Resource Series 21

Precambrian Tungsten and Copper-Zinc Skarn Deposits of South-Central Colorado

by E.W. Heinrich

Department of Natural Resources
Colorado Geological Survey
Denver, Colorado / 1981

COVER ILLUSTRATION: Mirror image sketch of a cut sample from the Cleora copper-tungsten skarn, Chaffee County, Colorado by Cheryl Brchan.

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PRECAMBRIAN TUNGSTEN AND COPPER-ZINC SKARN DEPOSITS OF SOUTH-CENTRAL COLORADO

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DOI: https://doi.org/10.58783/cgs.rs21.sgxa7618

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1313 Sherman Street, Room 715
Denver, Colorado
1981

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ABSTRACT

Three intergrading types of mineralized skarn deposits occur in the Precambrian metamorphic rocks of south-central Colorado (Park, Fremont, Chaffee and Custer Counties): tungsten (scheelite-powellite) skarns; copper-tungsten (scheelite) skarns; and copper-zinc skarns. The scheelite skarns are essentially confined to recrystallized and metasomatized calc-silicate gneiss layers and lenses, a minor metamorphic rock type. The other two types occur mainly in amphibolitic gneisses and biotitic and sillimanitic gneisses, all common rock types. The copper-tungsten deposits of the Cleora district, Chaffee County, comprise a distinct intermediate type characterized by fracture-controlled veins.

The deposits, partly of metamorphic and partly of metasomatic origin, are wall-rock-controlled (all three types) and fracture-fault-controlled (Cu-W, Cu-Zn). They all apparently were formed about 1700 m.y. ago and appear to be related genetically to intrusions of Boulder Creek granitoid plutons, syntectonically emplaced during the apogee of metamorphism of Idaho Springs rocks.

Many of the deposits have been prospected and a few of the copper-zinc deposits were developed during the latter part of the 19th and early part of the 20th century into significant mines (Betty, Isabel, Cotopaxi, Sedalia, Independence, Marion). Because of their geological restrictions, the tungsten deposits offer little hope for any substantial production, but some of the copper-zinc deposits are worth a modern re-examination.

INTRODUCTION

GENERAL STATEMENT

Skarn deposits of tungsten and of copper-zinc are widespread in the Precambrian terranes of south-central Colorado, especially in Park, Fremont and Chaffee Counties. The three main copper deposits, the Sedalia, the Cotopaxi, and the Betty, were discovered in the latter part of the 19th century. The Sedalia was located in October, 1881 (Van Alstine, 1969); Lindgren (1908) reports it was opened about 1883. It was noted by Cross (1895, p. 4), who states "The enormous dodecahedrons (of garnet), so widely distributed by mineral dealers, come from a fine chlorite schist near the Sedalia mine, and the copper deposit of the latter is a thick bed of actinolite schist richly impregnated with copper minerals." These famous Sedalia garnets (p. 94) had been analyzed by Penfield and Sperry in 1886 (see Dana, 1909, p. 441).

The Cotopaxi mine was reported in production in 1883 by Corregan and Lingane (see Lovering and Goddard, 1950, p. 67). It was already famous mineralogically for fine specimens of gahnite, which had been studied by Genth and analyzed by Kellar in 1882 (see Dana, 1909, p. 223). The early history of the Betty mine is obscure; it was studied by Boyd (1933) and also by Eckel in 1932 (see Lovering and Goddard, 1950, p. 69), who also examined the Isabel mine.

Many of the tungsten skarns of Chaffee County apparently were first prospected during World War I and were reprospected during World War II. Tungsten ore was discovered in the Tarryall district of Park County in the summer of 1943, and intensive prospecting took place in Park and Fremont Counties during World War II and the Korean War.

The deposits are generally referred to as "skarns", an old Swedish mining term originally used for the silicate gangue assemblage (amphiboles, pyroxenes, garnets, etc.) of some Archean iron and sulfide deposits, especially ones developed by replacement of calcitic and dolomitic marbles. Today the term is used for coarse-grained granoblastic (nonfoliated) assemblages of calcium-bearing silicates developed in high-grade regional metamorphic rocks of calcareous or dolomitic composition by recrystallization and metasomatic introduction of such elements as Si, Al, Fe and Mg. Mineralization is variable: deposits of iron oxide minerals, Cu, Zn and even Pb sulfides and scheelite occur as skarns. Unfortunately the term skarn also has been extended by many geologists to include Ca-Mg silicate assemblages of pyrometasomatic (contact metasomatic) deposits developed by recrystallization and metasomatism of sedimentary rocks along the contacts between igneous plutons and their wall rocks. This type is better differentiated as "tactites." Skarns may be localized along igneous pluton contacts but usually are not. Many geologists use "skarn" for both types of deposits, but in this report it designates metasomatic deposits developed exclusively in metamorphic rocks, usually not at igneous contacts.

LOCATION

Skarn tungsten deposits occur in south-central Colorado in Park County in the well-defined Tarryall district west of Lake George. The Guffey district is along the southern Park County line, with a few scattered deposits elsewhere in Fremont County. In Chaffee County the copper-tungsten vein-skarn deposits are closely bunched in the Cleora district in the southeastern corner of the county, with a few other skarn deposits on Poncha Pass.

Copper and copper-zinc skarns are less numerous by far than tungsten skarns and tend to occur scattered, isolated, or in small groups; thus they are not congregated in clearly defined districts. Examples occur in eastern and southern Park County, throughout Fremont County, and in the general vicinity of Turret in Chaffee County. A few also have been mined in the southern Wet Mountains of Custer County.

Precambrian cupriferous skarns are not confined to the south-central Counties of Colorado, but a few are also found widely scattered in Jefferson, Boulder, Grand, Larimer, Clear Creek and Gilpin Counties (Lovering and Goddard, 1950). Similarly, Precambrian tungsten skarn deposits occur in the northern and central Front Range in Larimer, Jefferson and Gilpin Counties and in northwestern Saguache County (Tweto, 1960).

PREVIOUS WORK

The Cotopaxi and Sedalia deposits were studied first by Lindgren (1908); the Betty (Lone Chimney) mine by Eckel (1932), reported in Lovering and Goddard (1950). Reports on these Precambrian deposits were included in the thesis of Boyd (1934) and the summary by Gabelman (1953). A general study of the tungsten skarns was conducted by Tweto (1960), and individual prospects are described by Belser (1956).

The writer first examined both copper-zinc and tungsten deposits in Fremont, Park and Chaffee Counties in 1942-1943 while a member of the U.S. Geological Survey. Beginning in 1948 and continuing for about 30 years, students of the Department of Geological Sciences of the University of Michigan, under the writer's direction, have been mapping the geology of south-central Colorado with emphasis on the Precambrian rocks. The results are only partly published from the following PhD and MS theses:

Heinrich (1948) (PhD) - Eight Mile Park, Fremont County
Buckwalter (1950) (PhD) - Guffey area, Park and Fremont Counties
Bever (1954) (PhD) - Never Summer Mountains
Boyer (1959) (PhD) - Southern Wet Mountains, Custer County
Salotti (1960) (PhD) - Cotopaxi-Howard area, Fremont County
Gross (1962) (PhD) - Mt. Rosa area, El Paso and Teller Counties
Shappirio (1962) (PhD) - Tallahassee Creek area, Fremont County
Dahlem (1965) (PhD) - Lookout Mountain area, Fremont County
Vian (1965) (PhD) - Devil's Hole area, Fremont County
Reuss (1967) (MS) - Gem Park, Fremont and Park Counties

Moore (1969) (PhD) - Northern Wet Mountains, Fremont and Park Counties
Pierce (1970) (MS) - Copper Boy deposit, Fremont County
Reuss (1970) (PhD) - Wilson Park area, Fremont County
Boardman (1971) (PhD) - Salida-Guffey area, Chaffee County
Simmons (1973) (PhD) - South Platte area, Jefferson County
Spencer (1978) (MS) - Iron Mountain, Fremont County
Alexander (1981) (PhD) - McClure Mountain, Fremont County

In addition to the general field and laboratory studies of the deposits, the writer sampled many of them during a systematic search for nonpegmatitic beryllium deposits during 1958.

TYPES OF DEPOSITS

TUNGSTEN DEPOSITS

The Precambrian tungsten deposits of Colorado consist of disseminations of scheelite ± powellite in skarns. The skarns have been developed by the recrystallization and metasomatism of calc-silicate gneisses, which are minor stratiform metasedimentary units in the pre-1,700 m.y. metamorphic complex of south-central Colorado. The calc-silicate gneiss units, which form thin layers, lenses and pods commonly in the predominant biotitic, sillimanitic and amphibolitic gneisses, are dark to light colored rocks, some finely banded, some not banded. Mineralogically they are highly variable, with rapid changes across the strike. These units in many places have been recrystallized wholly or in part to skarns--coarse-grained, nonfoliated, granoblastic rocks consisting largely of the same minerals that make up the parent gneisses. In some skarns the grain size becomes gigantic, with single crystals of various species reaching six inches or more in size; i.e., they have pegmatoidal aspect.

In addition to recrystallization, material within the skarns has been rearranged, leading to monomineralic segregations and veins. Generally no systematic mineral distribution (i.e., zoning) is apparent. Scheelite and some powellite occur sporadically distributed through the skarns, but some skarn bodies are very sparsely mineralized or even not mineralized at all. The scheelite forms anhedral grains to euhedral tabular crystals ranging in size from microscopic to rarely an inch in length. Their distribution bears no relationship to fractures; they appear to have been formed by replacement.

COPPER-ZINC AND COPPER DEPOSITS

The copper-zinc and copper skarns generally avoid the calc-silicate gneisses; they prefer amphibolites as hosts and to a lesser degree anthophyllite- or gedrite-cordierite gneiss, sillimanite gneiss and rarely biotite gneiss. One has even been formed in pegmatite (Leeks Lode, p. 82).

The host hornblende-rich rocks are amphibolites (hornblende-plagioclase) or hornblende gneisses (hornblende-plagioclase-quartz), dark colored, banded or not banded. These rocks, along with adjacent or intercalated biotite, sillimanite or anthophyllite-cordierite gneisses, are locally recrystallized to coarse-grained (in places, pegmatoidal) aggregates of the rock-forming silicates (skarn rocks), which either duplicate or closely approximate the minerals of the metamorphic parent. As usual, the skarns are not foliated but granoblastic with irregular segregations and radial crystal groups. The mineralization usually includes zinc as early gahnite followed by a sulfide phase of chalcopyrite and sphalerite with less common galena.

COPPER-TUNGSTEN DEPOSITS

The copper-tungsten veins of the Cleora district in Chaffee County (Tweto, 1960; Boardman and Heinrich, 1971) are a distinctive type, structurally and mineralogically, that links the copper and the tungsten skarns. The Cleora deposits are tabular veins, fault and fracture-controlled, which occur mainly in amphibolites. They consist of a vein core rich in quartz and a vein margin of mainly biotite, calcite and scapolite both enclosed in sahlbands of mainly columnar comb-structure scapolite, all within a halo of scapolitized amphibolite (Fig.6). Copper mineralization is represented by chalcopyrite; tungsten by scheelite; zinc is absent.

GENERAL GEOLOGY

GENERAL STATEMENT

The Precambrian rocks of Park, Fremont, Chaffee and Custer Counties consist of four main groups:

1. Pre-1700 m.y. metamorphic rocks
2. Migmatite
3. Granitoid plutons of three main age groups
4. Gabbroic dikes

Locally preserved, mainly as downfaulted blocks, are remnants of Paleozoic and Mesozoic sediments (Ordovician to Cretaceous). Intruding the Precambrian metamorphic rocks and migmatites is a cluster of alkalic-mafic-carbonatitic plutons of Cambrian age (McClure Mountain-Iron Mountain, Gem Park, Democrat Creek and several minor bodies, plus their dike retinues). These are in southern Fremont and northern Custer Counties.

The area falls within two main structural provinces: the eastern, which includes Park, Fremont and Custer Counties, is separated from the western (Chaffee County) by the Paleozoic-Mesozoic block of the Sangre de Cristo Range. On opposite sides of this block the Precambrian rocks differ markedly, as do the Tertiary units. The line of demarcation is the trace of the Pleasant Valley Fault about five miles west of Cotopaxi. Along this fault Precambrian rocks have been thrust westward over Paleozoic rocks. The Sangre de Cristo block, well exposed along the Arkansas River between Howard and the Chaffee County line, consists of Paleozoic sediments (Ordovician to Permian) folded into a major recumbent syncline. At the Chaffee County line Ordovician sediments rest unconformably on Precambrian metamorphic rocks, which here are hosts for the Cleora district Cu-W veins.

Tertiary volcanics in Park and Fremont Counties have descended southward from centers in Park County (Thirtynine Mile Volcanic Field). Volcanic formations in Custer County have come mainly from the Westcliffe-Silver Cliff center. A third distinctive group of Tertiary volcanic rocks occurs as capping remnants over about 10% of the Salida-Turret area.

Tertiary sediments are present along with volcanics in a number of erosional or structural basins, e.g., Tallahassee Creek area and Echo Park graben ("Big Hole"). A few patches of high-level Tertiary gravels lie as much as 1100 feet above the present Arkansas River level.

Quaternary sediments include river terrace gravels, travertines (closely related to faults), landslide deposits, and valley alluvium.

METAMORPHIC ROCKS

General

The pre-1700 m.y. metamorphic rocks of Park and Fremont Counties have generally been referred to as "Idaho Springs Formation" in recognition of their general similarity to rocks of the same metamorphic age and same gross petrology (both bulk composition and metamorphic mineralogy) as those in the type section of the Idaho Springs Formation about 25 miles west of Denver. Tweto (1977, p. D5) has been critical of such practice: "...indiscriminate extension has made it (the name) a wastebasket for a compositional suite of metamorphic rocks; in such usage the term has no stratigraphic meaning..." In his summary on the nomenclature of Colorado Precambrian rocks, rocks of the Idaho Springs Formation are designated as Precambrian X, a usage also followed by Taylor and others (1975a, 1975b) on their maps of the Royal Gorge and Cotopaxi quadrangles. The W-X-Y-Z nomenclature devised for major Precambrian units by the U.S. Geological Survey is awkward, and has received unsympathetic attention from geologists not bound by the Survey's restrictions. As has been pointed out by Hawley and Wobus (1977, p. B5), three main approaches have been made in attacking the problems of naming and correlation of Precambrian units: "(1)...to name and describe the rock units lithologically without recourse to formational names, (2) to assign local formation names, and (3) to use very general formational names over wide areas. None of these is wholly satisfactory." I agree with Hawley and Wobus.

The writer prefers modification of the last approach, recognizing that the designation "Idaho Springs Formation" carries with it recognition of metamorphic age and petrologic similarities but not necessarily absolute stratigraphic identities, which may never be determined. This may well make the term "Idaho Springs" a basket but perhaps a useful one. Furthermore, as will be shown, not all of the metamorphic rocks in Fremont County belong in the category of the Idaho Springs Formation. What the practice has clearly demonstrated is that metamorphic "formations" cannot always be strictly defined and not on the same criteria as sedimentary formations, as described in the following discussion.

Idaho Springs Formation

General

Rocks assigned to the Idaho Springs Formation in Park and Fremont Counties are a thick complex of high-grade metasedimentary and meta-igneous layers that have been strongly folded, extensively faulted, and migmatitized to varying degrees. Owing largely to the extensive migmatitization and the absence of useable marker beds, the delineation of major fold structures is exceedingly difficult. Isoclinal folding is common, and the layers can be complexly contorted on a small scale, especially where migmatitization has been intense.

With the exception of some of the lime-silicate layers and pods and some amphibolites, the metamorphic rock units are markedly to strongly foliated. In most places this foliation conforms to the attitude of any compositional banding and that of contacts between units of contrasting petrology and thus is inherited from original bedding. In some places, however, especially where petrologic units grade complexly and abruptly along their strike, especially within zones of isoclinal folds, into other units of markedly different composition, the foliation may be axial-plane cleavage and is not derived from original bedding.

In the northern Wet Mountains south of the Arkansas River in Fremont and Custer Counties Singewald and Brock (1956) have mapped three longitudinal belts showing different fold styles (p. 580); "One belt is dominated by a broad, doubly plunging major anticline on whose limbs are subordinate folds and structural terraces; the lineation, essentially parallel to fold axes, generally plunges less than 40 degrees. Another belt is a homoclinal zone of steep dips in which lineation is mostly wanting. The third belt is one of crumpled isoclinal folds in which lineation is subperpendicular to the strike of the foliation but essentially parallel to minor fold axes."

Neither the bottom nor the top of the Idaho Springs has been observed, but estimates of its minimum thickness, which can be made in several areas, range from 2000 to 8000 feet.

In the western part of the Texas Creek-Devil's Hole area, two major anticlinal structures have been deciphered (Vian, 1965). In the vicinity of Texas Creek the axis of the Texas Creek anticline trends nearly east-west, plunging eastward. This antiform is transected by the north-northeast-trending Texas Creek fault, and the steeply plunging nose of the fold is repeated east of the fault. Northwest of the Devil's Hole and Bull Gulch a major anticlinal axis (Antelope Gulch anticline) trends northwest and plunges southeastward. The folds, defined by the layering and foliation of the Idaho Springs rocks and the foliation of the Boulder Creek granite, appear to have been initiated just before the intrusion of the syntectonic granite and, in part, controlled the intrusion of the pluton.

Petrology

The petrologic rock types of the Idaho Springs Formation in south-central Colorado are listed in Table 1.

The most abundant rocks are the feldspathic gneisses, the biotitic and sillimanitic gneisses and amphibole gneisses and amphibolites. Rare are quartzites, lime-silicate gneisses and cordierite gneisses. Marbles are absent, and, except for a single small occurrence in the Cotopaxi area, iron formation also is absent. In the metapelites, sillimanite is usually the sole representative of the Al_2SiO_5 polymorphs.

The interlayering of the several rock types is on a range of scales, from several and tens of feet (Table 2) to scores and even hundreds of feet.

Origin

The Idaho Springs rocks of south-central Colorado are very similar to metamorphic rocks of the Central City Quadrangle in the east-central part of the Front Range described by Sims and Gable (1964, 1967). Here the main petrologic types and their interpreted parents are:

microcline gneiss - arkose
biotitic gneisses } interlayered graywacke and shale
sillimanite gneiss }
amphibolite - mainly impure Ca-Mg-rich sediments
cordierite-gedrite rocks - "uncertain"
calc-silicate gneisses - impure carbonate rocks

The feldspathic gneisses of the Idaho Springs have been assigned various parentages: 1) orthogneisses either from a) granitoids or b) rhyodacitic volcanics (flows and tuffs) (Taylor and others, 1975a, 1975b); 2) paragneisses from arkoses. In south-central Colorado of this report the writer believes that none of the feldspathic gneiss units represent metagranitoids but were derived from rocks that were originally layered (sediments or volcanics). Reasons for this conclusion are:

1. The feldspathic gneiss units are invariably generally concordant with the contacts of adjacent units of markedly different petrology.

2. The gneiss commonly is well banded.

3. It grades into biotite and sillimanite gneisses both along and across the strike, and it also interfingers with these rock types which are clearly of sedimentary ancestry.

Table 1. Rock Types of the Idaho Springs Formation, South-Central Colorado

Type	Mineral Assemblages	Relative Abundan
Feldspathic gneiss	plag - qtz - bio	Very abundant and widespread
	plag - K spar - qtz - bio	
	ortho-bio ± plag, gar	
Biotite gneiss and schist	bio - K spar - qtz ± musco	Very abundant and widespread
	bio - K spar - qtz - plag	
	bio - qtz - plag	
	bio - hbld - qtz - plag	
Muscovite schist and gneiss	musco - qtz ± sill, gar	Locally importan in units of restricted size
	musco - qtz - bio ± plag	
	musco - qtz - K spar - bio	
Sillimanite gneiss and nodular sillimanite gneiss	qtz - bio - sill	Abundant and widespread
	qtz - sill (nodules and lenses)	
	qtz - sill - musco ± gar	
	qtz - bio - sill - musco ± plag	
Garnet gneiss	bio - qtz - gar ± sill	Locally common
	bio - qtz - plag - K spar - gar	
Cordierite gneiss	musco - bio - sill - qtz	Uncommon
	plag - cord	
	quartz - bio - plag - cord	
Quartzite	qtz - musco	Rare
	qtz - sill	
	qtz - gar	
	qtz - mag (martite)	
Amphibolite and amphibole gneiss	hbld - plag - qtz	Very abundant and widespread
	hbld - plag - gar, epi	
	hbld - cumm - plag ± bio, qtz	
	hbld - bio - plag - qtz	
	hbld - anth - plag	Rare
	hbld - clinoz - diop	Rare
	hbld - micro - qtz - plag	
	hbld - bio - ol - mag - plag	Rare
	hbld - qtz ± bio	
	anth - cord ± bio	Rare

Table 1 (Cont.).

Type	Mineral Assemblages	Relative Abundance
Lime-silicate gneiss	scap - diop	Rare
	qtz - K spar - scap - epi - diop	
	qtz - hbld - epi - gar - mag	
	qtz - gar	
	qtz - gar - diop ± epi	
	qtz - diop - epi - gar ± scap	
	epi - act	
	qtz - plag - diop	
	qtz - epi	
	calc - qtz - diop - epi	
	hbld (act)	
	calc - diop	
	calc - gar	
	calc - qtz - epi ± scap, chlor	

Abbreviations:

act - actinolite; anth - anthopyllite; aug - augite; bio - biotite; calc - calcite; chlor - chlorite; clino - clinozoisite; cord - cordierite; cumm - cummingtonite; diop - diopside; epi - epidote; gar - garnet; hbld - hornblende; spar - potash feldspar (either orthoclase or microcline);
mag - magnetite; micro - microcline; musco - muscovite;
ol - olivine; ortho - orthoclase; plag - plagioclase; qtz - quartz; scap - scapolite; sill - sillimanite.

Table 2. Partial stratigraphic section in Hindman Gulch, Texas Creek, Colorado (Vian, 1965).

Unit	Thickness, in feet
Biotite gneiss, medium gray[1], grades upward to muscovite schist	10.5
Hornblende gneiss	14.5
Biotite gneiss, dark gray	0.6
Hornblende gneiss	35.0
Biotite gneiss, dark gray	5.6
Hornblende gneiss	1.3
Biotite gneiss, dark gray	2.5
" , medium gray	8.7
" , dark gray	1.8
" , medium gray	2.5
" , dark gray	3.1
" , medium gray	5.0
Granite sill	13.0
Biotite gneiss, medium gray	1.0
" , dark gray	1.4
" , medium gray	1.0
" , dark gray	4.4
" , medium gray	4.6
" , dark gray	1.9
Hornblende gneiss	2.6
Biotite gneiss, medium gray	23.3
" , dark gray	5.0
" , medium gray	7.5
Hornblende gneiss	6.7
Biotite gneiss, medium gray	30.0
Hornblende gneiss	2.5
Biotite gneiss, light gray	11.5
Hornblende gneiss	7.5
Biotite gneiss, medium gray	7.5
Shear zone	

[1] Color darkens with increasing biotite content.

4. The feldspathic gneiss encloses small thin lenses, pods, and stringers of biotite gneiss, sillimanite gneiss, amphibolite, hornblende gneiss, calc-silicate gneiss, and cordierite-amphibole rock.

From these geological characteristics and from the detailed petrography, the writer has concluded, in agreement with Sims and Gable (1967), that most of the feldspathic gneisses were arkoses initially. The suggestion by Taylor and others (1975a, 1975b) that extensive volumes of rhyodacitic ash and flows were the parent material is unacceptable. No relict textural features (e.g. blastoporphyritic) remain to suggest a volcanic origin, and the intergradation to and interlayerings with what are clearly paragneisses argues for an arkosic parent. Some of the amphibolite lenses and layers within the feldspathic gneiss are derivatives of basalt flows. The inclusion of subordinate basaltic layers within a predominantly felsic volcanic sequence is an unlikely combination.

Biotitic and sillimanitic gneisses are closely related spatially and compositionally and intergrade. Garnet occurs in some units of both types, and some sillimanite gneiss contains essential cordierite. On the basis of geological characteristics and compositions the original rocks consisted of an interlayered graywacke-shale sequence. The biotite-quartz-plagioclase gneiss represents the graywacke, with hornblende-bearing variants being derived from graywacke sediments somewhat richer in lime, and garnetiferous types from graywackes somewhat enriched in iron and manganese. Interbedded shales were recrystallized to sillimanite-biotite gneisses, with garnet-bearing and cordierite-bearing types stemming from iron-manganese-rich facies and magnesium-rich, calcium-poor facies, respectively.

The nodular sillimanite gneisses are widespread. In these distinctive rocks, ellipsoidal nodules flattened parallel with the foliation and ranging in size from a few millimeters to 16 centimeters, weather to a relief that imparts a pseudoconglomeratic aspect to the rock surfaces. Excellent examples occur in Henthorn Gulch near Cotopaxi; in East Gulch of the Devil's Hole area, and along the northern part of Copper Gulch, all in Fremont County. The nodules consist of quartz, 20-70% sillimanite and commonly retrograde coarse muscovite replacing sillimanite.

Nodular sillimanite gneisses are widespread rocks in the Precambrian of the Rocky Mountains (e.g. see Heinrich, 1950, for occurrences in the Cherry Creek Group of southwestern Montana; Spurr and Garrey, 1908, for occurrences in the Georgetown quandrangle, Colorado). Various theories of origin for these enigmatic nodules have been proposed, including:

1. metamorphism of quartz-kaolinite nodules,
2. boudinage (± rotation) of original quartz-kaolinite layers, and
3. metamorphic differentiation.

The writer favors hypothesis 2, above. In any single outcrop area the nodules all tend to fall within a relatively restricted size range.

Cordierite-rich mica gneisses are rare, constituting about 1% of the total volume of the Idaho Springs. One notable example occurs in the Texas Creek area and is well exposed along U.S. 50 and in Hindman Gulch about four miles east of Texas Creek. Here a layer of nodular cordierite-muscovite schist, 1280 feet thick, has round, blocky or ellipsoidal nodules of cordierite, as much as 15 cm. long, set in a muscovite-quartz matrix (Travis, 1956; Vian, 1965). The blocky ones are single-crystal porphyroblasts, whereas the others are polygranular. This unit is one of the few easily recognizable marker beds in the Idaho Springs of central Fremont County.

The calc-silicate rocks, the principal hosts for the tungsten skarns, are petrologically the most variable of the Idaho Springs units and may be recrystallized and metasomatized to skarns. The original (pre-skarn) metamorphic rocks were probably impure carbonate rocks. Calc-silicate gneisses form small lensoid and podiform units usually only a few feet thick with lengths rarely as much as a few thousand feet. Most are much shorter. Some grade into amphibole gneiss. A more detailed description of these rocks appears in the section on the tungsten skarns.

Amphibolites and hornblende gneisses are both widespread and abundant. It is estimated that these dark hornblende-rich rocks constitute as much as 20% of the Idaho Springs. Typically they are interlayered with biotite gneiss (Table 2) into which some grade to form biotite-hornblende gneiss. The layers range greatly in size from ribbons a few inches thick to huge blocks 0.75 mile thick and two miles long. Some units form massive bodies that are conformable with the enclosing biotite gneiss only in a very general way, and, in a few examples, amphibolite contacts transect both the foliation and layering of other Idaho Springs units. In general amphibolite (hornblende-plagioclase) dominates in the massive bodies, whereas hornblende gneiss (hornblende-plagioclase-quartz) predominates in the interlayered types. Some amphibolitic skarn bodies are developed in hornblende gneiss.

Unlike in the Salida area of Chaffee County (p. 14), where the grade of metamorphism is sufficiently lower so that original igneous and sedimentary textural features have been partly preserved, in Park and Fremont counties original diagnostic textural characteristics have been obliterated during metamorphic recrystallization. Consequently, it is exceedingly difficult to differentiate between orthoamphibolites and para-amphibolites solely on the basis of mineralogy and texture. The writer concludes that both types are represented in Park and Fremont Counties; orthoamphibolites from basalts and diabases and para-amphibole gneisses from calcareous and dolomitic shales. Some of the orthoamphibolites may also represent metaspilites.

Cordierite-amphibole gneisses, either with anthophyllite or gedrite, are the least common rock type of the Idaho Springs. Lensoid bodies a few feet to tens of feet wide and as long as several hundred feet are typical.

As Sims and Gable (1967) have pointed out, these rocks are unusually high in both ferrous iron and magnesium and abnormally low in calcium, sodium and potassium as compared with any known ordinary sedimentary or igneous rock. These rocks range from silica-poor types to others with excess silica.

Cordierite-amphibole gneiss also are transformed locally to skarns of similar mineralogical composition which contain copper mineralization. Most of the cordierite-anthophyllite/gedrite rocks of Fremont and Park Counties are associated closely with amphibolites. In the Central City quadrangle they are associated with cummingtonite-hornblende gneisses (Sims and Gable, 1963, 1967).

Vallance (1967) has pointed out that cordierite-anthophyllite/gedrite rocks are the compositional equivalent (apart from less H_2O) of mafic lavas that have undergone extreme alteration under low-temperature, hydrous conditions of late-magmatic and diagenetic environments, which has resulted in major chemical reconstitutions. Thus the special chemical requirements of these rocks are met with only in a very restricted group of highly altered parent materials. There is apparently no need to have recourse to mechanisms of metasomatic transfer during subsequent metamorphism. Such a genetic interpretation is in accord with the geology of these rocks in Park and Fremont Counties where they

1) are very small and rare units,

2) are associated with amphibole gneisses (possibly metabasalts),

3) and where all other rock types have been recrystallized isochemically.

It has also been suggested that the unusual composition of these rocks has resulted from the removal of an anatectic granite fluid from the parent rock during partial melting associated with high-grade metamorphism (Lal and Moorhouse, 1969). This is unacceptable for the south-central Colorado occurrences where these rocks show little granitization. Nor do their neighbors display unusually strong granitization from any "expelled" anatectic fluids.

All of the Idaho Springs rocks in Fremont, Park and Custer Counties have been metamorphosed to upper amphibolite facies, as is indicated by the following stable assemblages:

mafic: hornblende-intermediate to calcic plagioclase

pelitic: orthoclase-sillimanite

Other diagnostic minerals include cordierite, gedrite-anthophyllite; cummingtonite, diopside, and grossularite. In addition, regional migmatitization (see p. 18) is widespread in rocks of pelitic composition.

Two types of sillimanite are widespread: 1) disseminated needles in biotite-quartz-K feldspar gneisses, and 2) sillimanite needles randomly oriented in quartz-sillimanite nodules. In the first occurrence sillimanite replaces biotite probably via the reactions described by Shelley (1968):

$$K_2Fe_5Al(OH)_4Si_5Al_3O_{20} + 2SiO_2 \rightarrow 2KAlSi_3O_8 + Al_2SiO_5 + {}^{2}H_2O + 5FeO$$

biotite quartz orthoclase sillimanite

Retrograde metamorphic effects are widespread, apparently related to the final stages of cooling of both the Boulder Creek and Silver Plume granite plutons. The main retrograde changes include:

a) in sillimanite gneiss, replacement of sillimanite by coarse metacrysts of muscovite;

b) in cordierite gneiss, pinitization of cordierite;

c) in amphibolite and hornblende gneiss, sericitization and saussuritization of plagioclase and chloritization of hornblende.

Metasomatic epidote-rich rocks also are widely developed, locally in large bodies, as, e.g., northeast of Lookout Mountain in Fremont County (see Green Dove mine, p. 91), where epidotization has strongly affected 1) hornblende gneisses, 2) calc-silicate rocks and 3) a red leucogranite.

Salida Area

The metamorphic rocks of the Salida area differ in many aspects from those in Park and Fremont Counties. Both groups were derived primarily from clastic sediments, most of which were fine-grained, argillaceous but rather impure shales. However, in the Salida area amphibolites and quartzites are significantly more abundant than in Park and Fremont Counties. Neither group contains any pure marbles or iron formation. In addition the metamorphic rocks east of the Sangre de Cristo block are more strongly migmatitized, more intensely and complexly deformed, more strongly intruded by pegmatites, granitoid dikes and sills, and diabase dikes, and have undergone, in general, a slightly higher grade of metamorphism and deformation. As a result, few relict sedimentary or igneous structures or textures remain.

The Salida metamorphic rocks have been divided into two groups: (Boardman, 1971, 1976) a northern strongly foliated group and a southern weakly foliated group which contrast in several ways (Table 3). The contrasts in mineralogy between metapelites and amphibolites of the two groups are shown in Figure 1.

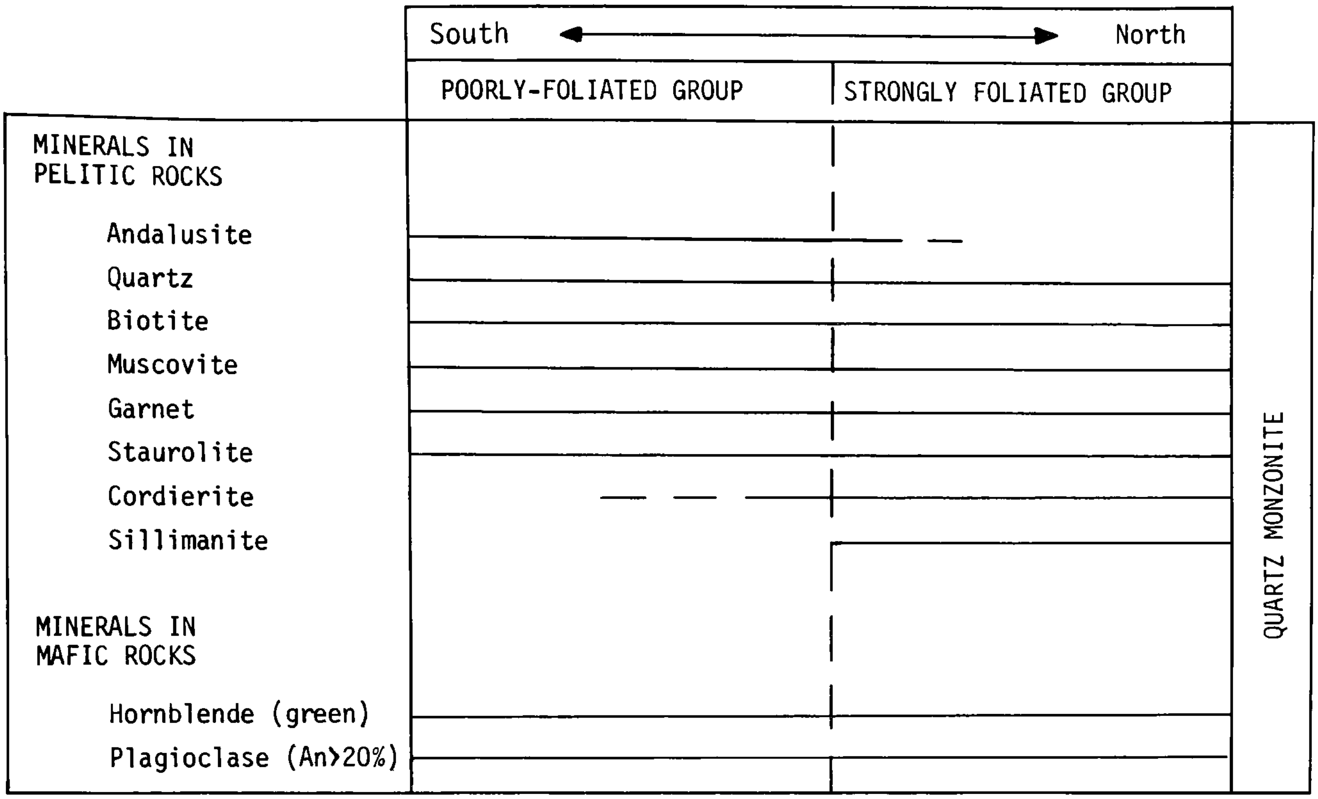


Figure 1. Distribution of minerals in metapelites and amphibolites of the Salida area with respect to metamorphic group and distance from the quartz-monzonite (Boardman, 1976).

Gooseberry Gulch Series

In Fremont County three relatively small and widely separated areas are underlain by a group of distinctive metamorphic rocks that differ markedly from the Idaho Springs rocks in 1) bulk composition, 2) metamorphic grade, and 3) tectonic style. The differences are so striking that they have been separated as an autonomous metamorphic unit named the Gooseberry Gulch Series after occurrences in Gooseberry Gulch in Mitchell Park (Heinrich, Salotti and Reuss, 1968). The areas are: 1) Mitchell Gulch, northwest of Cotopaxi, 2) Wilson Park, northwest of Canon City, and 3) Cover Mountain - Phantom Canyon, north and northeast of Canon City on the north side of the Canon City embayment.

In Mitchell Gulch, four miles north of Howard, an unusual group of light-colored, gently folded, albitic quartzose metasediments underlies an area about four miles long (N-S) (Salotti, 1960) and continues to the south for another about 1.5 miles in migmatitic form. This lensoid area is bounded on the west by the eastern marginal fault of the Sangre de Cristo tectonic block, the Pleasant Valley fault (p. 27) and by Paleozoic

Table 3. Comparison of the strongly and weakly foliated groups of metamorphic rocks of the Salida area (Boardman, 1976).

	Strongly-foliated Group	Weakly-foliated Group
Main rock types	Amphibolites Quartz-feldspar gneisses Mica schists and gneisses	Amphibolites (mostly metagabbros and meta basalts) Meta-welded tuffs Quartzites Banded metapelites
Relationship to quartz monzonite	Occur immediately south of intrusive (within 5 km of contact) Pegmatites abundant	Separated from the qua monzonite by the strongly-foliated group. Nowhere close than 3 km to the pluton. Pegmatites rare.
Rock units	Complexly deformed; considerable interlayering and interfingering Discontinuous lenses Regional trend ENE, variable	Well-defined and continuous along strike trend ENE
Metamorphic structures	Strongly developed foliation; few relict structures	Weakly developed folia tion (except in pelites); relict structures widesprea
Metamorphic grade	Upper amphibolite facies	Middle amphibolite facies; slight decrease in grade southward.
Thickness	6000 m maximum	5000-7500 m

sediments. On the northeast, east and south the Mitchell Gulch rocks are in contact with the Cotopaxi pluton of Boulder Creek granitoid. They are nowhere in contact with rocks assigned to Idaho Springs Formation. The group includes predominantly fine-grained quartz-albite-mica schists, quartz-albite-anthophyllite schists, quartz-albite-garnet schists, and quartz-sericite phyllites.

In addition these rocks contain a distinctive suite of widely distributed accessory minerals including andalusite, epidote minerals, rutile and cordierite (minor). In rocks of pelitic composition sillimanite is totally absent, but one body of sillimanite quartzite crops out in migmatitized and hydrothermally altered rocks near a Boulder Creek cupola. Rocks of mafic composition are absent, and no hornblende or intermediate to calcic plagioclase is present.

To the south the Mitchell Gulch rocks are slightly migmatitized, slightly as compared to "normal" migmatitic effects in Idaho Springs rocks. However, the series has been conspicuously hydrothermally altered with widespread introduction of tourmaline, fluorite, topaz and pyrite (Salotti, 1960). The series is interpreted as polymetamorphic in origin, with contact metamorphism of the albite-epidote hornfels facies superimposed on rocks previously regionally metamorphosed under greenschist facies conditions (Salotti, 1962).

In Wilson Park the Gooseberry Gulch Series consists of a 0.6-mile-thick sequence of quartzite (about 40%), metaconglomerate (<1%), muscovite schist (8%), muscovite-biotite schist (3%), biotite-sillimanite schist (10%), garnet schist (5%), staurolite ± andalusite schist (3%), nodular cordierite gneiss (1%) and banded actinolite-garnet gneiss (trace) (Reuss, 1970, 1974). Relict sedimentary bedding and cross-bedding are remarkably well preserved in the quartzites, sufficiently so that the application of paleocurrent analysis indicates that a major current direction during deposition was from north-northeast to south-southwest.

The northeast-trending tabular block of metasediments is bounded on its northeast end by the Mikesell Gulch fault whose scarp there forms part of the Canon City embayment boundary; its southwestern terminus is capped by remnants of Jurassic and Cretaceous sediments; on its northwest flank it is in intrusive contact with Boulder Creek quartz monzonite; and on its southeast side it is in fault contact with Boulder Creek quartz monzonite. Again, as in Mitchell Gulch, there are no contacts with typical Idaho Springs rocks.

The layers have been deformed into a major nearly isoclinal fold, the Gooseberry Gulch syncline, which has a wavelength and amplitude greater than 2.5 miles, a nearly vertical axial surface and is doubly plunging. Its regional pattern is modified by four pairs of folds arranged en echelon across the sequence; these have wavelengths and amplitudes from 180 to 550 ft. In addition parasitic folds 0.5 inch to 90 feet across and crenulations 0.05 to 0.5 inch across disturb the layer and foliations (Reuss, 1974). No such combination of fold styles has been found in Idaho Springs rocks.

The sequence is only very slightly migmatitized with only a few micaceous gneiss layers affected and these just locally where they have been intruded by pegmatites. However, along the northwest contact with Boulder Creek the contiguous metaconglomerate bed has been tourmalinized and feldspathized with the development of blocky K-feldspar metacrysts similar to feldspar megacrysts in the Boulder Creek.

The metasedimentary block is interpreted by Reuss (1974) as the root of a major roof pendant in the batholithic quartz monzonite. Deposited as mature sediments during alternating advance and retreat of the Precambrian sea over a transitional tidal flat and/or low-relief alluvial plain under stable tectonic conditions, the Gooseberry Gulch rocks contrast markedly with the relatively impure metasediments of the Idaho Springs.

Toward the northeast along the strike of the block, similar quartzites crop out on Cover Mountain and in Phantom Canyon. At the latter the quartzites have been sericitized and somewhat granitized by the enclosing granite.

The Gooseberry Gulch Series shows some similarities to the Coal Creek quartzite-schist group along Coal Creek, five miles south of Boulder. Formerly considered a tectonically younger stratigraphic unit of lower metamorphic grade than the Idaho Springs Formation (Lovering and Goddard, 1950), it is now regarded as a rather localized lithologic facies of the Idaho Springs (Wells and others, 1964). Unfortunately, unlike at Coal Creek, the Gooseberry Gulch Series is not in contact with typical Idaho Springs rocks, so the relations of the two remain obscure.

MIGMATITES

The Idaho Springs rocks are generally migmatitized but to varying degrees, some areas very slightly, other sections so intensely that the individual metasedimentary units can no longer be mapped separately, but the terrane must be mapped collectively as "migmatite." Most of the migmatite is of the regional type, but in several places contact migmatites are well developed; e.g., just west of Texas Creek along the margin of the Texas Creek-Cotopaxi pluton of Boulder Creek granodiorite. However, not all such contacts are marked by contact migmatitization, as, for example, on Eight Mile Park where a huge body of regional migmatite, largely along and south of the Royal Gorge is separated from the Boulder Creek pluton to the north by a one-mile wide zone of essentially nongranitized Idaho Springs rocks intruded mainly by numerous large pegmatites.

Excellent examples of intensely transformed regional migmatites include rocks (all in Fremont County):

1) in the Grape Creek drainage,

2) on both sides of Copper Gulch and its tributaries,

3) in the Oak Creek area, south of Canon City,

4) in the Arkansas Canyon east of Texas Creek,

5) in Road Gulch south of Lookout Mountain,

6) in the Grand Canyon Hills area south of the Royal Gorge, and

7) along Tunnel Drive along the north side of the Arkansas River at its emergence from the Royal Gorge. Here are exposed classic examples of lit-par-lit gneiss.

The migmatites are extremely diverse in texture and in the ratio of granitoid material (neosome) to remaining metamorphic rock (paleosome). The structural relationships of the neosome fractions to the paleosome cover the full range of commonly recognized types of migmatites. In some the neosome is in small conformable lenses and patches; in others it forms continuous layers (lit-par-lit gneiss); in still others it is highly irregular as cross-cutting dikes and masses. Nearly all rock types have been affected by migmatitization, although it is rare and not intense in quartzites. Amphibolites and hornblende gneisses, in general, are less intensely affected than metapelites, which are usually most intensely altered.

Even some orbicular migmatites occur, as, for example, in amphibolite in Kuntz Gulch about one mile west of Cotopaxi and south of the Arkansas River (Salotti and Fouts, 1964). Many of the migmatites show two or more generations of granitic material, the early ones in at least partly conformable units, whereas the younger occur mainly as cross-cutting dikes. The textures of the neosome also are variable, ranging from granitic to aplitic and pegmatitic.

Much of the granitic material in amphibole gneisses is extrinsic, redistributed either from contiguous or nearby pelitic units or injected from nearby granite plutons. Truly migmatitic amphibolite with neosomes consisting mainly of andesine plus quartz such as have been found in the Rustic quadrangle in the northern Front Range (Shaver, 1980) have not been recognized in south-central Colorado.

That much of the regional migmatitization preceded the emplacement of Boulder Creek plutons is demonstrated by the transection of lit-par-lit gneiss structure by pegmatitic, aplitic and granitic dikes of Boulder Creek age. Elsewhere in Colorado xenoliths of migmatite have been found within Boulder Creek plutons.

GABBROIC AND INTERMEDIATE IGNEOUS ROCKS

Several different types of gabbroic to dioritic igneous rocks in small bodies have been mapped in Fremont County:

1. In the vicinity of the McIntyre pegmatite quarry, at the head of McIntyre Gulch, above and south of the Arkansas River, about four miles east of Spike Buck. This massive to foliated body of gabbro intrudes Idaho

Springs gneisses and is cut by granodiorite and tonalite of Boulder Creek age. It lies adjacent to the southern contact of Boulder Creek tonalite and is intruded by the McIntyre pegmatite, a probable Boulder Creek pegmatite.

2. A similar metagabbro occurs in a small body about four miles southeast of Cotopaxi between McCoy and Sand Gulches, intruding Idaho Springs rocks.

3. Two small stocks of hornblende diorite porphyry crop out on Burned Timber Mountain about seven miles northwest of Cotopaxi. Although they were interpreted as being intrusive into Boulder Creek granite (Salotti, 1960), they are cut by pegmatite dikes of Boulder Creek age.

4. Two bodies of diorite crop out in the gulch south of Sheep Basin, 0.5 and 2.5 miles south of the Arkansas River (Dahlem, 1965). Some phases are porphyritic. They occur in migmatitic biotite gneiss and are locally discordant.

5. An irregular body of hornblende leucodiorite is exposed near the June No. 4 carbonatite about one mile east of Lookout Mountain (Dahlem, 1965), intruding Idaho Springs gneisses. Lookout Mountain is underlain by a Boulder Creek pluton.

These bodies are apparently either pre-Boulder Creek or Boulder Creek in age. Minor mafic to intermediate igneous rocks closely associated with Boulder Creek magmatism are reported from:

1. The southern Tarryall region in Park County (Hawley and Wobus, 1977) - metadiorite, metagabbro and biotite hornblendite, where some cut Boulder Creek tonalite and are regarded as late phases of the Boulder Creek plutonic episode.

2. Metagabbro, gabbro, diorite and tonalite also occur as post-Boulder Creek granodiorite intrusions in the Central City quadrangle in the central Front Range (Sims and Gable, 1967).

Mafic plutons associated with the Front Range Boulder Creek batholith are approximately the same age as the batholith, although some appear slightly older and others slightly younger (Gable, 1980).

BOULDER CREEK GRANITOIDS

The Boulder Creek granitoids (about 1700 m.y.) occur in a series of plutons of highly varying size and shape from just west of Canon City to the bounding Pleasant Valley fault. In addition major batholiths occur in Chaffee and Park Counties.

The main plutons include:

1. The drainage of Currant Creek and its tributaries in southern Park County and northernmost Fremont County, mainly south but also west and northwest of Guffey (Bever, 1954).

2. The Wilson Park-Eightmile Park pluton (Fremont County) (Reuss, 1970, 1974; Heinrich, 1948). This body has 0.5-mile wide border phases of tonalite at both its northern and southern ends.

3. The Parkdale-Twelvemile Park body (Fremont County), the western continuation of (2), west of the Ilse Fault. The tonalitic southern border is 1.5 to 3 miles wide (Shappirio, 1962). The northern border is in the southern part of the Tallahassee Creek drainage.

4. Eight small elongate bodies crop out south of the Webster Park graben both east and west of the Ilse Fault, extending from Goat Park on the west to Dawson Mountain on the east, in southern Fremont County.

5. South of these, centered around Curley Peak is the large Wet Mountain pluton of Boulder Creek granodiorite, in southern Fremont County.

6. Seven small elongate plutons occur east of the Texas Creek fault south of the Arkansas River extending from Heck Gulch on the south to Lookout Mountain on the north (Dahlem, 1965), in Fremont County.

7. One of the largest bodies is the Cotopaxi pluton extending westward from just west of Texas Creek to the Pleasant Valley fault, mainly on the north side of the Arkansas River. A few small outlying bodies are south of the river (Salotti, 1960, Vian, 1965), in Fremont County.

8. North of Turret in Chaffee County, a pluton of Boulder Creek quartz monzonite extends nearly to Leadville, forming a batholithic mass 40 x 6 miles in Chaffee County. (Van Alstine, 1969; Boardman, 1971, 1976). The southern contact is strongly protoclastic.

The Boulder Creek rocks of the Tarryall District are described on p. 34.

The Boulder Creek plutons consist of tonalite, granodiorite and quartz monzonite. In gross form they tend to be concordant or subconcordant with the structure of the enclosing Idaho Springs rocks. The marginal zones, commonly tonalitic, tend to be more strongly foliated than interiors, which are less well foliated or massive. Tonalitic borders grade into granodioritic interiors usually with lesser amounts of quartz monzonite, but tonalite also occurs in small separate plutons. Aplitic and pegmatitic dikes are abundant and widespread, usually as an exterior retinue, although some occur within the granitoid plutons themselves, especially near their borders.

Much of the granodiorite is sufficiently well foliated to permit strike and dip determinations, and the attitude of the foliation is usually parallel with that of the metamorphic foliation of the wall rocks. The foliation partakes of the following elements:

1) parallel orientation of biotite flakes;

2) parallel orientation of long axes of subhedral to euhedral microcline megacrysts;

3) Isodynamically oriented, thinly tabular xenoliths of biotite gneiss ranging in size from an inch or two to six feet; and, less commonly

4) cataclastic features and shear planes.

One- to two-inch megacrysts of microcline are conspicuous and abundant in the "porphyritic" phase of the Boulder Creek. Identical megacrysts also have been developed in the tabular xenoliths of biotite gneiss. Some megacrysts are homogeneous; others are zoned, each consisting of two or three zone pairs--a thick (2.0 to 4.0 mm) inner layer of microcline and a thin (0.5 to 1.0 mm) rim of sodic plagioclase (Ab65-75) (Reuss, 1970). The plagioclase grains of the rims are optically disoriented; microcline of the zone is either optically continuous or forms grains whose outlines transect the zone boundaries. There exists a complete size gradation between the small microcline crystals of the matrix, some of which are zoned or rimmed with plagioclase, and the megacrysts.

Identical microcline metacrysts also occur abundantly in conglomeratic quartzite of the Gooseberry Gulch Series as red euhedral crystals, within 25 feet of the Boulder Creek granite contact in Wilson Park, locally forming as much as 20% of the rock.

The textural and size relations of the microcline crystals, their relationships to smaller plagioclase grains and their occurrences in a) biotite gneiss xenoliths, b) in migmatite (dents-de-cheval), and in the conglomeratic quartzite indicate that they have been formed by recrystallization. Inasmuch as they are oriented parallel with the general foliation, their development must have taken place during the application of regional stress. Boulder Creek granitoids in the Central City quadrangle also were emplaced during metamorphism and crystallization took place under directed compressive stresses, and the result was a foliation and lineations subconcordant to that in the country rock (Sims and Gable, 1967, p. E41-42). Relations are similar in the Tarryall District (p. 46). It is generally agreed that the Boulder Creek granitoid plutons were emplaced at the culmination of the metamorphism that transformed the Idaho Springs rocks.

The Boulder Creek plutons display a remarkable variety of contact and exomorphic phenomena:

1. Hydrothermal metasomatism
    a. In Mitchell Gulch - tourmaline, fluorite, topaz, pyrite, sericite
    b. In Wilson Park - tourmaline
2. Development of sillimanite from biotite in pelitic gneisses: Micanite area, Park County (Bever, 1954).
3. Dents-de-cheval of microcline
    a. In migmatites, conglomeratic quartzite
    b. In biotite gneiss xenoliths
4. Contact migmatites
5. Granite-amphibolite hybrid rocks: Twin Mountain, north of Eightmile Park, Fremont County (Cooperrider and Heinrich, 1978).
6. Belts of exterior and marginal pegmatites and aplites: Eightmile Park (Heinrich, 1948).

The problem of the relationships of the skarn deposits and the Boulder Creek granitoid plutons is discussed in a later section (p. 34).

SILVER PLUME GRANITOIDS

Granitoids of Silver Plume affinity occur in only two areas in Fremont County:

1. In the northern part of Wilson Park continuing southwestward into the Cottonwood Creek drainage and the northeastern part of the Tallahassee Creek area (Shappirio, 1962; Reuss, 1970). This is the southwestern end of the Cripple Creek granite pluton.
2. In a NNE-trending belt transecting the Arkansas River and confined between the Echo Park graben faults on the East and the Cotopaxi faults on the west (Salotti, 1960; Taylor and others, 1975B).
    a. The Devil's Hole pluton, on the north side of the Arkansas River, measures 4 miles (NS) by as much as 2.5 miles (EW), with three small satellites.

b. The Texas Creek pluton, on the south side of the river, is 6 miles long (NE-SW) and as wide as 2.75 miles. It has seven smaller and minor satellites. This body has been quarried for dimension stone about 1.5 miles south of the Texas Creek station on the west side of Texas Creek (Vian, 1965). One of the satellites has been quarried on a prominent knob overlooking the west side of the McCoy Gulch, south of Cotopaxi (Salotti, 1960).

The southeastern corner of the Devil's Hole pluton is a pegmatitic phase well exposed in the Arkansas River canyon just west of Echo where it has been quarried on the north side of the river along the railroad tracks by the Denver and Rio Grande Western Railroad for track riprap (Vian, 1965).

These bodies have been dated as 1.45 b.y. by Carl Hedge (1971, see Taylor and others, 1975b).

The Cripple Creek pluton in the Wilson Park-Tallahassee Creek areas consists of a generally medium-grained, orange to pink, equigranular quartz monzonite. Much of it is biotite poor (about 5%), and aplitic (essentially biotite-free) phases are common. Marginal parts are weakly to poorly foliated and richer in biotite with schistose structures relict from assimilated wall rock. Locally interior phases are porphyritic. Small nonzoned, irregular pegmatites occur in the granite, and aplites also are widespread both as interior and exterior dikes. In the northern part of Wilson Park the Cripple Creek granite cuts the tonalitic marginal phase of the Boulder Creek pluton (Reuss, 1970).

In the Cotopaxi area the Silver Plume quartz monzonite is a light gray, medium- to coarse-grained rock with slender K-feldspar laths in subparallel orientation. Matrix biotite is, however, unoriented. Irregular, blocky to rounded xenoliths of highly different sizes of amphibolite are strongly biotitized (Salotti, 1960).

The Silver Plume granitoids, unlike the syntectonic Boulder Creek intrusions, are post-tectonic. They are massive to flow-foliated, whereas Boulder Creek granitoids are stress-foliated. The K-feldspar megacrysts, so prominent in much of the Boulder Creek, are absent in Silver Plume rocks, which are either equigranular or have fluidally oriented thinly tabular K-feldspar laths. Some phases contain muscovite as well as biotite.

Contact and exomorphic effects marginal to Silver Plume plutons include:

1) Retrograde coarse muscovitization of sillimanite developed during Boulder Creek plutonism,

2) Contact migmatites,

3) Exterior aplite and pegmatite dikes, and

4) Marked local deformation of wall rock foliation.

Apparently the intrusion of Silver Plume plutons initiated a major thermal event in many parts of the Colorado Precambrian. Gable (1980) has noted that a postcrystallization event was superimposed on the 1,700 m.y. old Front Range Boulder Creek batholith at 1,340 m.y. (Sr^{87}/Sr^{86}). Normand (1973), for the Precambrian rocks of the northern Sangre de Cristo Range, has a thermal event between 1,200 and 1,300 m.y.

A series of K^{40}/Ar^{40} dates, obtained by the writer on various metamorphic and plutonic rocks in Fremont County shows a widespread thermal event between 1,290 and 1,375 m.y.:

1.	Biotite, Boulder Creek granodiorite, U.S. 50, 8 miles west of Canon City	1,370 ±60 m.y.
2.	Biotite, Boulder Creek tonalite, Wilson Park	1,350 ±40 m.y.
3.	Biotite, Cripple Creek granite, Miners Gulch	1,290 ±40 m.y.
4.	Biotite, Silver Plume granite, Texas Creek	1,320 ±60 m.y.
5.	Muscovite, muscovite schist, Gooseberry Gulch Series, Mitchell Gulch, Cotopaxi	1,290 ±40 m.y.
6.	Muscovite, muscovite schist, Gooseberry Gulch Series, Mitchell Park	1,290 ±50 m.y.
7.	Muscovite, cordierite-muscovite gneiss Idaho Springs Formation, Texas Creek	1,375 ±30 m.y.

The analyses were performed by Geochron Laboratories, Inc.

GABBROIC DIKES

Numerous gabbroic dikes of highly variable size and shape, cut Idaho Springs rocks, migmatite, Boulder Creek granitoids and Silver Plume granitoids from Canon City to Cotopaxi. A few similar dikes cut metamorphic rocks in the Salida area. The dikes are largely diabasic, but fine-grained equigranular, aphanitic, and microporphyritic to porphyritic types are not uncommon. Thicknesses range from a few inches to 20 feet, with strike lengths up to several hundred feet. Some sets of dikes are undulatory sheets; others dip steeply; still others are irregular small boss-like intrusions. Most are bifurcate or irregularly branching. Chilled margins are common, and grain size, in general, increases with the size of the intrusive body. The petrographic types present are diabase, microgabbro, gabbro; olivine gabbro; and norite.

Some dikes contain deuteric hornblende or biotite. Many show various degrees of alteration to chlorite, serpentine, talc, hematite and carbonate.

These dikes are distinctly different from the lamprophyres of the dike halo of the McClure Mountain alkalic intrusive complex, which are of Cambrian age (Heinrich and Dahlem, 1966). In Baker Gulch in Fremont County the writer mapped a lamprophyre cutting and offsetting one of the diabases (Dahlem, 1965). Although these dikes are assigned a Cambrian age by Taylor and others (1975a), it is more likely that in Fremont County they represent the youngest Precambrian intrusives. Diabase dikes have not been found cutting Pikes Peak granite in Park, Jefferson, Teller and El Paso Counties, and it is possible that the diabase dikes are of post-Silver Plume and pre-Pikes Peak age.

PIKES PEAK GRANITE SERIES

Before age-dating data were available on the plutons in Park and Fremont Counties, some of the Boulder Creek bodies there were originally designated as Pikes Peak granite (Hanley and others, 1950). Now that detailed mapping of the Precambrian areas of these counties and of Teller and El Paso Counties has been nearly completed, it has been established that granite plutons of Pikes Peak age (about 1040 m.y.) are present only to the east of the area in which the skarn deposits occur, chiefly in eastern Park County, and adjacent Jefferson, Douglas and Teller counties and in westernmost El Paso County. The major Pikes Peak batholith underlies an area of at least 1,200 square miles. Plutons of Pikes Peak granite and its relatives are sharp-walled, massive, posttectonic, and epizonal in style (Hawley and Wobus, 1977).

As Table 4 shows and as Hawley and Wobus (1977) have pointed out, the Pikes Peak magma series is much more variable and much more differentiated than those of Boulder Creek and Silver Plume ages. It ranges from granite to syenite and even gabbro. It includes derivatives that are mildly alkalic (Windy Point), peralkaline (Mt. Rosa) and peraluminous (Redskin).

Some aplitic dikes in Fremont County may be of Pikes Peak affinity. Biotite from a red aplitic gneissoid granite dike (?) from Smith's Gulch in the Tallahassee Creek area yielded a K40/Ar40 age of 1,165 ±40 m.y.

FAULTS

Most of the major fault systems have general north-south trends. From east to west, these are 1) Ilse fault on the west side of Webster Park, 2) Echo Park Graben fault, 3) Texas Creek fault, 4) Cotopaxi fault,

Table 4. Sequences of petrologic units of Pikes Peak age.

South Platte District (Hutchinson, 1960; Simmons and Heinrich, 1980)	Tarryall District (Hawley and Wobus, 1977)	Cripple Creek District (Graton,1966)	Mt. Rosa Area (Gross and Heinrich, 1965)
			Lamprophyres
			Mt. Rosa riebeckite granite
	Redskin granite		
			Windy Pt. granite
	Tarryall Mtns. granite		
	Tarryall Creek gabbro-quartz monzonite ring complex; Lake George syenitic ring complex	Olivine syenite-olivine gabbro	Fayalite granite and porphyritic granite
Pikes Peak pluton 1. granite-outer zone 2. quartz monzonite granodiorite-intermediate 3. quartz monzonite-granite-central zone	Pikes Peak pluton	Pikes Peak pluton	Pikes Peak pluton

and 5) Pleasant Valley fault. In addition numerous smaller and subsidiary faults fall into two main sets: a northeast-trending group and a northwest-trending group. A few faults strike essentially east-west. Many of these faults, if not most of them, were active in Laramide and/or Tertiary times. However, some, especially some of the major ones, represent Precambrian faults that were reactivated in Laramide time. One of these ancestral faults was the Ilse fault which was in existence in early Cambrian time (Singewald, 1966). The halo of alkalic dikes, carbonatites, and thorium-rich fenite veins around the McClure Mountain

alkalic complexes is remarkably extended northward parallel with the fault, which acted as a conduit (Moore, 1969). Singewald (1966) traced the fault across the Arkansas River at Parkdale. This writer has mapped it past Gribble Mountain where the northernmost carbonatite is found, northwestward along Currant Creek and thence northward along Currant Creek at least as far as a point west of Guffey in Park County.

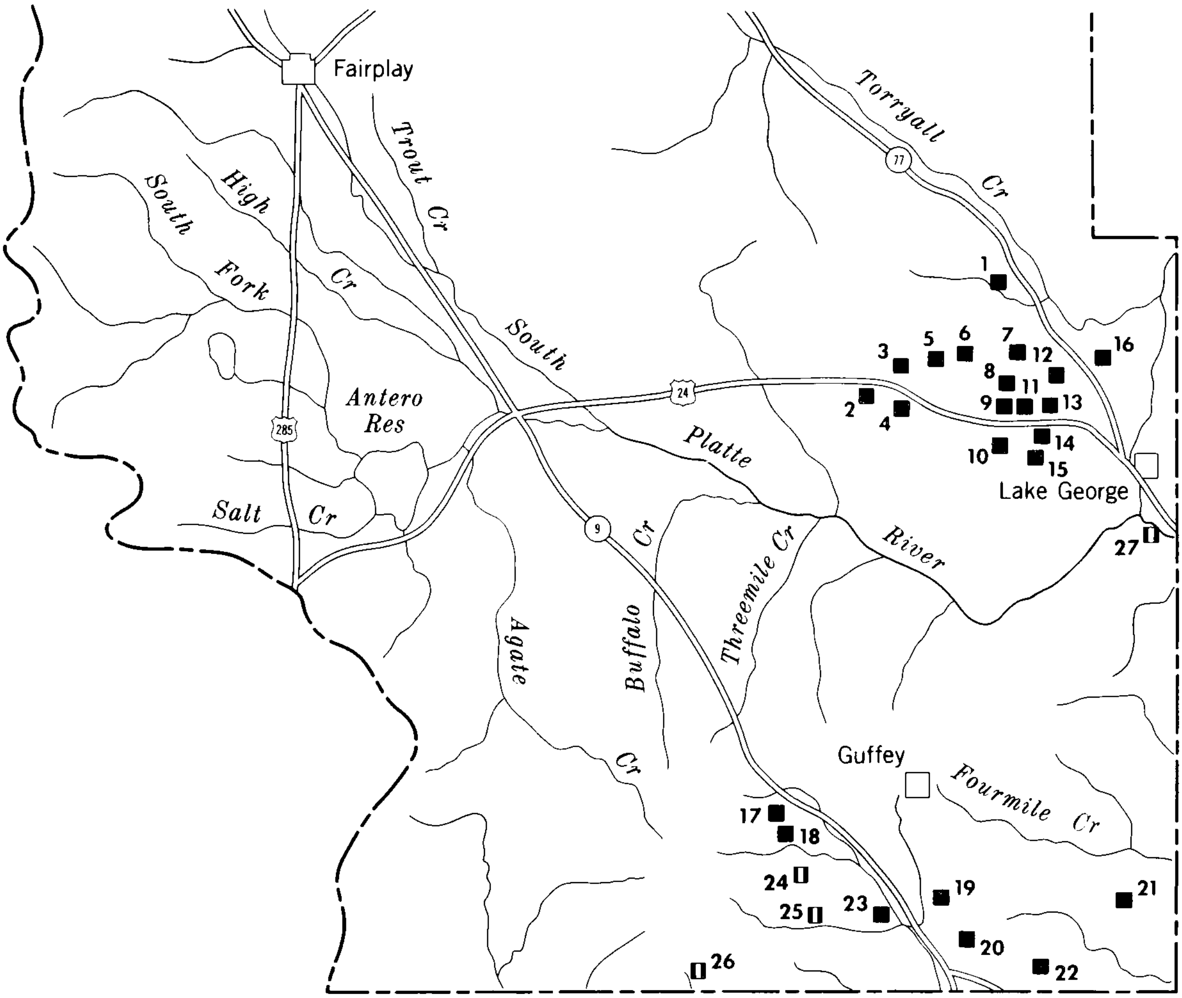
Further evidence of a possible Precambrian existence of some of the smaller faults stems from 1) the intrusion of probable late Precambrian diabase dikes along them, and 2) the localization of some of the Precambrian Cu-Zn skarn deposits (p. 61).

Along the Texas Creek fault in Texas Creek Gulch, Vian (1965) found a sandstone dike composed of mature orthoquartzitic sand grains. One possible source of such material is the Harding Formation of Ordovician age, remnants of which occur north of Cotopaxi to the west (Salotti, 1960). Similar sandstone (now quartzite) dikes, probably derived from the Cambrian Sawatch Formation, occur in Idaho Springs rocks and Pikes Peak granitoids in the South Platte area in Jefferson County (Simmons, 1973).

It seems probable, therefore, that many or even most of the faults in south-central Colorado had Precambrian precursors, as is the case in the Colorado mineral belt (Tweto and Sims, 1963). Some of the Precambrian faults are post-Boulder Creek in age; others are of post-Silver Plume age; and still others are younger than the intrusion of the Pikes Peak batholith.

The relationships are similar in the Salida area where the evidence for Precambrian faulting includes 1) localizations of skarn deposits, 2) well-developed foliation along linear zones and 3) the intrusion of persistent lamprophyres and some other Precambrian dikes along linear features (Van Alstine, 1960; Boardman, 1971).

The main N-S faults and the lesser NE-SW and NW-SE faults display a moderately well-defined geometrical pattern, with the N-S faults bisecting the 115-120° angles between the latter. Around the McClure Mountain alkalic complex the fault pattern is crudely radial, suggesting that these faults are post-Cambrian. Some smaller faults within this complex were developed during the multistage intrusive history of this complex and thus are of Cambrian age.



TUNGSTEN SKARNS ■

1. Nix
2. Pedro
3. Hallie
4. Saint Joe
5. Scheelite No.1 & 2
6. Badger
7. Dorothy
8. Victory
9. Round Mountain
10. Little Abner
11. Wilfley
12. Jefferyes
13. Jasper Queen
14. Abel
15. Holmes Ranch
16. Gilley Ranch
17. B & G
18. School Section
19. West
20. Lues Ranch
21. Nash Ranch
22. Johnson Ranch
23. Townsend Ranch

Cu-Zn SKARNS ▯

24. Betty
25. Copper King & Copper Queen
26. Mill Gulch
27. Blue Mountain

Figure 2. Map of Park County, showing location of skarn deposits.

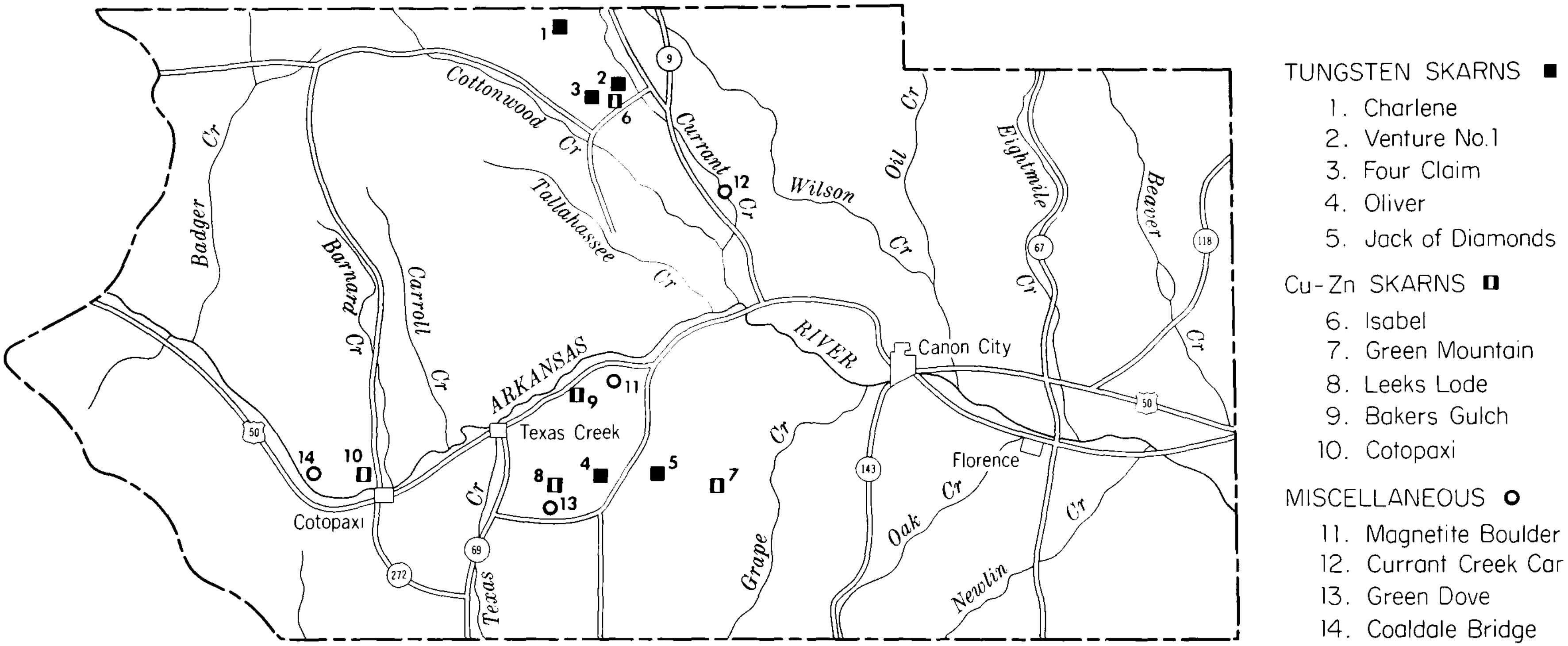
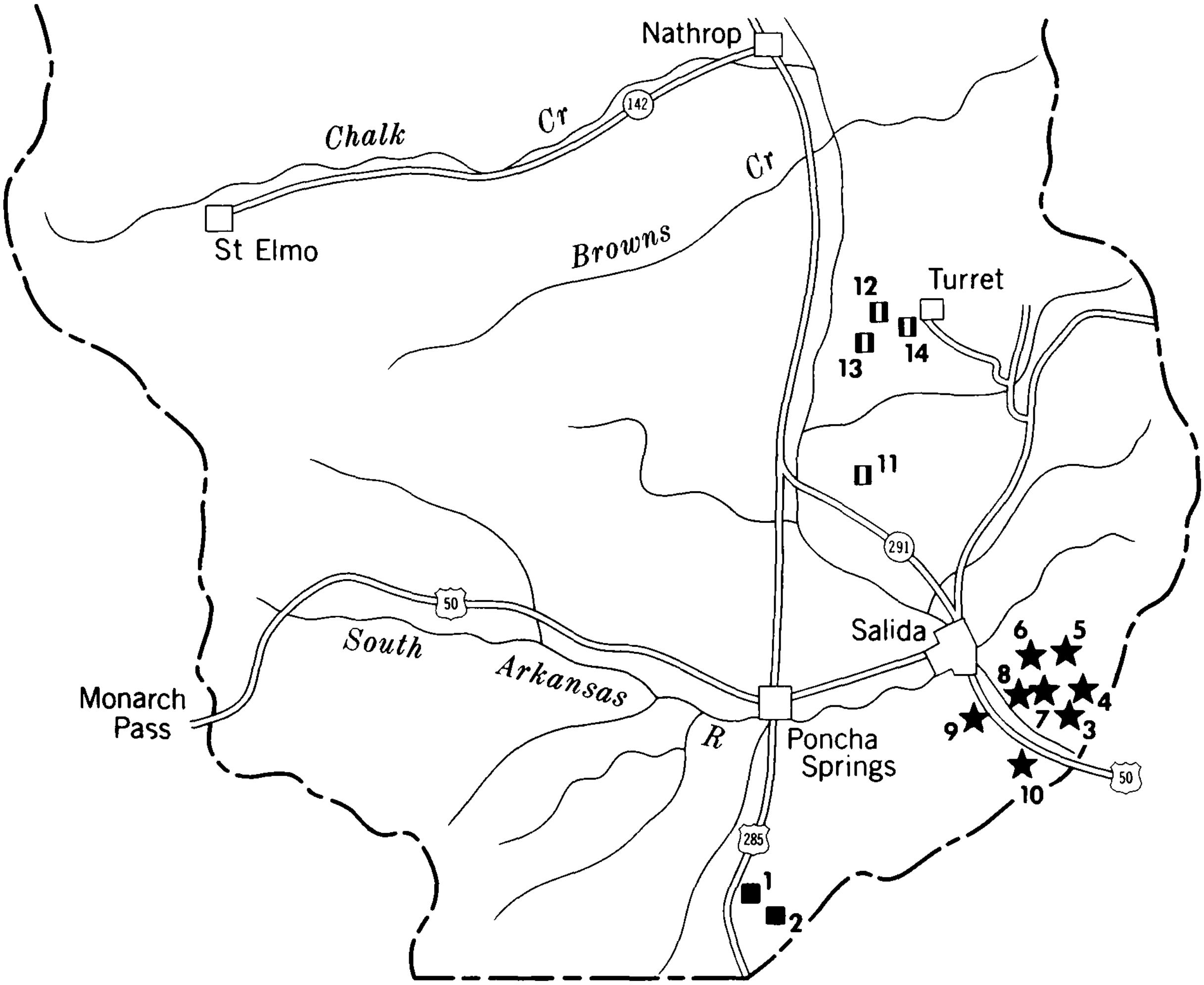


Figure 3. Map of Fremont County, showing location of skarn deposits.



TUNGSTEN SKARNS ■

1. Poncha Pass
2. Lucky

Cu-W SKARNS ★

3. Cleora No. 2
4. Grand View
5. Mute Lode
6. Hub Tunnel
7. Stockton
8. Uncle Andy
9. North Star
10. Saddle

Cu-Zn SKARNS ◘

11. Sedalia
12. Independence
13. Ace High-Jackpot
14. Turret

Figure 4. Map of Chaffee County, showing location of skarn deposits.

TUNGSTEN SKARNS

GEOLOGY

Distribution

The tungsten skarns tend to occur in groups or districts. In part is certainly reflects the local abundance of the host rocks, lc-silicate gneisses, but not entirely so, for unmineralized and at ast partly recrystallized calc-silicate rocks occur not uncommonly tside of the districts. The main districts are the Tarryall district in rk County and the Guffey-Tallahassee district in Park and Fremont unties (Figs. 2, 3). Tungsten skarns also occur on Poncha Pass, but st of the tungsten deposits of Chaffee County are of the Cu-W vein types leora District) (Fig. 4).

As with the copper-zinc skarns, tungsten skarns occur outside of the uth-central group of counties. Tweto (1960) has described a small strict in Lake Fork Gulch, four miles east of Blackhawk, Gilpin County, inly in sec. 22, T3S, R72W. Here scheelite is chiefly in two layers of lc-silicate gneiss, a few feet thick, within a 200- to 300-foot thick yer of amphibolite. The calc-silicate bands grade into amphibolite and ntain hornblende and conspicuous scapolite. Discontinuous scheelite neralization was traced for about 3000 feet along an east-west strike.

Similar deposits also occur near the Cache La Poudre River in uthern Larimer County (Tweto, 1960).

Shape and Size

Most of the deposits are lensoid, not uncommonly with blunt noses. hers are thinly tabular; still others form irregular pods. Individual nses tend to occur in series, arranged along one or two horizons in the jor enclosing gneiss, either biotitic or amphibolitic. The spacing tween lenses ranges widely but may reach several times the length of dividual lenses (Tweto, 1960).

Sims and Gable (1964, p. C24) report that "Many podlike bodies occupy e crests of small folds; the more continuous layers locally constitute ratigraphic marker beds on fold limbs," suggesting that some of the diform bodies may be boudins.

Contacts between host calc-silicate gneisses and skarn rocks are adational, and the distinction between the two is somewhat arbitrary. e gneisses usually are banded and well-foliated, and some are fine ained. The skarns are heteroblastic, usually not foliated. They tend be coarser grained and much more variable mineralogically over short stances. Some bodies are transgressive to their host beds. Scheelite nds to favor the skarns, but some scheelite may occur in neighboring recrystallized gneiss. Some deposits have small vugs into which lcite, vesuvianite and garnet euhedra protrude.

The deposits vary greatly in size, and the skarns themselves are usually more extensive than their scheelite-bearing parts. Widths of mineralized skarns range from a few inches to 15 feet, lengths from a few feet to 15 feet. Down dip dimensions may also be limited to a few feet to a few tens of feet. For many deposits widths are a few inches to several feet and lengths from a few feet to tens of feet. In contrast, the length of a few calc-silicate gneiss layers may reach almost a mile. Thus the relatively small size of the tungsten skarns is in part a function of the small size of the host units whose dimensions provide maxima, rarely achieved, for the dimensions of the skarns.

Host Rocks

The control of the tungsten mineralization is almost exclusively the composition of the host rock; nearly all of the scheelite skarns occur in rocks that were originally calc-silicate gneisses or rocks of closely related composition. Essentially the remaining few are in hosts that were originally amphibolites or cordierite-anthophyllite gneiss (Fig. 5). Sims and Gable (1964) distinguished two subtypes of calc-silicate gneiss:

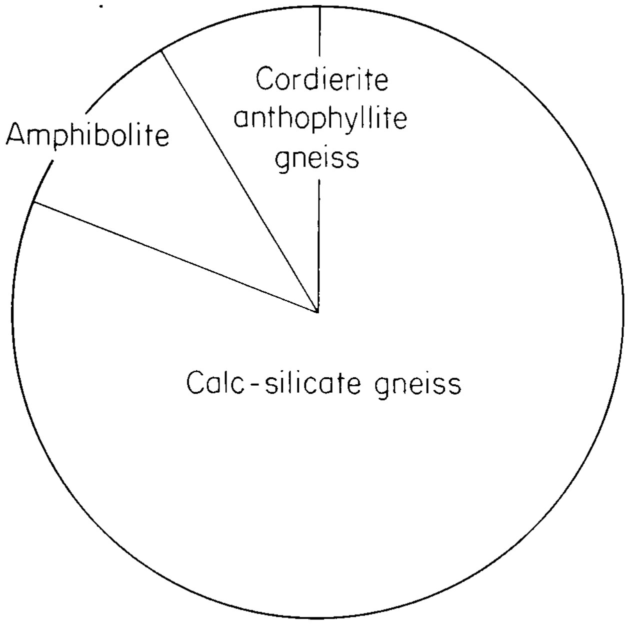


Figure 5. Distribution of host rocks for tungsten skarns.

1. One consisting mainly of dark silicates (garnet, diopside, hornblende, epidote). Massive, of somewhat variable grain size, tending to occur in small pods.

2. One consisting of light-colored calc-silicates or of alternating layers of light (quartz, plagioclase, scapolite) and dark silicates (epidote, garnet, diopside, hornblende). Forms rather long narrow layers or blunt masses.

In a district the two occur together, but one type usually predominates in a particular calc-silicate unit. Both types are closely associated with amphibolite, and type 2 may grade into amphibolite. Some calc-silicate skarns developed from amphibolite consist of garnet-quartz-epidote bodies that transect the foliation of the amphibolite and are separated from amphibolite by diopside-rich rock which also is transgressive (Hawley, 1969). In addition to their occurrence in amphibolite and hornblende gneiss, calc-silicate gneiss layers and pods also occur in sillimanite-biotite gneiss and fine-grained biotite gneiss.

The parent materials for the calc-silicate gneisses were impure carbonate rocks consisting of minimum mixtures of dolomite, quartz and clay minerals. Many of the resulting skarns, however, are too rich in iron to have been formed directly from any common sedimentary carbonate parent, and their formation requires (at least) iron metasomatism. Pure and even slightly impure calcitic and dolomitic marbles are very rare in the Idaho Springs Formation, in marked contrast to the Precambrian Cherry Creek Group of southwestern Montana which contains numerous and thick marble layers (Heinrich and Rabbitt, 1960).

Structural Control

Unlike the copper-zinc skarn bodies whose formation is in part clearly allied to fault proximity (p.62), the tungsten skarn deposits display no evidence of fracture or fault localization. The writer agrees with Tweto (1960, p. 1409) that "...fractures exert no control, and in most deposits the observed fractures are younger than the scheelite." The exceptions, of course, are the Cu-W veins of the Cleora district (p.56), which are fracture-controlled veins regarded as transitional between the Cu-Zn and W skarn deposits. Similarly, as again Tweto (1960, p. 1409) notes, "Folds exert no evident control, except insofar as they influence distribution and shape of the 'favorable' rock layers."

Relations to Granites

As is the case for the copper-zinc skarns, tungsten skarns occur in terranes that incorporate either plutons of Boulder Creek age or, in the Tarryall District, plutons of both Boulder Creek and Silver Plume age. Hawley, (1969, p. A9) favors a genetic association with Silver Plume granite in the Lake George area, "Small metalliferous deposits in calc-silicate rocks are scattered throughout the mapped area, but to the south of the area they occur mainly in or near plutons of Silver Plume (?) granite, where they probably were formed by the contact metamorphism of calcium-rich metamorphic rocks." This viewpoint is reaffirmed (Hawley and Wobus, 1977, p. B24) - "The association of tungsten-bearing tactite deposits with the Silver Plume (?) is particularly noticeable in the northeastern part of T12S, R72W."

Tweto (1960, p. 1414) strongly suggests a genetic link with a particular type of pegmatite. He states (for the Tarryall District):

> "All the rocks are cut by numerous pegmatites, which are of two kinds and ages. The older variety is a coarse-grained,

> gray or white biotite pegmatite that apparently was the source of numerous irregular bodies of grayish bull quartz that lie within or cut the gneisses near the pegmatites. This gray pegmatite and associated quartz are cut by a younger coarse-grained, pink feldspathic pegmatite that closely resembles the pegmatites of the Pikes Peak granite..."

On p. 1415 he further states, "Scheelite occurs principally in the complex calc-silicate rocks, and within these, shows a definite concentration in the neighborhood of the gray pegmatite and its related bull quartz." Tweto (p. 1419) speculates that even though a little scheelite occurs in the gray bull quartz, other skarn minerals also occur in it, and "the postulate that the scheelite was introduced by the pegmatite becomes debatable." Rather, he concludes, these occurrences "...indicate an active and localized exchange of materials between the quartz or pegmatite and the wall rocks."

However, some Colorado pegmatites do contain scheelite as a primary constituent. Some of these are located on Tweto's map (1960, p. 1408, Fig. 1), and include Cochetopa in Saguache County, Mt. Vernon Canyon in Jefferson County, and Guy Hill in Jefferson County.

Outside of the Tarryall District in other parts of Park County and in Fremont and Chaffee Counties there is no close spatial or any other link between the scheelite distribution and any pegmatites. Similarly in the Blackhawk district of Gilpin County the scheelite does not show a close spatial relation to pegmatite (Tweto, 1960).

The writer believes that the tungsten skarn deposits are genetically linked to the Boulder Creek granitoid plutons rather than the Silver Plume plutons for the following reasons:

1. They occur only in terranes intruded either solely by Boulder Creek bodies (Chaffee County; Guffey District) or in terranes invaded by both Boulder Creek and Silver Plume bodies (Tarryall District).

2. In the Tarryall District they show <u>some</u> type of linkage with older pegmatites which the writer believes are of Boulder Creek affinity and are cut by younger pegmatites which the writer believes are of Silver Plume age (not Pikes Peak age as postulated by Tweto, 1960). Hawley and Wobus (1977, p. B23) state that "...many of the granite pegmatites of the region also are related to the Silver Plume."

3. The tungsten skarn deposits, like the copper-zinc skarns, are in part of <u>regional</u> metamorphic origin. They are not of contact-metamorphic origin, i.e., they are not, as Hawley (1969, p. A9) has dubbed them, tactites (see p. 1). The Silver Plume plutons do not have a pyrometasomatic halo; none

of the other rock types near Silver Plume plutons in Park County are affected by any high-temperature contact effects.

4. The tungsten skarns locally carry copper sulfides; a few copper-zinc skarns carry scheelite and molybdenite; the veins of the Cleora district carry values in both copper and tungsten. All three types are closely allied in form, mineralogy, age relations and probably in origin. If this is valid, and since certainly the copper-zinc skarns are of Boulder Creek affinity, it follows that the tungsten skarns also are Boulder Creek-related.

MINERALOGY AND PETROLOGY

Assemblages

The calc-silicate gneisses and the skarns into which they grade are mineralogically and texturally the most variable of the Idaho Springs units; indeed, textural and mineralogical variability is a main characteristic. Some are nearly monomineralic, whereas others consist of numerous species; some are dark colored, others light; some are finely banded, some unfoliated (Tweto, 1960). Some are fine-grained, others pegmatoidal. Compositional changes across the strike are rapid; and in the skarns, extreme variations along the strike also are characteristic. Table 5 lists the mineral assemblages found by the writer and his students and also those reported by other investigators.

Textures

Extreme textural variability is a conspicuous skarn characteristic. Contrasting with the finer grained, banded unrecrystallized calc-silicate gneiss remnants are coarse-grained to pegmatoidal, xenoblastic, unfoliated aggregates, some of which are essentially monomineralic or bimineralic. Nodular aggregates, veinlike structures, and irregular segregations also occur. Some larger garnet subhedra are poikiloblastic, and scapolite may occur in vuggy prismatic columnar aggregates. Small vugs also may be present, and epidote crystals as long as three inches have been found in some.

Individual Minerals

Garnets. Considerable data have been evolved on the physical constants of the garnets - n, G and A_0, and calculations of their compositions in terms of end-member molecular percentages have been made (e.g., Sims and Gable, 1964; Salotti, 1960; Bever, 1954). However, subsequently Sims and Gable (1967, p. E18) report "...it was believed reasonable that percentages for garnets could be determined from combined X-ray and physical data. We now know that this assumption was erroneous."

Table 5. Mineral assemblages in calc-silicate gneisses and their skarns

Dark Assemblages

diop
diop-gar
diop-gar-qtz
diop-gar-plag-qtz-sph
diop-epi-qtz-gar
diop-epi-hbld
diop-epi-hbld-qtz-plag
diop-epi-hbld-qtz-scap
diop-hbld-epi-plag
diop-qtz-epi-
diop-qtz-epi-plag

hbld-diop-qtz-lab
hbld-diop-epi-lab-qtz
hbld-plag-diop-epi

act-diop-epi-lab-qtz

gar-diop
gar-diop-qtz
gar-plag-qtz
gar-qtz-epi
gar-qtz-mag

epi-hbld-qtz-sph
epi-hbld-plag-diop-mag
epi-act
epi-plag-qtz-sph
epi-qtz-mag-sph

clino-hbld
thu-act

Light Assemblages

woll-qtz-calc

scap-plag-epi-qtz diop
scap-diop

plag-qtz-hbld
plag-qtz-diop
plag-qtz-diop-hbld

qtz-gar
qtz-gar-epi
qtz-gar-diop
qtz-epi
qtz-epi-hbld
qtz-hbld-epi-gar-mag
qtz-plag-diop
qtz-micro-scap-diop-epi

calc-diop
calc-diop-gar-qtz
calc-gar
calc-qtz-epi-scap
calc-qtz-diop-epi-hbld

Abbreviations:

act - actinolite, calc - calcite, clino - clinozoisite, diop - diopside, epi - epidote, gar - garnet, hbld - hornblende, lab - labradorite, mag - magnetite, micro - microcline, plag - plagioclase, qtz - quartz, scap - scapolite, sph - sphene, thu - thulite, woll - wollastonite

Table 6. Mineralogy of the Tungsten Skarns

Silicates	Relative Abundance[1]
Forsterite	R
Chondrodite	T
Zircon	R
Sphene	U
Garnet	C
Vesuvianite	U
Andalusite	T-?
Datolite	?
Epidote group	
Zoisite	T
Thulite	R
Clinozoisite	C
Epidote	C
Melilite	?
Cordierite	T-?
Tourmaline	T
Pyroxene Group	
Hypersthene	?
Diopside	C
Hedenbergite	R
Pigeonite	?
Wollastonite	U
Mn-wollastonite	T
Bustamite	T
Amphibole group	
Tremolite	T
Actinolite	U
Hornblende	C
Arfvedsonite	T-?
Sericite	C
Talc	U
Chlorite	C
Serpentine	R
Prehnite	T-?
Microcline	U
Plagioclase (oligoclase, labradorite, bytownite)	C
Quartz	C
Scapolite	U

Table 6 (Cont.)

Oxides	
Hematite	R
Spinel	T
Pleonaste	T
Gahnite	T
Magnetite	C
Hydroxide	
Brucite	T
Sulfides	
Pyrite	R
Chalcopyrite	R
Bornite	T
Molybdenite	T
Oxysalts	
Calcite	C
Apatite	R
Svanbergite	?
Scheelite	C
Powellite	U
Halide	
Fluorite	T

---

[1] C = common; U = uncommon; R = rare; T = trace; ? = questionable identification

However the physical constants do show that 1) the garnets are highly variable in composition, both among deposits and within individual deposits and 2) most of them belong to the grossularite-andradite series, even though exact percentages of end-member components cannot be calculated from the data. Refractive indices range from n = 1.745 to 1.830. Within one deposit n ranged from 1.792 to 1.819. In the Tarryall District the range reported by Tweto (1960) is 1.745 to 1.775.

Vesuvianite: Vesuvianite is abundant in the Tarryall District but rare in the Guffey district and elsewhere in Fremont County. In Chaffee County vesuvianite is restricted to those vein deposits of the Cleora District developed in calc-silicate gneiss.

Epidote-group minerals: Usually more than one member of the group is present. In the Tarryall District clinozoisite "...is probably the most ubiquitous of all the minerals in the calc-silicate rocks" (Tweto, 1960, p. 1416). Epidote, however, also is abundant and widespread. In Fremont

County epidote is very abundant, but clinozoisite is rare. Zoisite is even rarer, but thulite is conspicuous in a few deposits. Epidote has been found replacing thulite, and much epidote is paragenetically late, forming veinlets.

Diopside-hedenbergite: Most of the clinopyroxene, based on optical properties, falls into the diopside range, e.g. $Di_{70}He_{30}$. Like the garnets, it varies considerably in composition with types of darker green color and higher indices favoring the darker skarns and lighter colored, lower-index types in the lighter calc-silicate rocks. Some rocks contain two different clinopyroxenes: a nearly pure diopside and a ferroan diopside. Diopside grains are commonly poikiloblastic and may be uralitized.

Wollastonite: Some of the calc-silicate rocks in the Tarryall District contain primary metamorphic wollastonite, but some younger Mn-wollastonite and bustamite also occur. The presence of wollastonite indicates that the calc-silicate rocks were recrystallized under partially open conditions that permitted the escape of CO_2 produced by the reaction

$$\text{calcite} + \text{quartz} \longrightarrow \text{wollastonite} + CO_2$$

Wollastonite is very rare to absent in Fremont County deposits.

Amphiboles: Hornblende varies in color from dark green in the iron-rich rocks to light green in rocks lower in iron. Not uncommonly grains are poikiloblastic. Some hornblende also forms by uralitization of pyroxene, and Moench (1964) reports uralitic arfvedsonite (based, however, solely on optical properties). Some of the green amphibole is actinolite, and in a few deposits coarse white tremolite has been developed. At the Four Claim deposit (p. 53) the tremolite fluoresces a pale salmon pink.

Scapolite: From measurements of refractive indices, the scapolites range from $Ma_{35}Me_{65}$ to about $Ma_{50}Me_{50}$. The abundant scapolite in the Cleora veins and their sahlbands (p. 57) is also $Ma_{50}Me_{50}$, reflecting the Na-Ca ratio in the plagioclase from which they were formed (Boardman, 1971). Some scapolite, in calcitic skarn, fluoresces dull orange.

Sulfides: Sulfides are not common or abundant. Copper sulfides include sparse chalcopyrite and bornite. No sphalerite was found. Noteworthy is the presence of small flakes of molybdenite, and thus molybdenum occurs in two phases, scheelite-powellite (early) and in molybdenite (late).

Scheelite-powellite: One of the more intriguing aspects of the mineralogy of the deposits involves the members of the scheelite-powellite series. As was pointed out by Tweto (1960), the scheelite shows a wide range in composition, not only in individual deposits but even in single grains. This had earlier been discovered by Bever (1953, 1954). The various relationships discovered are:

1. In single grains, cores of nearly pure scheelite and rims of molybdenian scheelite.

2. In single large grains, cores of scheelite with <0.1% Mo, rims with >5% Mo; accompanied by smaller grains of unzoned scheelite with <1.0% Mo.

3. Zoned crystals with the Mo-rich rim becoming progressively richer in Mo outward.

4. "Blotchy" composite grains formed by irregular aggregation of W-rich and Mo-rich subunits.

5. Scheelite grains, some zoned with molybdenian rims, accompanied by discrete grains of powellite.

Where textural relations are diagnostic, it is clear that the Mo content increases with decreasing age. Molybdenum continued to be deposited in very small amounts in the post-scheelite-powellite stage as the sulfide, molybdenite.

As Tweto (1960) has described, the scheelite ranges greatly in form and size, from anhedral specks to subhedral to euhedral crystals weighing 20 to 45 lb. Most of the larger crystals are euhedra of tabular habit modified by small prisms or a large number of triangular and trapezoidal faces. Scheelite is closely associated with quartz, especially near quartz stringers, pods or veinlets.

Tweto (1960) also has presented a semiquantitative spectrographic analysis of a scheelite crystal from the Tarryall Springs District: (in ppm) Cr 10, Cu 7, Fe 500, Mg 300, Mn 30, Mo 2000, Ni 5, Pb 10, Sn 20, Sr 10, V 10.

Minor Elements

The calc-silicate rocks of the Tarryall District were checked by Tweto (1960) via semiquantitative spectrographic analysis for major and minor elements (his Table 3, p. 1417):

Major elements (1000 ppm or greater) in order of abundance: Mg, Fe, Mn, Ti
Minor elements (1000-100 ppm): Ba, Cr, Cu, Mo, Ni, Sr, V, W, Zn, Zr
Trace elements (<100 ppm): Ag, Be, Bi, Co, Ge, La, Ni, Pb, Sn, Y

A number of the Tarryall deposits as well as other tungsten skarns in Park, Fremont and Chaffee Counties were sampled by the writer and checked for Be, but no anomalies were found. In general the Be contents are but a few ppm.

Paragenesis

In general, the sequence of events in the development of the tungsten skarn deposits is not so well definable, nor are the stages as sharply demarcated as in the copper-zinc skarns. In particular, in some deposits, the primary metamorphic stage is not easily separated from the silicate recrystallization (skarn) stage. In other deposits the two are, however, readily distinguishable.

Tweto (1960) outlined the following stages:

1. Regional metamorphism to form the calc-silicate gneisses
2. High-temperature reheating of the products of regional metamorphism ("primary metamorphic stage")
3. Retrograde metamorphic stage characterized by formation of hydrous minerals: talc, chlorite, sericite, serpentine, clinozoisite, and actinolite
4. High-temperature, secondary metamorphic stage in which the earlier, altered, silicates were recrystallized: clinozoisite, diopside, wollastonite, and epidote.
5. Minor (hydrothermal?) stage: quartz and epidote

According to Tweto (1960) the following minerals are not strictly definable in their paragenetic position but were introduced either during stage 3 (hydrous alteration) or stage 4 (secondary metamorphic): scheelite-powellite, fluorite, apatite, bustamite, Mn-wollastonite, chalcopyrite and bornite.

With this paragenetic model the writer cannot concur. The sequence of events in deposits studied by me is markedly simpler and does not involve the major fluctuations in temperatures between 2 (high), 3 (lower) and 4 (higher) that Tweto's requires:

1. Regional metamorphism
2. Skarn silicate stage (Tweto's 2 and 4)
3. Retrograde metamorphic-hydrothermal stage

In this model the scheelite, followed by powellite, was formed late in stage 2 and the hydrous minerals and sulfides, including molybdenite, were introduced early in stage 3. The tungsten and the copper-zinc skarns are closely linked and have very similar paragenetic histories.

Tweto (1960) concluded that the tungsten is not an extrinsic element but existed in the parent sediments, was recrystallized (as scheelite) in the gneisses and redistributed during a plutonic episode with the aid of pegmatites. He notes, however, that of all the parent sedimentary rocks, carbonate rocks are poorest in tungsten; therefore, insofar as the skarns themselves are concerned, tungsten is an extrinsic element but originally existed as a minor element in mafic and heavy accessory minerals in noncarbonate rocks.

However, it is not just the source of the tungsten that must be considered but that of the molybdenum as well, for the scheelite and powellite are closely linked in time and genesis.

Levinson (1980) gives the following data on the distribution of tungsten and molybdenum in sedimentary rocks:

	W	(ppm)	Mo
Shales	2		3
Black Shales	-		10
Sandstones	1.6		0.2
Limestones	0.5		1

Clearly, during regional metamorphism tungsten and molybdenum would originally have been concentrated in quite different gneisses or schists. Bituminous and sapropelic sediments are especially rich in molybdenum, and their metamorphic equivalents, graphitic schists, are absent in the Idaho Springs. Thus the concentration of scheelite and powellite in the pre-existing impure limestones would require the selective abstraction of tungsten and molybdenum from pre-existing shales (mica schists and gneisses) and tungsten from pre-existing sandstones (quartzites). Quartzites also are rare in the Idaho Springs Formation.

In summary, the metamorphic transfer model requires sources that are absent and mobilization circumstances that are implausible. All of the other rock units were transformed isochemically, probably even the rare anthophyllite-cordierite gneisses (see p. 12). So why and how could the calc-silicate rocks be an exception? That the skarns represent metasomatized calc-silicate gneisses is not only attested to by the presence of anomalies in such lesser elements as Ba, Cu, Mo, W and Zn, but in general the skarns are too rich even in Fe to have been derived isochemically from any common sedimentary parent.

It is clear from Table 7 that Colorado, chiefly within the Colorado Mineral Belt, represents a tungsten metallogenetic province in which tungsten is represented by essentially all major tungsten species occurring in a wide variety of deposits that extend from Precambrian into early and middle Tertiary time.

The types of Precambrian occurrences include:

1) a few scattered pegmatites,
2) calc-silicate scheelite skarns,
3) Cu-W veins (Cleora District),
4) minor occurrences in the Cu-Zn skarns (Cotopaxi mine),
5) wolframite occurrences in the Be greisens of the Badger Flats (Lake George) district, and
6) wolframite in veins in the Phantom Canyon area of Fremont County (Belser, 1956).

Tweto (1960) and others have speculated on the interrelationships of the Tertiary tungsten deposits to those of Precambrian age, suggesting that Tertiary magmas formed by fusion of Precambrian crustal rocks and thus, perhaps, Tertiary tungsten deposits represent recycled Precambrian tungsten. If this is indeed the case, an enormous number of the small, low-grade Precambrian deposits must have been engulfed in Tertiary furnaces, for Tertiary deposits are more numerous, larger and higher grade than their presumed parents. Yet large terranes of Precambrian rocks remain, and in these, Precambrian tungsten deposits are small and widely dispersed, presumably a true sample of all those that existed originally. It seems unlikely, therefore, that all or even most of the Tertiary tungsten has been derived from Precambrian ancestral tungsten deposits.

Table 7. Tungsten Deposits of Colorado

Type and Age	Chief W Mineral	Accompanying Elements
<u>Precambrian</u>		
1. Lime-silicate skarns (Boulder Creek)	Scheelite	Mo
2. Beryllium greisens (Pikes Peak)	Wolframite	Be, Sn
<u>Tertiary</u>		
3. Nederland District, Boulder County	Ferberite, some scheelite	--
4. Climax, Lake County	Huebnerite	Mo
5. San Juan Mtns., Silverton District	Huebnerite	F
6. Hoosier Pass, Summit and Park Counties	Huebnerite	F
7. Pitkin-Tincup District, Gunnison County	Huebnerite, minor scheelite	Mo
8. Ward District, Boulder County	Wolframite	--

INDIVIDUAL DEPOSITS

Park County

Skarn tungsten deposits in Park County are concentrated in two districts: 1) the Tarryall Springs district, in South Park west of Lake George both north and south of U.S. 24; and 2) the Guffey district, in the upper reaches of the Currant Creek drainage, south of Guffey, both northeast and southwest of Colorado Highway 9 (Fig. 2). The Tarryall Springs deposits have been described by Belser (1956) and Tweto (1960) and were examined and sampled by this writer in the late 1950s during the beryllium boom in South Park resulting from the discovery of the Be-W greisens of the Boomer and associated deposits. A very brief description of the tungsten skarn deposits also is given by Hawley (1969). The deposits near Guffey have been described by Bever (1953, 1954) and Belser (1956) and were first examined by this writer in the early 1950s.

Tarryall District

The Tarryall (or Tarryall Springs) district, in east-central Park County northwest of Lake George, is one of the largest group of tungsten skarn deposits in Colorado. After scheelite was discovered here in the summer of 1943, numerous occurrences were found within a few months over about 25 square miles. During the tungsten booms of World War II and the Korean War extensive prospecting took place (Tweto, 1960). In 1955 the beryllium greisen deposits (Boomer mine) of the Badger Flats area were discovered, which led to renewed interest in the skarn deposits. Inasmuch as some of the beryllium (beryl-bertrandite) greisens also contain some tungsten in the form of wolframite, the scheelite skarns also were prospected for beryllium minerals. However, the two types of deposits are not genetically related, and no Be concentrations were found in the scheelite skarns.

The district extends westward from about 4.5 miles northwest of Lake George to Wilkerson Pass, a distance of about 6.5 miles. Tweto (1960) has grouped the deposits into three belts from east to west:

1. Firefly belt. Northeasterly trend; 5 deposits north of U.S. 24, 4 south of U.S. 24; about 0.5 mile wide, about 3 miles long.

2. Round Mountain belt, just southeast of Round Mountain. Northeasterly trend; 5 deposits north of U.S. 24, several minor occurrences south of U.S. 24; 0.5 to 1.3 miles across.

3. Badger Mountain belt, northeast and south of Wilkerson Pass. Nearly E-W trend; 4 deposits north of U.S. 24, at least one south of U.S. 24; about 3 miles long, at least several hundred feet across.

Scattered deposits also occur outside of these three belts.

The host rocks for the tungsten skarns are several types of Ca-rich gneisses that occur as units of limited dimensions within the Idaho Springs Formation. The sequence of major Precambrian rock units in the district is (Tweto, 1960; Hawley, 1969; Heinrich, personal observation):

1. Idaho Springs Formation: migmatitic biotite gneisses, some sillimanite-bearing; calc-silicate gneiss; quartzite.

2. Amphibolite and hornblendite.

3. Calc-silicate skarn rocks, developed locally in calc-silicate gneisses of (1) and in amphibolite of (2).

4. Boulder Creek granodiorite.

5. Silver Plume granite.

6. Pikes Peak granite and related gabbro, monzonite and the Redskin Granite stock with its associated beryllium greisen deposits.

In the Firefly belt the metamorphic foliation strikes northeast, dipping 60 to 80° NW. The biotitic gneisses have been intruded by Silver Plume granite, and the belt is terminated westward by a body of Silver Plume granite, 1 to 1.5 miles across. The Round Mountain belt, also intruded by a sill-like pluton of Silver Plume granite and by numerous large lensoid sills of pegmatite, is bordered on the west by a body of Boulder Creek granodiorite, about 0.75 mile across. Within this belt is developed one of the major structural elements of the area, the Round Mountain syncline, whose north-northeast-trending axis lies within Boulder Creek granitoid. In the southeastern part of the belt the Dorothy Scheelite deposit occurs in some eight skarn pods arranged around the crest of an anticline plunging northeastward.

In general the Boulder Creek is gneissic with lineations plunging northeastward, or subparallel with lineation trends in the Idaho Springs (Hawley, 1969). The Boulder Creek phacolith is a syntectonic pluton, and it and its host rocks, Idaho Springs and amphibolite, were involved in a period of plastic deformation. During the subsequent intrusion of the Silver Plume granite, these units were again strongly deformed and retrogressively metamorphosed (Hawley, 1969).

The host Ca-rich gneisses, which occur as thin layers and lenses, include (in the Idaho Springs) calcite-wollastonite gneiss, impure marble, and calc-silicate gneiss (the chief host); and (in amphibolite), hornblende-diopside gneiss, amphibolite and hornblendite.

All of the rocks are cut by numerous pegmatites of two types and two ages (Tweto, 1960). The older type is a gray-white biotitic pegmatite with which bodies of gray bull quartz are closely associated. The younger is a pink feldspathic pegmatite.

The skarn rocks consist mainly of garnet, epidote, zoisite, clinozoisite, wollastonite, vesuvianite, diopside, quartz, and calcite.

Scheelite is the only tungsten mineral. Sulfides include bornite (chief), chalcopyrite, chalcocite, covellite, and a few flakes of molybdenite. Some skarns contain small amounts of manganese silicates (bustamite, rhodonite), and some of the epidote species are manganiferous (thulite).

The skarn bodies form irregular masses, boudins, and stubby lenses, many only a few tens of feet long. They are not foliated, and some are transgressive to the metamorphic foliation. The scheelite, according to Tweto (1960), is concentrated in the skarns close to bodies of gray pegmatite (type 1) and its related quartz pods.

Nix Group

The Nix Group, which includes the Jack Rabbit, Spike Buck and Bozo claims, is on the west side of the Tarryall townsite in W/2 NW/4 sec. 6, T11S, R72W, 6th P.M. Owned by Ben Nix, the claims were developed via three discovery holes and 225 feet of bulldozer trenches. The deposits, which occur to the northeast of, but along the strike of the Badger Mountain belt, are in steeply dipping lime-silicate beds parallel with the foliations of Idaho Springs gneisses and schists intruded by pegmatites. The skarn rock consists mainly of quartz, garnet and epidote with disseminated scheelite (Belser, 1956).

Pedro Claims

The Pedro No. 1 and No. 2 claims, west of Wilkerson Pass in SE/4 SW/4 sec. 2, T12S, R73W, 6th P.M., also are in the Badger Mountain Belt. The lime-silicate beds dip steeply and strike northeastward within Idaho Springs gneisses intruded by pegmatites. The quartz-garnet-epidote skarn contains crystals and grains of scheelite. On the Pedro No. 2 claim, the skarn zone is 2 feet wide and can be traced for 240 feet; it contains little garnet. The location hole on the Pedro No. 1 claim exposes a 3 foot garnetiferous zone (Belser, 1956).

Hallie Claim

The Hallie claim on the east side of Badger Mountain in sec. 36, T11S, R73W, 6th P.M., has a discovery hole that exposes garnet-rich rock. Belser (1956) reports "...that the garnetized zone carries scheelite with a fair assay value."

Saint Joe Group

The three Saint Joe claims on the north side of U.S. 24 in NW/4 SE/4 SW/4 secs. 6, T12S, R72W, 6th P.M., are south of the Badger Mountain belt. The workings consist of a 1,200 foot crosscut adit, three shallow shafts, and several pits (Belser, 1956).

The adit transects four lime-silicate layers that strike N85°E and dip 75°N. The layers are parallel with the foliations of Idaho Springs gneisses intruded by numerous pegmatites. Layer 1, 528 feet from the portal, is developed along the south side of a 36 foot pegmatite dike.

Layer 2 was cut 588 ft from the portal. Layer 3, 608 feet from the portal, is along the north side of a pegmatite dike. Layer 4, a siliceous garnetized zone in mica schist, is 1030 feet north of the portal. It is 6 feet wide. The skarns are mainly garnet-epidote-quartz-chlorite rocks with disseminated scheelite.

Scheelite No. 1 and No. 2

The Scheelite No. 1 and No. 2 claims, in sec. 30, T11S, R72W, 6th P.M., are in the Round Mountain belt. The steeply dipping, northeasterly striking lime-silicate lenses contain mainly garnet, quartz and epidote and scattered scheelite grains.

Badger Group

The Badger group of ten claims is in the Round Mountain belt, in E/2 sec. 32, T11S, R72W, 6th P.M., about 1.5 miles north of U.S. 24. A 3-foot skarn zone, in Idaho Springs rocks cut by pegmatites, consists of quartz, garnet, epidote, vesuvianite and scheelite. The lenses trend northeastward and dip steeply. Several bulldozer trenches and ten discovery pits comprise the workings (Belser, 1956).

Dorothy Group

The four claims of the Dorothy group are in SE/4 sec. 34, T11S, R72W, 6th P.M., about 1.75 airline miles north of U.S. 24 in the Round Mountain belt. A 50-foot zone that trends N30°E and dips 65°SW contains two skarn zones as much as 8 feet wide. They consist principally of garnet, epidote and quartz and irregularly disseminated scheelite. Belser (1956) reports an assay of 0.80% WO_3 over a 4.2-foot width.

Victory Group

The four claims of the Victory group are in NE/4 NW/4 sec. 3, T12S, R72W, 6th P.M., adjoining the claims of the Round Mountain group to the northeast. The garnet-rich skarns with scattered scheelite grains have been explored by means of a 40-foot shaft and several shallow pits. Belser (1956) reports that the shaft exposed a 1-foot zone of scheelite-bearing rock that widened to 8 feet near the bottom of the shaft and assayed 1.82% WO_3.

Round Mountain Group

The Round Mountain group of four claims are just east of Round Mountain in W/2 sec. 3, T12S, R72W, 6th P.M., about one mile by a road northeast of the junction of the Tarryall road (Colo. 77) with U.S. 24. The lime-silicate lenses, which strike N17-56°E and dip 70°NW, consist mainly of garnet, vesuvianite and epidote. The workings include eight trenches, seven pits, and five shafts, 10 to 27 feet deep. Belser (1956) reports that in the 20-foot shaft a 2-foot streak of scheelite ore assayed 0.60% WO_3. During World War II, a shipment of 14 tons of ore, assaying 0.63% WO_3, was made to the Salida stockpile.

Little Abner Group

The three Little Abner claims are on the north side of U.S. 24, southeast of Round Mountain in NW/4 sec. 10, T12S, R72W, 6th P.M. They were developed by means of several trenches and shallow pits. The lime-silicate lenses, which trend northeast and dip steeply northwest, consist mainly of quartz, garnet, vesuvianite and epidote, with scattered scheelite grains. Belser (1956) reports that a scheelite-bearing zone, 9 feet wide, exposed in a 12-foot pit, could be traced for 190 feet.

Wilfley Group

The seven Wilfley claims, in NE/4 SE/4 sec. 10, T12S, R72W, 6th P.M., are just north of U.S. 24 and about one mile southeast of Round Mountain. Reportedly originally developed for gold (Belser, 1956), the vertical lenses of quartz-epidote-garnet skarn rock strike northeastward. A 100-foot shaft, a 140-foot shaft, several pits and three cuts constitute the workings.

Jeffreys Group

The five patented and two unpatented claims of the Jeffreys group are in SE/4 SE/4 NW/4 sec. 1, T12S, R72W, 6th P.M. The garnetiferous skarns, with irregularly distributed scheelite of varying concentrations, trend northeasterly. The workings include pits, cuts, short adits and shallow shafts (Belser, 1956).

Jasper Queen Mine

The Jasper Queen Deposit, in SE/4 sec. 2, T12S, R72W, 6th P.M., near the boundary with sec. 11, has been developed via a short shaft, two trenches and 10 shallow pits. During World War II the Hayden Mining Company shipped 3,700 lb of ore assaying 1.30% WO_3, and 14 tons assaying 0.62% WO_3 to the stockpile at Boulder (Belser, 1956).

The skarn lenses in lime-silicate layers contain garnet, quartz, epidote, vesuvianite and are mineralized by scheelite and minor molybdenite and copper sulfides. The host beds, in Idaho Springs gneisses and in amphibolite, are 25 to 100 feet wide, striking N15°E. The largest ore bodies were 15 to 20 feet long, 10 to 12 feet thick and 5 to 10 feet deep.

Abel Property and Holmes Ranch

The Abel Property is a 160-acre tract in sec. 15, T12S, R72W, 6th P.M., south of U.S. 24 on which the mineral rights were reserved when the land was purchased for the Holmes Ranch (Belser, 1956). The deposits, near the southwestern end of the Firefly belt, are steeply dipping, northeast striking lenses containing mainly quartz, garnet, epidote and vesuvianite. Scheelite was found in a 3-foot garnet-rich zone that was traced for 1,300 feet (Belser, 1956). Workings include a 36-foot shaft and six small pits.

The zone reportedly continues southwestward onto the Holmes Ranch itself where it has been tested by a few trenches and shallow pits (Belser, 1956).

Gilley Ranch Deposit

The Gilley Ranch deposit, sec. 32, T11S, R71W, 6th P.M., one of the most northeasterly of the deposits of the Tarryall district, is two miles east of Colorado Highway 77. The northeast-striking, nearly vertical lime-silicate gneisses contain skarn bodies of quartz, garnet, epidote and vesuvianite. The workings consist of a 50-foot shaft with a 75-foot drift. The scheelite-bearing zone is five feet wide in the bottom of the shaft and reportedly averaged 1% WO_3 (Belser, 1956).

Guffey District

General Geology

The Guffey district is underlain chiefly by Precambrian rocks covered to various degrees by Tertiary volcanics. The former tend to crop out mainly in the valley of Currant Creek and its tributaries and on Micanite Ridge and the plateau to the east, whereas the volcanics mainly inhabit higher elevations and become generally continuous northeast, north and northwest of Guffey (Bever, 1954).

The Idaho Springs Formation contains principally biotite-sillimanite gneiss, biotite gneiss, and hornblende gneiss and amphibolite. Minor rock types are feldspathic gneiss, calc-silicate gneiss, cordierite gneiss, sillimanite-quartz gneiss, and anthophyllite-cordierite gneiss. Large sections of these rocks, especially the biotitic gneisses, show moderate to strong migmatitization.

The main granitoid pluton, of Boulder Creek age, extends northward from Fremont County. At the county line exposures are six miles across, bordered on the east by sillimanite gneisses and covered to the west by volcanics of the Thirtynine-Mile series. The outcrop area of Boulder Creek and Idaho Springs tapers northwestward in the valley of Currant Creek and essentially ends at about the Hammond Ranch, about 7 miles north of the county line.

The Boulder Creek pluton has two phases: a predominant quartz-monzonitic phase and a lesser more mafic tonalitic to granodioritic phase. On the eastern margin of the pluton on Micanite ridge the mafic phase forms a border zone.

One small pluton north of Dicks Creek was assigned by Bever (1954) to Silver Plume age, but the correlation is tentative. A few diabase dikes cut all these Precambrian rocks.

The Boulder Creek pluton is cut off to the west by Chumway Park fault, a sinuous, north-trending fault downdropped on the west where a large body of Fountain Formation has been preserved. These are conspicuous red beds of arkosic sandstone and polymictic conglomerate. The area is partially covered by volcanics and pierced by two Tertiary rhyolite breccia pipes. Another major fault, east of the Chumway Park, which may represent the northern extension of the Ilse fault (p. 26), has localized the course of Currant Creek and has downdropped several small blocks of Dakota (?) Sandstone, some of which were mineralized by uranium-bearing fluids.

The Tertiary volcanics include: an older felsic series (Chumway Rhyolite) consisting of rhyolitic flows and tuffs, the breccia pipes and trachyte flows; and a younger, more extensive Thirtynine-Mile Andesite Series consisting of andesite, basalt and, just north of Guffey, a small plug of biotite monzonite porphyry (Bever, 1954).

B and G Claim

The B and G claim, staked by Mining Ventures, Inc. in 1952, is in NW/4 SE/4 SW/4 sec. 25, T14S, R74W, 6th P.M., 10 miles northwest of Guffey. Garnetiferous skarn lenses contain small flakes and thin coatings of scheelite. Two shafts, 10 and 15 feet deep, have been dug (Belser, 1956).

School Section Prospect

The School Section prospect is in N/2 NW/4 NW/4 sec. 36, T14S, R74W, 6th P.M., on land owned by the State of Colorado. A steeply dipping skarn zone between two north-trending pegmatites consists of quartz, garnet, epidote and vesuvianite. Developments are two 15-foot shafts and 5 cuts, the largest of which is 12 feet deep and 25 feet long. A sample from the deepest cut assayed 0.84% WO_3 for 16 feet (Belser, 1956).

West Deposit

The West tungsten deposit, about 1.5 miles south of Guffey and about 0.25 miles east of the junction of Colorado Highway 9 and the Guffey road, is in S/2 NE/4 sec. 23, T15S, R73W, 6th P.M. It has been described by Bever (1953, 1954) and Belser (1956). It is on the 160-acre West Ranch. The host skarn rock, giant-grained, occurs as lenses in biotite gneiss the foliation of which is vertical and strikes northwest. A small body of Boulder Creek granite, several hundred feet long (east-west), crops out just north of the deposit. The deposit overlooks the valley of Currant Creek to the west, which has been developed along a major northwest-trending fault. Along this fault[1] small blocks of sandstone (Dakota?) have been preserved by downfaulting. The deposit has been explored by several small trenches.

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[1] Probably the northern extension of the Ilse fault (p.26)

The skarn is a coarse crystalloblastic aggregate of quartz, epidote, actinolite, calcite and grossularite. Milky white scheelite is present in subhedra to euhedra as much as 0.8 inch on edge. The centers of the larger crystals fluoresce blue-white, whereas narrow margins fluoresce yellow, indicating an early-formed core rich in tungstate and a later rim rich in molybdate (Cannon and others, 1942; Greenwood, 1943). According to the scheelite fluorescence analyzer prepared by Cannon and Murata, the core contains <0.1 wt. % Mo, whereas the rim has well in excess of 5 wt. % Mo. Many of the grains, especially the smaller, are not zoned and fluoresce near-white, indicating an average Mo content of slightly less than 1.0 wt. % (Bever, 1953, 1954). Indices of refraction for the three types are (Bever, 1954):

blue white	$w = 1.925 \pm 0.001$
white	$w = 1.922 \pm 0.001$
yellow	$w = 1.924 \pm 0.001$

Inasmuch as the indices presumably decrease with increasing Mo content, it appears that the optical data are not in agreement with the fluorescence data, as Bever (1954) pointed out. Greenwood (1943) has indicated that small amounts of Mn and Cu may affect the fluorescent colors, and these elements are present in Tarryall Springs District scheelite (p. 41).

Lues Gulch Prospect

A few small pits have explored a small skarn pod just northeast of the mouth of Lues Gulch, a tributary to Currant Creek about 2 miles south of Guffey, 0.25 miles north of Colorado Highway 9. The lens, enclosed in biotitic gneiss whose foliation strikes northwest and dips at moderate to steep angles to the northeast, consists of quartz, grossularite, diopside and epidote. Small vugs, usually less than an inch across, are encrusted by brilliant orange-brown grossularite euhedra. Small grains of scheelite are sparsely dispersed in the skarn. The skarn rock contains 1 to 5 ppm Be.

This prospect apparently is the one described by Belser (1956) under the name of the Skinney prospect and is located at SW/4 SW/4 sec. 24, T15S, R73W, 6th P.M.

Nash, Johnson, and Townsend Ranches

In the mid-1950s Mining Ventures, Inc., held options on the mineral rights (in particular, for tungsten) on the Nash, Johnson, and Townsend Ranches, several miles south and southeast of Guffey in T15S, R73W, 6th P.M. Lime-silicate skarns composed chiefly of quartz-garnet rock and small grains of scheelite are exposed in several places on these properties. Only a few small pits and trenches were dug (Belser, 1956).

Fremont County

Charlene Claims

The Charlene Claims (Nos. 1-4) (Fig. 3), staked by George E. West and others of Guffey, is in secs. 3 and 10, T16S, R73W, 6th P.M., about one mile south of the Fremont-Park County line on the north side of Cottonwood Creek, a tributary of Currant Creek. An access road 4.1 miles long leads to the deposit from Colorado Highway 9. At the No. 1 claim an upper cut, 12 x 35 feet, and a lower adit, 33 feet long, have explored the deposit. The lime-silicate skarn, 3 to 13 feet wide and 1,500 feet long, consists of quartz, calcite, garnet, and epidote with small grains, crystals, and flakes of scheelite (Belser, 1956). Claim No. 2 has been explored via a bulldozer pit.

Venture No. 1 Claim

The Venture No. 1 claim, which was located in 1953, is in NE/4 sec. 29, T16S, R72W, 6th P.M., on the west side of Currant Creek about one mile north-east of the Isabel Mine (p. 80). Development consists of a 10-foot discovery shaft and 6 shallow trenches. The country rock, as mapped by Shappirio (1962) consists of Idaho Springs gneisses and migmatites. According to Belser (1956) the deposit consists of a recrystallized lime-silicate unit, 10 feet wide and 800 feet long, containing thin flakes of scheelite in a quartz-garnet gangue. The vertical zone trends N20°W.

Four Claim Group

The Four Claim Group of scheelite prospects is on the west side of a small tributary to Smith Gulch (SW/4 NW/4 sec. 25, T16S, R73W, 6th P.M.) about one mile west of the Tallahassee (county) road. Several small cuts expose a very coarse-grained body of lime-silicate skarn, as much as 10 feet thick and at least 100 feet long. The skarn consists chiefly of diopside, epidote, grossularite, tremolite and calcite. Some garnet crystals are several inches across, and tremolite, which fluoresces salmon pink, forms blades as long as 6 inches. Sparse scheelite is locally disseminated through the skarn as grains and crystals (Belser, 1956). Shappirio (1962), who found only very minor amounts of scheelite, also reports quartz, apatite, sphene, chlorite, zoisite, clinozoisite and thulite as constituents of the skarns in the Tallahassee Creek area. Garnet is commonly replaced in part by epidote and by scheelite, which is one of the latest minerals to form.

The scheelite fluoresces in two distinct colors; blue-white and yellow. Index of refraction measurements indicate the blue-white type contains less than 2% of powellite, and the yellow-type contains about 7% powellite (Shappirio, 1961).

Spectrographic analysis of the skarn rock established the presence of:

Mn	0.08 - 0.5%	
Ba	75 - 350	ppm
Li	15 - 75	ppm
Mo	20 - 100	ppm
Ni	100 - 500	ppm
Sr	500 - 2500	ppm
Zr	500 - 2500	ppm

Oliver Prospect

The Oliver prospect, in secs. 33 and 34, T19S, R72W, 6th P.M., is east of the Copper Gulch headwaters and northeast of Goat Park. The migmatitized gneiss contains a lens of amphibolite, mineralized with scheelite. The deposit, which was prospected via several shallow pits (the largest is 6 feet wide and 15 feet deep), produced four tons of 2% WO_3 ore in 1942 (Belser, 1956).

Jack of Diamonds Prospect

The Jack of Diamonds tungsten prospect--SE/4 sec. 20, T19S, R72W, 6th P.M. (unsurveyed)--is near the head of Sunset City Gulch, a south-flowing tributary of Copper Gulch. A small amount of exploratory work in the early 1960s revealed skarn rock containing garnet, diopside, epidote, and quartz. Exposures are very poor, but the skarn zone appears to have been localized along a north-northeast-trending fault. The host rocks are various highly migmatitic biotite and sillimanite gneisses and amphibolite. A lensoid pluton of Boulder Creek granodiorite about one mile long, crops out about a mile east of the deposit.

Devil's Hole

Small skarn pods in which no scheelite was found occur in the Devil's Hole, north of Texas Creek, SE/4 NW/4 sec. 20, T11S, R73W, 6th P.M. (unsurveyed). Highly variable mineralogically and texturally, they contain diopside, quartz, garnet, calcite, and epidote, some of which is in late veins. Thulite and scapolite also were found and some garnets are dodecahedral euhedra (in calcite) as much as 0.75 inch across.

Chaffee County

Poncha Pass Claim

The Poncha Pass deposit is in sec. 5, T48N, R8E, New Mexico P.M., on the east side of U.S. Highway 285 on the north descent from Poncha Pass, at an elevation of about 9,000 feet (Fig. 4). It was held, in the early 1970s, under three claims (Lucky No. 1, 2, and 3) by C. L. Johnson of 1404 Hudson St., Denver, Colorado. The 2-foot-wide quartzose skarn zone in amphibolite strikes E-W and is vertical. It contains garnet, diopside and epidote, and, according to Belser (1956), a vein sample assayed 0.17% WO_3. A short shaft and a small cut have explored the zone.

Lucky Claim

The Lucky Claim is 1500 feet southeast of the Poncha Pass deposit at an elevation of about 9,050 feet (sec. 5, T48N, R8E, New Mexico P.M.). The quartzose vein-like skarn zone, which strikes northwest and dips 80°NE, is exposed in a 15-foot cut and a short adit. It can be traced for 60 feet. According to Belser (1956), it contains "spots of low-grade scheelite but a one-inch streak of nearly pure scheelite was found in...the bottom of the adit."

COPPER-TUNGSTEN SKARNS

CLEORA DISTRICT, CHAFFEE COUNTY

General

The deposits of the Cleora district, which is on both sides of the Arkansas River about two miles east and southeast of Salida (Fig. 4), differ from the other skarn deposits of the region in several respects, one of which is that the Cleora deposits consist of well-defined fracture-filling quartzose veins that have been mineralized by both copper and tungsten minerals. Thus this type of deposit is intermediate in metallogeny to the other types of skarn deposits which are usually either Cu-Zn or W skarns. Zinc minerals, i.e., gahnite and sphalerite, do not occur in the Cleora deposits.

The deposits, which have been described by Belser (1956), Tweto (1960), Boardman and Heinrich (1971), and Boardman (1971), reportedly were worked first in the late 19th century and again about the time of World War I. Eight mines and prospects are listed by Belser (1956):

Name	Location	Owner
(N. of Arkansas River)	(all in T49N, R93W)	
Cleora No. 2	Sec. 11	Mining Ventures, Inc.
Grand View	Sec. 11	Rainbow Mining Co.
Mute Lode	Sec. 2	Martin Kenick and others
Hub Tunnels	Sec. 2	Gobetti
Stockton	Sec. 10	Rainbow Mining Co.
Uncle Andy	Sec. 10	Mining Ventures, Inc.
(S. of Arkansas River)		
North Star	Sec. 10	Martin Kenick and others
Saddle	Sec. 15	"

Tweto (1960) mentions another mine, the Gertrude, but this is a name for one of the veins at the Stockton deposit.

The Cleora deposits consist of fracture-controlled quartzose veins with sahlbands of altered amphibolite. The moderate to steeply dipping veins strike northeast to east. At the Grandview deposit a major flat fault, represented by 40-50 feet of breccia and flat-lying gouge seams, contains fragments of copper and tungsten ore dragged in from nearby veins. Chunks containing as much as 60 lbs. of high-grade scheelite have been found here (Tweto, 1960). Tweto also notes the presence of cuprotungstite and cuproscheelite. The first is a hydrous copper tungstate formed by the supergene alteration of scheelite. The second is a mixture of cuprotungstite and scheelite.

The country rocks are banded micaceous gneisses (deposits in Longfellow and Hub Gulches) and poorly foliated amphibolite (all others on both sides of the Arkansas River). Individual veins rarely more than 3 feet wide and 200 feet long show marked and even spectacular zonation in amphibolitic hosts. Two contrasting gangue silicate assemblages are present. The more common is characterized by widespread scapolite; the other, found only at the Stockton mine, is characterized by the vesuvianite-grossularite-diopside assemblage. The scapolite-bearing veins and their wall rocks show the following zones (Fig. 6). 1) vein core, 2) vein margin, 3) sahlband (vein selvage), 4) scapolitized amphibolite and 5) unaltered amphibolite (Table 8).

The core of the vein was formed by fracture filling, whereas the other zones have been developed by recrystallization and metasomatism of amphibolite, with the grain size of the minerals and the total amount of exchanged material becoming progressively finer-grained and less abundant away from the core of the vein.

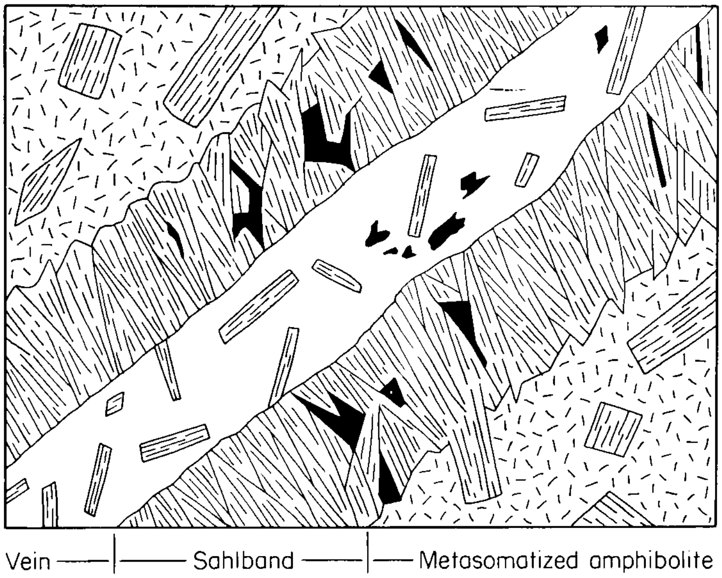

Figure 6. Diagrammatic representation of mineralized zonation in the Cleora district, Chaffee County.

Scapolitization, which may extend to as far as six feet from the vein core, is the most conspicuous alteration. Coarse scapolite euhedra are scattered throughout vein core quartz (Fig. 6). In the vein margin it is the predominant mineral, forming slender prisms as long as two inches arranged in comb structure (Fig. 6). In the altered amphibolite it appears as disseminated gray-white euhedral to subhedral metacrysts randomly arranged, which decrease in size and abundance away from the vein. Based on its average refractive index, it contains 50% meionite, i.e., about equal amounts of Ca and Na. As Boardman (1971) has pointed out, this is compatible with its formation by reorganization of the plagioclase of the amphibolite, which averages An_{50}.

Scheelite occurs 1) in quartz of the vein cores as disseminated grains, 2) with scapolite and hornblende in the sahlbands and 3) in the grossularite-vesuvianite-diopside skarn. The grain sizes range from <1 mm to about 1 cm, and its yellow fluorescence indicates a high powellite content (Tweto, 1960).

Sulfides are disseminated in the core, margin and sahlband. None were noted in the grossularite skarn which locally is studded by small vugs lined with garnet and vesuvianite euhedra. Pyrite and chalcopyrite are the principal sulfides; Tweto (1960) also reports bornite. Supergene copper carbonates are widespread.

The skarn rocks and the amphibolite are very similar in bulk composition. Added by the vein-forming solutions were Si, CO_2, S, Cu and W.

Individual Deposits

Capsule descriptions are provided by Belser (1956), modified by the writer.

Cleora No. 2

C N/2 sec. 11, T49N, R9E, New Mexico P.M.; east side of Longfellow Gulch. Vein is 1 to 4 feet wide, several hundred feet long, strikes N70°E, dips 63°NW. A 150-foot adit. Three low-grade scheelite zones, each 15 to 20 feet long. No production.

Grand View

NE/4 sec. 11, T49N, R9E, New Mexico P.M.; northeast side of Arkansas River; 7 adits and a shaft. Adit 1 is 25 feet above railroad, 115 feet long in unmineralized amphibolite. Adit 2 is 150 feet above No. 1, 170 feet long, N35°E, local bands of crushed quartz with scheelite specks. Adits 3 and 4, 50 and 100 feet long, 30 to 50 feet above and west of No. 2, in amphibolite. Adit 5 (caved) is at the same elevation as No. 4; the quartz vein strikes N85°E, dips 56°NW, it contains some chalcopyrite. Adit 6, 16 feet long, exposes malachite-stained quartz vein material. Adit 7 is 60 feet long. The shaft is caved. The deposit was worked for copper from 1890-1905. Tungsten mineralization is weak, and no tungsten ore has been produced.

Mute Lode

SE/4 sec. 2, T49N, R9E, New Mexico P.M.; on the east branch of Hub Gulch. An adit (150 feet long) follows a 4-inch quartz vein with copper sulfides and scheelite. It strikes N70°E and dips 60°NW. No production of scheelite.

Table 8. Mineral zonation in veins of the Cleora District, Chaffee County, (modified from Boardman, 1971).

	Association		Zone 1	2	3	4	5
Mineral	Scapolite	Grossularite-vesuvianite-diopside	Vein core core	Vein margin margin	Sahlband	Scapolitized amphibolite	Unaltered amphibolite
Chlorite	(X)		(X)				
Quartz	X	X	X	X	(X)		
Ilmenite	(X)			(X)			
Vesuvianite		X		X			
Grossularite		X		X			
Scheelite	(X)	X		X			
Pyrite	X		(X)	X	(X)		
Chalcopyrite	X		(X)	X	(X)		
Calcite	X	X	(X)	X	(X)		
Apatite	(X)			(X)			
Sphene	(X)			(X)			
Diopside		X		X			
Epidote	X	X	X	X	X	(X)	(X)
Scapolite	X		X	X	X	X	
Biotite	X			X	X	X	(X)
Plagioclase	X					X	X
Hornblende	X				X	X	X

(X) - accessory

Hub Tunnel

SE/4 sec. 2, T49N, R9E, New Mexico P.M.; 0.75 mile up Hub Gulch. A 20-foot adit follows a 4-inch cupriferous quartz vein. A small cut west of the adit exposes a vein that can be traced for 100 feet, strikes N80°E and dips 75°SE. Three samples from this vein averaged 1.08% WO_3 over a width of 1.2 feet. The upper Hub adit, 40 feet above and 50 feet east of the lower, exposes an 18-inch quartz vein with copper and a little tungsten mineralization. No production recorded.

Stockton

This mine, the largest in the district, is on the north side of the Arkansas River in N/2 SW/4 sec. 10, T49N, R9E, New Mexico P.M. It was developed by about 1,500 feet of workings from two adits, 500 and 600 feet long, and a shaft with three short levels. Nine northeasterly-striking veins were found, including the two major veins, the Stockton and the Gertrude. The former strikes N83°E and dips 83°SE parallel with the metamorphic foliation. It contains sulfides and scheelite, some in relatively large crystals.

The deposit was first worked for copper in the 1870s. The presence of scheelite was first noted during World War I. Production during World War II was only two tons of ore valued at $110.00. Small reserves of tungsten ore are present.

Uncle Andy

E/2 SW/4 sec. 10, T49N, R9E, New Mexico P.M.; near the mouth of Hub Gulch. The workings consist of a caved adit. Copper mineralization is present, and scheelite is reported. No production.

North Star

SW/4 sec. 10, T49N, R9E, New Mexico P.M.; on the south side of the Arkansas River and U.S. 50. The scheelite-bearing quartz vein, exposed in a small cut, strikes E-W and dips 40°N. Little development and no production.

Saddle

Sec. 15, T49N, R9E, New Mexico P.M.; on the south side of the Arkansas River. Eleven shallow pits expose a 50-foot fracture zone in amphibolite impregnated with copper sulfides and a little scheelite. The dumps, containing 40 to 50 tons, assayed 0.4% WO_3. A vein sample assayed 0.17% WO_3.

COPPER-ZINC SKARNS

GEOLOGY

Distribution

The tungsten skarn deposits of Colorado are confined to Precambrian metamorphic rocks of pre-Boulder Creek granite age. They do not occur in granitic terranes. Those described here occur in central and southern Park County (Fig. 2), in various parts of Fremont County (Fig. 3), and in southeastern Chaffee County (Fig.4). Also described are several aberrant occurrences in Custer County.

Deposits of this type are not confined to the Precambrian of south-central Colorado but also occur sparsely in various parts of the Front Range. Lovering and Goddard (1950), who provided the first modern general summary of the geology of these deposits, listed in addition to some in south-central Colorado, the following similar deposits:

In Jefferson County:

1. F. M. D. property, 2 miles northeast of Evergreen.
2. Malachite mine, 1.25 miles east of the F. M. D. property.
3. Empire mine, 6.5 miles west of Fort Collins.
4. Hosa Lodge mine, about 1 mile northwest of Hosa Lodge.

In Grand County:

5. St. Louis mine, 11 miles southwest of Fraser.
6. High Lonesome mine, 2 miles south of Monarch Lake.

In Larimer County:

7. Trails End prospects, on Trail Creek, 30 miles northwest of Fort Collins.

Sims and others (1958) also report a copper-zinc deposit in layered anthophyllite-cummingtonite-actinolite skarn in the northern part of the Front Range, in Larimer County.

Most of the deposits have been copper producers; a few produced primarily zinc ores; some yielded both copper and zinc. Galena, usually present in small amounts, may be slightly argentiferous. Molybdenum is represented in some by sparse molybdenite. Gold values are very low to negligible. Scheelite occurs in the Cotopaxi deposit.

Shape and Size

The copper-zinc skarn deposits are extremely variable in detailed shape and even more so in size. Most are crudely tabular or lenticular with gradational contacts with unrecrystallized ("normal") metamorphic host rocks. Some bodies are generally concordant with the attitude of the metamorphic foliation and layering, as in the Sedalia ore body, but are transgressive in detail. Many are grossly discordant, transgressing metamorphic foliation (Betty, Green Mountain, Independence).

Widths range from a few inches to 150 feet (Sedalia), and lengths are a few tens of feet to about 1,000 feet. For many, mineralization was restricted to strike lengths of a few hundred feet. Downdip dimensions usually involve maxima of a few tens of feet to several hundred feet.

In terms of the sulfide mineralization, the deposits are best described as epigenetic disseminated-replacement deposits. Well-defined veins are usually not present except in the Cleora district (p. 56) where they are the rule.

The copper-zinc skarns are far less numerous than the tungsten skarns but attain much greater dimensions than the latter, most of which are uniformly rather small.

Host Rocks

In contrast to the tungsten skarns, which are developed overwhelmingly in calc-silicate gneiss (Fig. 5), the copper-zinc skarns are formed mainly in amphibolite and hornblende gneiss (47%), and biotite gneisses (28%) (Fig. 7). Other lesser hosts include sillimanite (± cordierite) gneiss (12%), cordierite-anthophyllite gneiss (7%) and calc-silicate gneiss and pegmatite (each 3%). In those deposits in which more than one type of host rock is present, amphibolite is usually greatly favored, volumetrically, over adjacent biotite gneiss. From these relations it is clear that host rock composition has been a major factor in control of mineralization, even though not as exclusive as in the tungsten skarns.

Structural Control

Structurally, two types of deposits can be distinguished:

1. Those generally conformable but cross-cutting in detail with the metamorphic layering and structure - foliation-controlled deposits.
2. Those strongly transgressive to the metamorphic layering and foliation - fracture- and fault-controlled deposits.

Even the generally conformable deposits commonly are cut by faults or lie in close proximity to faults.

Relations to Granitic Rocks

Inasmuch as the copper-zinc skarns occur in terranes that have been invaded by plutons of both Boulder Creek and Silver Plume granitoids, it becomes significant to determine with which type a spatial (and possibly a genetic) association exists. It is clear that neither spatial nor genetic associations exist between the copper-zinc skarns and Pikes Peak plutons.

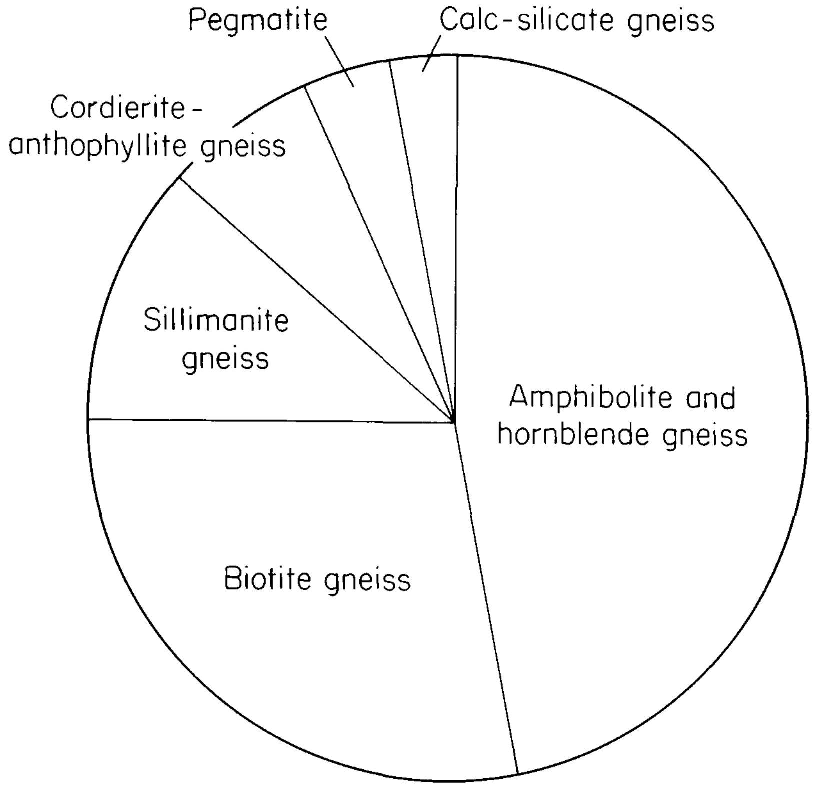

Figure 7. Distribution of host rocks for Cu-Zn skarns.

An examination of the geological maps of the mineralized areas in Fremont, Chaffee, and Park Counties show that, although these skarns <u>do</u> occur in terranes intruded by both Boulder Creek and Silver Plume granitoids, they also are found in terranes intruded solely by Boulder Creek plutons (Chaffee County) and are absent in those terranes in which Silver Plume granitoids are the sole intrusive type.

Furthermore for 27 deposits the spatial relations are as follows:

Closest granite	No. of deposits
Boulder Creek	22
Silver Plume	3
Not known	2

The three deposits that are closest to Silver Plume granite, indeed occur in a xenolith or roof pendant within the San Isabel granite (assigned by Tweto, 1977, to Silver Plume age), are those in Custer County (p. 105). Raymond and others (1980) have shown that these unusual sapphirine-bearing skarns were metamorphosed about 1700 m.y. ago, i.e., in Boulder Creek time. Thus this anomalous spatial association is not anomalous in time. The Cotopaxi deposit gives further evidence of the

Boulder Creek-skarn relationship, inasmuch as it occurs in a xenolith or roof pendant near the center of the Cotopaxi Boulder Creek pluton.

Some further evidence of the genetic link between the skarns and Boulder Creek magmatism comes from the pegmatites of Eight Mile Park which are of Boulder Creek age. In several of these, particularly in the Mica Lode pegmatite, gahnite is a not uncommon accessory mineral (Heinrich, 1948). In addition, argentiferous copper sulfide has been a conspicuous accessory in the Mica Lode pegmatite where it was observed in the mid-1940s in a 6-foot lensoid mass (Heinrich, 1948). Originally identified via polished-section characteristics as chalcocite, it was later X-rayed and found to be djurleite. This mineral also occurs in lesser amounts in the School Section pegmatite. Thus Cu and Zn, two unusual pegmatitic elements, are concentrated in pegmatites of Boulder Creek age.

Gable (1980) has presented information on the copper content of granodiorites and biotites from the Front Range Boulder Creek batholith:

	Range	Average
Granodiorite (30)	2-300 ppm	32 ppm
Biotite (7)	10-150	55

This compares with a general copper content in granitoid (acid) rocks of 16 ppm (Granite G-1 has 13 ppm). Thus the Boulder Creek batholith and especially its biotites show a significant copper enrichment.

According to Phair and Mela (1956) galena from the Cotopaxi deposit is probably not much younger than 1,300 ± 100 m.y., but "Lead isotope studies on galena from Precambrian sulfide deposits in Colorado gave the same general 1,700 m.y. age" (Bruce Doe, oral commun., 1979, in, Raymond, and others, 1980).

In addition to these various lines of evidence of consanguinity, it should be emphasized that most of the early gangue minerals of the skarns are recrystallized counterparts of the essential minerals of the host rocks. The skarns represent a stable assemblage of *metamorphic* minerals, which, although nonfoliated, were recrystallized under p_l-t-p_f conditions of the amphibolite facies. Thus the deposits are in part of metamorphic origin and had their beginnings at the peak of the last major metamorphic episode, i.e., 1700 m.y. ago, which time also marked the intrusions of the syntectonic Boulder Creek plutons.

At the Sedalia deposit (p. 97) pegmatite dikes that reportedly cut the skarn ores underground have not been altered or mineralized; thus the deposit is apparently pre-Boulder Creek pegmatites in age. At the Leeks Lode near Lookout Mountain, copper mineralization is post-pegmatite.

MINERALOGY AND PETROLOGY

Assemblages and Textures

To a considerable degree the overall mineralogy of the skarn deposits, in particular their primary silicate mineralogy, is a function of the mineralogy of the host rock:

Host rock	Main skarn silicates
Hornblende gneiss and amphibolite	Hornblende, actinolite, anthophyllite, epidote, thulite, quartz, calcic plagioclase, chlorite, clinohumite, garnet.
Biotite ± garnet gneiss	Biotite, quartz, garnet, microcline
Sillimanite ± cordierite gneiss	Sillimanite, cordierite, biotite, quartz
Anthophyllite-cordierite gneiss	Anthophyllite, gedrite, cummingtonite, cordierite, quartz

The transformations from various gneisses to the respective skarn assemblages involve the following changes:

1. Generally, but not always, the destruction of the metamorphic foliation
2. Recrystallization and commonly increased size of the metamorphic species - pegmatoidal textures are common
3. Formation of special aggregate textures, e.g., radial: hornblende, actinolite, anthophyllite, tourmaline
   nodular: chlorite, epidote
   graphic: cordierite-quartz, gahnite-quartz,
   cordierite-gahnite
4. Segregation of some species into relatively large monomineralic masses: epidote, thulite, cordierite
5. Formation of euhedral porphyroblasts and metacrysts: garnet, tourmaline, gahnite, cordierite (rare), corundum, diopside

Textures and grain sizes vary widely and even over short distances. Textural and mineralogical heterogeneity, within the limits imposed by wall rock mineralogical control, are the rule.

The complete mineralogy of the Cu-Zn skarns is summarized in Table 9.

Table 9. Mineralogy of the Cu-Zn skarns

I. Primary skarn silicates	Relative Abundance[1]
Forsterite	T
Clinohumite	R
Zircon	R
Sphene	U
Garnet	C
Vesuvianite	T or ?
Sillimanite	C
Kyanite	?
Sapphirine	R
Epidote group	
Zoisite	R
Thulite	U
Clinozoisite	U
Epidote	C
Allanite	T
Cordierite	C
Tourmaline	R
Pyroxene group	
Enstatite	T
Hypersthene	R
Diopside	R
Amphibole group	
Anthophyllite	C
Gedrite	U
Cummingtonite	U
Tremolite	R
Actinolite	C
Hornblende	C
Mica group	
Muscovite	T
Phlogopite	U
Biotite	C
Chlorite	U[2]
Microcline	T
Plagioclase series	
Albite	U
Calcic plagioclase (andesine, labradorite, bytownite, anorthite)	U
Quartz	C

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[1] C = common; U = uncommon; R = rare; T = trace; ? = questionable identification

[2] Except in the Turret deposit

Table 9 (Cont.)

II.	Primary skarn nonsilicates	
	Magnetite	C
	Gahnite	C
	Hoegbomite	T
	Ilmenite	R
	Rutile	R
	Corundum	U
	Apatite	C
	Scheelite	T
III.	Sulfides	
	Bornite	U
	Chalcopyrite	C
	Pyrite	C
	Marcasite	T
	Pyrrhotite	U
	Sphalerite	C
	Galena	U
	Molybdenite	R
IV.	Retrograde skarn minerals	
A.	Silicates	
	Sericite	C
	Talc	C
	Chlorite (incl. pinite)	C
	Brucite	T
	Serpentine	-
	Kaolinite	U
B.	Nonsilicates	
	Calcite	C
	Siderite	R
	Fluorite	T
V.	Supergene minerals	
A.	Cu minerals	
	Copper	R
	Chalcocite	U
	Tenorite	T
	Covellite	U
	Cuprite	T
	Malachite	C
	Azurite	C
	Chrysocolla	U
	Aurichalcite	T
	Chalcanthite	R
	Brochanthite	T
B.	Zn minerals	
	Hemimorphite	T
	Hydrozincite	T
	Smithsonite	T
	Willemite	T
C.	Pb minerals	
	Anglesite	T
	Cerussite	T

Table 9 (Cont.)

D. Others	
Gold	T[1]
Silver	T[1]
Calcite	C
Strontianite	T
Barite	R
Gypsum	T
Melanterite	T
Hematite	C
Leucoxene	T
Psilomelane	U
Opal	U

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[1] Only at the Sedalia mine

Individual Minerals

Clinohumite: Brownish anhedral clinohumite occurs locally in relative abundance at the Cotopaxi mine, usually in galena-rich ore. It is closely associated with forsterite, which it replaced in amphibolitic skarns.

Garnet: The composition of the garnet depends on the composition of the host rock. Salotti (1965) recognized three types of garnet at the Cotopaxi deposit: 1) almandite (Fe-Mg) derived from biotite gneiss which contains high iron almandite; similar garnet occurs in skarn derived from sillimanite gneiss, 2) high-Mg garnet occurs in skarn developed in amphibolite from the hydrothermal alteration: actinolite-garnet + biotite; 3) scheelite is associated with Ca-rich garnet euhedra. The famous large garnet euhedra at the Sedalia mine are almandite:

Analysis of Sedalia Garnet
(Penfield and Sperry, 1886)

SiO_2	37.61%
Al_2O_3	22.70
Fe_2O_3	-
FeO	33.83
MnO	1.12
MgO	3.61
CaO	1.44
	100.31

G = 4.163

Sillimanite: Sillimanite is largely restricted to those skarns developed in sillimanite gneisses. At the Betty mine spectacular parallel "pencils" of snow white sillimanite as long as 6 inches occur in quartz-sillimanite skarn rock. At the Cotopaxi mine nodular sillimanite schist is one of the hosts for skarns. In it sillimanite is replaced by gahnite and by amazonite-type microcline anhedra in whose cores relict sillimanite rosettes are preserved (Salotti, 1965). During the retrograde silicate stage, much original and recrystallized sillimanite was sericitized.

Sapphirine: Sapphirine has been found only in the three Custer County deposits (p. 107; Raymond and others, 1980). The following assemblages are reported:

AMETHYST PROSPECT

Sapphirine-amphibole-cordierite-zincian spinel

Sapphirine-amphibole-cordierite±plagioclase±biotite±sulfides

Sapphirine-amphibole-plagioclase-zincian spinel±biotite

Sapphirine-amphibole-zincian spinel±cordierite±biotite±sulfides

Sapphirine-amphibole-zincian spinel±biotite±corundum

Sapphirine-cordierite-plagioclase-zincian spinel

Sapphirine-cordierite-zincian spinel-biotite

Sapphirine-zincian spinel-biotite±corundum±sulfides

UNNAMED PROSPECT

Sapphirine-amphibole-orthopyroxene±sulfides

Sapphirine-orthopyroxene-zincian spinel-biotite±sulfides

Sapphirine-amphibole-cordierite±sulfides

Sapphirine-amphibole-zincian spinel±sulfides

UPPER ADIT, MARION MINE

Sapphirine-amphibole±zincian spinel±biotite

These occurrences of sapphirine are the first recorded for the Rocky Mountains of western North America.

Epidote group: Epidote-group minerals are common and widespread, primarily in amphibolite skarns. Deep green epidote and pink to lilac thulite are the most common. Ordinary zoisite, clinozoisite and allanite were identified only microscopically. All of the minerals are massive, anhedral and finegrained. Unlike the epidote of the tungsten skarns which not uncommonly forms well-developed crystals in calcite-rich skarns, epidote crystals are exceptional in amphibolite skarns. Thulite forms masses a few inches to a foot across; from the variability of its color, its manganese content is highly variable, even in individual deposits.

Cordierite: Recrystallized cordierite occurs in skarns developed from sillimanite-cordierite gneisses and from cordierite-anthophyllite gneisses. Nearly all cordierite is anhedral, but at the Betty mine a few euhedra, 0.5 inch across were found in quartz-cordierite pegmatoid (Bever, 1953). Graphic intergrowths of cordierite-gahnite also have been noted. The cordierite of the skarns is relatively fresh, unlike that of some pegmatites in the area[1] which has been thoroughly pinitized. Both (+) cordierite (2V=83-90°) and (-) cordierite (2V=75-90°) have been noted.

Tourmaline: Tourmaline, an uncommon skarn mineral, was noted at only a few deposits (e.g., Cotopaxi, Green Mountain). It is the variety schorl and forms slender black prisms an inch or less in length, in some places arranged in sunbursts.

Pyroxene group: Orthopyroxenes, chiefly hypersthene, occur in the Custer County deposits. Both orthopyroxene and diopside are rare amphibolite skarn species. Coarsely twinned crystals of diopside weighing as much as 25 lb have been found at the Cotopaxi deposit.

Amphibole group:

Orthoamphiboles: Anthophyllite is widespread in skarns, forming either by replacement of hornblende in amphibolites or by recrystallization of original metamorphic anthophyllite in cordierite-anthophyllite gneiss. In the latter the anthophyllite characteristically forms radial-fibrous groups, whereas in the former it is usually in parallel, subparallel or decussate arrangement.

At the Sedalia deposit both anthophyllite and gedrite occur but are antipathetic, the gedrite occurring with garnet and anthophyllite with biotite.

Clinoamphiboles: Cummingtonite is the rarest amphibole; it was identified only microscopically. Actinolite is probably the most common skarn amphibole, occurring in a variety of fabrics: stellate, decussate, or parallel. The rarity of tremolite testifies to the abundance of Fe^{2+} in the system. Hornblende commonly is a relict metamorphic species, usually partly replaced by actinolite. However, it may also persist as a skarn species, being recrystallized to pegmatoidal dimensions or to stellate aggregates. A few amphibolites are actinolite rather than hornblende amphibolites, and in these skarn actinolite has formed by recrystallization, or anthophyllite replaces actinolite.

A bluish green (sodic?) amphibole occurs in small amounts in the amphibolitic skarn of the Green Mountain deposit.

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[1] The Climax pegmatite in the Micanite district across the Fremont County-Park County line contains strongly pinitized single-crystal masses of beryllian cordierite as much as three feet long (Heinrich, 1950B).

Mica group: Muscovite is very rare, but sericite is widespread. Most of the biotite in the skarns is brown to pale brown in thin section, but some colorless phlogopite is formed in the amphibolitic skarns. At the Cotopaxi deposit Salotti (1965) noted a progressive bleaching of biotite in the increasing skarnification of biotite gneiss.

Chlorite: Primary coarse-grained chlorite is widespread (e.g., Baker Gulch, Turret). Most is unfoliated but at Turret both vein chlorite, granoblastic, foliated and foliated-corrugated varieties testify to a long interval of chlorite formation beginning at a time when regional stresses were still prevalent during metamorphism and continuing through the post-stress, fracture-forming skarn period. Most chlorite is developed from hornblende in amphibolitic skarn.

A great deal of fine-grained chlorite is retrograde, replacing such species as actinolite, garnet, biotite, phlogopite, cordierite, gahnite, and anthophyllite-gedrite.

Microcline: Microcline occurs as a relict species in the skarns developed in biotite and some sillimanite gneisses. At the Cotopaxi deposit, microcline, commonly pale green amazonite, replaces nodular sillimanite masses, as anhedra as large as 1.5 inches across (Salotti, 1965).

Plagioclase: Plagioclase, ranging from andesine to anorthite, occurs widely as an accessory skarn species, mainly in amphibolitic skarns. In the recrystallized biotite gneiss at the Cotopaxi deposit, coarsely crystalline albite is a rare skarn component.

Magnetite: Magnetite can appear in several generations. Early magnetite is coarse grained (as much as an inch across), anhedral, and occurs preferentially in quartzose pegmatoids. In deposits that originally contained relatively abundant pyrrhotite, much of this mineral has decomposed to complex magnetite. Intergrowths of pyrite plus a third generation of magnetite appears to have formed in veinlets, either with serpentine plus calcite or with quartz plus galena near the end of the sulfide mineralization phase (Salotti, 1965).

Gahnite: Perhaps the most characteristic mineral of the copper-zinc skarns is gahnite which occurs widely in a variety of forms. The color ranges from light grass-green to blackish-green. Much of it is anhedral-granular, some is massive, but euhedral metacrysts are very common. The finest occur at the Betty mine where octahedra two inches from point to point were discovered. Intergrowths with cordierite and quartz are common.

The Cotopaxi mine was famous early for fine gahnite specimens. Genth analyzed this gahnite in 1882 (Palache and others, 1944, p. 691):

Al_2O_3	60.76%
Fe_2O_3	0.58
ZnO	23.77
FeO	4.56
MnO	-
MgO	10.33
	100.00

Raymond and others (1980, p. 12-13) report that spinel from the Marion mine in Custer County contains (by microprobe analysis):

Mg	12.0%
Zn	10.0%
Fe	2.0%

They further state (p. 13) that "qualitative studies using a scanning electron microscope indicate that the relative amounts of magnesium, zinc, and iron vary considerably in spinels from the three sapphirine localities...the amounts of zinc, estimated from peak intensities, range from low or moderate to dominant, suggesting probable compositions ranging from zincian spinel to gahnite." From the color variations both within individual deposits and among deposits, it is probable that the composition of gahnite is highly variable, and most of the gahnites are strongly magnesian, with variable amounts of iron. The substitution of Zn for Mg in the spinel must have expanded its stability field, thus allowing the coexistence of quartz and gahnite at high temperatures and pressures (Salotti, 1965).

Not all the spinels are zincian. Zinc-free spinel occurs at the Turret deposit and "...no zinc was detected in one (spinel) sample..." from the Custer County deposits (Raymond and others, 1980. p. 13).

Hoegbomite: The rare mineral, hoegbomite, $Mg(Al,Fe,Ti)_4O_7$(?), was identified with corundum and spinel at the Turret deposit.

Corundum: Corundum, a relatively uncommon skarn constituent, has been found at the Turret deposit (Heinrich and Griffiths, 1948) and at the Amethyst prospect and Marion mine (Raymond and others, 1980). The three occurrences have completely different paragenesis. At the Amethyst, corundum occurs with sapphirine, amphibole, gahnite and biotite; at the Marion it occurs in sapphirine-free sillimanite.

At the Turret deposit, a major corundum occurrence, a corundum-bearing chloritite with quartz and schorl forms a zone, 2 to 6 feet thick along the northeastern margin at the southeastern end of the skarn body (Fig. 16). The corundum forms grayish barrel-shaped euhedra usually about 0.25 inch in diameter. Some are as long as 1.25 inches.

Scheelite: Except in the copper-tungsten veins of the Cleora district (p. 56), scheelite is either absent in the Cu-Zn skarns or is very rare. At the Cotopaxi mine scheelite is irregularly distributed as <1 mm, very rare aggregates of anhedral grains in pegmatoidal gahnite-anthophyllite-actinolite-clinohumite skarn, associated with small lime-rich garnet euhedra. The scheelite is veined by chalcopyrite and galena. From its fluorescence this scheelite is essentially molybdenum-free.

Sulfides:

Copper sulfides: chalcopyrite is ubiquitous; bornite is much less common and absent in many deposits; chalcocite and covellite are rare and supergene. Where associated with sphalerite, the chalcopyrite is slightly younger (Salotti, 1965).

Sphalerite: In many deposits sphalerite is the most abundant sulfide; in others it ranks second to chalcopyrite. Sphalerite is dark brown to black, invariably iron-rich. In a few specimens it displays a bluish iridescence. Sphalerite is post-gahnite and pre-chalcopyrite in paragenetic position.

Iron sulfides: Pyrite is widespread but rarely abundant. Two generations have been noted: an older pre-pyrrohotite euhedral pyrite and a younger pyrite, which, either alone or with magnetite, replaces pyrrhotite. Pyrrhotite may have been far more abundant than its present distribution indicates for pseudomorphs of pyrite, pyrite plus magnetite and marcasite after pyrrhotite have been noted in polished section (Salotti, 1965). Hypogene marcasite probably is rare. It was found as a widely distributed microscopic mineral consistently associated with pyrite in specimens free of supergene alteration.

Galena: The youngest sulfide species, galena, varies in texture from fine-grained, "steely" aggregates to impregnated masses nearly a foot across with parallel cleavage traces (pegmatoidal-poikiloblastic) (Hamblin and Salotti, 1964). Galena, if present at all, is usually very irregularly distributed.

Molybdenite: Molybdenite is scarce, forming flakes up to 0.5 inch in width, commonly in quartz-biotite-garnet rock, but some smaller flakes occur in amphibolitic skarn with their c-axes normal to the foliation (Salotti, 1965).

It should be noted that, in terms of the quantity of sulfide mineralization, these types of amphibolitic skarns can be delineated:

1. essentially unmineralized (e.g., Currant Creek Canyon),
2. weakly mineralized (e.g., Baker Gulch, Turret), and
3. strongly mineralized (e.g., Betty, Isabel, Cotopaxi, Sedalia).

The distribution of the sulfides in the silicate-oxide skarn is highly irregular, ranging from rather uniformly disseminated ore to high-grade massive shoots.

Paragenesis

Detailed studies of the mineralogy of the Cotopaxi, Betty and Salida-Turret area deposits by the writer (Heinrich and Salotti, 1959), Salotti (1965) and Boardman (Boardman and Heinrich, 1971) as well as similar studies of most of the other copper-zinc skarns by the writer indicate that these deposits developed in a series of distinctly definable but overlapping stages:

Stage 1: Pre-metasomatic isochemical metamorphism under the environment of the amphibolite facies but generally in the absence of stress. During this episode the rock-forming species of the host rocks were recrystallized to nonfoliated coarse-grained aggregates. Temperatures prevailing from the preceding period of metamorphism were maintained as high as about 700°C (sillimanite-grade) (Fig. 8). The volatile components consisted essentially of H_2O and O_2.

Stage 2: Preliminary metasomatic stage. This involved continued recrystallization of rock-silicates plus formation of "new" minerals containing exogenic elements. Much pegmatoidal quartz was formed. The introduced elements included Si (quartz), Al, Mg (cordierite, anthophyllite), K (microcline), Fe (magnetite), Zn (gahnite), W (scheelite), B (tourmaline), F (clinohumite, phlogopite, fluorite), and Mo (molybdenite). The paucity of sulfide species within this pegmatoidal stage probably stems from a low sulfur content in the metasomatizing solutions rather than being attributable to high temperatures alone. The fluid phase consisted of H_2O, F and only minor S.

Stage 3: Sulfide stage. The general sequence of the sulfides is iron, zinc, copper and lead sulfides, similar to worldwide occurrences in many types of sulfide deposits. This stage was marked by little or no recrystallization but mainly by replacement and fracture-controlled vein formation. At the beginning, temperatures were within the stability field of pyrrhotite; with declining temperatures and increased availability of sulfur, pyrrhotite changed to pyrite. Extrinsic elements include Fe, Zn, Cu, and Pb. The fluid phase was composed of H_2O, S and minor CO_2.

Stage 4: Retrograde stage. With cessation of the flow of metasomatizing solutions and a decline of temperatures to those of the green-schist facies, isochemical retrograde metamorphism partly transformed many of the skarn silicates (and gahnite) to such hydrous species as sericite, chlorite, talc and serpentine. The deposition of galena may have overlapped slightly into the retrograde stage (Salotti, 1965). Although some retrograde changes characterize the silicates of the Idaho Springs gneisses, they are nowhere as intensive as in the skarn deposits, probably reflecting the local concentration of H_2O, which at this stage, constituted essentially all of the fluid phase, accompanied by very minor CO_2.

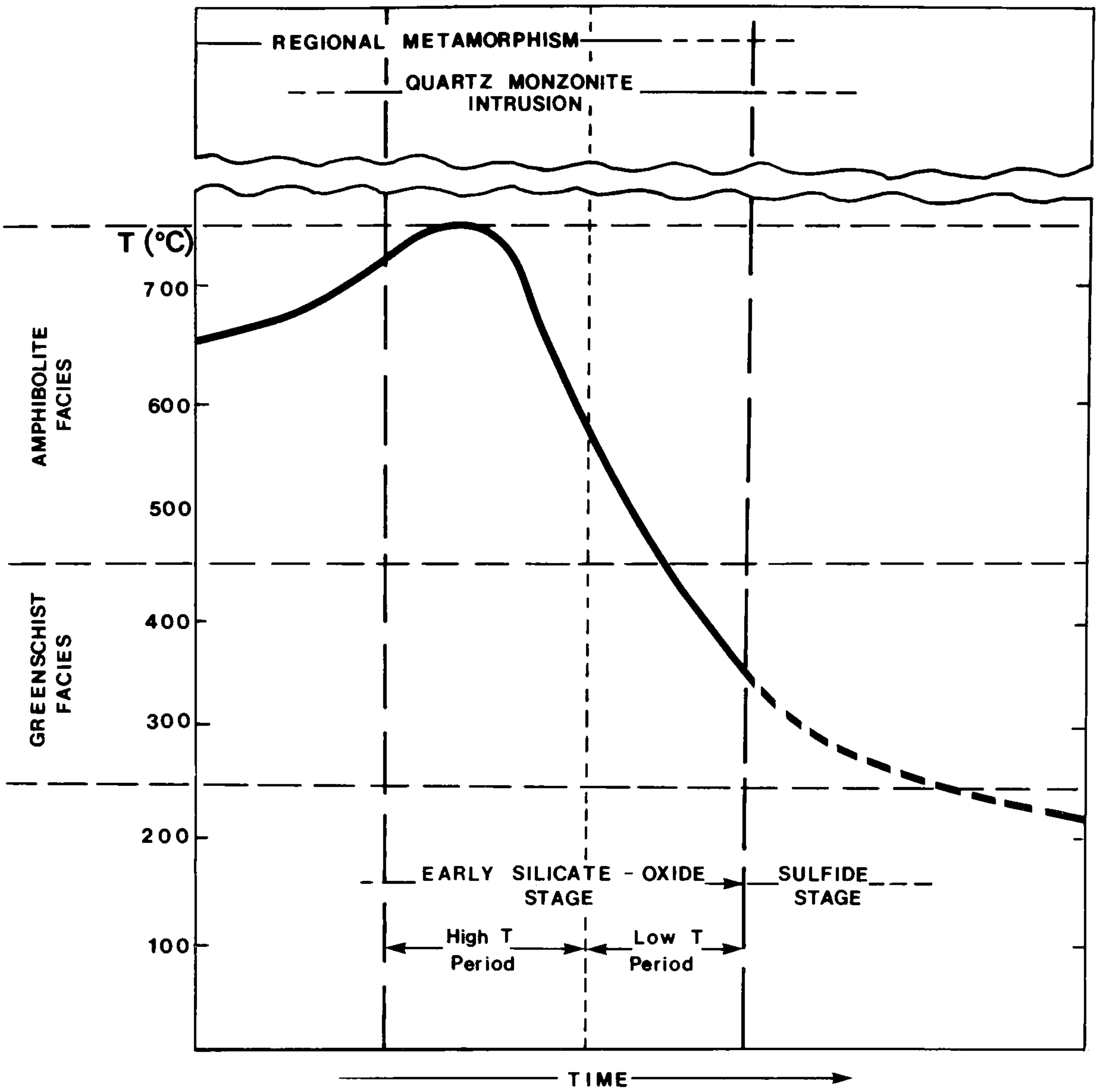


Figure 8. Representation of variation of temperature with time in early silicate-oxide stage of copper-zinc mineralization in skarn deposits of the Turret district, Chaffee County (Boardman, 1971).

Salotti (1965) has pointed out 1) that in each succeeding stage, various elements were successively recycled into new minerals and 2) that the deposits show a strong tendency toward equilibrium, at least for each individual stage, within limited rock volumes. This combination plus the different pressure, temperature and component activities of the several stages, all indicate that the overall mineralization extended over a considerable period of time.

INDIVIDUAL DEPOSITS

Park County

Betty Mine

The Betty Mine, also previously known as the Lone Chimney mine, is about 0.25 mile south of the Black Mountain road and about one mile west of Currant Creek (Colorado Highway 9) in W/2 NW/4 NE/4 sec. 21, T15S, R73W, 6th P.M. It was visited by Eckel (1932), whose examination is reported by Lovering and Goddard (1950), and has been studied by Bever (1953, 1954) and by Heinrich (Heinrich and Bever, 1957). The workings consist of a 300-foot shaft (Howell Shaft) with minor drifting and a younger 30-foot shaft (Dell Shaft) from which a 30-foot drift followed the mineralized zone northeastward. A short crosscut did not penetrate the hanging wall of the zone. In the early 1950s the Howell Shaft was reopened briefly. Much of the sulfide-rich dump material was hauled off for milling in the 1960s. In the 1950s the mine was owned by A. B. Dell and his sons, Buford and Charles.

The district, which also includes the Copper King, Copper Queen, and Mill Gulch Mines, had a small recorded production in 1945-47.

Copper	8500	lb
Zinc	2600	"
Lead	3700	"
Silver	168	oz
Gold	11	oz

The gold and lead are presumed to have been obtained from the Betty Mine inasmuch as ores from the other three deposits are free of these metals.

The Precambrian metamorphic rocks at the Betty Mine include quartz-muscovite schist, biotite gneiss, sillimanite-cordierite gneiss, and amphibolite. Just east and south of the mine these rocks have been intruded by a pluton of Boulder Creek granite which may represent a cupola from a batholith of Boulder Creek granite that underlies large areas both to the south and to the north of the mine between Currant Creek on the East and the major Chumway Park fault to the west (Bever, 1954).

The Precambrian metamorphic rocks are cut by two dikes of Tertiary age (probably Oligocene). One dike forms the hanging wall of the mineralized zone, which strikes N42°E and dips 65°SE across the foliation of the metamorphic rocks, which strikes N22°E and dips 55-65°E. This breccia dike, which is not mineralized, has been intruded along the reopened fracture-controlled mineralized zone. This dike can be traced in outcrop for about 1,200 feet. The parallel breccia dike to the northwest is traceable for about 3,300 feet. The Betty breccia dike is cut by an arcuate fine-grained basaltic dike. All of these dikes belong to the Guffey volcanic series (Bever, 1954).

The mineralized zone, 10 to 12 feet wide, is developed in skarn rocks formed by recrystallization and metasomatism of the metamorphic rocks. Major skarn types are:

1. Sillimanite-quartz rock, snow-white, with highly attenuated columnar aggregates of parallel sillimanite needles (6 inches long).

2. Nonfoliated pegmatoidal cordierite-sillimanite-quartz rock, with aggregates of anhedral cordierite as much as 4 inches across. A few euhedral cordierite crystals in quartz, 0.5 inches across, also have been found (Heinrich and Bever, 1957). The cordierite contains 0.3% Mn and only 5 ppm Be.

3. Cordierite-quartz rock, some pegmatoidal, some with graphic textures.

4. Cordierite-anthophyllite (±anorthite, An_{99}) rock.

5. Anthophyllite rock, with rosettes of anthophyllite as large as 1.5 inches across.

6. Actinolite (±biotite) rock, with rosettes of actinolite reaching a diameter of 2 inches.

7. Gahnite-quartz pegmatoids and massive gahnite rocks. Gahnite, which is mainly anhedral, also forms fine euhedral octohedra as much as 2 inches across. Gahnite also may be an accessory constituent of all the above rock types.

Calcite, epidote, magnetite, biotite, muscovite, chlorite, grossularite, and hornblende are locally abundant skarn species. Vesuvianite, reported by Eckel (1932), was not found; it probably was confused with fine-grained, light green, granular gahnite.

All of these rocks are locally mineralized to varying degrees by the sulfides--chalcopyrite, sphalerite, galena, pyrite, bornite, and covellite (in probable order of abundance). Much near-surface material is stained by azurite and malachite. Most of the sulfides are in anhedral disseminated grains and aggregates, occurring as veinlets, cleavage and fracture replacements and general ("massive") replacements. Their form and texture have been mainly controlled by the older replaced silicate skarn species, especially anthophyllite. Sphalerite, chalcopyrite, and galena typically are localized along grain boundaries or cleavage planes in anthophyllite. In some specimens they replace anthophyllite blades pseudomorphously. In some graphic cordierite-quartz rock galena forms skeletal poikiloblasts as much as an inch across. Both the sulfide ore and the silicate gangue (cordierite-free) were checked for Be; both contain less than 1 ppm.

The sequence of mineral formation has been (Bever, 1954; Heinrich and Bever, 1957) 1) recrystallization of metamorphic species and formation of actinolite, epidote, and anthophyllite; 2) quartz, gahnite; 3) pyrite; 4) galena, bornite; 5) chalcopyrite; 6) sphalerite; 7) covellite; 8) chlorite; and 9) malachite, azurite (supergene).

Copper King and Copper Queen Prospects

The Copper King deposit, in NE/4 SW/4 sec. 21, T15S, R73W, 6th P.M., is on the north side of Thirtyone Mile Creek, 1.5 miles west of its junction with Currant Creek (Colorado Highway 9). A narrow northeast-trending pegmatite was mined for feldspar in the 1930s by the Colorado Feldspar Company of Canon City, Colorado (Hanley and others, 1950). The Copper Queen prospect is several hundred feet to the east. Several adits, one of which transects the Copper King pegmatite, have been dug in prospecting for copper.

The mineralized rocks, which consist of actinolite and anthophyllite skarns, occur within a body of biotite-sillimanite gneiss about 1980 feet across, bordered to the north and west by Boulder Creek granite and covered to the east by Tertiary rhyolite. At the Copper King the chief host for disseminated chalcopyrite and bornite is nonfoliated actinolite-clinozoisite-sphene magnetite rock; whereas at the Copper Queen the main host for the copper mineralization is a rock consisting almost entirely of rosettes of brown anthophyllite, as much as 0.75 inch across.

The Copper King deposit reportedly yielded some native copper ore.

Mill Gulch Mine

The Mill Gulch Mine, not examined by the writer, is in E/2 NW/4 sec. 33, T15S, R73W, 6th P.M., at the head of Mill Gulch. The old shaft was already inaccessible in 1932 (Eckel, 1932). Its copper ores contained some native copper, and shipped ore reportedly assayed 3 to 50 oz/ton Ag with no gold or lead.

Blue Mountain

Blue Mountain, a NNW-trending ridge about 2.5 miles long and 0.25 mile wide, begins about 1.5 miles south of Lake George in NW/4 NE/4 sec. 8, T13S, R71 W, 6th P.M. It is an "island" of metamorphic rocks within Precambrian granites (Cross, 1894). The ridge is held up by resistant quartzites and gneisses, migmatitized to various degrees. The metamorphic foliation strikes nearly north-south and is very steeply dipping to vertical. The rocks consist of sillimanite quartzite, biotite gneiss, sillimanite-cordierite gneiss, and sillimanite gneiss. Copper mineralization occurs in the sillimanite-cordierite gneiss on the northeast side of the ridge near its base, about 0.75 mile southeast of its northern end. The deposit, which has been prospected via a short adit, consists of disseminated chalcopyrite. The host rocks are finely banded blue-gray gneisses with layers of 1) sillimanite-quartz±biotite, 2) quartz and 3) cordierite-quartz, all strongly migmatitized by medium-grained to pegmatitic brown leucogranite. The pegmatitic parts contain muscovite, and accessory magnetite and chalcopyrite. Mingling of the granitic material and the metamorphic host has produced pegmatoidal hybrid rocks containing cordierite aggregates over 0.5 inch long. Much of the granitic material is arranged lit-par-lit, with locally transgressive patches and dikelets.

A chemical analysis of the sillimanite-cordierite gneiss is:

SiO_2	40.7%
Al_2O_3	36.9
Fe_2O_3*	15.2
TiO_2	0.9
CaO	0.1
MgO	3.8
Na_2O	0.4
K_2O	1.8
	99.8

*total Fe reported as Fe_2O_3

The sparse copper mineralization appears to be restricted to a narrow zone and is not of economic significance.

Fremont County

Isabel Mine

The Isabel Mine (center, N. boundary, sec. 31, T16S, R72W, 6th P.M., is on the north bank of Smith Gulch, two miles west of the junction with Currant Creek, on the Tallahassee road (Shappirio, 1962). The mine was already inaccessible in 1932 but had produced a substantial quantity of high-grade zinc ore, containing a little lead and copper. Several tons of zinc-lead ore remained on the dump in 1932. The deposit was worked via a shaft at least 100 feet deep (filled with water in 1961) and more than 100 feet of workings (from the size of the dump) (Lovering and Goddard, 1950).

The host rocks are chiefly amphibolite and lesser migmatitized biotite gneiss whose foliations trend N20-60°E and are vertical. A conformable vein of coarse white quartz trends N60°E for about 75 feet and northeastward swings to N20°E, apparently pinching out within 100 feet (Eckel, 1932). It was 2 to 4 feet wide and consisted mainly of brecciated quartz with blebs, masses and veinlets of sphalerite, galena, and chalcopyrite which also impregnate the recrystallized amphibolite along the vein margins. Here the host rock has been converted to a nonfoliated aggregate of quartz, fibrous actinolite, zoisite, garnet, minor gahnite and pyrite. The ore minerals, which from dump specimens are in a ratio of

20:2:1 (sphalerite: galena: chalcopyrite), transect and replace the gangue species. Although a few dump specimens of biotite gneiss contain specks of sulfides, most of the ore minerals are in recrystallized amphibolite and shattered vein quartz.

Green Mountain Mine

The Green Mountain Mine, also known as the Copper Boy Mine, is on unsurveyed land--sec. 26, T19S, R72W, 6th P.M.--on the south edge of Goat Park at the headwaters of Sawmill Gulch, an east-flowing tributary of Grape Creek. It can be reached over a poor jeep road up Talbert Gulch five miles from the Copper Gulch county road. It was examined by Heinrich in 1962 and 1966, and specimens collected by him were studied by Pierce (1970).

Country rocks consist of migmatitized biotite gneisses, sillimanite gneisses, and amphibolites. A few Cambrian dikes of lamprophyre and trachyte that cut these rocks belong to the dike halo of the McClure Mountain-Iron Mountain mafic-alkalic complex (Heinrich and Dahlem, 1966). About one mile to the northeast is the eastern end of a lensoid pluton of Boulder Creek granodiorite, about 2.5 miles long and a half mile across. The major Ilse fault (N-S) is 2.5 miles east of the mine, but a subsidiary WNW-fault, on the south side of Sawmill Gulch, extends to within about 0.5 mile of the mine, or even closer.

The workings, inaccessible in 1966, consist of a shaft, at least 50 feet deep, and a shallow pit 200 feet southeast of the shaft. The metamorphic foliation strikes N30°E and dips very steeply to the northwest. Both the shaft and the pit appear to have been dug in mineralized rock, and a line connecting the two trends N45°W. Within the shaft collar the sulfide zone strikes NE-SW and is vertical.

The metamorphic rocks found in scattered small exposures and in dump specimens include biotite-garnet gneiss, hornblende-biotite-cordierite gneiss, and amphibolite.

Recrystallization of both biotitic and hornblendic rocks has resulted in skarn. The biotite gneiss shows a considerable increase in quartz, and an increase in grain size to pegmatoidal dimensions in the hornblende rocks cordierite has been eliminated and hornblende has been converted to actinolite. New skarn species include cummingtonite, anthophyllite, almandite, and hypersthene. These skarns are decussate, with semiradial clusters of actinolite blades, some as long as an inch. Gahnite and magnetite are abundant, with the former apparently restricted to anthophyllite skarn. Schorl crystals as much as one inch long were found in one skarn specimen.

Sulfides, introduced following the formation of the spinels, include sphalerite (deep red-brown), chalcopyrite, pyrite, rare galena and very rare molybdenite. The mineralization is disseminated, following fractures and cleavage planes but also is foliation-controlled. The post-sulfide stage consists of low-temperature alterations of the skarn silicates:

K-feldspar - kaolinite, sericite
Plagioclase - kaolinite, sericite
Cordierite - pinite, chlorite
Biotite - quartz + magnetite + calcite
Biotite - chlorite
Garnet - chlorite ± biotite
Hornblende } Combination of
Cummingtonite } chlorite, biotite
Hypersthene } talc
Anthophyllite - chlorite, biotite, Na-amphibole, calcite

Leeks Lode

Although most of the Precambrian copper mineralization in south-central Colorado has been developed in metamorphic rocks, especially in amphibolite, a few exceptions have been found. These include the Leeks Lode, which is one of several mineralized pegmatites in Washtub Gulch, a tributary of Copper Gulch, in secs. 5 and 9, T19S, R72 W, 6th P.M. In the mid-1960s the property was owned by Max E. Leek of Pueblo, Colorado. The workings consist of about 180 feet of adits and drifts, a 60-foot shaft and two small pits. The upper adit was driven on pegmatite; the lower, longer adit was driven to intersect the pegmatite at depth; the shaft was sunk along the hanging wall of the pegmatite. The deposit has been studied and mapped by Dahlem (1965) and examined by Heinrich.

The pegmatite is a 5- to 10-foot sill in mica schist with numerous small parallel satellitic pegmatites. It has been mineralized by discontinuous lenses of sulfide ore containing chalcopyrite, bornite, chalcocite, and pyrite. The lenses, about one foot wide and 1.5 to 2 feet long, are enveloped by a shell of calcite-rich rock. These carbonate haloes may continue through unmineralized pegmatite and mica schist.

In sec. 30, T18S, R72W, a similar mineralized pegmatite has apparently been entirely mined out via a small open pit. The stockpile contains pegmatite with introduced bornite and chalcopyrite.

Baker Gulch Prospect

Baker Gulch is a northwest-trending tributary of the Arkansas River about two miles east of Spikebuck Gulch and Spikebuck siding on the Denver and Rio Grande Western Railroad. Near its mouth just south of U.S. 50, a small cut has explored a copper showing on the northeast side of the gulch--sec. 29, T18S, R72W, 6th P.M. (unsurveyed). The mineralization, which consists of sparsely disseminated chalcopyrite, occurs in a coarse chlorite rock formed by alteration of amphibolite intruded by a pegmatite dike. The amphibolite and associated migmatites form a band about 0.25 mile across between the tonalitic border phase of large Boulder Creek batholith to the north and a small outlying pluton of Boulder Creek granodiorite to the south and southwest. Mineralization was controlled by a north-northwest-trending fault that cuts both igneous bodies as well as the metamorphic rocks, crossing the Arkansas River at the mouth of Baker Gulch.

Cotopaxi Mine

The Cotopaxi copper mine is in a small gulch about 0.5 mile northwest of the bridge across the Arkansas River at Cotopaxi in the E/2 SE/4 sec. 25, T48N, R11E, New Mexico P.M. (Fig. 9). It had been idle for many years when it was first examined by Lindgren (1908), but at one time it was a considerable source of copper ore, probably in the 1800s. There have been several attempts to reopen the mine in the 1950s and 1960s, none of which were successful. In the late 1960s the mine was owned by P. G. Owens of Canon City, Colorado.

In addition to the visit by Lindgren, the deposit has been studied by Heinrich (Heinrich and Salotti, 1959) and by Salotti (1960, 1965) in detail. It has long been famous as a source of fine specimens of gahnite (Dana, 1898, who incorrectly located it in Chaffee County).

The workings consist of 1) a lower adit (elevation about 6,750) from which several hundred feet of drifts and crosscuts extend (Fig. 10); 2) an upper adit (elevation about 6,780 ft) with several hundred feet of drifts and stopes (Fig. 11); 3) an open-cut glory hole which connects with stopes from the upper adit and 4) several short shafts and small prospect pits.

The deposit occurs in a xenolith or roof pendant of Idaho Springs metamorphic rocks fully enclosed in granitic rocks. The xenolith, about 0.75 x 0.5 mile in size, occurs near the southern margin of a major granitoid pluton. Intially this granite had been correlated tentatively with the Pikes Peak granite (Salotti, 1965), but recently age determinations have indicated that it is of Boulder Creek age (Taylor and others, 1975B). Near the deposit the granite is fine grained and reddish, nearly aplitic, and probably represents a border phase. The typical granitoid is a coarse-grained, gneissoid, pink, and locally megacrystic (microcline) rock containing essential quartz, microcline, and biotite and ranging in composition from granite to granodiorite. Accessories are magnetite, sphene, apatite, zircon, tourmaline, local hornblende, and locally abundant allanite.

Rocks exposed in the xenolith include biotite schist, nodular sillimanite schist, biotite gneiss, hornblende gneiss, amphibolite and rare calc-silicate gneiss.

The xenolith and its deposit lie just a few hundred feet west of the major Cotopaxi fault, a north-south fault along which Barnard Creek has been developed and which Salotti (1960) originally named the Barnard Creek fault. This fault is one of several major north-south faults (e.g. Texas Creek and Ilse faults) that were developed in late Precambrian time and were reactivated in Laramide time (p. 27). Within the xenolith a number of subsidiary faults trend north, north-northeast, and nearly east-west (Fig. 9), subdividing the xenolith into some half-dozen fault block units, each characterized by its own orientation of the metamorphic foliation (Fig. 9).

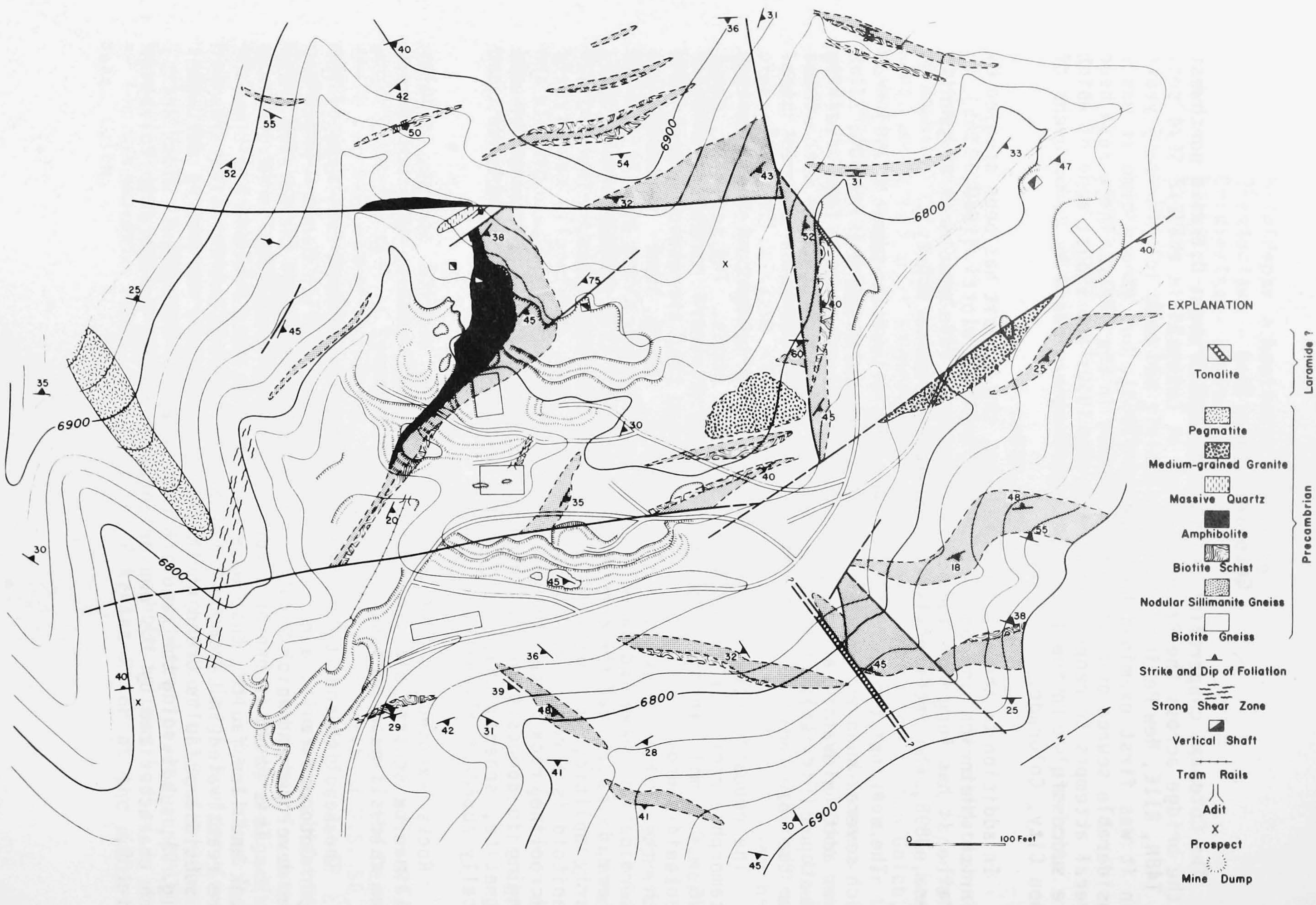


Figure 9. Geologic map of the Cotopaxi mine area, Fremont County (Salotti, 1965).

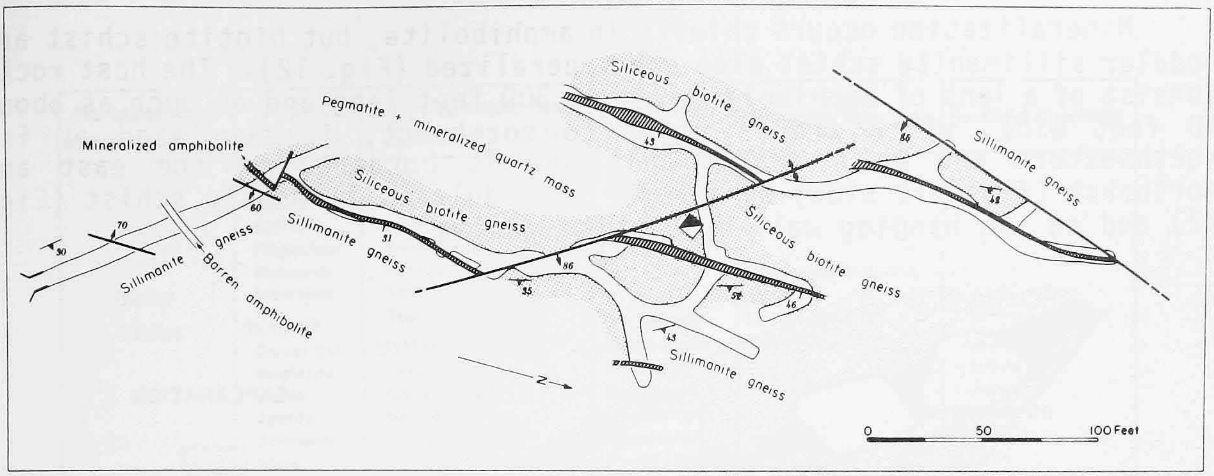


Figure 10. Plan of lower adit, Cotopaxi mine, Fremont County (Salotti, 1965).

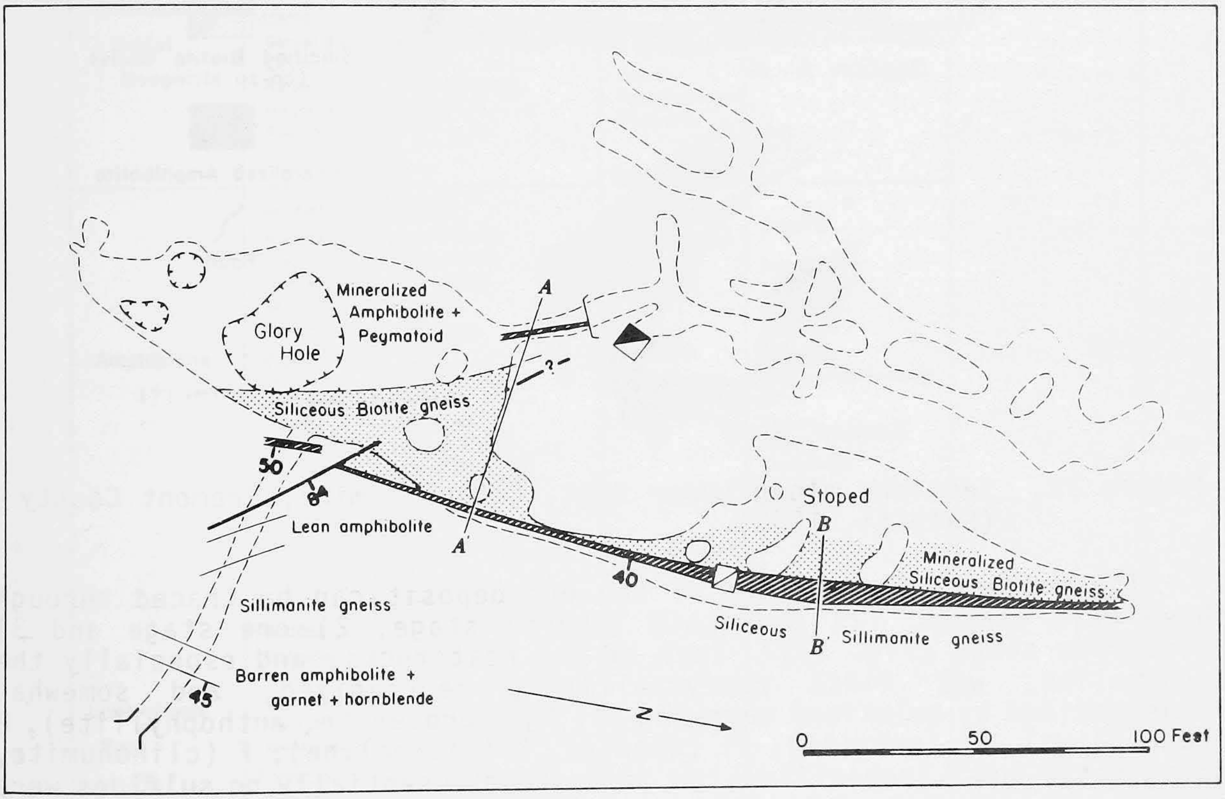


Figure 11. Plan of upper adit, Cotopaxi mine, Fremont County (Salotti, 1965).

Mineralization occurs chiefly in amphibolite, but biotite schist and nodular sillimanite schist also are mineralized (Fig. 12). The host rocks consist of a lens of amphibolite, about 300 feet long and as much as about 50 feet wide, which trends north to northwest, is truncated at its northwestern end by a small fault and is bordered on the east and northeast (footwall side) by a layer of nodular sillimanite schist (Fig. 12) and on the hanging wall by biotite gneiss.

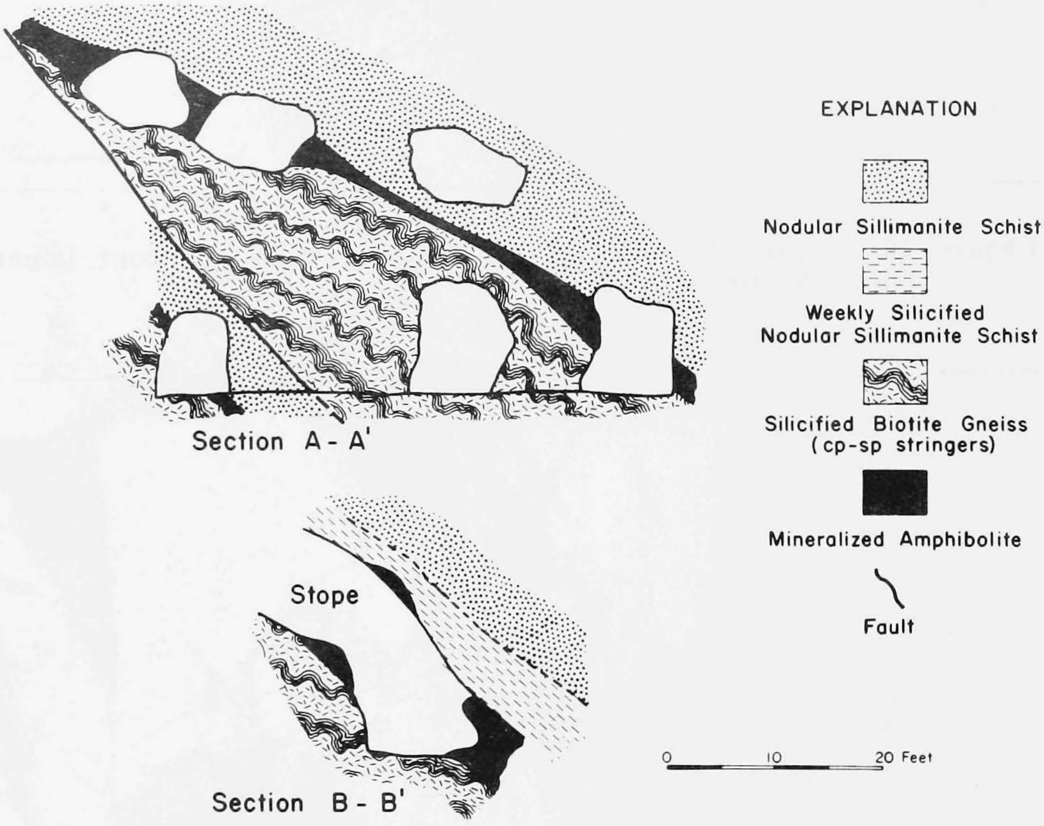


Figure 12. Sections along upper adit, Cotopaxi mine, Fremont County (Salotti, 1965).

The process of formation of the ore deposit can be traced through three main stages: 1) pegmatoid (skarn) stage, 2) ore stage and 3) retrograde stage (Fig. 13). Each of the host rocks, and especially the amphibolite, was first recrystallized, reorganized, and somewhat metasomatized by solutions carrying Al, Mg (cordierite, anthophyllite), B (tourmaline), Zn (gahnite), Si (quartz), K (microcline), F (clinohumite, phlogopite) and W (scheelite). At this stage essentially no sulfides were deposited. It was followed by sulfide-rich deposition, including molybdenite, pyrite, pyrrhotite, sphalerite, chalcopyrite, marcasite and galena, accompanied by quartz, magnetite, siderite, and fluorite. The terminal retrograde stage was characterized by the development of various chlorites, sericite, epidote minerals, serpentine and albite.

Pre-Mineralized Metamorphic Rock	Original Mineralogy	Early Pegmatoid Stage (Silicate and Oxide)	Main Ore Stage	Retrograde Alteration	Surficial Alteration
Biotite Gneiss	Essential Quartz Biotite Plagioclase Muscovite Microcline Accessory Garnet (Fe) Magnetite Zircon Apatite Sillimanite Rutile	Essential Quartz Microcline Biotite (>Mg) Gahnite (L) Albite (L) Tourmaline (L-R) Accessory Zircon Garnet (Fe-Mg) Molybdenite Cordierite (L-M)	Ore Minerals Molybdenite Magnetite Pyrite Pyrrhotite Sphalerite Pyrite (Po→Py) Chalcopyrite Pyrite + Magnetite (Po→Py + Mag.) Pyrite + R Carbonate (Po→Py + R Carbonate) Marcasite (Po→Mc) Galena Tetrahedrite(?) Magnetite Non-ore Minerals Quartz Siderite Garnet (Ca) Epidote Fluorite Wall Rock Alteration Amphibolite→ Biotite + Garnet (Fe)	Fine-grained Muscovite Albite (M) Epidote group (M) Diabantite	Hematite Goethite Limonite Covellite (M) Malachite Azurite Chrysocolla Cuprite Anglesite Calcite Gypsum Strontionite (R)
Nodular Sillimanite Schist	Essential Quartz Sillimanite Biotite Muscovite Plagioclase Microcline Accessory Garnet (Fe) Zircon Rutile Magnetite Apatite	Essential Quartz Gahnite Cordierite Amazonite (L) Biotite (>Mg) Sillimanite Accessory Zircon Garnet Tourmaline (L)		Fine-grained Muscovite Serpentine Albite (M) Epidote (M)	
Amphibolite (?)	Essential Hornblende Plagioclase Diopside (L) Quartz (L) Epidote group Accessory Biotite Allanite Sphene Garnet (Fe) Magnetite	Essential Mg-Actinolite Anthophyllite Garnet (Mg) Diopside Phlogopite Gahnite Clinohumite Accessory Forsterite Garnet (Ca-L) Scheelite (L-M)		Talc (R) Diabantite Clinochlore Amesite ? Antigorite Fine-grained Muscovite Albite Epidote Thulite Clinozoisite Calcite Magnetite	
Lime-silicate Rock (?)	Essential Scapolite Garnet (Ca) Diopside Quartz Epidote group Accessory Calcite Sphene Apatite	(?)			

L = Local
M = Minor
R = Rare

Figure 13. Paragenesis of the Cotopaxi deposit (Salotti, 1965).

Although the deposit once was a significant producer, operations since the early 1900s have been intermittent and short-lived, and these operations were submarginal at best. In 1883 the ore consisted mainly of sphalerite and chalcopyrite; galena was not present. After sorting it assayed 58% Zn; 4.6% Cu and 10 oz/ton Ag (Lovering and Goddard, 1950). In the 1900s only high-grade ore was shipped, and much of the dump material probably averages a few percent sulfide. This already mined rock could possibly be milled profitably, if all values of Cu, Zn, and Pb could be recovered. Essentially nothing is known of the deposit at depth, and thus some drilling to test for mineralization in the amphibolite skarn down dip would appear to be warranted.

The deposit has been a source of fine mineral specimens for collectors, especially of gahnite, molybdenite, cordierite, anthophyllite, actinolite, chlorites, clinohumite, diopside, thulite, phlogopite, biotite, garnet, amazonite, sphalerite, chalcopyrite, magnetite, and galena. Although diopside is rare, coarsely twinned crystals weighing as much as 25 lb have been found isolated in a finer grained actinolitic matrix. Massive thulite occurs in pieces as long as 1.5 feet. Clinohumite, in brown anhedra as much as an inch long, is associated with skeletal poikiloblasts of galena many inches across, with fine-grained galena, and with anthophyllite, forsterite, thulite, and chalcopyrite. Some pegmatoids consist of iridescent black sphalerite (1 x 2 inches) in white coarse quartz with chalcopyrite and biotite.

Both the sulfide-rich ores and the silicate gangue were checked for Be and contained about 1 ppm.

Carson Mining Company Prospect

The prospect of the Carson Mining Company, 3 miles northeast of Cotopaxi in SE/4 NE/4 sec. 18, T48N, R12E, New Mexico P.M., was worked in the late 1950s by Sam Irving of Colorado Springs. He drove a short inclined shaft and developed about 200 feet of underground workings in an elongate roof pendant of gneiss in Boulder Creek granite. The weak mineralization, which consists of disseminated chalcopyrite, is in a uniformly banded hornblende-microcline gneiss (Salotti, 1960), in which hornblende-rich bands 1 mm to 2 cm in thickness alternate with quartz microcline bands. Associated with the gneiss in the xenolith are migmatite and migmatitized biotite schist and gneiss. The chalcopyrite is largely restricted to the leucocratic bands. Flakes of gypsum occur as a supergene mineral.

Unmineralized Skarns

Coaldale Bridge

Two occurrences of essentially unmineralized skarn rocks of amphibolitic derivation have been found in Fremont County. One is on the east side of the Arkansas River Valley about 4 miles west-northwest of Cotopaxi and about 7 miles southeast of Howard in SW/4 sec. 28, T48N, R11E, New Mexico P.M., near the Coaldale bridge. This occurrence, noted by Salotti (1960), was originally believed to be a "hooded" pegmatitic diabase dike hydrothermally modified by a pegmatitic intrusion. The lensoid body, which measures about 40 x 40 x 100 feet, occurs as a xenolith in Boulder Creek granodiorite very close to the intersection of the major NNW-trending Pleasant Valley fault and an east-northeast fault that continues northeastward to pass just north of the Cotopaxi mine. The Pleasant Valley fault is the eastern structural boundary of the Sangre de Cristo tectonic block between Cotopaxi and Salida. The skarn body, which may be localized along the north side of the ENE fault or is truncated by it, is well exposed on the north wall of the first gulch south of the Coaldale siding of the Denver and Rio Grande Western Railroad.

Much of the body is strongly foliated, but nonfoliated rock occurs irregularly distributed, ranging from very fine-grained sugary to pegmatoidal in texture. The skarn body is cut by dikelets of Boulder Creek granodiorite and a large irregular pegmatite. The granite pegmatite, which contains red microcline, white sodic plagioclase, and biotite, appears to have both migmatitized the original skarn rock and also transformed it along the contacts to chloritite. The skarn includes the following major rock types:

1. Pegmatoidal quartz-andesine (Ab_{64})-hornblende-actinolite-biotite rock. Some of the amphibole crystals are as long as 2 inches. Accessories are epidote, coarse magnetite, and a trace of fine-grained chalcopyrite (common).

2. Recrystallized amphibolite consisting of hornblende, plagioclase, coarse magnetite, large metacrysts of biotite, and veinlets of chlorite (common).

3. Actinolite-biotite rock, fine-grained to coarse-grained, slightly to nonfoliated (rare).

4. Fine-grained, porcelanoid, gray-green (clinozoisite-epidote rock which resists weathering and protrudes as knobs (common).

5. A banded rock consisting of 1- to 2-inch layers of light gray clinozoisite-tremolite alternating with dark anthophyllitic bands (rare).

6. Fine-grained chloritite (very common).

Currant Creek Canyon

The other occurrence of unmineralized skarn rocks is in the floor of the canyon of Currant Creek, about 1.5 miles southeast of Gribble Mountain, north of Twelvemile Park, (east-central part of SE/4 NE/4 sec. 24, T17S, R72W., 6th P.M.) Discovered by the writer, the occurrence has been studied in detail by Reuss (1970). The exposure, on the east side of the canyon, consists of a 400- x 600-foot mass of actinolitic rocks (Fig. 14). This body, which is transgressive to the attitude of the foliation of migmatitized Idaho Springs in which it occurs, is cut by pegmatite dikes. The southeastern contact of the Boulder Creek granite pluton of Wilson Park is less than 0.25 mile to the east and north.

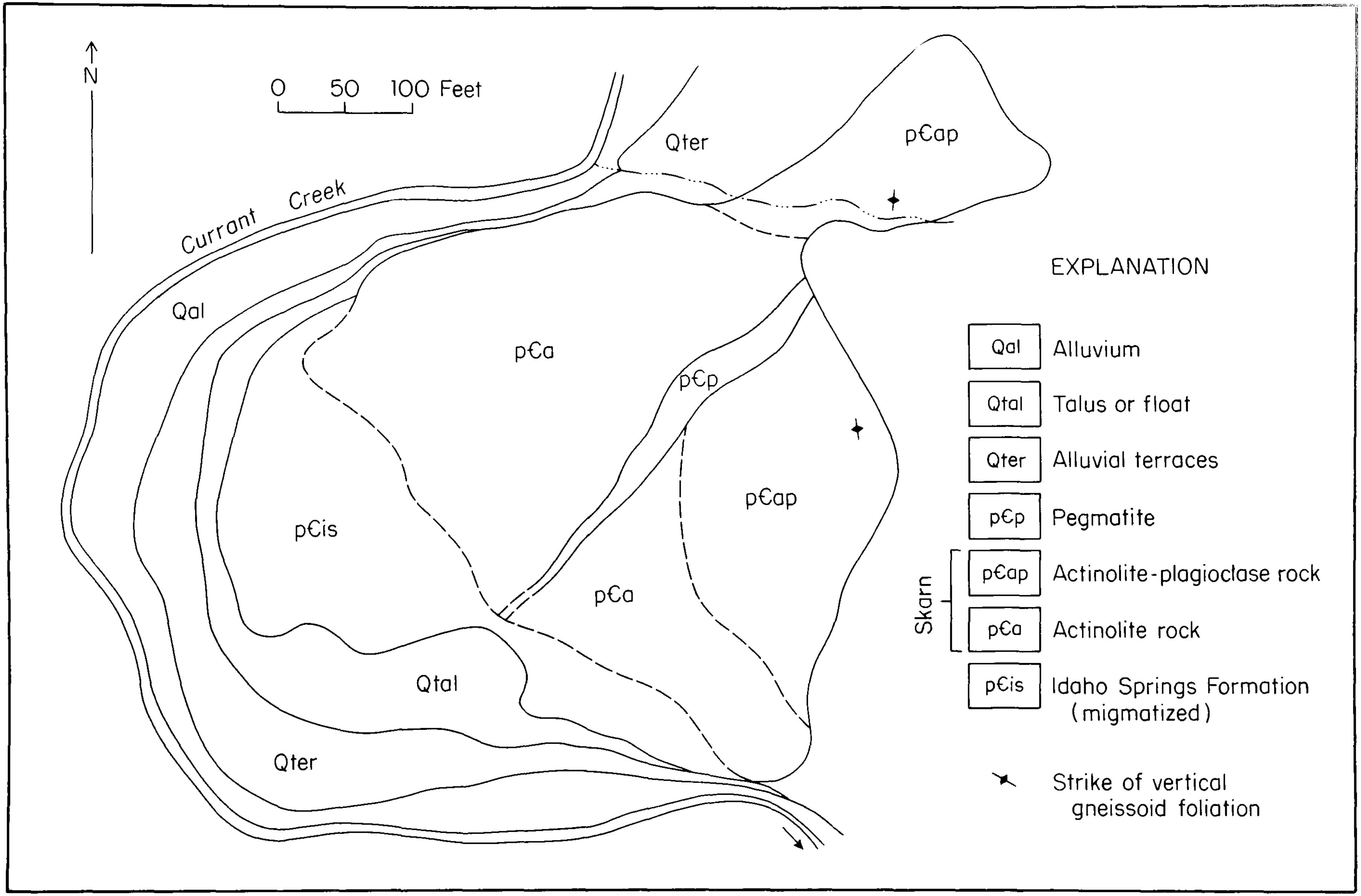


Figure 14. Map of the Currant Creek skarn body, Fremont County (Ruess, 1970).

The nonfoliated gray-green outcrops consist chiefly of massive actinolite rock in the western part and actinolite-plagioclase (Ab_{55}) rocks, locally gneissic, in the eastern part (Fig. 14). Cross-fiber veins of actinolitic hornblende, as much as 0.5 inch across, cut the actinolitic rock locally.

The matrix of the actinolite-plagioclase rock also contains fine-grained sericite, chlorite and talc as well as accessory magnetite, biotite and zircon. Reuss (1970) also reports that some specimens from the area mapped as actinolite-plagioclase rock contain cordierite, sillimanite, staurolite and biotite. Sulfide mineralization was not found.

Green Dove Mine

Epidotized rocks, which underlie a considerable area east of Lookout Mountain and north of Road Gulch, have been formed by replacement of two rock types: 1) a red aplitic granite probably of Boulder Creek age and 2) amphibolites of the Idaho Springs group. In the latter they occur as epidotites, rocks consisting of 90%+ of epidote or as epidote-garnet rocks. Many of the bodies have been prospected and in sec. 4, T20S, R73W, 6th P.M., a pit 12 x 20 feet was dug in epidotite. The Green Dove I, II, and III claims were staked by D. L. Banks, Q. Barnes and J. Wadsworth who quarried the bright green rock until 1963. It was marketed in both Canon City and Florence as colored aggregate.

The epidotite consists of 90%+ epidote (±clinozoisite) with subordinate sodic plagioclase and accessory sphene, magnetite and carbonate (Dahlem, 1965). This may be the world's only epidote mine. The epidotized rocks were tested for scheelite, but none was observed under the ultraviolet lamp.

Magnetite Boulders

One of the most unusual mineral occurrences in Fremont County is just north of the Magnusson pegmatite about 1,100 feet above the Arkansas River on the south side of the canyon (secs. 21 and 22, T18S, R72W 6th P.M.), and at the top of McIntyre Gulch, about 4 miles west of its mouth. The Magnusson pegmatite quarry is three airline miles southwest of the Parkdale siding on the Denver and Rio Grande Western Railroad.

Both just north of the quarry and about 1 mile to the northeast the Precambrian rocks are capped by remnants of high-level terrace gravels. The capping to the north is very small, but the eastern is over 0.5 mile long and as much as 100 feet thick. These patches have been designated by Taylor and others (1975A) as belonging to the upper part of the Dry Union Formation of Pliocene age. Discovered by this writer in the late 1950s, the gravels contain unusual boulders of iron ore. The gravels consist of rounded to subangular boulders, cobbles, and pebbles of a wide variety of rocks ranging in age from Precambrian to Tertiary. Conspicuous among these are: 1) "exotic" gneisses and schists not present in the Precambrian of the Arkansas River canyon between Canon City and Cotopaxi;

2) lower Paleozoic orthoquartzite with Lingula; 3) various cherts, sandstones, and gray quartzites; 4) at least 3 different types of iron formation; 5) numerous types of volcanic rocks including abundant red andesite and trachyte; and 6) gray fine-grained Tertiary granodiorite and tonalite.

The boulders of magnetite rock, which lie just north of the pegmatite quarry, are subrounded to subangular and reach a maximum length of 3 feet. There are hundreds of boulders one foot or less long. Some of the boulders must weigh well over 1,000 lb. Some of the magnetite boulders contain scattered large chlorite plates. No foliation or layering appears to be present.

The ore consists of a relatively fine-grained (up to 2 mm) aggregate of magnetite, ilmenite, hematite, and gangue silicates. Magnetite predominates over ilmenite. Both are anhedral as is quartz of the gangue; feldspar occurs as tabular anhedra.

Two types of hematite are present. The more abundant has formed by martitization of magnetite along octahedral planes. This results in a lattice texture in the magnetite grains consisting of lamellar hematite elongated parallel with (0001). In some magnetite grains martitization has proceeded to such an extent that only small irregular relicts of magnetite remain, and the hematite loses its bladed texture. In most others sparse hematite blades are confined to the peripheral parts of the host magnetite grains. In the second type, elongated plates of hematite also occur as exsolution lamellae in ilmenite, oriented parallel with (0001) of the ilmenite. Usually these are confined to the interior parts of the ilmenite grains which have a narrow border zone free of exsolution hematite. In a few ilmenite grains central hematite units are coarse and boat-shaped. In some boulders the ilmenite is essentially free of hematite or contains only a few very thin highly elongated rods of hematite. In specimens in which martite is markedly developed, ilmenite is strongly altered to leucoxene.

The source of the boulders remains an enigma. The Magnusson pegmatite intrudes a body of pre-Boulder Creek hornblende meta-gabbro (p. 19) which adjoins the southern contact of the tonalitic border phase of the Boulder Creek granodiorite pluton that extends north from the Arkansas River between Eightmile Park to Sheep Basin. It was originally hypothesized that the magnetite-ilmenite boulders might have been derived from magnetite-ilmenite ores occurring at Iron Mountain, 9 airline miles due south of the Magnusson occurrence. However, the Iron Mountain ores, which have been studied in detail by Spencer, Heinrich, and Alexander (Spencer, 1978), are totally different in texture and mineralogy. Furthermore, although at least one major paleovalley of Oligocene or Early Miocene age drained northeastward from Iron Mountain, there is no evidence for the existence of a similar drainage directly northward from Iron Mountain. In addition most of the boulders in the high-level gravels have been derived from rock exposures in the Arkansas River Valley far to the west, and many have been transported from north of Salida. Thus the source of the magnetite-ilmenite boulders, which are both the largest and the densest components of the gravels, remains unknown and puzzling.

Chaffee County

Sedalia Mine

The Sedalia copper-zinc deposit, once the largest copper mine in Colorado, is in NE/4 NW/4 sec. 18, T50N, R9E, New Mexico P.M. on the northeast side of the Arkansas River Valley about four miles northwest of Salida. The deposit was located in October 1881 and operated intermittently until 1923. When examined by Lindgren (1908) in 1907 it was an active producer. Ores were shipped to various smelters, but mainly to the Canon City zinc-lead paint plant of U. S. Smelting Company, which utilized the zinc for paint and smelted the residues for copper matte. Some ores were treated in Salida. By 1907 60,000 to 75,000 tons of copper-zinc ore (mainly oxidized) had been shipped. The ores contained at least 5% Cu, about 10% Zn, and $1 to 2.50/ton of Au and Ag. Heyl (1965) estimates the total production to have been about 100,000 tons of partly oxidized and sulfide ores. A small pocket of rich native silver ore was discovered on a lower level.

Boardman (1971) has compiled production data based on reports by Freeman (1919) and Swanton (1922) (Table 10). According to Boardman's historical summary, the mine was operated continuously from 1888 to 1918 at which time the government subsidy for copper was dropped, resulting in a marked fall in the price of copper from $0.26 to 0.11/lb. The mine then was never reopened on a regular basis. Essentially all the production was obtained from blocks of secondarily enriched ore. Initial concentration by hand cobbing provided rich shipping ore containing 15 to 37% Cu.

Table 10. Production records, Sedalia Mine (Boardman, 1971)

	Production	
Years	Tonnage	Gross Value Reported
1888-1897	22,277	$ 829,672.67
1898-1918	37,505	987,922.10
	59,782	$1,817,594.77
1915-1918	18,000 Cu	315,364.71
	2,500 Zn	30,324.02
		$ 345,688.73

From consulting reports, estimates of the grade of reserves (both secondary copper carbonate and primary copper sulfide ores) range from a high of 5% Cu and 10% Zn in older reports to about 1.5% Cu in more recent evaluations. Although some estimates of total reserves are as great as one million tons of ore, detailed evaluations of the deposit in the 1960s and early 1970s by the New Jersey Zinc Company and Noble American Minerals, Inc., did not lead to reopening of the mine.

In 1906 the leaching plant near the mine was replaced by a 50-tpd concentrating mill. Heyl (1964) has pointed out that the partly oxidized Cu-Zn ore with some Pb, Au, and Ag is difficult to sell because abundant Zn is detrimental to copper smelting and, conversely, abundant Cu as well as the incomplete oxidation of the zinc minerals are detrimental to zinc smelting.

Workings, which range in altitude from an adit at about 7,475 feet at the foot of the range to a pit at about 8,200 feet near the top of the ridge, are extensive, involving five main adits, several other short adits, some half-dozen shafts of various depths, and numerous prospect pits (Fig. 15). From these Lindgren (1908) reported underground workings totalling about 5,000 feet. Van Alstine (1974), from an examination of company maps dated 1917 reports a total of 8,100 feet of drifts and crosscuts and many raises and slopes extending for about 420 feet between the first and third levels. He reports the main workings to be:

Adit	Altitude	Extent
No. 1	7,896 ft	1,000 ft
No. 2	7,796	2,800
Dewey	7,796	300
Jack Pot	7,696	800
No. 3	7,475	3,200

Van Alstine (1974) reports that until about 1974 the mine was owned by Anne A. Preston and Allison P. C. Goodheart of Denver, with six patented claims recorded in Salida. In 1969-1970 the mine was owned by Joseph V. Dodge and A. A. Hanson of Colorado Springs (Boardman, 1971).

The deposit was studied first by Lindgren (1908), later by Heyl (1964), Boardman (1971), and Van Alstine (1974). It has been examined on numerous occasions since the late 1940s by Heinrich (Heinrich and Salotti, 1959; Boardman and Heinrich, 1971). The general geology of the Salida area has been investigated by Cross (1893, 1895), Bhutta (1954), Van Alstine (1969, 1971, 1974) and Boardman (1971, 1976).

The deposit has long been famous for its large euhedral garnet crystals, some as much as 6 inches across (Penfield and Sperry, 1886; Dana, 1898) (see p. 68).

The deposit occurs in a thin unit in a series of metamorphic rocks assigned by Boardman (1971, 1976) to his strongly foliated group of Precambrian rocks which, together with quartz monzonite, underlies the northern half of the Salida-Turret area. This group contrasts with his

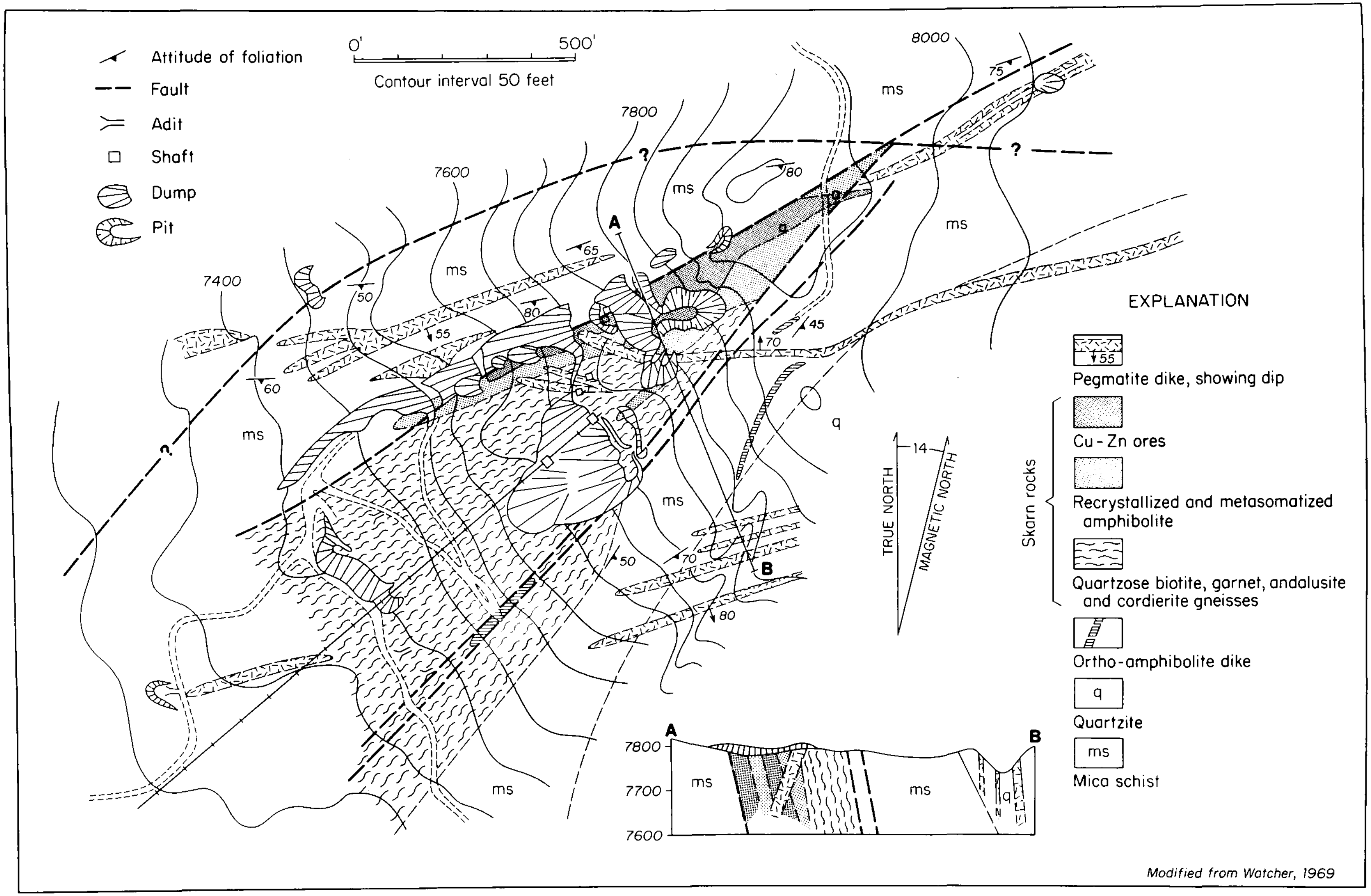


Figure 15. Geologic map of the Sedalia mine, Chaffee County.

weakly foliated group which underlies the southern half of the area. The two groups intergrade over several hundred feet, and this contact is about 0.5 mile southeast of the Sedalia mine, trending northeastward and then swinging to the east (Boardman, 1976, Fig. 1). The two groups, generally similar in petrology, originally formed a single complex of sedimentary and igneous rocks prior to metamorphism within middle amphibolite facies conditions. Although metamorphosed to nearly identical mineral assemblages, the two groups differ principally in that in the southern weakly foliated group recrystallization took place under static conditions, whereas in the northern strongly foliated group deformation (i.e., stress) was intense. Thus, relict structures, including bedding, graded bedding, cross-stratification, chilled margins, ophitic textures, amygdules, and breccia textures, have been preserved in the metasediments, metasills, and metavolcanics of the weakly foliated group, whereas in the strongly foliated group these features have been obliterated. Andalusite characterizes metapelites of the weakly foliated group; sillimanite characterizes them in the strongly foliated group (Fig. 1).

Quartz monzonite, which underlies the northernmost part of the area, is the southern terminus of a batholith that extends northward 35 miles nearly to Leadville (Van Alstine, 1969). Along its contact with the strongly foliated group of metamorphic rocks the granitoid itself is intensely foliated, with augen of potash feldspar in a sheared, chloritized matrix. The age of the pluton is 1.65 to 1.70 b.y., and on this basis, plus its general composition and texture, it can with reasonable confidence be assigned to the Boulder Creek clan of intrusions (Van Alstine, 1969; Boardman, 1976). The quartz monzonite outcrops nearest to the Salida deposit are about 3 miles to the northwest. Numerous patches of Tertiary volcanics cap the metamorphic rocks.

The foliation and the layering in the metamorphic rocks generally strike ENE and dip steeply southeastward. The Sedalia deposit is on the southeast limb of a faulted anticlinal structure. At the deposit the foliation strikes N30-75°E, and dips 45-85°SE, whereas, across the northeast-trending fault 0.5 mile northwest of the mine, the northeast-trending foliation is vertical or dips 50-75°NW.

At the deposit itself the sequence of metamorphic units has been disrupted by at least three major faults (Fig. 15), but on the top of the ridge northeast of the mine, a relatively undisturbed sequence is exposed (northwest-southeast; lower to higher):

1. Biotite-muscovite schist with local bands containing andalusite porphyroblasts. Cordierite porphyroblasts occur adjacent to unit 2.

2. Skarn-ore unit

3. Like unit 2

4. Spotted amphibolite, 4 to 5 ft thick, with epidote. Intrusive into unit 6, ends in a rounded nose

5. Quartzite

At the deposit the sequence of units is similar, but complicated by faulting (Fig. 15). From northwest to southeast (underlying to overlying) the units are:

1. Biotite-muscovite schist

2. Skarn-ore unit

3. Quartzose biotite, garnet, andalusite, and cordierite gneisses wedged out to the northeast by faulting

4. Biotite-muscovite schist

5. Quartzite

All of these units are cut by tabular pegmatite dikes that strike east-northeast (Fig. 15) and dip steeply. These dikes also reportedly cut the skarn-ore unit underground and have not been altered or mineralized; nor are they offset by any of the faults.

The skarn unit is about 1000 feet long at the surface, with a maximum width of about 150 feet. Although generally parallel with the regional trends of the metamorphic units, in detail it is transgressive. It trends northeast and dips 50-70°SE. It has been developed mainly in two types of metamorphic rocks: 1) amphibolite (the chief host) and 2) quartzose biotite-garnet-andalusite-cordierite gneiss. Watcher (1969) recognized two major faults, one of which bounds the skarn unit on its northwest side and the other which bounds the quartzose gneiss on its southeast side. The skarn unit is pinched out to the northeast at the convergence of these two faults (Fig. 15). Although mineralization is restricted to the wedge block between these two faults at the surface, it is most intense near their convergence. Watcher (1969, p. 4) states that "...the dominant ore-controlling structure is a third major fault zone striking more east-west than the two boundary faults and dipping 30° to 50° south. This fault zone is not well expressed in surface exposure, but is the most obvious feature underground. All stopes apparently lie on or near the central trace of this zone, particularly at the intersections with the more steeply dipping faults and shear zones."

Because of the two contrasting host rocks, two contrasting types of skarn can be distinguished: 1) those formed in amphibolite and rich in magnesium and aluminum minerals such as anthophyllite, gedrite, actinolite, cordierite, gahnite and chlorite and 2) those formed in quartzose biotite gneiss, rich in silica and containing abundant quartz and locally abundant andalusite, sillimanite, almandite, and cordierite (Boardman, 1971).

Amphibole-rich skarns, the more spectacular recrystallization products, are concentrated along the bounding faults especially near their convergence. In general the amphibolite host appears to have been more intensely recrystallized and metasomatized than the quartzose biotite gneiss. Boardman (1971) distinguishes the following mineralogical types of skarns developed within amphibolite:

1. Anthophyllite/gedrite skarn. Medium to coarse-grained, nonfoliated. The two orthoamphiboles do not occur together. Gedrite, in randomly oriented blades, occurs with garnet, whereas anthophyllite, in radial aggregates is associated with biotite. Cordierite and quartz are local essential species; zircon, rutile, gahnite, and magnetite are accessories.

2. Actinolite skarn. Dark green, mattes of coarse actinolite blades, largely altered to talc. Some actinolite forms radial aggregates. Minor epidote, sphene, zircon, and apatite. Some sphene crystals are an inch long.

3. Tremolite skarn. Coarse-grained tremolite-thulite rock localized along the southeastern contact of the skarn unit at higher levels.

4. Hornblende-epidote rock. This nodular rock occurs as a layer within quartzose biotite schist. The nodules, up to a foot across, are restricted to a zone only a few feet wide. They range in shape from spheroidal to lensoid. Zoning within them is conspicuous: cores, principally of epidote, are surrounded by two to four zones consisting of epidote, or hornblende or quartz-plagioclase (Boardman, 1971).

5. Chloritite. A body of chloritite, 125 x 25 feet in outcrop, occurs near the center of the skarn unit. It contains magnetite euhedra and the famous euhedral garnet crystals first described by Penfield and Sperry (1896). The almandite crystals, which have been largely chloritized, locally constitute >50% of the rock.

Other skarn minerals reported by Van Alstine (1974) include bytownite, calcite, clinozoisite, corundum, cummingtonite, diopside, kyanite, labradorite, phlogopite, and vesuvianite. Scapolite was found by the writer.

Sulfide minerals are disseminated in both the quartz-rich and amphibole-rich skarns, with some massive replacement of amphibolitic skarns. The hypogene sulfides include chalcopyrite, pyrite, marcasite, galena, sphalerite, and pyrrhotite, all of which are younger than the skarn species, replacing or veining them. Covellite and chalcocite are supergene. Native gold and silver also are reported (Van Alstine, 1974). A mixed sample of sulfides and gangue contained about 5 ppm Be.

Following the introduction of the sulfides, the skarn body underwent a retrograde silicate stage during which chlorite, talc, sericite, and minor fluorite were formed, usually replacing higher temperature silicates.

At the surface the ores are completely oxidized, and partial oxidation extended to 300 feet (Heyl, 1964). The upper 100 feet consisted of a limonite-quartz-malachite gossan, and the second hundred feet consisted of an oxidized ore body of secondary zinc and copper minerals. These oxidized ores are mineralogically very complex. Heyl (1964) and Van Alstine (1974) reported the presence of anglesite, aurichalcite, azurite, barite, calcite, cerussite, chalcanthite, chrysocolla, cuprite, gypsum, hematite, hemimorphite, hydrozincite, limonite, malachite, melanterite, opal, psilomelane, smithsonite, tenorite, willemite, and an unidentified yellow Pb-Cu sulfate (reported by Lindgren, 1908).

The possible sequence of events in the Salida-Turret area and at the Sedalia deposit is:

Precambrian

1. Beginning of regional metamorphism

2. Climax of regional metamorphism including the intrusion of the quartz monzonite batholith (about 1,700 m.y.)

3. Faulting

4. Introduction of fluids along faults, cessation of regional stress, maintenance of temperatures of the lower part of the amphibolite facies, recrystallization and replacement to form the skarn rocks

5. Metasomatism of skarns by sulfides of Cu, Zn, Pb, and Fe

6. Intrusion of pegmatites

7. Retrograde metamorphism of the silicate skarns

Tertiary

8. Renewed faulting and uplift

Recent

9. Deep oxidation of the ore body

Independence Mine

The Independence Mine, first briefly described by Lindgren (1908), is in the NE/4 NW/4 sec. 32, T51N, R9E, New Mexico P.M., about 0.5 mile west-northwest of Turret. Lindgren (1908, p. 166) reports that "A considerable tonnage of copper ore, low in gold and silver, was hauled down to the railroad in 1907 and sold to smelters, where it is used for purposes of flux in matte concentration." The workings, which extend about 400 feet along the strike, consist of several shafts and a pit 20 feet across. From the size of the dumps, underground workings must have been extensive; Lindgren (1908) reports that explorations were extended 200 feet downdip. The deposit was studied by Boardman (1971) and has been examined by Heinrich. The country rocks are chiefly micaceous schists and gneisses with minor amphibolitic, granitic, and pegmatitic units (Boardman's strongly foliated group). The foliation strikes N70°W and dips 60°NE. The contact of the quartz-monzonite batholith is about one mile to the north and 0.5 mile to the east.

The skarn has been localized along a major fault that trends N35°W and dips 45°NE. The fault zone exposed in the pit is marked by contortion of the foliation, intense shearing, fracturing, and conspicuous staining by copper carbonate species.

The coarse-grained skarn assemblage includes garnet, biotite, quartz, actinolite, and cordierite, developed mainly in amphibolite. The mineralization consists of chalcopyrite, pyrite, molybdenite, gahnite, and magnetite (Boardman, 1971). Lindgren (1908) reports that the width of the ore body was 30 feet, with a richer streak five feet wide. In the pit the skarn zone has a maximum width of 25 feet.

Ace High-Jack Pot Prospect

The Ace High-Jack Pot prospect (NW/4 sec. 32, T51N, R9E, New Mexico P.M.) is about 700 feet above Railroad Gulch about one mile southwest of Turret. It has been examined by Van Alstine (1969) and is recorded by Boardman (1971). In 1969 it was claimed by Glen R. Lemberg and son of Salida.

Although the deposit does not crop out, Van Alstine (1969, p. 43) reconstructs it as "...a lenticular mass in metasomatized hornblende gneiss between two north-trending faults that localized a narrow chalcopyrite-quartz vein dipping 85°W and a vertical pegmatite dike." The workings consist of an inaccessible shaft and an incline driven north along the vein. The country rocks are part of Boardman's (1971, 1976) strongly foliated group of Precambrian gneisses. Quartz-monzonite crops out about a mile to the east and 1.5 miles to the north.

At the prospect the layering and foliation of the gneisses strike north and dip 50°E, but both to the immediate east and to the south in Railroad Gulch, where a major unit of amphibolite crops out, foliation trends are highly variable, with northwest strikes and northeast dips east of the prospect and northeast strikes and northwest dips south of the prospect.

From the dump specimens Van Alstine (1969) concluded that the hornblende gneiss (consisting originally of hornblende, bytownite, cordierite, and small amounts of biotite, quartz, and epidote) has been reorganized into a coarse-grained, locally schistose skarn composed chiefly of hydrous Mg, Ca, Fe, and Al silicates. The banded rock consists of layers of one or more of the following: actinolite, anthophyllite, apatite, biotite, calcite, chlorite, cummingtonite, gahnite, phlogopite, quartz, sphene, talc, tremolite, and zoisite (Van Alstine, 1969). Locally magnetite and chalcopyrite impregnate the skarn silicates. Supergene alteration has produced malachite, chalcocite, azurite, chrysocolla, brochantite, chalcanthite, calcite, barite, opal, and psilomelane.

Turret Deposit

The Turret deposit, which may be the same as the Copper King deposit mentioned by Lindgren (1908, p. 166) as "...another deposit of very similar character situated between Turret and the Independence mine," is about 0.25 mile south of Turret in the SE/4 sec. 29, T51N, R9E and NE/4 sec. 32, T51N, R9E, New Mexico P.M. This skarn deposit, although generally similar to others in the area, is unusual in the local abundance of corundum (Heinrich and Griffitts, 1948).

It is probable that this occurrence of corundum is the one noted by Dana (1898, p. 36) as "...corundum in mica schist" and repeated in the 7th edition of Dana (Palache and others, 1944, vol. 1, p. 525): "In Colorado small blue crystals (of corundum) occur in mica schist near Salida, Chaffee County." This occurrence is not to be confused with the better known deposit of sapphire near the Calumet Iron mine (Heinrich and Griffitts, 1948) where thin blue basal plates of corundum occur in sillimanite- and graphite-bearing schist of Pennsylvanian age, contact-metamorphosed by a Tertiary granitoid stock.

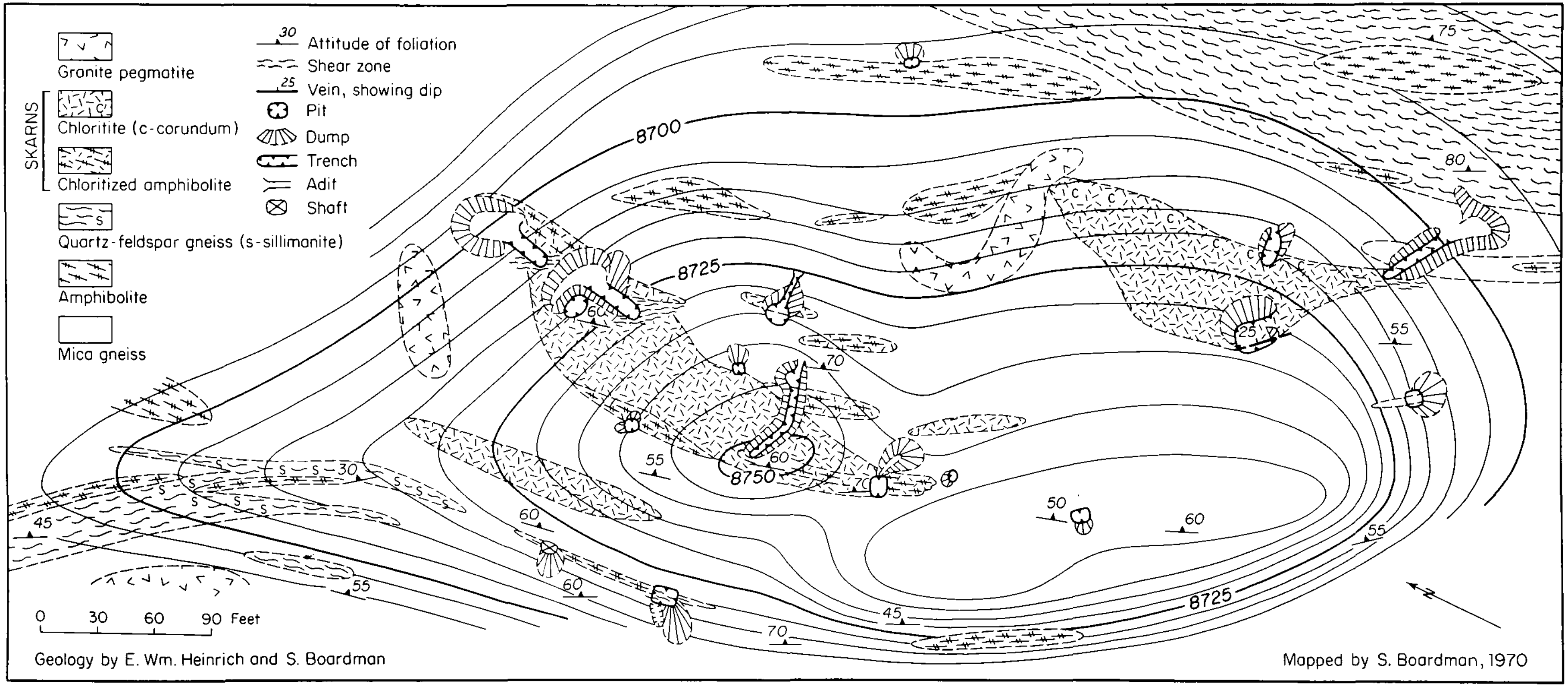
Skarn rocks are exposed over a northwest-trending area about 700 x 300 feet in size (Fig. 16). The workings consist of about 20 trenches and pits, all shallow. The deposit was first examined by Heinrich in 1943 and has been studied by him in detail. It was mapped under his direction by Boardman (1971).

The unaltered country rocks consist of biotite gneiss, biotite-garnet schist, quartz-feldspar gneiss, nodular sillimanite gneiss, hornblende gneiss, amphibolite and granite pegmatite (some of which contains sillimanite). To the north directly across the valley from the deposit are outcrops of magnetite-rich quartzite, probably representing low-grade iron formation. Three pegmatite pods exposed at the deposit transgress the trend of the skarn zone and the metamorphic foliation which strikes NNW and dips 30-80° NE, parallel with the contact of the quartz-monzonite pluton. At this contact, which is exposed 100 to 200 yards east of the deposit, the granitoid body has a strongly foliated border zone, a few score to 650 feet wide, in which a secondary foliation has been developed by crenulation of the schistosity.

The skarn zone appears to have been developed chiefly in several isolated lenses of amphibolite in mica gneiss. To the southeast of the deposit quartz-feldspar gneisses crop out (Fig. 16), and to the northwest nodular sillimanite gneisses are prominently exposed. The metamorphic foliation strikes N5-45°W and dips 30-70°NE.

As in the other cupriferous skarns of the area, two mineralogical types are present: 1) those developed in micaceous schists and gneisses and 2) those developed in hornblende gneisses and amphibolites.

Skarn rocks formed by reorganization of the biotitic gneisses and sillimanite gneisses are mainly quartz-cordierite-garnet ± biotite assemblages. In some both the biotite and garnet have been extensively chloritized. Ilmenite, gahnite, and apatite are accessories. These gray rocks, poorly foliated, commonly have large garnet poikiloblasts in a finer grained matrix of quartz, cordierite, and biotite. In addition to the chloritization, cordierite is extensively pinitized, and ilmenite is converted to leucoxene. A few cross-seams of epidote occur locally, and some chlorite has been formed along fractures.



Geology by E. Wm. Heinrich and S. Boardman

Mapped by S. Boardman, 1970

Figure 16. Geologic map of the Turret skarn deposit, Chaffee County.

From the hornblende-rich metamorphic rocks, the following skarn types have been formed: a) anthophyllite-cordierite skarn, b) gedrite-cordierite ± garnet skarn, c) actinolite ± garnet skarn, and d) chloritites. Anthophyllite and gedrite are antipathetic on a local scale, but these two types of skarns are closely associated and intergrade. They form poorly foliated lensoid bodies as much as 120 feet long. Medium- to coarse-grained, with blades of orthoamphibole as much as 1.5 inches long and an inch across, they range greatly in composition on a small scale from nearly 100% orthoamphibole to nearly 100% cordierite. Other constituents are quartz, ilmenite, allanite, and apatite. Again strong retrograde reactions have affected the rocks: amphiboles are extensively chloritized and cordierite is pinitized.

The green actinolitic skarns consist of fine to coarse needles of unoriented to poorly oriented actinolite. Garnet is present in some, and some are also intensely chloritized.

The most abundant and conspicuous rocks at the deposit are the chloritites, which form irregular masses as long as 250 feet and as wide as 60 feet. They vary greatly both in texture and mineralogy. Rocks consisting mainly of chlorite can be classified on textural variations:

1. Foliated chloritites (fine- to medium-grained)
    a. Schistose
    b. Schistose-corrugated

2. Nonfoliated chloritites
    a. Fine-grained
    b. Porphyroblastic
    c. Vein chloritite, very coarse grained

The chief mineralogical types are:

1. Chlorite-corundum rock
2. Chlorite-tourmaline rock
3. Chlorite-anthophyllite rock
4. Chlorite actinolite rock

Accessory minerals in the chloritites are quartz, gahnite, hoegbomite, rutile, and zircon. Tourmaline (schorl) appears as slender black triagonal prisms as long as 2 inches. Corundum, also randomly oriented, forms blue-gray, barrel-shaped hexagonal euhedra usually about 0.25 inch in diameter; a few are 1.25 inches long. Both corundum and tourmaline are restricted to the northeastern margin of the large chloritite mass at the southeastern end of the skarn zone, i.e. closest to the quartz-monzonite pluton. The corundum-rich zone is 2 to 6 feet across.

The chloritites appear to have been formed by replacement of the amphibole-rich skarns, by direct chloritization of non-skarn amphibolite, and, to a small degree, by replacement of the quartz-cordierite-garnet-biotite skarn.

The chlorite-actinolite rock was formed by direct replacement of amphibolite. Small remnants of amphibolite also occur locally in chloritite. Actinolite appears to be restricted to the eastern end of the deposit.

The foliation of the schistose chloritites may have been inherited from the amphibolites, but the corrugated chloritites clearly have been subjected to post-metasomatism deformation. The schistose layers are crinkled into folds about 0.25 inch high and 0.4 inch across, arranged in en echelon ridges. Chlorite plates and flakes also are elongated and oriented parallel. This secondary foliation may have been developed at the same time that the crenulation foliation was developed in the highly foliated border zone of the quartz-monzonite pluton.

Other chloritites are clearly post-stress in origin. These include the peculiar porphyroblastic types which consist of large (up to 2 inches) plates of chlorite randomly oriented in a fine-grained chlorite matrix. Other nonfoliated chloritites were apparently formed along fractures. These very coarse-grained chloritites (>1.0 inch) show comb structures and banding. In the pit second from the eastern end of the deposit a vein of coarse chlorite, 1.5 feet thick, dips at a shallow angle northward, within finer grained chloritite. The deposit clearly has been extensively fractured and sheared. In addition to fracture-controlled chlorite, numerous slickensided surfaces coated by serpentine are conspicuous.

The skarn rocks are weakly mineralized; only chalcopyrite and pyrite were noted, but copper carbonate staining is, as usual, widespread.

The sequence of events at the Turret deposit appears to have been:

1. Onset of regional metamorphism

2. Climax of regional metamorphism: emplacement of quartz-monzonite pluton; beginning of recrystallization of amphibolites and mica gneisses to skarns

3. Boron metasomatism to form tourmaline

4. Introduction of sulfides

5. Intrusion of pegmatites

6. Beginning of retrograde metamorphic stage - chlorite, pinite, sericite

7. Renewed stress with local development of secondary foliation in schistose rocks

8. Fracturing and shearing; formation of vein chloritites.

Custer County

Marion and Related Mines

Three skarn sulfide deposits occur in Custer County along Amethyst Creek, a tributary of the St. Charles River in the southern Wet Mountains. They are in secs. 9 and 10, T24S, R69W, 6th P.M., about 2.5 miles west of San Isabel. The largest of the three, the Marion mine, is on the north side of the creek, and the other two, the Amethyst and Dewey mines are less than a mile to the southwest (Fig. 17). The Marion deposit, examined by Babbit (1911), Boyd (1934) and Gabelman (1953), was studied in detail by Boyer (1959, 1963).

The 12 original claims on the Marion deposit, staked by Sam Davis in 1881, were acquired in 1906 by the Marion Mines and Milling Company, who worked the deposit until 1912, building an expensive concentrating plant at the mine (Babbitt, 1911; Parmalee, 1910). In the 1920s the property was obtained by the West Gold Mining Company (Boyd, 1933). The ores contained 12 to 22% Zn, 3 to 5% Cu, a few ounces per ton of silver and close to $1 per ton in gold (1911 price of gold, Babbitt, 1911, p. 548). Workings are extensive, with a 225-foot adit to the vein, about 250 feet of drifts on the vein with stopes above, and an incline to 100 feet with drifts. The total recorded vertical exposure of the mineralized zone is about 350 feet. The zone was as much as 25 feet wide, averaging 15 feet, and was about 300 feet long. It strikes N55°E and dips 30°NW and shows considerable breccia and gouge.

The zone is a mineralized lens of calc-silicate gneiss, which is a unit in a xenolith of various migmatitized paragneisses and paraschists enclosed in Precambrian granites (Fig. 18). The main granite, the San Isabel granite, is about 1,400 m.y. old (Tweto, 1977) and thus belongs to the Silver Plume period of granitic intrusion. The xenolith extends from San Isabel granite across the contact into a small body of older gneissic granite (Boyer, 1963), which may be of Boulder Creek age (Fig. 17).

The Amethyst mine, probably operated in the 1920s, is in sec. 10, T24S, R69W. A short adit explored a sheared mineralized lens of skarn which has a surface exposure 15 feet long and 3 feet wide. It strikes N80°E and dips 47°NW enclosed in San Isabel granite (Boyer, 1959, 1963).

The Dewey prospect, 1/4 mile west of the Amethyst deposit, was developed in a fracture and shear zone that strikes N70°E and dips 56°NW.

These deposits have recently been restudied by Raymond and others (1980), who found in the skarns the rare mineral sapphirine, $(Mg,Fe)_2Al_4O_6(SiO_4)$ (see p. 69 for the several mineral assemblages involved). The skarns, developed from amphibolitic host rocks, consist of various combinations of sapphirine, cordierite, orthorhombic and monoclinic amphiboles, biotite, gahnite, corundum, plagioclase (andesine to labradorite), and orthopyroxene. Other minerals in calc-silicate gneiss include forsterite, garnet and clinohumite. The sulfides are chalcopyrite, sphalerite and galena.

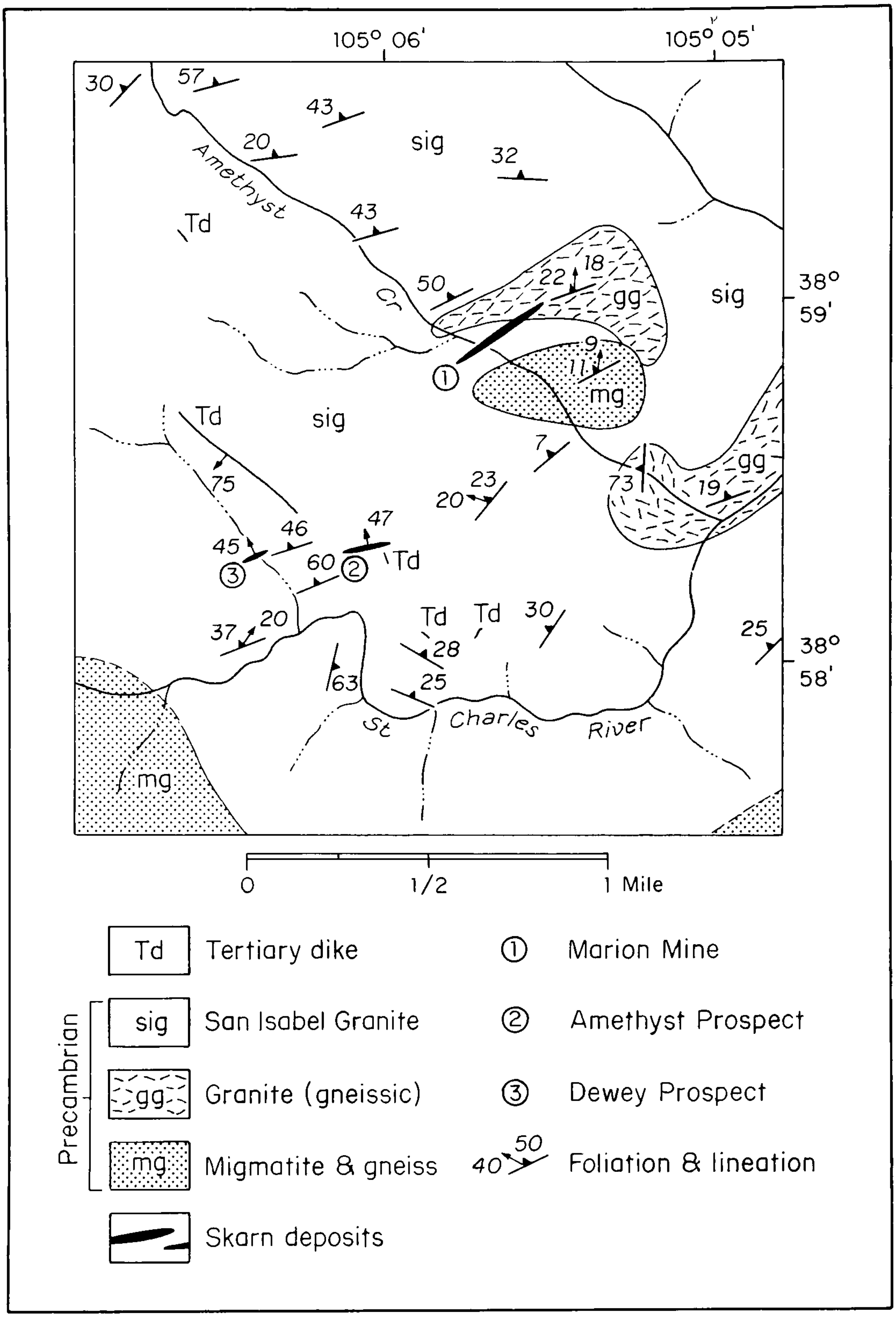


Figure 17. Location of skarn deposits in Custer County (Boyer, 1963).

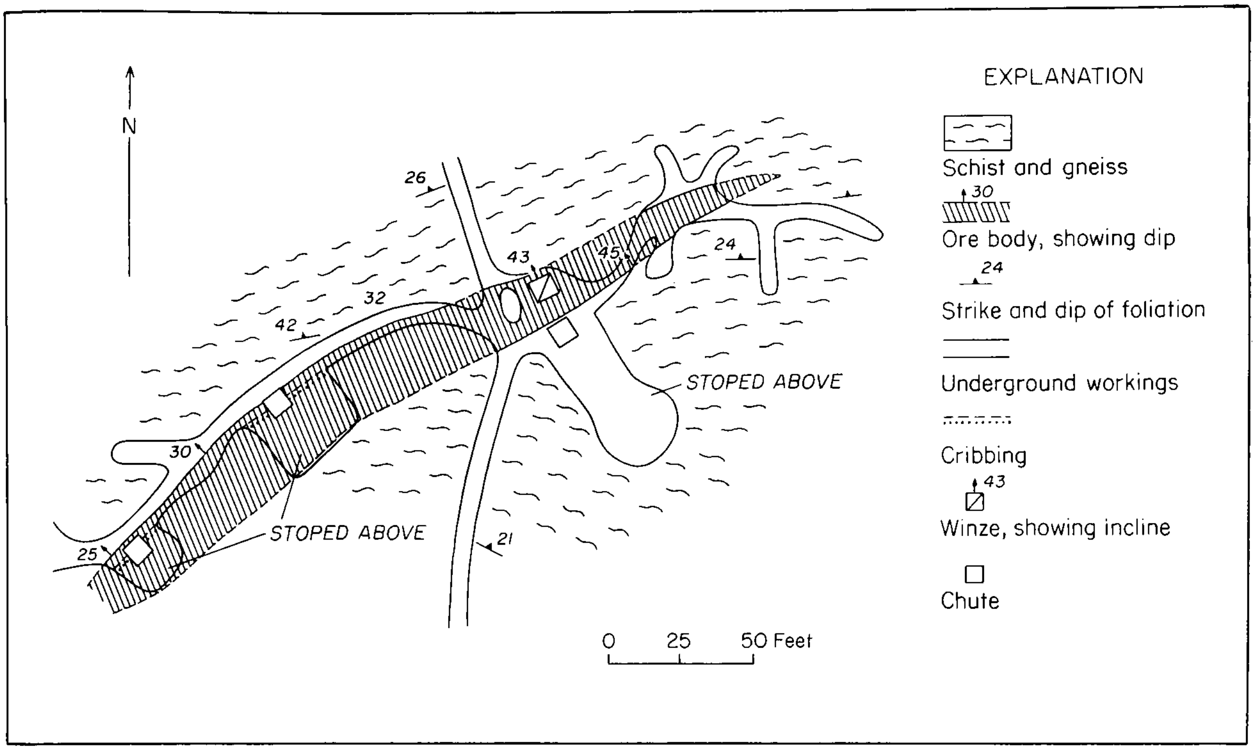


Figure 18. Geologic map of the Marion mine, Custer County (Boyer, 1963).

Boyer (1959, 1963) also reported, as skarn minerals, calcite, quartz, tremolite and wollastonite, with the additional sulfides, pyrite, pyrrhotite, arsenopyrite and bornite. Malachite, chalcedony and calcite are supergene, the latter two occurring as veinlets, crustifications and vug fillings.

The sapphirine assemblages are believed to have crystallized under the p-t conditions of the amphibolite-granulite transitional facies (Raymond and others, 1980), and thus the deposits were formed under slightly higher grade conditions than the other copper-zinc skarns which formed under upper amphibolite facies environment's. This may stem from the fact that, although the deposits are dated as about 1,700 m.y. (Boulder Creek),they occur as a xenolith or roof pendant in granite of Silver Plume age and thus may have been subjected to polymetamorphism.

Economic Aspects

Tungsten

The Colorado tungsten skarns to date have been of but minor economic significance. Even under the artificial stimulus of several wartime economies (World Wars I and II, Korean War) the Colorado deposits have yielded probably a total of only several hundred tons of ore, including ore from those in Larimer County. The reasons for this disappointing total are mainly geological.

1. Although scheelite is widely disseminated and concentrations containing several percent WO_3 have been found, typically ore bodies are small, discontinuous and of erratic grade. Absent are mineable, medium- to high-grade shoots as well as larger disseminated deposits of lower but uniform grade.

2. The host rocks are thin layers or podiform, representing the second least common rock type in the Idaho Springs Formation.

3. Prospectors have tended to overestimate the tungsten content from sample fluorescence for three reasons (Tweto, 1960): a) the scheelites contain some powellite in solid solution; 2) the fluorescence of discrete powellite grains is mistaken for that of scheelite, and 3) silicate species are poikiloblastically contained in the scheelite grains and crystals.

The most important single factor against the probability of finding large tungsten skarn deposits in south-central Colorado remains the strict host-rock control exercised over the deposits, a host rock that exists in units of severely restricted volumes.

COPPER AND ZINC

The economic aspects of the copper-zinc skarn deposits are far more encouraging than those of the tungsten deposits. The reasons for this comparative optimism are:

1. The host rocks for the copper mineralization are skarns developed mainly in amphibolites, hornblende gneisses, sillimanite gneisses and biotite gneisses, all present abundantly in the Idaho Springs Formation and in units of large dimensions.

2. Most of the ore mined in the past consisted of relatively small localized high-grade shoots. Volumes of lowergrade disseminated ore were ignored or discarded.

3. Most of the deposits were never systematically explored by diamond drilling, particularly to depth. Indeed both at the Sedalia and Cotopaxi mines a considerable part of the production came from oxidized ore.

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