reported for mines in that part of the area south of the Animas River and Cunningham Gulch west to the quadrangle boundary (Silver Lake, Shenandoah-Dives, Pride of the West-Green Mountain, Iowa-Royal Tiger, and Highland Mary and Trilby), probably closely represents the bulk of ore production for the entire quadrangle during that time period.

Most ore produced was from vein deposits in Tertiary volcanic rocks peripheral to the Silverton caldera. The veins consisted of silver-bearing base metals and/or gold-bearing pyrite and chalcopyrite occurring in gangues of quartz, barite, and carbonate minerals. Although the area has been extensively prospected and explored, most of the mines except for those mentioned above produced only small quantities of ore. Most of the mines were inaccessible for examination, but are believed to have been small and developed only to shallow depths. The few mines examined and described in some detail within the map area are discussed in Ransome (1901), Henderson (1926), Burbank (1933), King and Allsman (1950), and Varnes (1963); several mines and(or) their types of mineralization have been the subject of master or doctorial studies (Hagen, 1951; Cook, 1952; Schwarz, 1967; Hardwick, 1984). Of mineralogical interest, some hübnerite (tungsten ore) was recovered in the Maggie Gulch area, and specular hematite occurs in notable quantities in several veins in the vicinity of Howardsville.

Alteration

Most if not all of the volcanic rocks within the Silverton caldera and peripheral to it have been propylitically altered to varying degrees. This rock alteration (Burbank, 1960), caused by effusions of water and carbon dioxide, intensifies with depth, and ranges from weakly carbonatized and chloritized to locally albitized and epidotized; it occurred during and shortly after magmatic resurgence of the caldera and concomitant emplacement of igneous intrusives within and near the caldera ring-fault zone. This alteration preceded vein formation and the general introduction of sulfur and metals.

Typical epithermal quartz-sericite-pyrite alteration is coextensive with the numerous stages of vein-forming solutions that yielded the many siliceous, often compound, sulfide veins in the caldera area and is generally restricted to within a few feet of the veins and ore bodies. This alteration, including some clay products, calcite, and chlorite, was more or less associated with the introduction of certain ores and gangues in the vein deposits.

Several episodes of more intense hydrothermal, near-surface alteration of an advanced argillic or acid sulfate type were then superimposed upon the earlier propylitic alteration that leached and redistributed the rock bases (Burbank and Luedke, 1961). These highly altered rocks, not as prominent nor extensive in this quadrangle as in the Ironton and Silverton quadrangles (fig. 1), are found along the Silverton caldera ring-fault zone (Animas River valley) from the west edge of the map northeasterly around to Minnie Gulch, and consist of rocks replaced by quartz, various clay minerals, alunite, and pyrite.

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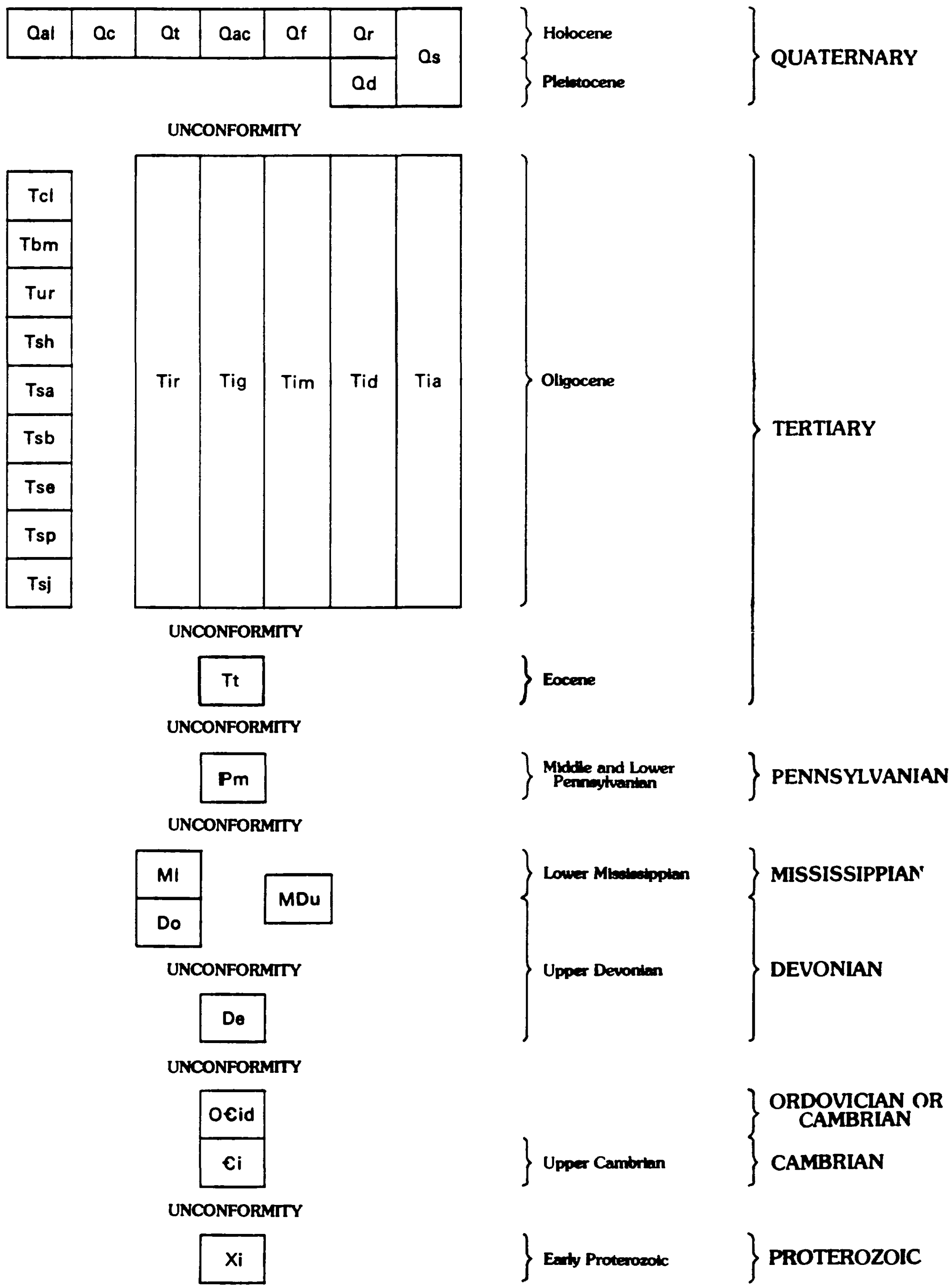
CORRELATION OF MAP UNITS



DESCRIPTION OF MAP UNITS

SEDIMENTARY, VOLCANIC, AND INTRUSIVE ROCKS

Surficial Deposits

Qal — Alluvium (Holocene)--Unconsolidated fluvial deposits of silt, sand, gravel, and rounded to subrounded boulders up to 1½ ft (0.5 m) in diameter in valley bottoms

Qc — Colluvium (Holocene)--Unconsolidated and unsorted silt- to boulder-sized rubble in part as alluvial fill and in part as residual and slope-wash materials on gentle slopes and in upland flats and valley bottoms; often boggy. Locally includes organic-rich material, some talus, alluvial-cone and landslide deposits, and glacial drift

Qt — Talus (Holocene)--Angular rock fragments forming cones, aprons, and slope cover commonly at the base of cliffs and along steep slopes. Silt and sand content increase on slopes of decreasing steepness; unit may grade into colluvium

Qac — Alluvial cone deposits (Holocene)--Unconsolidated sand, gravel, cobbles, and subrounded to angular boulders forming lobate masses which have steep slopes and commonly coalesce at mouths of many tributary streams and gullies

Qf — Alluvial fan deposits (Holocene)--Unconsolidated sand, gravel, and cobble deposits which form broad gentle-sloping lobate masses at mouths of Minnie and Cunningham Gulches

Qr — Rock glacier deposits (Holocene)--Thick tongue-shaped masses of angular rock fragments ranging from sand-size particles to blocks 3 ft (1 m) or more in length, found in cirques and basins in high alpine valleys. Semiactive to actively advancing rock glaciers exhibit flowage as shown by their steep, lichen-free boulder fronts and by the concentric and parallel ridges and troughs on top; many contain interstital ice and some, an interior ice core

Qs — Landslide deposits (Holocene and Pleistocene)--Poorly sorted materials derived mostly from bedrock. Exhibit typical hummocky and broken surfaces and often flowage features including a steep toe and marginal ridges and troughs. Included are small earthflows and larger slumps and block slides. Landslide mass on west and south slopes of Sheep Mountain in southeast part of quadrangle exhibits recent scars and scarps of smaller recently active slumps on its upper surface

Qd Glacial drift (Pleistocene)--Unconsolidated to semiconsolidated, unsorted materials consisting mainly of of till and ranging in size from clay to boulders; locally may contain some outwash gravels

Intrusive Rocks

Tir Rhyolite (Miocene? and Oligocene)--White to light-gray, dense to very fine grained with phenocrysts of sanidine, quartz, and sparse plagioclase and biotite. Platy or flow banded. Weakly to extremely altered. Occurs as dikes, plugs, and a large irregular-shaped mass at mouth of Stony Gulch. Plug in southeastern corner of quadrangle, mapped as rhyolite by Cross and others (1905) and Lipman (1976), is an altered trachyte or high-potassium trachydacite

Tig Granite (Oligocene)--Light-green to white equigranular to porphyritic rock with abundant phenocrysts or coarser grains of feldspar (plagioclase and orthoclase), quartz, and minor biotite in a very fine granular groundmass of potassic feldspar and quartz. Occurs as dikes and small irregular-shaped masses in southwestern part of quadrangle; also exists as a mass of unknown shape and size underground near the Old Hundred mine portal

Tim Quartz monzonite (Oligocene)--Pinkish-white to light-gray, porphyritic rock with phenocrysts of feldspar (plagioclase and orthoclase) to 1 cm in size, quartz, hornblende, and locally biotite in a dense to fine-grained groundmass of feldspar and quartz. Occurs as dikes and small irregular-shaped plutons throughout quadrangle, and as a very large bifurcating dike 0-1,000 ft thick in the southeast wall of Animas River valley from Cunningham Gulch to Maggie Gulch

Tid Dacite (Oligocene)--Brownish-gray to medium gray dacite containing 15-25 percent phenocrysts (1-2 mm across) of plagioclase, some quartz, and locally biotite and(or) hornblende in a very fine-grained groundmass of feldspar and quartz. Occurs as dikes

Tia

Andesite (Oligocene)--Dark-greenish gray to dark gray, dense to slightly porphyritic rock with small (1-2 mm) phenocrysts of whitish plagioclase feldspar, pyroxene, and in places hornblende in a dense to very fine-grained groundmass. Weathers generally dark brown or greenish-black and is considerably altered to chlorite, epidote, calcite, sericite, and quartz. Occurs as dikes of thin to moderate thickness; some have considerable length within the quadrangle

Extrusive and Related Rocks

(Volcanic rock units absent locally in map area due to nondeposition and/or local erosion)

Tcl

Crystal Lake Tuff (Oligocene)--Mostly altered white to yellowish-gray, devitrified, weakly to densely welded rhyolitic ash-flow tuff found in four small erosional patches in northeastern part of map; unaltered rock medium gray. Rock is sparsely to moderately crystal-rich with 5-10 percent crystals of quartz, feldspar, biotite, and sparse pyroxene in a dense, generally eutaxitic groundmass; accessory dark lithic fragments 1 cm across are common. Unit overlies an erosional surface of low relief. Thickness zero to 210 ft (0-65 m). Limited extent extent of unit exposures do not permit positive identification or correlation; Lipman (1976) assigned these rocks in his regional study of the adjacent Lake City area to the Crystal Lake Tuff presumed to have erupted about 27.5 Ma from its postulated source area, the Silverton caldera

Tbm

Blue Mesa Tuff (Oligocene)--Partly altered, moderately to densely welded red-brown rhyolitic ash-flow tuff. Sparsely porphyritic rock with less than 10 percent phenocrysts of quartz, sanidine, and biotite. Unit forms upper cliffs only on Sheep and Greenhalgh Mountains in southeastern part of quadrangle. Thickness about 310 ft (95 m)

Tur

Ute Ridge Tuff (Oligocene)--Gray to grayish-brown crystal-rich, moderately to densely welded quartz latitic ash-flow tuff. Phenocrysts principally are plagioclase, sanidine, and biotite; small accidental rock fragments locally common. Unit considerably hydrothermally altered; exposed only in southeastern part of quadrangle. Thickness about 360 ft (110 m)

Silverton Volcanics (Oligocene)--Lava flows and related volcaniclastic rocks of predominantly intermediate composition, but ranging from andesite to rhyolite

Tsh Henson Member--Gray, brown, and black, thin to thick, lenticular, locally crossbedded and water-reworked sandy and shaly tuffs; complexly interbedded with lava flows and tuff breccias of both pyroxene andesite member and Burns Member. Thickest and most extensive outcrops in northeast and northwest parts of quadrangle; notable outcrops on Little Giant Peak and King Solomon Mountain in southwest part and Green Mountain in south-central part. Thickness ranges from zero to about 500 ft (0-150 m)

Tsa Pyroxene andesite member--Brownish weathering, dark-gray, dense to porphyritic trachyandesite; occurs as thin to thick, commonly amygdaloidal lava flows and flow breccias mostly in north half of quadrangle. Locally interbedded with lava flows of dark-gray, two-pyroxene and olivine-bearing andesite, and in northeastern part of quadrangle, medium-gray, hornblende-bearing dacite; some interbedded thin lenticular sandy tuff beds. Maximum thickness about 650 ft (200 m)

Tsb Burns Member--Light- to dark-gray massively interbedded flow breccias, tuffs, thin to thick massive flows and some fluidal-banded flows. Consists of predominantly porphyritic trachyandesite or high-potassium andesite with euhedral to subhedral phenocrysts of plagioclase, amphibole, pyroxene, and some biotite 1-5 mm in size in a dense aphanitic groundmass; more silicic flows of high-potassium dacite comprise upper part of Canby Mountain and and flat-topped ridge north of Sheep Mountain in southeastern part of quadrangle. Unit almost everywhere propylitically altered to chlorite and calcite, and very locally to epidote and albite. Overlies a very uneven erosion surface. Zero to about 1,800 ft (550 m) thick outside, and possibly thicker inside San Juan and Silverton calderas

Sapinero Mesa Tuff (Oligocene)

Tse Eureka Member--Gray to greenish-gray, moderately to densely welded ash-flow tuff of high-potassium dacitic to low-silica rhyolitic composition. Moderately abundant crystals of feldspar (plagioclase and sanidine), biotite, minor quartz, and locally hornblende in a propylitically altered fine-grained to cryptocrystalline matrix with prominent eutaxitic structure; contains abundant subangular mafic fragments to 1 cm across and very locally, reflecting the underlying basement, rounded amphibolite, gneiss, schist, or granite fragments to 5 cm in diameter. Also contains irregular-shaped, small to large bodies of locally fossiliferous limestone and dolomite, some about 500 ft (150 m) in length, that have been locally hydrothermally altered and mineralized; exposed in valley walls of Cunningham Gulch and underground in Osceola and Pride of the West mines. Minimum total thickness about 2,300 ft (700 m)

Tsp

Picayune Megabreccia Member--Slightly altered, dark-gray, moderately porphyritic rocks in thin to medium thick, brownish-gray-weathering, commonly amygdaloidal lava flows of basaltic andesite that crop out in Spencer Basin and on Sugarloaf in the southwest part of quadrangle. Thickness zero to 100 ft (0-30 m)

Tsj

San Juan Formation (Oligocene)--Thick-bedded to massive, gray to greenish-gray, locally purple or red, reworked lahar or mudflow breccia consisting of finely comminuted matrix and fragments 1½ ft (0.5 m) across of volcanic debris predominantly of intermediate composition; intermixed with sandy tuff and tuff conglomerate throughout area, and lava flows (near-source rocks or vent facies) of dark-gray to black, porphyritic andesite south of Greenhalgh Mountain. Propylitically altered throughout. Formation representative mostly of outflow facies in coalescing marginal volcaniclastic aprons of stratovolcanoes centered north to northeast of quadrangle. Unconformable basal contact. Thickness ranges from zero to more than 650 ft (0-200 m) in southeast part of quadrangle

Sedimentary Rocks

Tt

Telluride Conglomerate (Eocene)--Gray indurated conglomerate with a slightly calcareous silty to sandy matrix. Subangular to subrounded fragments of schist, gneiss, and quartzite range from 1-10 cm in size. A few scattered remnants of the formation are preserved in hollows on underlying erosion surface within the south half of the quadrangle, and on both sides of the graben in upper Cunningham gulch. Deposition of the unit was preceded and followed by extensive erosion.

Thickness ranges from zero to 35 ft (0-10 m)

PRE-TERTIARY ROCKS

Sedimentary Rocks

Pm Molas Formation (Lower and Middle Pennsylvanian)--Thin lenticular beds of reddish-brown and red calcareous mudstone, shale, sandstone, and minor chert- and limestone-pebble conglomerate. A few thin pinkish sandstone and limestone beds in uppermost part and a thickness of about 100 ft (30 m) suggest that some of the overlying Hermosa Formation of Upper and Middle Pennsylvanian age may be included in the outcrop on the east side of the graben near the upper (south) end of Cunningham Gulch

Ml Leadville Limestone (Lower Mississippian)--Medium to dark gray fine-grained limestone, locally dolomitic, in medium-thick to massive beds. Locally coarsely crystalline, brecciated, or with irregular-shaped pods and stringers of black chert. Uppermost part of unit exhibits solution-weathered limestone fragments intermixed in red shale and mudstone. Exposed in graben in upper Cunningham Creek gulch. Thickness about 195 ft (60 m)

MDu Undivided Leadville (Lower Mississippian) and Ouray (Upper Devonian) Limestones--Exposed as irregular-shaped masses or blocks of very light gray to blue-gray limestone wholly within the Eureka Member in Cunningham Gulch and as a layered erosional remnant unconformably on Proterozoic rocks in Stony Gulch. Random orientation of blocks suggests they slid off the surrounding highlands to the south onto the floor of the subsiding caldera and were engulfed by ash flows closely adjacent to the steep caldera wall

Do Ouray Limestone (Upper Devonian)--Irregular thin- to medium-thick beds of gray to light-brown, dense to fine-grained limestone, locally dolomitic with a few thin calcareous shale partings. Fossiliferous with crinoid columnals and brachiopods; contains some mud cracks. Exposed in graben in Cunningham Creek gulch, and undergound in Pride of the West mine. Thickness 40 to 50 ft (12-15 m)

De Elbert Formation (Upper Devonian)--Thin bedded yellow or buff, red, and green calcareous shale and fine-grained sandstone; a few thin sandy limestone beds. Exposed in graben in Cunningham gulch; unconformably overlies metamorphic rocks of Proterozoic Irving Formation. Thickness about 40 ft (12 m)

Ꞓi Ignacio Quartzite (Upper Cambrian)--Well-bedded dense white quartzite with a few thin yellow and red shaly partings; at base is quartzite-pebble conglomerate 3 ft (1 m) or less in thickness. Unconformable basal contact upon metamorphic rocks of Proterozoic Irving Formation. Exposed only on north wall in headward basin of Deer Park Creek, southwest part of quadrangle. Thickness about 40 ft (12 m)

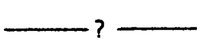
Intrusive Rocks

OꞒid Diabase (Ordivician or Cambrian)--Dark greenish-gray to black, fine- to medium-grained diabase dikes about 3 ft (1 m) thick. Composed of labradorite and augite in a subophitic texture; locally altered to chlorite and calcite. Found only in Proterozoic rocks in southern part of quadrangle. Some or all of these dikes possibly may be of Precambrian age

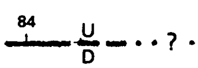
Metamorphic Rocks

Xi Irving Formation (Early Proterozoic)--Metasedimentary and metavolcanic rocks composed principally of gray to greenish-gray, foliated and banded plagioclase-quartz-biotite gneiss interlayered with thin layers of biotite schist, muscovite schist, hornblende schist, and black amphibolite; volcanic origin of amphibolite, in part, is indicated by relict pillow structure in vicinity of Highland Mary Lakes (Barker, 1969). Exposed in southern part of quadrangle and in Rocky and Stony Gulches

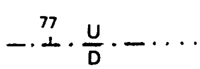
EXPLANATION OF SYMBOLS



Contact--Queried where uncertain



Fault--Showing dip. Dashed where approximately located; dotted where concealed; queried where uncertain. Dip not shown where vertical. U, upthrown side; D, downthrown side



Vein or mineralized fault or fissure--Showing dip. Dotted where concealed. Dip not shown where vertical or where unmeasured. U, upthrown side; D, downthrown side

Dike--Showing dip

Slump scarp--Hachures indicate direction of slumping

Strike and dip of beds

- Inclined
- Horizontal
- Vertical

Strike and dip of foliation

- Inclined
- Vertical

Bearing of plunge of lineation--Combined with foliation symbols

Hydrothermally altered rock--Quartz-sericite-clay type commonly associated with ore deposits or structural features related to ore localization; locally includes quartz-clay acid sulfate type along the Animas River valley