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PRECAMBRIAN GEOLOGY AND MINERAL DEPOSITS OF THE SALIDA AREA, CHAFFEE COUNTY, COLORADO

by

Shelby Jett Boardman

A dissertation submitted in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy
(Geology)
in The University of Michigan
1971

Doctoral Committee:

Professor E. Wm. Heinrich, Chairman
Assistant Professor Bruce R. Clark
Professor Donald F. Eschman
Professor Jack L. Hough
Professor William C. Kelly

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INTRODUCTION

OBJECTIVES AND SCOPE OF STUDY

The study of the Precambrian rocks in the vicinity of Salida was undertaken because the area is particularly well suited for the consideration of several problems of general geological significance. The objectives are: 1) to determine the geologic history of approximately 50 square miles of previously unstudied Precambrian rocks, 2) to compare the history of these rocks to that of the Precambrian Idaho Springs Formation east of the Sangre de Cristo structural break, which has been studied in detail, 3) to examine the numerous copper-zinc and copper-tungsten skarn occurrences in an attempt to obtain information on the origin of this type of mineral deposit, and 4) to determine the origin of the extensive and variable group of amphibolites that underlie a major part of the area.

LOCATION

The area is east of the Arkansas River in Chaffee County, Colorado, immediately north and east of Salida, the county seat (Figure 1). The ghost town of Turret, seven aerial miles north of Salida, can be reached from Ute Trail, the main access road through the area (Plate 1). The highest point, Green Mountain (elev. 10,276 feet), in the northernmost part of the area, is nine miles north of Salida. The lowest point, at the intersection of the Fremont County line and the Arkansas River

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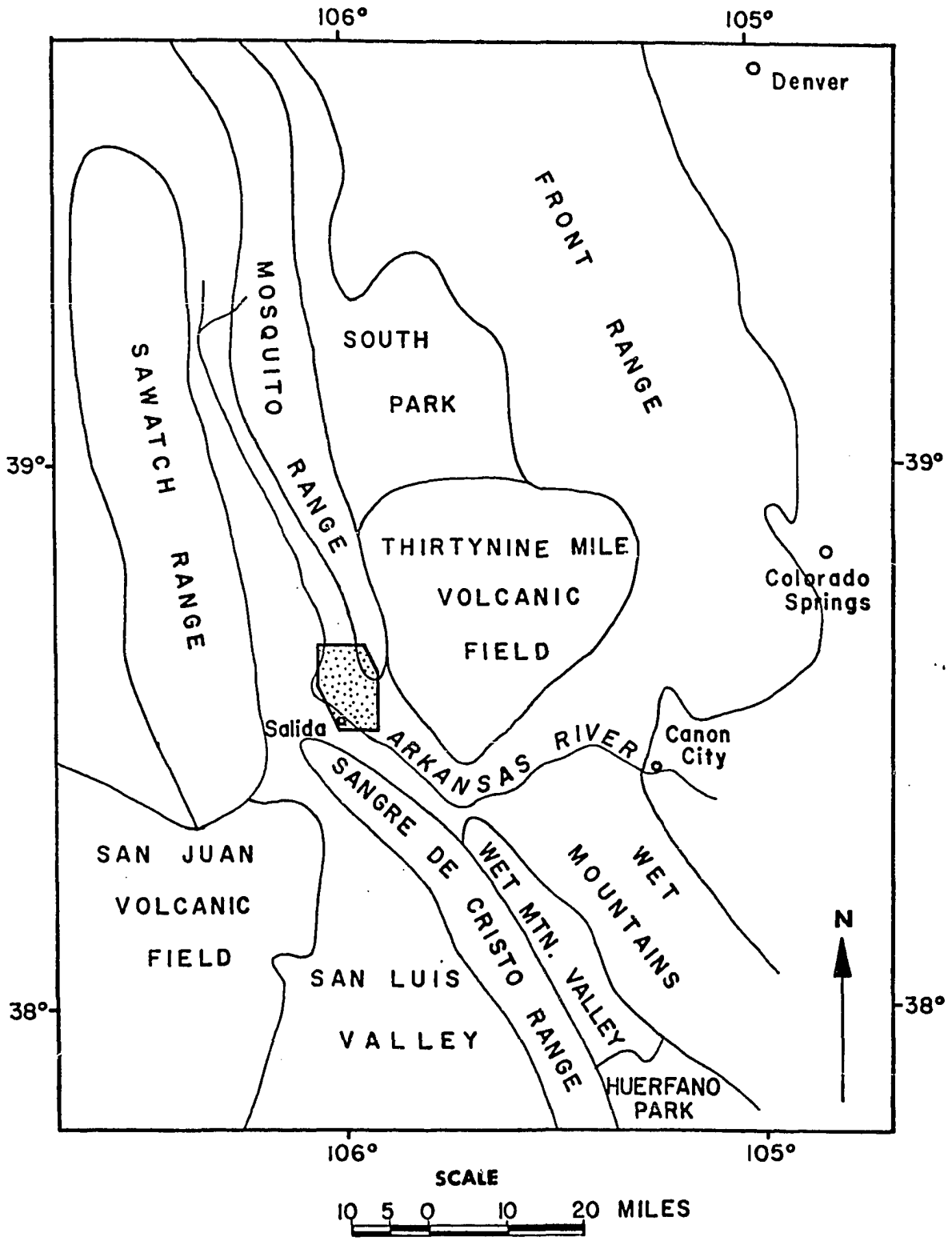

Figure 1. Index map of south-central Colorado, showing location of area of present study in relation to the major physiographic-tectonic units (modified after Van Alstine, 1969).

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(elev. 6920 feet) in the southernmost part of the area, is three miles southeast of Salida. The western half of the area is included in the U.S. Geological Survey Poncha Springs topographic quadrangle and the eastern half is within the U.S. Geological Survey Cameron Mountain topographic quadrangle. The limits of the mapped area are the Arkansas River valley on the west and south, Paleozoic sedimentary rocks on the east, and an arbitrary line within a Precambrian quartz monzonite batholith on the north.

PREVIOUS WORK

The earliest published work dealing with the Precambrian geology of the Salida area is by Cross (1895) who provided a brief description of the metamorphic rocks exposed along the eastern edge of the Arkansas River valley from Brown's Canon southeast to the Fremont County line. A part of the Precambrian rocks was mapped in a generalized way by Azar (1954). Van Alstine (1969) mapped the Poncha Springs NE quadrangle, which includes the northwest corner of the area. Some of the areas underlain by Paleozoic rocks and Tertiary igneous rocks have been mapped as parts of several masters' theses (Rold, 1950; Skipp, 1956; Van Diver, 1958; Normand, 1968).

The skarn deposits have been discussed briefly by Lindgren (1907), Belser (1956), and Tweto (1960). Generalized surface and subsurface geologic maps of the Sedalia mine were prepared by Watcher (1969), but his report was concerned principally with the economic

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potential of the mine rather than with its geology and mineralogy.

METHODS OF INVESTIGATION

Field work for this study was conducted during the summers of 1969 and 1970. Mapping was done on U.S. Department of Agriculture Forest Service aerial photographs (series ECB, flown in 1956) and U.S. Geological Survey topographic maps of the Poncha Springs and Cameron Mountain quadrangles. Detailed maps of mineral deposits were made by using pace and compass, tape, and plane table - telescopic alidade methods.

Standard mineralogic and petrological laboratory work was carried out at the Department of Geology and Mineralogy, The University of Michigan.

REGIONAL GEOLOGIC SETTING

The area of Precambrian igneous and metamorphic rocks is on the east flank of the Sawatch anticlinorium, a major structural feature whose axis is defined approximately by the Sawatch Range crest (Figure 1). The range is composed mainly of Precambrian gneisses, schists, and granitic rocks and Tertiary intrusives and volcanics.

East of the area, a series of Paleozoic sedimentary rocks forms the backbone of the Mosquito and Sangre de Cristo ranges. Still farther east, in the southern Front Range and northern Wet Mountains, the metamorphic rocks of the Idaho Springs Formation have been intruded by Precambrian granites of at least four different ages. The Pleasant

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Valley Fault, a major structural break separates the Paleozoic rocks along the eastern side of the Sangre de Cristos from the Precambrian rocks of Fremont County (Salotti, 1960). South Park and the Tertiary Thirtynine Mile Volcanic Field bound the area to the northeast.

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PART I - GENERAL GEOLOGY

ROCK UNITS

The area is underlain by Precambrian igneous and metamorphic rocks, Paleozoic sedimentary rocks, and Cenozoic igneous rocks and alluvium (Table 1). The Precambrian rock units are defined in this section, but their detailed petrology is considered in another part of the study. The petrology of the Tertiary igneous rocks, on the other hand, is discussed in some detail in this section, as they are not described later. The Paleozoic rocks and Cenozoic alluvium are characterized briefly below.

The following grain size designations are used throughout this report:

< 0.1 mm	: very fine-grained
> 0.1 mm < 1.0 mm	: fine-grained
> 1.0 mm < 10 mm	: medium-grained
> 10 mm < 3 cm	: coarse-grained
> 3 cm	: very coarse-grained

PRECAMBRIAN

Metamorphic Rocks

Except for Tertiary volcanics and a few Precambrian dikes, the southern 75% of the area is underlain by Precambrian metamorphic rocks (Plate 1). Two main groups of metamorphics can be recognized on the basis of texture and structure: a northern group of strongly-

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Table 1. Rock units in the Salida area.

Cenozoic
Quaternary
Alluvium, landslide material, and terrace gravels
Tertiary
High-level gravels
Volcanics
Intrusives
Paleozoic
Pennsylvanian
Kerber formation
Belden shale
Minturn formation
Mississippian
Leadville limestone
Devonian
Chaffee formation
Ordovician
Fremont formation
Harding sandstone
Manitou dolomite
Cambrian
Sawatch quartzite
Precambrian
Intermediate and mafic dikes (some possibly Tertiary)
Pegmatites
Aplite
Quartz monzonite
Poorly-foliated metamorphic group
Poorly-foliated amphibolites
Quartzites
Banded micaceous gneisses
Strongly-foliated metamorphic group
Amphibolites and hornblende gneisses
Mica schists and gneisses
Quartz-feldspar gneisses

foliated, relatively coarse-grained rocks that locally display conspicuous results of plastic deformation, and a southern group of poorly-foliated, generally finer-grained rocks less complexly deformed. The

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boundary between them is gradational and extends west parallel to the metamorphic layering from Ute Trail in the central part of sec. 10, T.50N., R.9E. to the central part of sec. 18, T.50N., R.9E.

The strongly-foliated group contains amphibolite, hornblende gneisses, quartz-feldspar gneisses, and quartz-biotite schists and gneisses in units ranging in size from a few feet to several thousand feet. Only the larger units are differentiated in Plate 1. Contact relationships between small units typically are sharp, but are gradational to interfingering between large units. Regional foliation trends east-northeast and typically is steeply-dipping, but local deviations are common, particularly near the quartz monzonite where the foliation parallels the contact and dips moderately in the direction of the intrusive.

The southern group is made up of amphibolites, quartzites, and banded, fine-grained quartz-mica gneisses. Individual units large enough to be mapped on the scale of Plate 1 normally extend for considerable distances along strike. Locally, they contain relict primary sedimentary and igneous textures and structures. The units also strike east-northeast and vary in dip from nearly vertical in the vicinity of Ute Trail to nearly horizontal along the Arkansas River in the southern end of the area.

Igneous Rocks

Coarse-grained quartz monzonite that crops out at the north end of the area is the southern tip of a narrow batholith that extends northward nearly to Leadville. It contains numerous biotite schist xenoliths

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or roof pendants up to 300 feet long and is cut by aplitic and pegmatitic bodies of variable size. The latter also are widespread throughout the northern group of strongly-foliated metamorphic rocks, generally trending sub-parallel with the foliation and crosscutting it in dip.

Most of the quartz monzonite displays poorly-developed foliation. Along the contact with the metamorphic rocks, however, it displays well-developed intrusive foliation that conforms to the trend of the contact. Also, near faults and shear zones it is strongly-foliated and locally mylonitized. Metamorphic foliation is not recognizable.

Various other dike rocks transect the quartz monzonite and the metamorphic rocks. These include spessartite lamprophyre, peridotite (one dike), diabase, andesite, and basalt dikes. A Precambrian age is assigned to these dikes, although those of andesitic and basaltic composition may be Tertiary.

PALEOZOIC

Between 2000 and 3000 feet of Paleozoic sedimentary rocks unconformably overlie the Precambrian rocks along the eastern edge of the area. The unconformity, which is best exposed along U.S. Highway 50 in the southeast corner of the area (Figure 2) appears to be a surface of low relief. The sediments strike to the north and dip generally at moderate angles to the east. They represent a shallow marine sequence consisting of carbonate rocks and subordinate shale, sandstone, conglomerate, and quartzitic sandstone.

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Figure 2. Precambrian - Paleozoic unconformity, U.S. Highway 50, 3 miles southeast of Salida. Darker, banded metasediments overlain by lighter colored, Lower Paleozoic sedimentary rocks.

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CENOZOIC

Intrusive Rocks

The Whitehorn stock, a Tertiary intrusive at least 30 square miles in area, crops out in the northeast corner of the area and extends to the east for several miles. A smaller, and presumably related, intrusive is present about 8 miles south near Longfellow Gulch. In addition, two small Tertiary intrusive bodies crop out along the Arkansas River at Cleora (Plate 1).

The Whitehorn stock is discussed in detail by Normand (1968) who interprets it as being a composite intrusive with diorite the dominant rock type, but ranging from gabbroic to granitic in composition. In the vicinity of Marble Quarry Gulch this rock is gray, medium-grained, and contains anhedral andesine (70%), augite (15%), and biotite (10%) as essential minerals. Quartz, magnetite, apatite, and zircon are the accessories. The only visible alteration is the uralization of about 60% of the augite.

Xenoliths of Paleozoic and Precambrian rocks have been reported near the margins of the stock (Behre et al., 1936) and are particularly conspicuous in a quarry on Ute Trail in sec. 35, T.51N., R.9E. where they commonly are more than a foot long. Most of them are angular fragments of contact metamorphosed shale, some of which still display bedding. The margins of the xenoliths are coarse-grained and contain minor pyrite.

The Tertiary intrusive body exposed in Longfellow Gulch is a

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hypabyssal tonalite. It appears gray-brown and uniformly fine-grained in outcrop. The essential minerals are andesine, quartz, hornblende, and biotite. In general, quartz is more abundant than in the coarser diorite to the north. Magnetite, apatite, and zircon are accessory minerals. Plagioclase is moderately sericitized and magnetite and biotite are partially altered to hematite. The texture is anhedral granular and equigranular except for rare coarser plagioclase laths (< 3 mm). Fine-grained phases megascopically similar to this tonalite have been found within the stock itself.

Volcanic Rocks

Tertiary volcanic rocks, which cover about 10% of the area, are the remnants of a once much more extensive volcanic field. Most of them occupy topographic highs, but in several places they crop out in gullies, indicating original deposition on a surface of moderate relief. This is also suggested by the fact that the flow banding present in many of these rocks commonly dips at angles greater than 30 degrees in areas where there does not appear to have been any subsequent deformation. Most of the volcanics are located in the vicinity of Brown's Canon, the western end of Railroad Gulch, and Tenderfoot Hill.

Welded rhyolite tuff, the most abundant rock type, is underlain locally in the Brown's Canon-Railroad Gulch area by a thin, weathered, unconsolidated tuff containing abundant wood fragments and a prominent black, rhyolitic vitrophyre up to 20 feet thick. The vitrophyre is well-

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banded and consists of about 70% glass and 30% phenocrysts (< 4 mm) of sanidine and ologoclase-andesine. The sanidine has been rounded by marginal resorption and the plagioclase commonly is fractured. Minor biotite and magnetite are present.

The welded tuff varies in color from gray to reddish brown, displaying well-developed banding formed by flattening of shards and pumice fragments. The degree of welding generally decreases eastward from the Brown's Canon-Railroad Gulch area to the Longs Gulch-Ute Trail area. The essential species are sanidine (20-25%) and oligoclase (5-15%). Biotite, hornblende, zircon, and sphene are present in minor amounts. Tridymite occurs locally in minor amounts as vesicle fillings. The shards and pumice fragments (< 2 cm) are present in amounts up to 25%, and the devitrified glass matrix forms the remaining 40-70% of the rock. The characteristically resorbed sanidine grains commonly are zoned. Oligoclase is present as zoned, twinned, and broken lath-shaped euhedra. Most phenocrysts are between 1-6 mm in size with sanidine being slightly coarser than plagioclase.

Rocks of basaltic composition are confined to the Tenderfoot Hill area and include basalt, basalt porphyry, vesicular basalt, and basaltic volcanic breccia. Euhedral phenocrysts of complexly twinned and zoned labradorite and augite (< 5 mm) constitute up to 25% and 10% of the rock respectively. Magnetite and biotite are widespread accessories. The matrix consists of the same minerals in approximately the same proportions.

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Van Alstine (1969) describes in detail the volcanic rocks of the Poncha Springs NE quadrangle which includes the western end of Railroad Gulch.

Alluvial Deposits

A small patch of gravel, containing well-rounded, predominantly quartzitic pebbles and cobbles, covers part of the summit of a hill in the NE $\frac{1}{4}$ sec. 35, T.51N., R.8E. This gravel was mapped by Van Alstine (1969) as a remnant of the Tertiary Dry Union Formation and is interpreted by him as being Miocene and Pliocene in age.

Quaternary alluvium in the Salida area consists of 1) terrace deposits in the vicinity of the mouth of Ute Creek and Tenderfoot Hill which contain locally derived sub-angular Precambrian and Paleozoic material (Figure 3), 2) minor gravels deposited on the flanks of the terraces and consisting of well-rounded pebbles and cobbles of quartzite and intrusive rocks derived from outside the area, and 3) Recent alluvium that consists of angular to sub-angular material of local derivation which currently fills many gulches and valleys.

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PRECAMBRIAN PETROLOGY

PETROGRAPHY OF THE METAMORPHIC ROCKS

Strongly-Foliated Group

Quartz-feldspar Gneisses

Quartz-feldspar gneisses constitute about 50% of the strongly-foliated group of metamorphic rocks. Individual units range from only a few feet to several thousand feet in thickness. Contacts of larger units with the other strongly-foliated metamorphic rocks, particularly the mica schists and gneisses, typically are gradational, whereas smaller units normally have sharp contacts. The rocks, which vary in color from medium gray to pink, are relatively resistant to erosion and commonly form cliffs.

Essential mineralogy (in order of abundance)

quartz-microcline-oligoclase/andesine

oligoclase/andesine-quartz

microcline-quartz

quartz-sillimanite-muscovite-oligoclase/andesine

Accessories

1) Widespread: biotite, magnetite, muscovite, epidote, zircon, sphene, allanite

2) Rare: garnet, hornblende, apatite

Retrograde alteration

feldspars ——→ sericite, clay

biotite ——→ hematite, chlorite, epidote

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sillimanite ⟶ muscovite

magnetite ⟶ hematite

Texture and grain size

equigranular, granoblastic

fine- to coarse-grained

myrmekitic and granophyric intergrowths common

With increasing mica content the quartz-feldspar gneisses grade into mica schists and gneisses. Sillimanite, common in the vicinity of Stafford and Cat gulches, occurs in two associations: as replacements of biotite and intergrown with quartz in spherical to ovoid nodules up to 10 cm in diameter (Figure 4).

Mica Schists and Gneisses

Mica-rich schists and gneisses, which make up about 30% of the strongly-foliated metamorphic rocks, are interlayered with and grade into both the quartz-feldspar gneisses and the amphibolites. Size range and contact relationships of individual units are similar to those of the quartz-feldspar gneisses. The extreme color variation, from light gray to black, is principally a function of the biotite content.

Essential mineralogy (in order of abundance)

quartz-biotite-muscovite, ± microcline and oligoclase/andesine

quartz-biotite-oligoclase/andesine

quartz-biotite-garnet-(sillimanite)

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Figure 3. Quaternary terraces along Arkansas River. View looking southeast from Tenderfoot Hill.

Figure 4. Sillimanite nodules in quartz-feldspar gneiss ($SE\frac{1}{4}$ sec. 29, T.51N., R.9E.).

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quartz-biotite-muscovite-andalusite-oligoclase/andesine

Accessories

1) Widespread: apatite, epidote, magnetite, zircon, sphene

2) Rare: calcite, sillimanite, allanite

Retrograde alteration

biotite ⟶ chlorite

feldspars ⟶ sericite

magnetite ⟶ hematite

Texture and grain size

anhedral; equigranular to elongate grains

fine- to medium-grained; granophyric textures commonly developed

poikiloblastic garnet or andalusite present locally

Amphibolites

The remaining 20% of the strongly-foliated group consists of amphibolites. Individual units, highly variable in size and shape, normally occur as pods, discontinuous bands and lenses, and large irregular masses. Interlayering with quartz-feldspar gneisses and mica schists and gneisses is common, but gradational contacts, which occur only locally, are restricted normally to the micaceous rocks. In outcrop they are dark gray or black, commonly displaying mineralogical banding resulting from alternating layers rich in hornblende and plagio-

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clase. With increasing amounts of quartz, the rocks grade into hornblende gneisses.

Essential mineralogy (in order of abundance)

hornblende, andesine/labradorite, ± biotite

hornblende, andesine/labradorite, quartz

hornblende, andesine/labradorite, diopside

anthophyllite, quartz, labradorite, biotite

Accessories

1) Widespread: quartz, diopside, sphene, magnetite, apatite

2) Rare: microcline, calcite, zircon, allanite, biotite

Retrograde alteration

hornblende ⟶ epidote, chlorite

plagioclase ⟶ epidote, sericite

magnetite ⟶ hematite

Texture and grain size

typically anhedral, equigranular

fine-grained, but locally containing medium- to coarse-grained aggregates of plagioclase or quartz resulting in a maculose texture

feather amphibolite present locally with coarse, unoriented laths of poikiloblastic hornblende

Epidote is widespread and locally abundant, but appears to be principally either a retrograde species formed from hornblende and

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plagioclase or a late alteration product formed by saussceritization of plagioclase along fractures. Uncommon calcite appears as late clots, lenses, and veinlets in amounts up to 1-2%.

Poorly-Foliated Group

Banded Micaceous Gneisses

In the southern third of the area fine-grained banded rocks occur interlayered with and grading into quartzites and poorly-foliated amphibolites. These rocks constitute about 15% of the poorly-foliated group of metamorphic rocks. In outcrop they display a considerable color variation, but most are medium to dark gray or brown. Individual bands, which reflect differences in composition and/or grain size, range from a fraction of an inch to about a foot in thickness. Foliation normally cannot be distinguished in outcrop, but where it is, in some of the mica-rich units, it is parallel to the banding. Very fine-grained, thinly-banded amphibolite units, interlayered with the banded micaceous gneisses, are mapped with this unit. Locally, these amphibolites display relict sedimentary cross-stratification (sec. 10, T.49N., R.9E.).

Essential mineralogy (in order of abundance)

quartz-biotite-muscovite, $\pm$ plagioclase, $\pm$ garnet

biotite, hornblende, plagioclase

quartz, biotite, muscovite, staurolite

Accessories

1) Widespread: garnet, magnetite, apatite

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2) Rare: epidote, tourmaline, zircon, ilmenite

Retrograde alteration

plagioclase ⟶ sericite

biotite ⟶ chlorite

magnetite ⟶ hematite

Texture and grain size

equigranular, granoblastic, locally with poikiloblastic and euhedral garnet and staurolite

very fine-grained

The very fine-grained nature of these rocks made whole-rock x-ray analysis necessary for reliable determination of the major species and a qualitative estimate of their relative abundances.

Quartzites

Quartzitic rocks underlie about 45% of the southern half of the area. Individual units are interlayered with the banded micaceous gneisses and to a lesser extent with the poorly-foliated amphibolites. They range from only a few feet to over 1000 feet in thickness and commonly extend along strike across the entire Precambrian exposure up to 3 miles. Color variation is extreme, from nearly white through gray or brown to black, depending principally on the biotite content. Locally, relict sedimentary structures such as cross-stratification (Figure 5), nodular structures which possibly are relict concretions (Figure 6), and small-scale banding have been preserved.

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Figure 5. Relict sedimentary cross-stratification in Precambrian quartzite (sec. 21, T.50N., R.9E.).

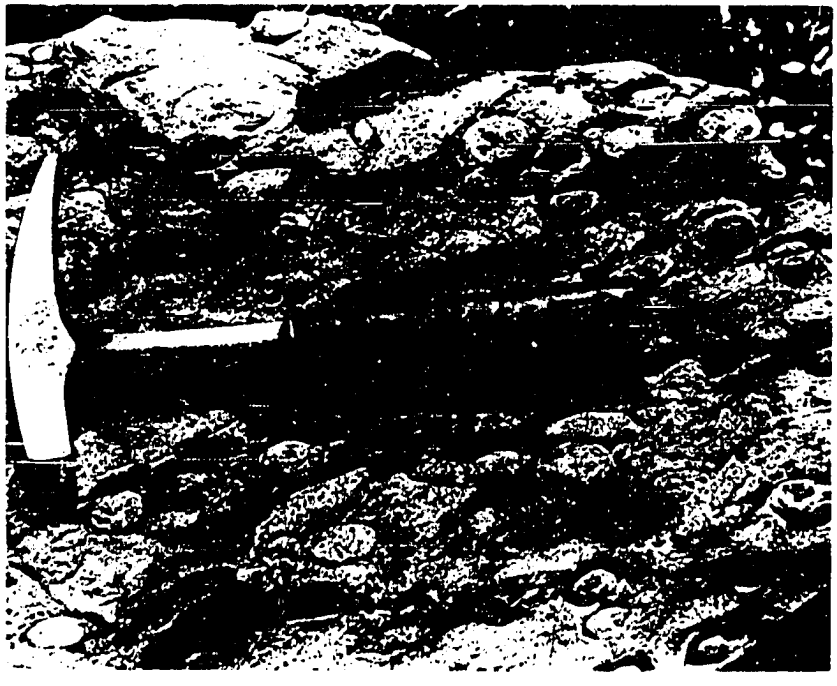

Figure 6. Nodular structures (relict-concretions ?) in quartzite (sec. 10, T.49N., R.9E.).

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Essential mineralogy (in order of abundance)

quartz, biotite, ± plagioclase, ± microcline, ± muscovite

quartz, plagioclase, hornblende, biotite (rare assemblage)

Accessories

1) Widespread: magnetite, calcite, apatite, epidote, garnet

2) Rare: zircon

Retrograde alteration

feldspars ⟶ sericite

biotite ⟶ chlorite

magnetite ⟶ hematite

Texture and grain size

equigranular, granoblastic with poikiloblastic garnet, micas, and plagioclase

very fine- to fine-grained except for poikiloblasts and relict quartz clasts

Two distinct variants of the quartzite occur. The first, which is relatively minor, is extremely fine-grained, pure, and commonly white in color. This type is present as beds rarely more than a foot thick which are restricted in their distribution to secs. 10 and 11, T.49N., R.9E. They appear to represent chert horizons in the original sediment. The second variant is widespread and abundant. It is characterized by relatively coarse oligoclase-andesine euhedra and subhedra (< 1 cm) in a fine-grained quartz-feldspar-mica matrix. Units range in thickness

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from 5 mm bands interlayered with normal quartzite to beds several hundred feet thick. Some units contain fragments up to 6-8 cm long of fine-grained mica quartzite which appear to be relict sedimentary "rip up" structures.

Because of the very fine-grained nature of the quartzites, optical examination was supplemented by x-ray diffraction of whole-rock powders to determine the relative amounts of quartz, plagioclase, and potassium feldspar.

Poorly-foliated Amphibolites

Poorly-foliated amphibolites constitute about 40% of the southern metamorphic group. Units range in thickness from a few feet to more than a thousand feet. The smaller units typically are interlayered with the banded micaceous gneisses and to a lesser extent with the quartzites. The larger units, however, rarely contain zones of quartzite or banded micaceous gneiss. In outcrop the rock normally is dark green to black and locally takes on a spotted appearance on weathered surfaces. Contacts between the thinner amphibolite layers and the other poorly-foliated rocks are conformable, but in a few places the larger units appear to crosscut adjacent beds at low angles.

Essential mineralogy (in order of abundance)

hornblende-andesine/labradorite

hornblende-plagioclase, $\pm$ quartz, $\pm$ biotite

Accessories

1) Widespread: sphene, magnetite, apatite

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2) Rare: zircon, ilmenite, pyrite(?), microcline

Retrograde alteration

plagioclase ⟶ sericite, epidote, chlorite

hornblende ⟶ chlorite

magnetite ⟶ hematite

Texture and grain size

extreme variation:

equigranular to highly variable grain size;

granoblastic to elongated laths of hornblende and/or plagioclase

very fine- to medium-grained

relict ophitic texture (grains < 5 mm) common in many of larger units

Calcite and scapolite locally are present in essential quantities, particularly southeast of Ute Trail, but are, at least in part, related to the skarn mineralization of that area.

ORIGIN OF THE METAMORPHIC ROCKS

Parent Materials

Strongly-foliated Group

Quartz-feldspar gneisses

Evidence significant to the genetic designation of parent materials for the quartz-feldspar gneisses includes:

1) high quartz content of many units

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2) gradation into mica schists and gneisses

3) presence of minor concordant marble layers in the Poncha Springs NE quadrangle (Van Alstine, 1969)

It can be concluded that these gneisses were derived from sedimentary rocks, principally arkoses and shaly sandstones.

Mica schists and gneisses

The mineral assemblages contained in this unit are characteristic of metamorphosed pelitic sedimentary rocks. For the most part clay-rich shales and quartz-rich shales predominated. In addition, the local abundance of feldspars and hornblende suggests feldspathic shales and slightly calcareous or dolomitic shales respectively also constituted a part of the parent material. No primary structures have survived metamorphism.

Amphibolites

The problem of determining the parentage of amphibolites is considered in detail in Part II, but a brief summary is presented here. Chemically, rocks of amphibolitic composition may be derived from either mafic igneous rocks (ortho-amphibolites) or sedimentary rocks made up of calcareous or dolomitic shale (para-amphibolites). Criteria used in this study to distinguish between these two types are based on field examination and mineralogical-textural examination of the amphibolites. Within the strongly-foliated group, however, no diagnostic field relationships or textures are preserved, leaving mineralogical criteria as the only indicators of the parent material. The presence of quartz

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and/or biotite locally in essential amounts, as well as the interlayering with rocks of almost certain sedimentary origin, favors a similar ancestry for these amphibolites. However, this evidence is minimal and, for the most part, the parentage of the strongly-foliated amphibolites is in doubt.

Poorly-foliated Group

Banded micaceous gneisses

The derivation of these rocks from pelitic sediments is indicated by: 1) their high quartz, muscovite, biotite content, 2) their persistent, uniform banding which is a function of grain size and mineralogy and is believed to reflect primary bedding (Figure 7), 3) the local preservation of relict sedimentary cross-stratification, and 4) their intercalation with and gradation into quartzites.

Quartzites

Most of the rocks that constitute the quartzite unit were undoubtedly derived from fine-grained clastic sedimentary rocks, rich in quartz and commonly containing abundant argillaceous and feldspathic material. The thin beds of very fine-grained and pure quartzite probably represent metamorphosed chert. The origin of the plagioclase euhedra (Figure 8), however, is difficult to establish.

The characteristics of these feldspar-rich units and the feldspar grains themselves are listed below:

1) The quartzites containing the plagioclase euhedra are abundant southeast of Ute Trail, but uncommon to the northwest.

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Figure 7. Banded micaceous gneiss (sec. 28, T.50N., R.9E.).

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2) Most of the plagioclase has a composition in the oligoclase-andesine range. Microcline is present locally, but much, if not all of it, has metasomatically replaced plagioclase.

3) Carlsbad, albite, and pericline twinning are common, but poorly developed.

4) There is abundant evidence that the plagioclase has been affected by metamorphic deformation. For example, biotite locally assumes "flow patterns" around the plagioclase and the feldspar grains commonly are fractured, with quartz and biotite filling the cracks.

5) Retrograde and/or metasomatic alteration to sericite and microcline is widespread.

6) Minute, unoriented quartz inclusions are present in almost half of the samples examined.

7) The plagioclase euhedra constitute from 5-50% of the units in which they occur.

8) Individual plagioclase-bearing units range from less than 5 mm to several hundred feet in thickness.

9) Contacts with normal quartzite are very sharp to gradational, with undulatory surfaces characteristic of the sharp contacts (Figure 9).

10) Locally, irregular inclusions of very fine-grained micaceous quartzite up to 6-8 cm long, believed to be ripped-up sediment, are found in the feldspar-bearing units.

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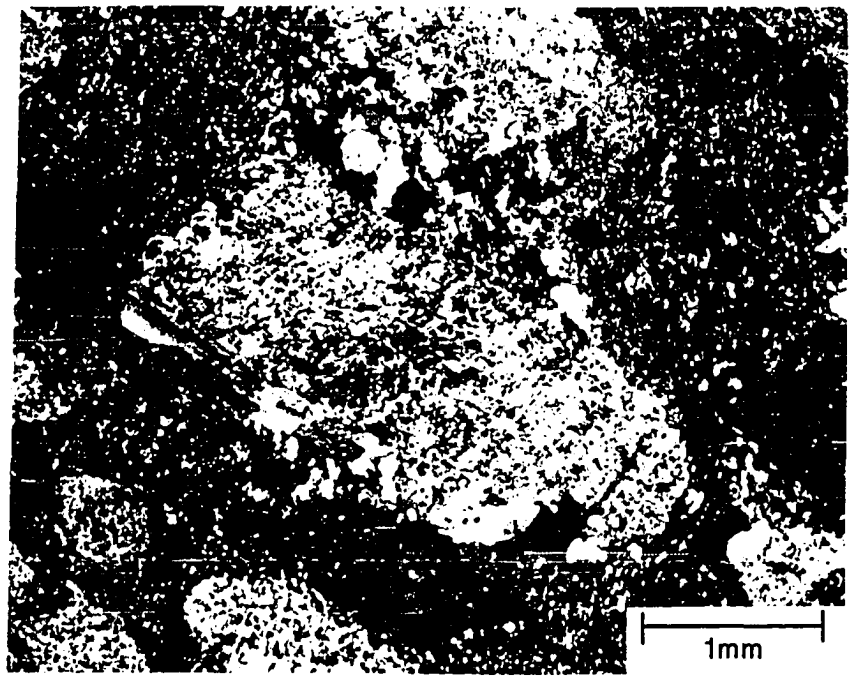

Figure 8. Photomicrograph of euhedral plagioclase in quartzite (sec. 34, T.50N., R.9E.). Polarized light.

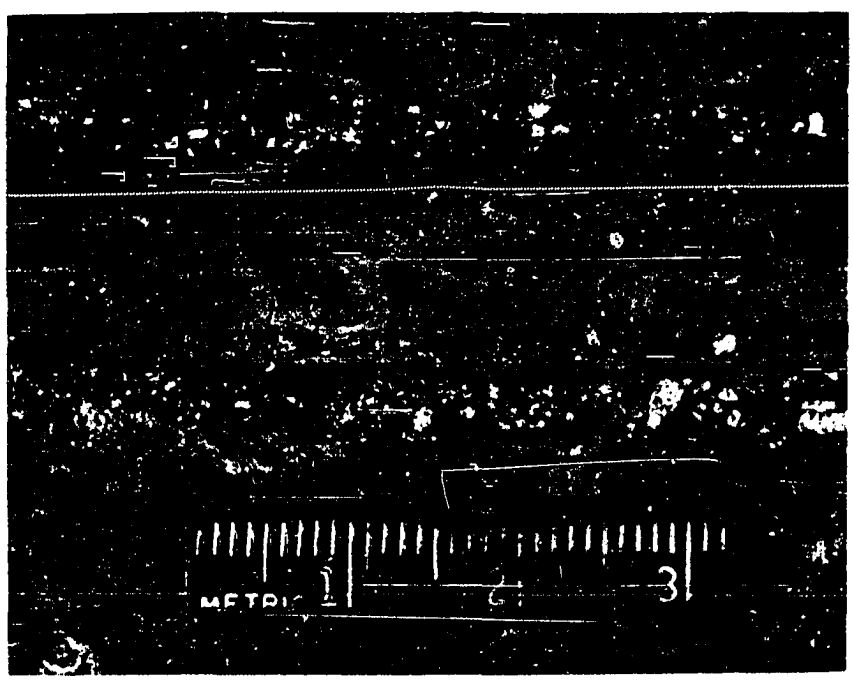

Figure 9. Interlayered feldspathic and "normal" quartzite. Specimen from sec. 4, T.49N., R.9E.

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11) The interbedded quartzite units commonly contain less abundant, but essential fine-grained feldspar (plagioclase predominating).

12) Rare "veinlets" only a few mm thick of the plagioclase quartzite crosscut the normal quartzite.

13) The grain size of the matrix quartz and biotite is slightly coarser than in the normal quartzites.

14) Rarely, hornblende-rich rocks contain similar plagioclase euhedra.

The feldspar euhedra are either: 1) porphyroblasts of early metamorphic origin, or 2) relict crystals introduced into the sediments as pyroclastic ejecta. A sedimentary clastic origin is ruled out because the grains could not have remained as coarse euhedra during transport. The pyroclastic origin is considered unlikely because 1) no other recognizable volcanic ejecta are present, 2) the grains appear to be complete crystals, not fragments, 3) twinning is poorly developed and zoning is absent, and 4) there are abundant quartz inclusions in many grains which are similar in size to the matrix quartz.

The formation of the plagioclase as a metamorphic mineral is considered to be more likely. The main problem associated with this interpretation is the composition of the rock. As much as 3% CaO and 4% Na_2O would be required to produce a rock containing 50% plagioclase with a composition of An_{30}. To include the plagioclase with the detrital minerals would require a source area rich in quartz and plagioclase,

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but poor in potassium feldspars. Moreover, this material would have to be deposited intermittently in layers ranging in thickness from 5 mm to hundreds of feet between normal quartzite units. This places highly unlikely restrictions on the provenance of the sediment. The general appearance of the individual bands indicates that they are relict primary sedimentary units and could not have been formed during metamorphism by either the local lateral migration of ions or metasomatism. Some, but probably not all, of the CaO could be derived from minor calcite in the sediment, but the Na_2O must still be accounted for.

One possible interpretation is that the Na_2O was derived from the seawater, possibly by the authigenic development of sodium zeolites. Authigenic zeolites (mainly clinoptilolite $(Ca, Na_2)\ [Al_2Si_7O_{18}] \cdot 6H_2O$) are not uncommon in marine sandstones, where they form by the alteration of vitreous volcanic tuff and volcanic ash (Deer et al., 1963). Very fine-grained pyroclastic material, transported far from the volcanic source could have been intermittently deposited in the sedimentary basin. This mechanism would account for the commonly sharp contacts and range in thickness of the units and also satisfy the compositional requirements necessary to form the plagioclase during metamorphism.

Poorly-foliated amphibolites

The origin of the poorly-foliated amphibolite is considered in detail in Part II, and the problems involved in establishing the parentage of amphibolites were summarized in the section on the origin of the amphibolites of the strongly-foliated metamorphic group. The amphi-

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bolites of the poorly-foliated group are more readily interpreted, however, due to the minimal metamorphic deformation that has taken place in these rocks, allowing primary structures and textures to be preserved locally. In brief, both ortho- and para-amphibolites are common in the area, but for many of the amphibolite units the origin remains obscure.

Amphibolites that are clearly of igneous origin (i.e., those displaying relict ophitic texture) contain both coarse hornblende pseudomorphous after pyroxene, and finer-grained hornblende replacing plagioclase and forming rims around the coarser hornblende. The finer-grained hornblende is definitely metamorphic in origin and the optical similarities between these grains and the coarser hornblende suggests that the latter also formed during metamorphism rather than by deuteric uralization.

Relationship Between the Strongly-Foliated and Poorly-Foliated Metamorphic Groups

The general characteristics of the two main metamorphic groups found in the area, the strongly-foliated rocks in the north and the poorly-foliated rocks in the south, are listed in Table 2. In addition, the contact between the two groups, which is gradational, roughly parallels the contact of the strongly-foliated metamorphics with the quartz monzonite. On the basis of this information, it is believed all of the metamorphic rocks, with the possible exception of the ortho-amphibolites, originally formed a continuous series, the differences between the northern and

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Table 2. Comparison of major features in the strongly-foliated metamorphics and the poorly-foliated metamorphics.

	Strongly-foliated Group	Poorly-foliated Group
Principal rock types	Amphibolites Quartz-feldspar gneisses Mica schists and gneisses	Amphibolites Quartzites (variable purity) Banded mica gneisses
Relationship to quartz monzonite	Occurs immediately south of intrusive (within 3 miles of contact) Pegmatites abundant	Separated from the contact by strongly-foliated group; 2 to 8 miles from contact Pegmatites rare
Individual rock units	Complex interlayering and interfingering Discontinuous lenses Regional trend ENE, variable	Well-defined and continuous along strike; trend ENE
Metamorphic fabric	Strongly developed foliation parallel to individual rock units	Poorly developed foliation parallel to individual rock units
Metamorphic environment	Upper amphibolite facies (sillimanite stable)	Middle amphibolite facies (andalusite; almandite-staurolite stable)
Thickness	17,000 feet maximum	15,000-23,000 feet

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southern group resulting from areal variations in the degree of metamorphism. Compositionally, the two groups are generally similar, and the layers have the same regional trend. The differences in metamorphic fabric, texture, and grade all are readily related to the proximity of the strongly-foliated group to the quartz monzonite intrusive. The confinement of the vast majority of external pegmatites to the strongly-foliated metamorphic rocks provides additional evidence for linking the development of the strong metamorphic fabric in this group to the intrusion of the quartz monzonite.

Regional Sedimentary Environment

In summary, most of the metamorphic rocks in the area have been derived from sedimentary rocks of probable marine origin, including: 1) quartz sandstone, generally fine-grained and locally arkosic and argillaceous; 2) siltstone and shale, generally quartz-rich, but locally calcareous or dolomitic; and 3) dolomitic or calcareous shales. Gradations were common between the sands and shales and between the shales and calcareous shales. The assemblage of fine-grained clastics and carbonate-rich clastics with locally preserved cross-stratification indicates that deposition took place in an unstable shelf environment. The amphibolites of igneous origin were intruded as mostly conformable diabasic sills into the sedimentary sequence sometime after the consolidation of the sediments, but before the end of metamorphism.

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Metamorphism

The grade of metamorphism decreases along a north-south axis from a maximum in the upper amphibolite facies in the northern end to the middle amphibolite facies at the southern end. The absence of any evidence of replacement of lower- by higher-grade species, except for rare sillimanite after biotite, indicates that equilibrium was established at the peak of prograde metamorphism; retrograde adjustments are widespread, but not generally abundant.

The stability fields of mineral assemblages that are of value in determining the P-T conditions of metamorphism in the area are plotted in Figure 10. In addition, almandite, biotite, hornblende, plagioclase (An > 15%), and muscovite-quartz occur throughout the area in rocks of appropriate composition. The positions of the curves are based on recent experimental data (Greenwood, 1963; Richardson, 1968; Richardson et al., 1969; Althaus, 1970), but due to the uncertainty involved in such experimental results, the plots can be used only to define general P-T limits of metamorphism.

Regions I, II, and III in the figure define the three grades of metamorphism that are recognizable in the area. Region I represents the products of the highest grade of metamorphism which include the strongly-foliated rocks closer to the quartz monzonite contact. Region II represents most of the remaining rocks of the strongly-foliated group and Region III represents the southernmost strongly-foliated rocks and the entire poorly-foliated group.

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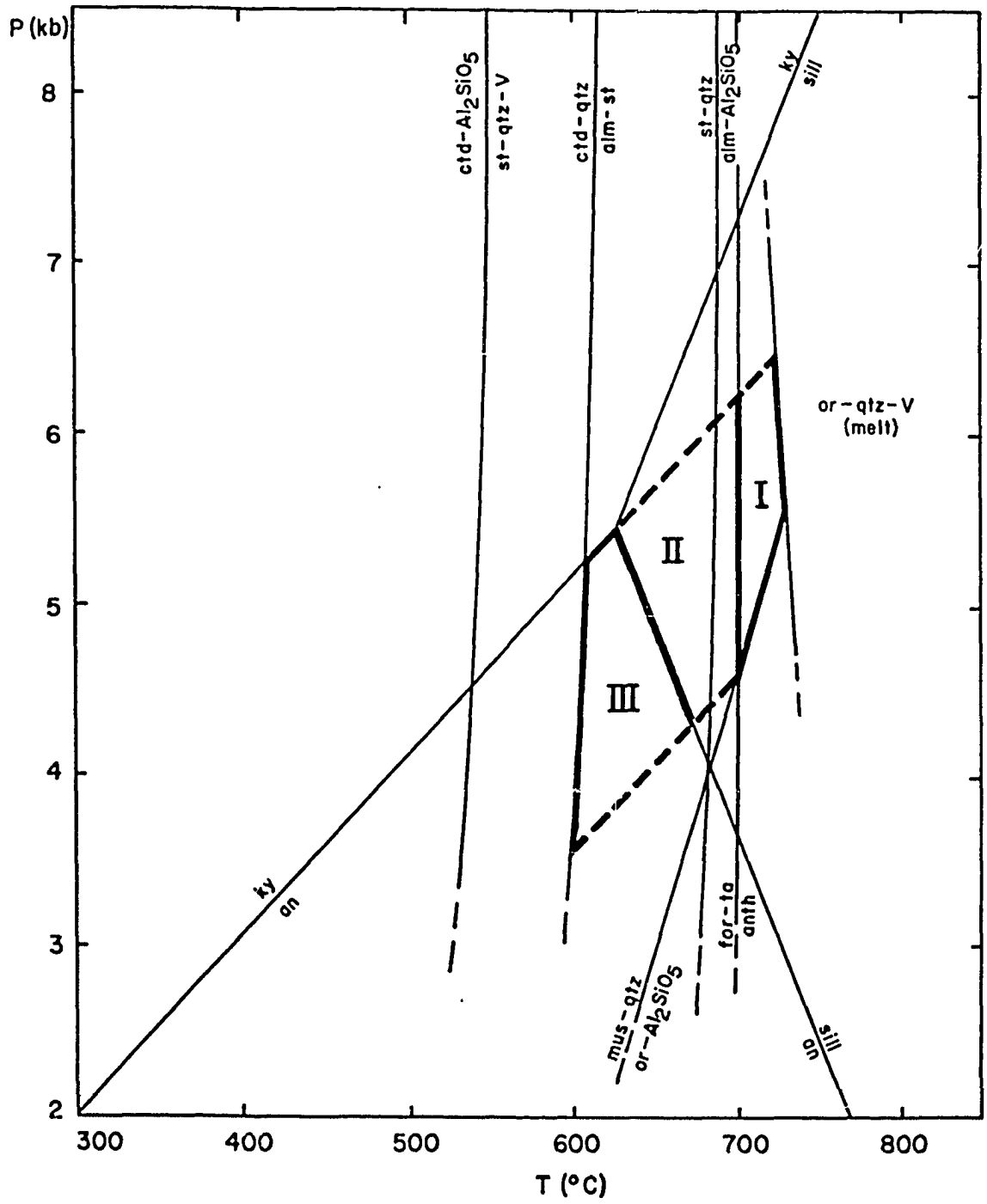

Figure 10. P-T stability fields of metamorphic assemblages in the Salida area. Region I: alm-sill-qtz-bio; anth-qtz-bio; mus-qtz. Region II: sill; mus-qtz. Region III: an-bio-mus-qtz; st-alm-mus-bio-qtz. Alm - almandite, anth - anthophyllite, bio - biotite, ctd - chloritoid, for - forsterite, ky - kyanite, mus - muscovite, or - orthoclase, qtz - quartz, sill - sillimanite, st - staurolite, ta - talc, V - vapor. Curves after Greenwood (1963), Richardson (1968), Richardson et al. (1969), and Althaus (1970).

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The position of the dashed lines in Figure 10 is based on estimated normal geothermal gradients and on gradients postulated for numerous regional assemblages (Turner, 1968) that have been readjusted to accommodate the present position of the Al_2SiO_5 triple point.

The progressive decrease in metamorphic grade from north to south is illustrated by Figure 10. Pressures and temperatures range from a high of about 4.5 - 6.5 kb and 700 - 730°C to a low of about 3.5 - 5.5 kb and 600 - 650°C. The grade of metamorphism, therefore, is entirely within the amphibolite facies, but approaches the granulite facies in the northernmost rocks. Field evidence clearly reflects this change. The highest grade rocks are the most strongly-foliated and the units are irregular in shape and variable in size. The lower grade rocks, on the other hand, consist of well-defined units, are poorly-foliated, and locally contain relict sedimentary and igneous textures and structures.

The fact that the metamorphic grade decreases and the metamorphic fabric becomes less distinct away from the intrusive contact strongly suggests that the syntectonic intrusion of the quartz monzonite was responsible for the local increase in regional metamorphic intensity. If this is the case, heat, rather than pressure, would have supplied most of the energy necessary to bring about these changes. For this reason pressures below 4 kb or above 6 kb are considered unlikely, as excessive pressure changes would then be necessary to produce the assemblages present in the area. In fact, all of the assemblages could have developed at the same pressure, somewhere between 4.5 - 5.5 kb.

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With a temperature difference during metamorphism of probably less than 100°C between the strongly-foliated and poorly-foliated groups, other factors must have been instrumental in the formation of such structurally and texturally dissimilar suites of rocks. The addition of water from the quartz monzonite and the generation of shearing stresses during intrusion could account for these differences. Whether or not water was added is not known, but the discontinuous, irregular form of the rock units and the abundance of small, complex folds in the northern group indicates that significant shearing stresses existed during metamorphism (Figure 11).

With the exception of chloritization along fault zones, retrograde metamorphism is restricted to the replacement of sillimanite and feldspars by muscovite, and biotite and hornblende by chlorite, and is not extensive. Metasomatism, on the other hand, does appear to have been widespread. The skarn deposits discussed in Part III are largely metasomatic in origin, and potassium metasomatism of the coarse plagioclase grains in the feldspathic quartzites is common. Calcite and epidote also occur throughout the area and appear to be partly metamorphic and partly metasomatic in origin.

Comparison With Idaho Springs Formation

Metamorphic rocks assigned to the Idaho Springs Formation underlie a considerable part of central and western Fremont County. These rocks, which are separated from the Precambrian rocks of the

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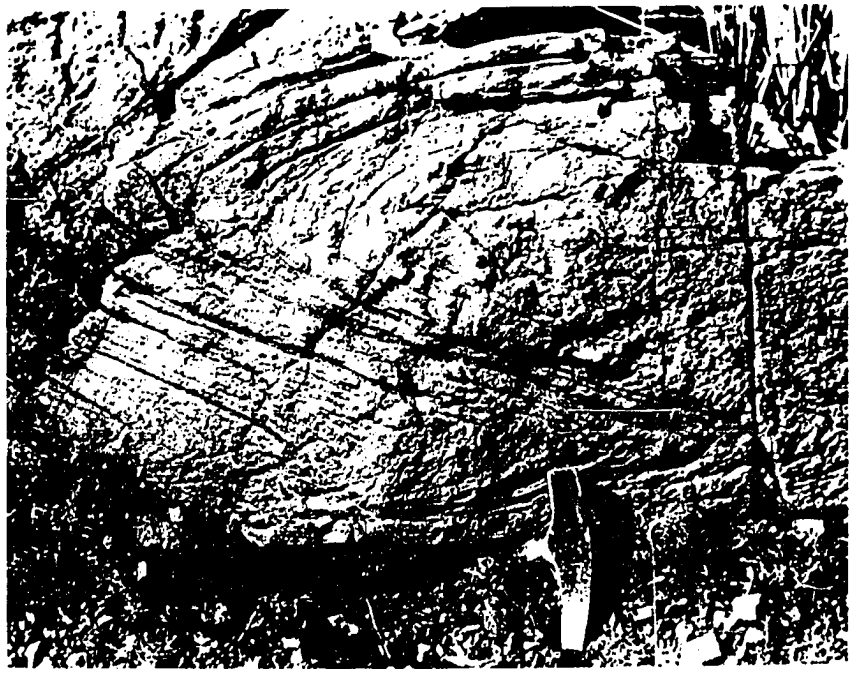

Figure 11. Tightly-folded quartz-feldspar gneiss (sec. 5, T.50N., R.9E.).

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Salida area by several thousand feet of Paleozoic sedimentary rocks and the Pleasant Valley fault, have been studied in detail by Heinrich (1947, 1948), Bever (1954), Salotti (1960), Shappirio (1962), Dahlem (1965), Vian (1965), and Reuss (1970). One of the purposes of this study has been to compare the metamorphic rocks of these two areas.

The general characteristics of the Idaho Springs Formation as it occurs in the Cotopaxi-Howard area and Lookout Mountain area are listed in Table 3, and the characteristics of each of the major metamorphic groups of the Salida area are given in Table 2. The principle similarity between the rocks of the two areas is that both were derived predominantly from clastic sediments, the majority of which were fine-grained and argillaceous. The strongly-foliated group of metamorphic rocks (Salida area) is similar also in grade of metamorphism, but has not undergone migmatization and does not appear to have been deformed as complexly as the Idaho Springs rocks. The southern group, on the other hand, is markedly different from the Idaho Springs rocks. Deformation is minimal, units are well-defined, quartzites are more abundant, pegmatites and migmatization are absent, and the grade of metamorphism is lower. The presence of kyanite in some Idaho Springs units suggests that pressures were significantly higher, at least locally, than in the Salida area.

In both areas, the intrusion of large bodies of granitic rocks has had a profound effect on the metamorphic rocks, but the Idaho Springs rocks were subjected to more widespread and generally more intense

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Table 3. Characteristics of the Idaho Springs Formation in Fremont County, Colorado.

	Cotopaxi-Howard area (Salotti, 1960)	Lookout Mtn. area (Dahlem, 1965)
Principal rock types	Qtz-olig-bio schist Hbld-plag (An_{30-50}) qtz gneiss Amphibolite Lime silicate skarn (rare) Qtz-sill-bio schist (Principally meta-sediments)	Biotite gneiss Feldspathic gneiss Hbld gneiss Amphibolite Musco schist (Principally meta-sediments)
Relation to intrusive	Abundant granite; lit-par-lit migmatization widespread	Several granitoid rocks in area; common lit-par-lit migmatite near intrusive contacts
Structure	Highly foliated scattered large xenoliths and roof pendants concordant with primary foliation of older granite Complexly contorted with isoclinal folding common	Well-foliated, banded Two large folds; little isoclinal folding
Metamorphic environment	Moderate-high intensity (almandite amphibolite)	Moderately high intensity regional (almandite amphibolite)
Thickness	2000-15,000 feet	8000 feet maximum

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modifications. The greater pressures, as indicated by kyanite and the presence of abundant migmatite, suggest that their depth of burial at the time of intrusion was significantly greater.

The age of the metamorphic rocks in these areas can only be established relative to the age of the igneous rocks that intrude them. The metamorphic rocks of the Salida area are older than the quartz monzonite (1.7 B.Y.) and the Idaho Springs Formation is older than the Boulder Creek granite (1.37 B.Y.), the oldest intrusive in the area (Reuss, 1970).

It is not possible to make any correlation of these two metamorphic groups on the basis of the information presently available. However, many of the present differences appear to be attributable to contrasting metamorphic histories in the two areas, particularly with respect to the associated intrusive granitic rocks. It is possible, then, that the metasedimentary rocks of the Salida area are part of the same series as the metasediments of the Idaho Springs Formation. On the other hand, the two areas may contain entirely different sedimentary units.

IGNEOUS ROCKS

Granitic Rocks

Quartz Monzonite

Quartz monzonite underlies about eight square miles in the northernmost part of the area. The rock extends north nearly to Leadville (Van Alstine, 1969). In all, it forms a batholithic mass measuring

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40 x 6 miles. The color ranges from light to medium gray to pinkish gray. Coarse potassium feldspar megacrysts up to 5 cm long are conspicuous. Foliation normally is poorly developed, but locally the rock is strongly gneissic and the megacrysts appear as augen. This highly foliated phase is most prevalent along the contact with the strongly-foliated group of metamorphic rocks. Aplitic and pegmatitic bodies are common and coarse-grained biotitic xenoliths are exposed in several places.

Essential mineralogy

microcline-quartz-oligoclase/andesine-biotite

Accessories

1) Widespread: magnetite, apatite, zircon, sphene

2) Rare: allanite

Alteration products

microcline ⟶ sericite, clay

plagioclase ⟶ sericite

biotite ⟶ chlorite, epidote

magnetite ⟶ hematite

Texture and grain size

equigranular to porphyritic (microcline megacrysts)

anhedral groundmass, euhedral megacrysts

medium-grained groundmass (megacrysts < 4 cm)

Several bodies of coarse-grained biotite schist, believed to be xenoliths or roof pendants, occur within the quartz monzonite. They

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are irregular in shape and variable in size, the largest exceeding 300 feet in length. Biotite (< 1.5 cm) and minor quartz and magnetite are the only visible minerals. Contacts are gradational over a distance of 4 - 12 cm.

Aplite

Aplitic bodies ranging in size from dikes less than a foot wide and a few tens of feet long to masses several thousand feet long (NE $\frac{1}{4}$ sec. 33, T.50N., R.9E.) are present throughout the quartz monzonite. They are light gray, buff, or pink in color. Contacts typically are sharp to slightly gradational over a distance of less than a foot.

Compositionally, the aplites are granitic, containing essential microcline, quartz, and subordinate albite. The accessory species, which constitute 1 - 2% of the rock, are muscovite, biotite, garnet, magnetite (generally partly altered to hematite) and rare epidote. Fine- to medium-grained anhedral-granular texture predominates.

Pegmatite

Granitic pegmatite dikes and lenses up to 2000 feet long and several hundred feet wide are abundant throughout the quartz monzonite and strongly-foliated metamorphic rocks. Most are structurally simple and consist of quartz, microcline, albite, and muscovite, with minor garnet, biotite, beryl, and magnetite present locally. Graphic granite is abundant. Columbite-tantalite has been recovered from a few of the pegmatites (Hanley et al., 1950). The Homestake quarry, developed in

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an unusually large and albite-rich pegmatite, was the only commercially important pegmatite in the area. It is described later in this report.

Origin of the Granitic Rocks

The aplites and pegmatites are believed to represent late-stage differentiates of the quartz monzonite intrusive. Crosscutting relationships indicate that the pegmatites are younger than the aplites. With pressures of about 4.5 - 5.5 kb present in the metamorphic rocks at the time of intrusion, a depth of 15 - 20 km is indicated for the emplacement of the quartz monzonite. Intrusion has significantly increased the grade of regional metamorphism within the country rocks up to three miles from the contact. A late metamorphic age for intrusion is indicated by the absence of significant metamorphic foliation within the quartz monzonite and the presence of strong intrusive flow foliation along the contact. Furthermore, the external pegmatites transect the metamorphic foliation and normally are undeformed.

The age of the quartz monzonite has been established as between 1.65 and 1.70 billion years based on rubidium-strontium dates from samples taken near the north end of the intrusive and near Trout Creek Pass (10 miles north of the area) respectively (Van Alstine, 1969). Correlation of the quartz monzonite with other Precambrian intrusives in Colorado is not justified, but the ages do coincide with widespread igneous activity in the Sawatch Range (Weatherill and Bickford, 1965).

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Intermediate and Mafic Dikes

Peridotite Dike

A highly altered, ten-foot thick, peridotite dike crops out for a distance of 300 feet in the SW $\frac{1}{4}$ sec. 3, T.50N., R.9E. It trends southeast, forming a low ridge, parallel to the foliation of the mica schist country rock. The dike is fine-grained, dense, and gray. The original minerals were olivine (60%) surrounded by a pyroxene (40%). The olivine has been completely altered to serpentine and magnetite, but the original grain form (1-3 mm) is still visible. The intergranular pyroxene is almost entirely altered to chlorite and magnetite. About 20% of the rock is now magnetite, some of which may be primary. Apatite is conspicuous, but constitutes less than 1% of the rock.

Lamprophyre Dikes

Several lamprophyre dikes, ranging in thickness from 10 to 25 feet and in length up to a mile, cut the rocks in the northern part of the area, particularly the quartz monzonite. They are steep-dipping, trend northeast to east, and form resistant ridges prominent enough to be seen on aerial photographs. Most are gray-green and noticeably porphyritic in hand specimen. Quartz monzonite zenoliths up to a foot long are abundant in some dikes. The contacts are sharp and chilled margins are indicated by a decrease in phenocryst size near the contacts.

The only essential minerals are zoned brownish-green hornblende and altered plagioclase. The dikes can be classified as spessartite

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lamprophyres, having a dioritic composition. Hornblende, which constitutes 75% of the rock, occurs both in the matrix and as phenocrysts (< 3 mm). Plagioclase generally is restricted to the fine-grained matrix, rarely occurring as phenocrysts. Accessories are apatite, sphene, quartz, and magnetite. Xenocrystic quartz grains (< 6 mm) are present in amounts up to 3%. Alteration is extensive; plagioclase has been replaced by sericite, epidote, and a clay mineral, and hornblende by chlorite, epidote, and calcite.

Diabase Dikes

Two north-trending, vertical diabase dikes crop out in sec. 29, T.51N., R.9E. They are 6 - 10 feet wide with a maximum outcrop length of 3000 feet. The dikes are dark greenish-gray and uniformly fine-grained. The texture is sub-ophitic with plagioclase laths set in slightly coarser grains of altered pyroxene (?). Grain size ranges from 0.5 - 2.0 mm. Magnetite is the only other essential mineral and quartz is present in trace amounts. Composition of the plagioclase and the identity of the mafic species could not be determined because of the high degree of alteration: plagioclase to sericite, clay, and epidote, and the mafic mineral to chlorite, hematite, epidote, and possibly biotite.

Andesite Dikes

Dikes of andesitic composition are common throughout the area north of Ute Trail. Most are nearly vertical, less than 15 feet thick, and crop out for distances up to $2\frac{1}{2}$ miles, generally parallel or sub-

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parallel to the foliation. Outcrops are gray to buff in color and phenocrysts of feldspar and a mafic mineral are visible.

Most of the primary minerals are recognizable, even though alteration is extensive. Phenocrysts are zoned, euhedral andesine (< 5 mm), biotite (< 3 mm), and hornblende (< 4 mm). In addition, quartz xenoclasts (< 1 cm) are common in some dikes. The groundmass, which constitutes 50 - 90% of the rock, contains predominantly very fine-grained plagioclase with minor biotite, hornblende, quartz, apatite, magnetite, and sphene. A few quartz-rich dikes are dacitic in composition. Alteration products consist of chlorite, calcite, epidote, and magnetite after biotite and hornblende; sericite and a clay mineral after plagioclase; and hematite after magnetite. Alteration, particularly of the mafics, commonly is complete.

Basalt Dikes

Vesicular basalt and basalt dikes have been found in secs. 17 and 32, T.51N., R.9E. respectively. The vesicular basalt contains labradorite laths (< 1.5 mm) (40%), fine-grained, euhedral magnetite (20%), and rounded vesicles (< 1.5 mm) (15%) filled with calcite and quartz, in a matrix of altered mafic minerals. Sphene is present as an accessory species. The alteration products are chlorite, magnetite, hematite, calcite, and sericite.

The black, very fine-grained basalt dike, which is only a few feet thick, is vertical and crops out for only a few hundred feet. Narrow

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laths of labradorite (?) (15%) and euhedral magnetite and pyrite (15%) occur within an extremely fine-grained, brown groundmass of undetermined composition.

Origin of the Dikes

The age of the mafic dikes is unknown, but none are older than 1.7 billion years, as they cut the quartz monzonite. The lamprophyres probably were not part of the same igneous episode that produced the quartz monzonite, because the chilled margins indicate that they were intruded after the quartz monzonite had cooled. The peridotite probably formed at great depth and is probably Precambrian in age. The andesite and basalt dikes, on the other hand, are very fine-grained and were probably emplaced at shallow depths, suggesting a more recent, possibly Laramide, age. The northeast to east trend of the lamprophyre and andesite dikes may serve to link these types and set them off from the basalt and diabase dikes, which trend north. There is no further evidence to support this idea, however. The fact that no dike rocks have been found in the Paleozoic sedimentary rocks is additional evidence for a Precambrian age. Elsewhere in Colorado, where the ages of similar rocks are known, the basalt, andesite and dacite dikes are of Laramide age, and the lamprophyre, diabase, and peridotite dikes are Precambrian in age.

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STRUCTURAL GEOLOGY

PRECAMBRIAN FOLDING

Within the strongly-foliated group, small-scale folds are visible in many places (Figure 11), but the irregularity of the rock units and later faulting prevented the delineation of any major folds. The largest fold that was identified is an irregularly-shaped dome situated near the confluence of Cat Gulch and Railroad Gulch. It is about 2000 feet in diameter with dips on the flanks ranging from 10-40 degrees. Most of the plastic deformation that the strongly-foliated group has undergone is believed to be related to local stresses resulting from the intrusion of the quartz monzonite.

The rocks of the poorly-foliated group have been relatively undeformed. Northward from the Arkansas River to the vicinity of Dead Horse Gulch, the dip of the units increases from nearly horizontal to vertical (Plate 2). A major synformal structure, with an east-trending axis, may be present in this area of steeply-dipping rocks. However, no evidence, other than the inward dip of the beds, has been found to substantiate the existence of the fold (e.g., closure or repetition of units, drag folding on the fold limbs, preservation of primary structures that would indicate the tops or bottoms of units). Most of the tilting of the Precambrian rocks is believed to be Precambrian in age because the Paleozoic rocks to the east normally dip less than 30 degrees and trend at right angles to the regional trend of both the Precambrian foliation and rock units. The direction of maximum compression that produced

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the major Precambrian tilting, folding (?), and regional foliation was NNW-SSE.

FAULTING

Numerous major faults cut the Precambrian rocks, particularly in the northern half of the area. Evidence for Precambrian faulting includes the localization of skarn deposits along or between fractures and the presence of chloritization and unusually well-developed foliation along linear zones. In addition, Van Alstine (1969) suggests that the "persistent east-trending lamprophyre dikes and some of the other Precambrian dikes, may have been intruded along faults." Laramide movement along many of these faults is evident, as they commonly cut Paleozoic sedimentary rocks and Tertiary volcanic rocks. Because of the difficulty in distinguishing between Precambrian and Laramide movements, all faulting is considered together.

Two major sets of faults are recognized, a northwest-trending set, which is "deflected" to a northerly trend in the northern part of the area, and an east-trending set. Many of the faults belonging to these sets are clearly visible on aerial photographs, where they commonly can be traced for several miles. The northwest set is a major structural element of regional extent. Tertiary volcanics cut by one of these faults in the vicinity of the mouth of Railroad Gulch have undergone about 500 feet of normal displacement. The eastern margin of the Arkansas River valley between Brown's Canon and Ute Trail may be defined by a fault belonging to this set. Northwest of the area the fluorite mineralization

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of the Brown's Canon District is localized along these faults (Van Alstine, 1969). Sharp (1970) considers this structural element to be related to faulting and associated hot spring activity across the Arkansas River valley in the vicinity of Mt. Princeton.

The east-trending faults have been found only in the quartz monzonite and adjacent Paleozoic rocks, but parts of Railroad Gulch and Longs Gulch may be situated along faults belonging to this set.

Many minor faults and shear zones of undetermined age, commonly with slickensided surfaces coated with epidote and calcite, cut the Precambrian rocks throughout the area. Inasmuch as epidote was formed both in the Precambrian skarns and Tertiary tactite deposits, its presence is non-restrictive in defining the ages of these faults.

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GEOLOGIC HISTORY

The geologic record in the Salida area began in Precambrian time with the deposition of several thousand feet of fine-grained sands, silts, shales, and carbonate-rich shales, probably in an unstable marine shelf environment. Following consolidation, several large diabase sills intruded the sedimentary series. Subsequent orogenic activity resulted in the regional metamorphism of the sedimentary rocks and diabase sills and the intrusion of a quartz monzonite batholith and related aplites and pegmatites 1.7 billion years ago. Strongly-foliated metamorphic rocks of upper amphibolite grade were formed within 3 miles of the quartz monzonite whereas poorly-foliated metamorphic rocks of middle amphibolite grade were formed farther from the intrusive. Numerous copper-zinc and copper-tungsten skarn deposits, formed during metamorphism, may be related to the quartz monzonite. Peridotite, lamprophyre, diabase, andesite, and basalt dikes transect all of the Precambrian rocks. Most are probably Precambrian in age, but the andesite and basalt dikes may be Laramide in age.

Following a long period of erosion throughout Late Precambrian time, Paleozoic sedimentation began with the deposition of the Cambrian Sawatch quartzite on the Precambrian unconformity. The Paleozoic Era was characterized by several periods of marine carbonate and clastic deposition with intermittent erosion, resulting in a total accumulation of 2000-3000 feet of sediments. Mesozoic rocks are not present in the area, but several thousand feet of marine and non-marine sediments may have

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once covered the region (Stark et al., 1949).

Beginning in late Mesozoic time, the entire Rocky Mountain area was involved in the deformation, magmatism, uplift and erosion of the Laramide orogeny. The Whitehorn stock was intruded east of the Precambrian rocks of the Salida area and several hundred feet of Oligocene volcanic rocks, probably related to the Thirtynine Mile Volcanic Field near Guffey, Colorado, were poured out over most or all of the area. Faulting, which at least in part was subsequent to volcanism, is characterized by north- to northwest-trending and east-trending sets of normal faults, many of which may be rejuvenated Precambrian structures. The maximum known vertical displacement is about 500 feet.

Late Tertiary gravels probably were deposited over much of the area (Van Alstine, 1969), but later erosion has removed both the gravels and most of the volcanic rocks. Alluvial deposition was widespread during the Quaternary, forming terraces and valley fill, but at the present time deposition is minimal, and most streams are cutting down through bedrock and the alluvium.

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MINERAL DEPOSITS

PEGMATITES

Homestake Deposit

The Homestake deposit (M. & S. Quarry), one of the largest pegmatites in the area, is located in Railroad Gulch in the SE $\frac{1}{4}$ sec. 34, T.51N., R.9E., about 300 yards northeast of the road to Turret (Chaffee County road 190). The quarry, which operated throughout the 1950's and early 1960's, was the largest feldspar producer in Colorado for several years (U.S. Bureau of Mines, 1951-64), with a maximum production for a single year of 29,650 tons in 1955 (Baillie, 1962). Most of the deposit has been mined out and the quarry is presently flooded. A detailed examination was conducted by Azar (1954) who concluded that the albite formed by fracture-controlled hydrothermal replacement of a pre-existing pegmatite, the solutions being related to the Tertiary intrusive to the east. Although very little of the deposit remains or is exposed in the workings, this hypothesis appears untenable, simply because of the lack of albitization in the Paleozoic rocks that lie between the intrusive and the deposit. A summary of the geology of the deposit, based on the present condition of the workings, is given in the following paragraphs.

The quarry occupies a roughly oval-shaped area about 600 feet long (E-W) and 400 feet wide. The pegmatite itself also appears to trend easterly with maximum original surface dimensions of about 500 x 300 feet. The country rock consists of highly sheared, chloritized, and

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mylonitized quartz monzonite and minor aplitic granite which is foliated near shear zones. Chlorite zones up to three feet wide occur locally along the contact. The Precambrian metamorphic rocks crop out about 300 yards south of the deposit. The eastern limit of the deposit is the Precambrian-Paleozoic unconformity. In several places, particularly along the eastern end of the deposit, the country rock and the albite-rich rock contain coarse, radiating, fibrous actinolite and disseminated pyrite. A massive actinolite rock with subordinate magnetite crops out on a peninsular projection into the flooded quarry from the east.

Relatively little coarse-grained material is exposed in the present workings, but coarse to very coarse quartz, albite, muscovite, and biotite have been found associated in various proportions in dump samples. The albite rock typically is massive and fine- to medium-grained, but locally is very coarse. It contains up to 20% quartz, muscovite, biotite, and pyrite, and has been cut by narrow quartz veinlets. No internal zonal structure could be established from the exposures.

Classical albitization does not appear to have been responsible for the formation of the albite, because of the absence of clevelandite or sugary textures. If the albite is primary, the composition of the pegmatite could not be granitic owing to the dearth of potash feldspar. A somewhat more intermediate composition is suggested by the presence of actinolite and the apparent excess of albite over quartz. Regardless of its origin, the deposit represents a unique type of occurrence for Colorado and possibly the United States.

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Other Pegmatites

Hundreds of granitic pegmatites transect both the quartz monzonite and the strongly-foliated metamorphic group of rocks. Many of them have been prospected and several have produced minor amounts of potash feldspar, scrap mica, columbite-tantalite,and beryl (Hanley et al., 1950), but no large scale mining has taken place except at the Homestake albite quarry.

SKARN DEPOSITS

Skarn deposits containing copper-zinc and copper-tungsten mineralization are widespread in the area. The copper-zinc skarns, which are confined to the strongly-foliated group of metamorphic rocks, are localized by faults and fractures, most commonly within rocks of amphibolitic composition. The copper-tungsten skarns of the Cleora district are narrow, zoned replacement veins in poorly-foliated amphibolite.

Sedalia Mine

The Sedalia mine, in the NW $\frac{1}{4}$ sec. 18, T.50N., R.9E., is the largest mine in the area. It is also the only skarn deposit for which production records are available. Most of the following information comes from reports by Freeman (1919) and Swanton (1922). A summary of the mine production and reserve calculations is given in Table 4. The mine was operated continuously from 1888 to 1918 when the government subsidy of copper was suspended, resulting in a drop in the market price

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from $.26/lb. to $.11/lb. The mine was never reopened. Virtually all of the production came from secondarily enriched pockets. Concentration by hand cobbing resulted in shipping ore containing 15% to 37% copper. Estimates of the grade of the reserves, which consist both of primary sulfides and secondary copper minerals, range from 5% copper and 10% zinc in the older reports, to about 1½% copper in more recent evaluations. Although as much as one million tons of ore still remain at the Sedalia mine, the prospects for profitable exploitation apparently are not great, as both the New Jersey Zinc Company and Noble American Minerals, Inc., have conducted detailed evaluations of the mine in recent years, but did not elect to reopen it.

Other Skarn Deposits

A few tons of tungsten ore were shipped from the Stockton mine in the Cleora district (Belser, 1956), but otherwise the district has been nonproductive. The detailed discussion of the geology, mineralogy, and origin of the skarn deposits of the Salida area is contained in Part III of this report.

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Table 4. Production records and reserve estimates, Sedalia mine.

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	Totals
1915-1918	18,000 Cu	$ 315,364.71	
	2,500 Zn	30,324.02	
		345,688.73	Total

Reserve Estimates			
Report	Tonnage	Grade (Cu%)	
1919 Report:	1,083,000	5.4%	
1968 Report:	829,000	1.5%	
1969 Report:	575,000	2%	"Cu equiv."

GOLD VEINS

Numerous abandoned mines and prospects, worked for gold during the late 1800's and early 1900's, are located in the vicinity of the ghost town of Turret (SE $\frac{1}{4}$ sec. 29, T.51N., R.9E). In addition, gold has been prospected for in the Paleozoic sedimentary rocks in the SW $\frac{1}{4}$ sec. 35, T.51N., R.9E., and the NW $\frac{1}{4}$ sec. 2, T.50N., R.9E. Very little has been published on the geology and mining history of the Turret district. Azar (1954, p. 142) reports:

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> The gold occurs in quartz-filled fissures developed in the Precambrian granite. Gold valued at over $100,000 (personal communication with old prospectors in Salida) has been taken out of these veins. It occurs in native form and is commonly associated with quartz, pyrite, chalcopyrite, galena, and some sphalerite and limonite.

Most of the workings appear to have been developed along structures such as faults and contacts between the quartz monzonite and dikes. Although the great majority of workings consist of small prospect pits and short adits, several mines have large dumps, indicating extensive underground workings.

Mineralized fractures typically are steeply-dipping to vertical, with no apparent pattern to their trend. The maximum vein width observed is about two feet. Two polished sections from the Golden Wonder mine (SW $\frac{1}{4}$ sec. 27, T.51N., R.9E) were examined and found to contain only pyrite, hematite, and fractured quartz. Quartz druses line cavities formed by fracturing. The only alteration found in the district is a 2 foot wide clay-rich zone adjacent to a mineralized fracture in quartz monzonite (NE $\frac{1}{4}$ sec. 28, T.51N., R.9E.).

The largest gold mine in the Paleozoic rocks is the Iron King mine (NW $\frac{1}{4}$ sec. 2, T.50N., R.9E). The workings (Figure 12), which are developed along a N30^{o}W-trending vertical fault zone cutting Paleozoic sandstone and limestone, consist of a large pit about 60 feet in diameter and 25 feet deep, several smaller pits, and two adits. The country rock in the mine area has been extensively silicified. A few hundred feet north and east of the workings, a Tertiary sill of intermediate composition, probably the source of mineralization, crops out.

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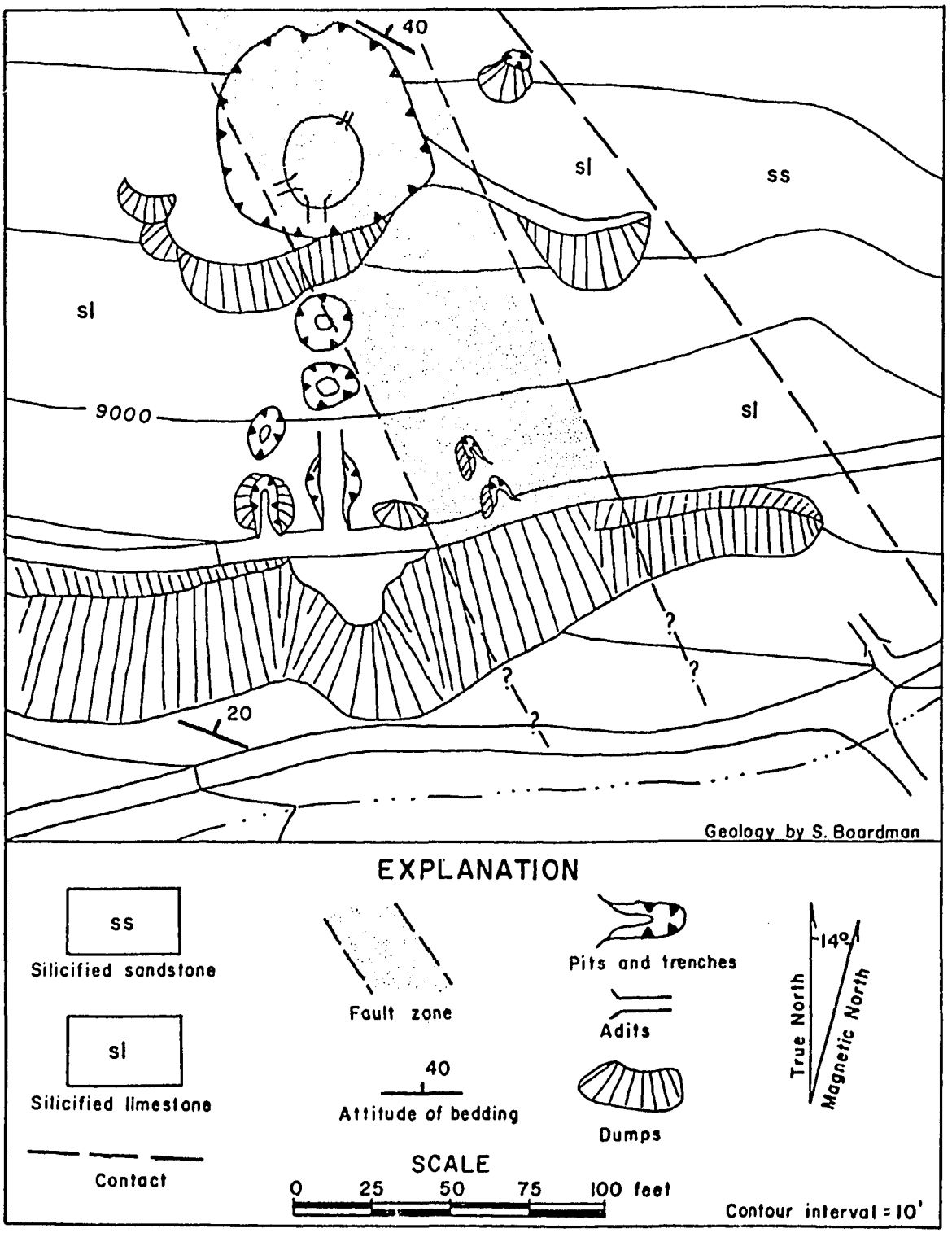

Figure 12. Geologic sketch map of the Iron King mine, NW $\frac{1}{4}$ sec. 2, T.50N., R.9E., Chaffee County, Colorado.

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The only visible mineralization consists of extensive hematization and silicification in the highly brecciated 40-60 foot wide fault zone, the center of the zone being the most highly fractured and altered. There is no evidence of mineralization along the strike of the fault beyond the immediate mine area. According to Behre et al. (1936), assays of nearly 2 oz./ton in gold are reported from the mine.

OTHER DEPOSITS

Calumet Mine

The Calumet iron deposit, in the SW $\frac{1}{4}$ sec. 26, T.51N., R.9E., is a contact metasomatic ore body confined to a lens of Leadville limestone that is bounded above by the main body of the Whitehorn stock and below by a sill-like extension of the stock. Behre et al. (1936) describe the geology, mineralogy, and paragenesis of the deposit. According to their report, the mine was operated continuously from 1882 to 1900, yielding a total of 228,781 long tons of iron ore. The iron content of ore shipped declined throughout the history of the mine from about 60% to 43%.

Brown's Canon Fluorspar District

The Brown's Canon fluorspar deposits are west of the Arkansas River, one mile southwest of the mouth of Railroad Gulch. A detailed account of the geology and history of the district is given by Van Alstine (1969). He considers the deposits, which are localized along the same northwest-trending system of normal faults that extend into this area, to

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be the result of Tertiary epithermal mineralization. Precambrian metamorphic rocks and quartz monzonite and Tertiary volcanics constitute the country rocks. About $5 million worth of fluorspar concentrates have been produced from the district.

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PART II - ORIGIN OF THE AMPHIBOLITES

INTRODUCTION

The problem of determining the origin of amphibolites stems from the fact their bulk composition approximates either mafic igneous rocks (basalts, basaltic tuffs, diabases, gabbros) or such sedimentary rocks as dolomitic shales or some calcareous shales. Criteria that have been used to assign amphibolites to either an igneous parentage (ortho-amphibolites) or a sedimentary parentage (para-amphibolites) are combined into three groups, those based on geological characteristics, those based on mineralogical and textural characteristics, and those based on relationships of major and minor elements derived from chemical analyses (Table 5). The first two approaches have been used by many geologists including Wilcox and Poldervaart (1958), Walker et al. (1960), and Heier (1962). More recent investigations, based on analytical methods, are in conflict with some of the field interpretations (Leake, 1964; Shaw and Kudo, 1965; Van De Kamp, 1968, 1969; Nelson, 1969; Preto, 1970). In particular, rocks previously considered to be para-amphibolites because of their banded appearance and close interbedded association with marbles have been re-interpreted as ortho-amphibolites (or meta-tuffs) on the basis of analytical criteria (Leake, 1964; Van De Kamp, 1968).

The greatest problem in the application of geologic and textural techniques to the determination of amphibolite parentage is that structural

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Table 5. Methods for the recognition of and distinction between ortho-amphibolites and para-amphibolites. Asterisks denote criteria used in this study.

I. Geological Characteristics
- A. Ortho-amphibolites
  - 1. Relict structures
    - a. Flow tops or pillows
    - b. Amygdules
    - c. Orbicules
    - d. Xenoliths
  - 2. Crosscutting relationships*
  - 3. Exomorphic and endomorphic mineralogical changes along contacts of layers
- B. Para-amphibolites
  - 1. Relict structures
    - a. Pronounced banding*
    - b. Concretions
    - c. Cross bedding or cut-and-fill*
  - 2. Close association with or gradation into metasedimentary rocks, especially marble*
  - 3. Compatibility with total sedimentary environment as indicated by other metasedimentary rocks*

II. Mineralogical and Textural Characteristics
- A. Ortho-amphibolites
  - 1. Occurrence of common normal zoning or well-developed twinning in plagioclase*
  - 2. Relicts of augite or hypersthene in central parts of hornblende
  - 3. Relict ophitic texture*
  - 4. Relict porphyritic texture*
- B. Para-amphibolites
  - 1. Abundant quartz, biotite, or microcline*
  - 2. Widespread accessory tourmaline

III. Chemical Relationships of Major and Minor Elements
- A. Presence of diagnostic trace elements and oxides (univariant analysis)
  - 1. Cr
  - 2. Ni
  - 3. Sc
  - 4. TiO_2
- B. Ratios of Niggli numbers for large numbers of analyses (divariant analysis)
  - 1. Major oxides
  - 2. Trace elements
- C. Discriminant function analysis (multivariant analysis)
  - 1. Major oxides
  - 2. Trace elements

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and textural features which would be diagnostic of an igneous or sedimentary origin normally are destroyed during the recrystallization and deformation that generally accompanies regional metamorphism of moderate to high grade. Moreover, the compositional variability possible in both igneous and sedimentary progenitors results in a considerable amount of mineralogical overlap between the ortho- and paraметamorphic equivalents. In fact, development of analytical techniques of amphibolite investigation in recent years was stimulated by the inadequacies of the more qualitative methods.

In the Salida area, however, at least 60% of the amphibolites are within the group of poorly-foliated metamorphic rocks that has undergone very little metamorphic deformation. As a result, relict igneous and sedimentary textures and structures have been preserved locally, permitting the designation of the origin of many amphibolite units without recourse to analytical methods. Even so, 25% of the amphibolites cannot be assigned a specific parentage with any degree of certainty.

ORTHO-AMPHIBOLITES

Table 6 lists the characteristics of the known ortho-amphibolites of the area. The most diagnostic feature of this group is the presence of relict ophitic texture (Figure 13). Amphibolites of this type crop out along Ute Trail and at the southern end of the area, along the Arkansas River. Other features that appear to characterize these amphibolites are the homogeneity of the units, their non-banded appearance, and the

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Table 6. Characteristics of the ortho-amphibolites of the Salida area.

Rock Units:
1. Generally more than 100 feet thick and 1000 feet long
2. Rarely interbedded with metasedimentary units
3. Non-banded, uniform appearance
4. Possibly cross-cutting in a few places
5. Contacts typically sharp

Mineralogy:
Essential minerals:
1. Hornblende (30-60%)
2. Andesine-labradorite (70-40%); twinning well developed

Accessory minerals: (total less than 5%)
1. Magnetite/ilmenite; skeletal crystals (< 1 mm) and tiny flakes in hornblende
2. Biotite

Texture:
1. Medium-grained (< 1 cm)
2. No visible foliation in outcrop or thin section
3. Ophitic texture well preserved; plagioclase laths and anhedral hornblende grains

presence of possible crosscutting relationships in a few places (Figure 14). The ortho-amphibolites are mineralogically distinct because they contain only minor accessory minerals and have a high plagioclase/hornblende ratio relative to the known para-amphibolites in the area.

It is apparent from the composition and texture of these rocks that they are meta-diabases. The only major change that they appear to have undergone is the alteration of the pyroxene to hornblende and the formation of some fine-grained hornblende. Their generally conformable relationship with the metasedimentary rocks indicates that they represent sill-like intrusions. About 20-30% of the amphibolites of the poorly-foliated metamorphic group are readily classified as ortho-amphibolites.

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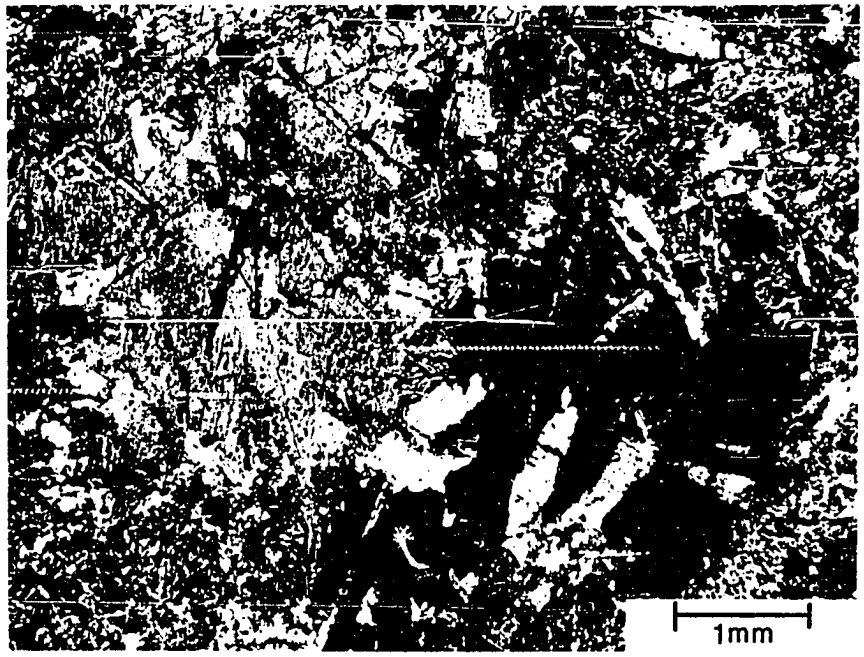

Figure 13. Photomicrograph of relict ophitic texture in ortho-amphibolite (sec. 15, T.50N., R.9E.). Ordinary light.

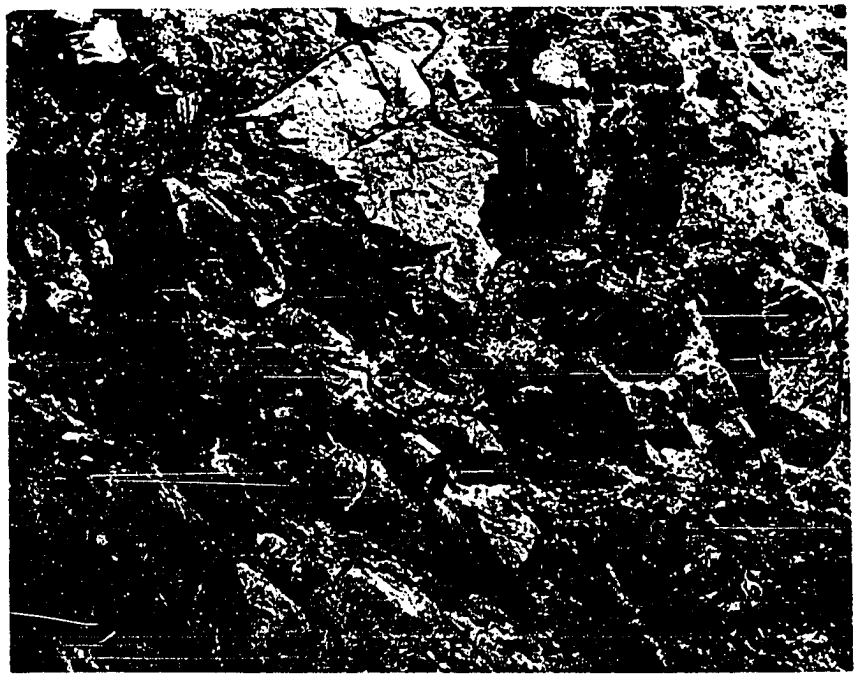

Figure 14. Intrusive contact between quartzite (below) and amphibolite (above). Note blocks of quartzite in amphibolite (SE $\frac{1}{4}$ sec. 16, T.50N., R.9E.).

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Another type of ortho-amphibolite occurs in the area, but it appears to be rare. It is represented by a $2\frac{1}{2}$ foot thick dike in SE $\frac{1}{4}$ sec. 10, T.49N., R.9E. (Figure 15), which locally crosscuts the nearly horizontal banded quartz-mica gneiss country rock, but is conformable over most of its exposure. The rock is uniformly fine-grained with no apparent contact effects either in the dike or the adjacent country rock. No foliation is visible either megascopically or microscopically in the dike. Hornblende is the most abundant mineral, constituting more than 90% of the rock. The only other minerals are quartz (5%), pyrite (1%), and biotite (trace). Grain size ranges from 0.1-1 mm. The apparent complete metamorphic recrystallization of this dike, and the few others like it that have been found, suggests that they may be older than the metadiabase sills, which have largely retained their original igneous texture.

AMPHIBOLITES OF PROBABLE IGNEOUS PARENTAGE

Rocks that do not have well preserved ophitic texture, but are similar in most other respects to the ortho-amphibolites described above, also are believed to be of igneous parentage. Individual units are similar in size and appearance to the ortho-amphibolites and the plagioclase/hornblende ratio is generally high. They typically are somewhat finer-grained than the ortho-amphibolites, but the plagioclase is lath-shaped. Quartz, biotite, epidote, and sphene are more abundant in many of these rocks than in the amphibolites of known igneous origin.

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Figure 15. Ortho-amphibolite dike cutting banded metasedimentary rocks (SE $\frac{1}{4}$ sec. 10, T.49N., R.9E.).

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EPIDOTE NODULES

The ortho-amphibolites that crop out along the Arkansas River in the vicinity of Cleora contain numerous nodular masses of epidote, locally exceeding 15 cm in diameter. The nearly spherical shape and sharply-defined borders of some of the nodules, particularly those in one outcrop in the Cleora Stockyard (SE $\frac{1}{4}$ sec. 10, T.49N., R.9E.), suggest that they may be relict structures (Figure 16). In this outcrop the nodules are concentrated in a 3 foot wide zone, the rocks above and below containing relatively few nodules. Within this zone, however, the nodules appear to be distributed randomly. No distinguishable petrologic difference exists between the matrix of the nodule-bearing amphibolite and the amphibolite without nodules.

Megascopically the nodules have a simple structure consisting of a dark green epidote core and a gray mantle, which is generally less than 5 mm thick and can be divided into two irregular zones (Figure 17). Hornblende grains (< 5 mm) similar to those in the amphibolite matrix are scattered throughout the nodules. Minor pyrite occurs both in the core and the mantle.

Thin sections show the core to contain about 85% fine-grained and anhedral epidote, the remainder being hornblende and minor magnetite, pyrite, and sphene. Hornblende has been replaced marginally by epidote, but relict sub-ophitic texture is still visible (Figure 18). Coarser epidote occurs along late fractures. Pyrite and magnetite are largely altered to hematite. The outer zone of the mantle is characterized by

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Figure 16. Epidote nodules in poorly-foliated amphibolite (SW $\frac{1}{4}$ sec. 10, T.49N., R.9E.).

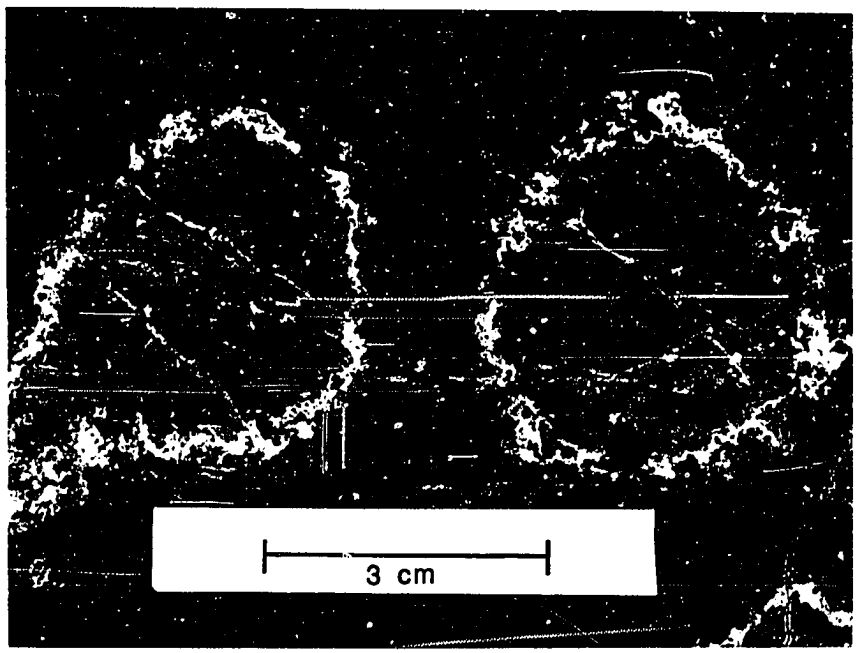

Figure 17. Epidote nodules displaying core, inner mantle zone, and outer mantle zone. Specimen from SW $\frac{1}{4}$ sec. 10, T.49N., R.9E.

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the presence of alteration products of plagioclase, biotite, and the finer-grained hornblende, principally sericite, clay, and hematite. The inner zone is similar, but also contains considerable epidote. The amphibolite, typical of those of known igneous parentage in the area, displays ophitic to sub-ophitic texture, with partly sericitized andesine-labradorite laths set in and around medium-grained hornblende. In addition, a great deal (up to 35%) of fine-grained hornblende, and accessory biotite, magnetite, and sphene are present.

Locally, scapolite occurs in the nodular amphibolites. In these rocks the nodules are much more irregular in form and contain no mantle where the scapolite is in direct contact with the nodule. In thin section, the textural relationships indicate that the nodules have grown around the scapolite (Figure 19).

Origin

No references to nodular epidote occurrences similar to those at Cleora have been found in the literature. Misch (1965) describes radial epidote glomeroblasts of metamorphic origin, the final stage in their formation being the development of "subspherical glomeroblasts composed of granoblastic epidote mosaic." These "epidote balls," however, are only 1-2 mm in diameter, whereas the nodules in the vicinity of Cleora average greater than 4 cm in diameter. Moreover, there is no evidence in the Cleora nodules for the existence of early stages containing radial epidote. It appears, then, that these epidote

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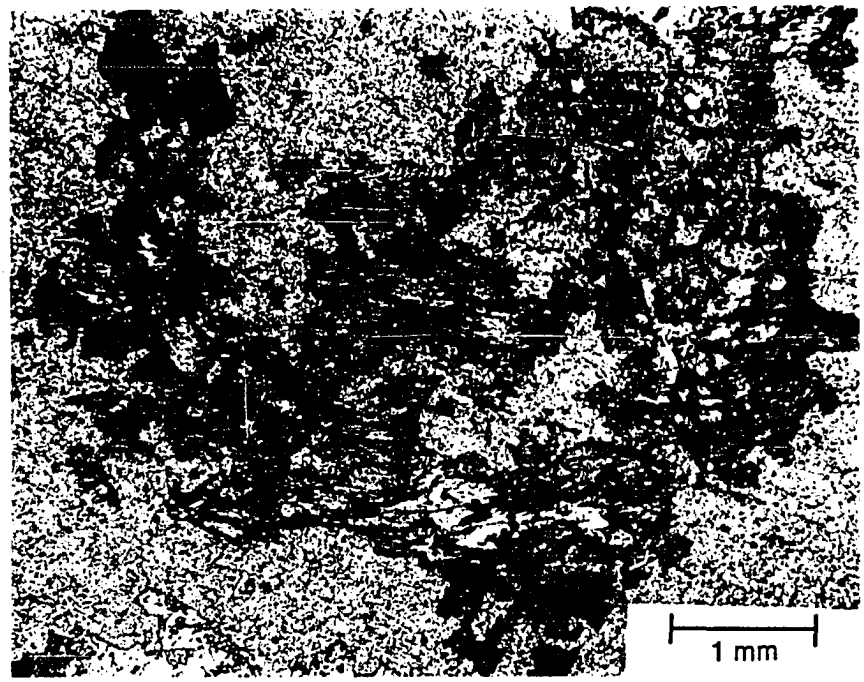

Figure 18. Photomicrograph showing hornblende with relict subophitic texture within epidote nodule (sec. 10, T.49N., R.9E.). Ordinary light.

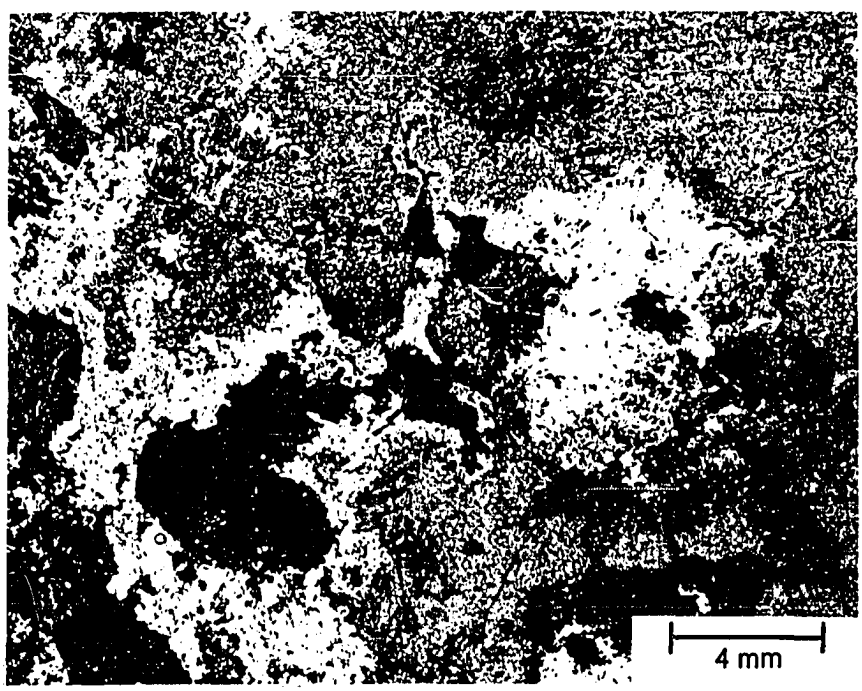

Figure 19. Photomicrograph showing irregular form of epidote nodule (gray) in contact with scapolite (white). Hornblende (dark gray) also present (sec. 10, T.49N., R.9E.). Ordinary light.

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nodules are very unusual, and possibly unique, in their occurrence.

Although the epidote nodules, particularly those in the Cleora Stockyard, appear superficially to be relict structures, the detailed examination of their mineralogy and texture indicates that they are secondary in origin. The following evidence supports this conclusion:

1. Representatives of all stages in the development of the nodules, from irregular, poorly-defined epidote concentrations to well-formed nodules, have been found.

2. Scapolite, definitely secondary in origin and related to the skarn mineralization, is older than the nodules.

3. The coarser hornblende, which is pseudomorphic after the primary pyroxene of the diabase parent rocks, is distributed evenly throughout both the amphibolite and the nodules.

4. The mantle zones display the progressive development of the nodules, with the initial alteration of plagioclase, fine-grained hornblende, and biotite in the outer zone, and the subsequent formation of epidote in the inner zone.

5. Internal structure is absent except for the mantle-core zonation.

Chemically, all of the elements needed to form the epidote are present in the minerals of the amphibolite, but sodium must be removed. The nearly spherical shape of many of the nodules suggests that their growth initiated at a point, but the mechanism by which nucleation occurred is not known.

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The nodules formed sometime following the peak of regional metamorphism, but the exact time is not known as epidote is present in the area in rocks as young as Tertiary in age. It is possible that they are related to the copper-tungsten skarns of the Cleora District, which also occur in the same amphibolites. While epidote is present in these deposits and minor pyrite occurs in the nodules, there is no additional evidence to support this idea.

PARA-AMPHIBOLITES

The only amphibolites of unquestioned sedimentary origin are intercalated with the banded mica gneisses near the southern end of the area. Locally, these rocks contain well-preserved relict sedimentary cross-stratification (Figure 20). They grade into much more abundant, uniformly fine-grained, evenly-banded amphibolite that is undoubtedly of similar origin. Because of the small size of the individual beds and their interlayering with other banded rocks, they have been mapped as part of the banded micaceous gneiss unit. Table 7 lists their characteristics. In addition to the diagnostic features mentioned above, these rocks are distinctive in their mineralogy. Plagioclase normally is less abundant than hornblende, and quartz and biotite are much more common than in the ortho-amphibolites. Rocks intermediate in composition between the para-amphibolites and mica gneisses are common and provide further supportive evidence of their similar origin.

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Table 7. Characteristics of the para-amphibolites of the Salida area.

Rock Units:

1. Generally 6 inches to 10 feet thick and continuous at least over a single outcrop
2. Characteristically intercalated with banded micaceous gneisses
3. Weak to strong banding, with individual bands ranging from 1/8 inch to 1 foot thick
4. Conformable with other metasediments
5. Contacts sharp to slightly gradational (1-3 mm)

Mineralogy:

Essential minerals:

1. Hornblende (10-90%) anhedral grains and laths
2. Plagioclase (10-40%) normally equigranular
3. Biotite (0-40%)
4. Quartz (0-30%)

Accessory minerals:

Sphene, magnetite, apatite, ilmenite, calcite, epidote

Textures:

1. Highly variable grain size within individual bands and between adjacent bands (normal range: 0.05 - 2 mm)
2. Banding is a function of grain size variation and compositional change
3. Foliation recognizable rarely

AMPHIBOLITES OF PROBABLE SEDIMENTARY PARENTAGE

About 10% of the amphibolites contain enough quartz (10-30%) or biotite (15-40%) to suggest that they were derived from sedimentary parent rocks. Banding and folia are not uncommon. The sedimentary origin of these rocks is supported by the local occurrence of relict pebbles of finely recrystallized chert or very fine-grained sandstone up to 2 cm in diameter within the amphibolites (Figure 21). These clasts apparently were deposited in the clay-carbonate muds during periods of relative turbulence.

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Figure 20. Fine-grained para-amphibolite with well-developed relict cross-stratification (NE $\frac{1}{4}$ sec. 10, T.49N., R.9E.).

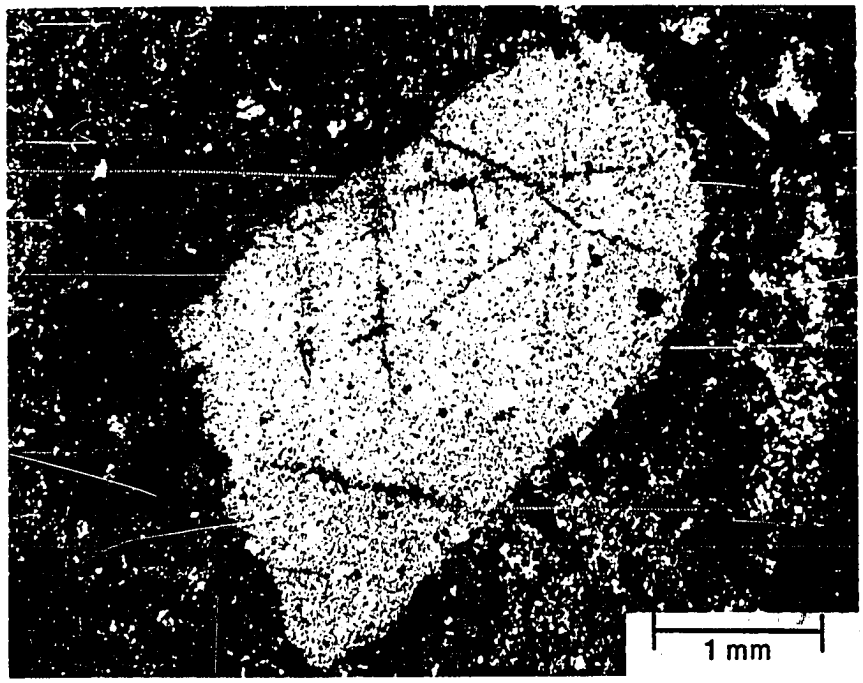

Figure 21. Photomicrograph of relict sandstone pebble in para-amphibolite (sec. 2, T.49N., R.9E.). Polarized light.

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AMPHIBOLITES OF UNDETERMINED ORIGIN

For about 25% of the amphibolites there are no diagnostic geological, mineralogical,or textural criteria that can be applied to establish their ancestry. They occur throughout the area, but appear to have no particular affinity for either the recognized ortho- or para-amphibolite units.

SUMMARY

Assignment of the origin of the amphibolites of the poorly-foliated metamorphic group is possible because relict structures and textures have been preserved in these relatively undeformed rocks. Both ortho- and para-amphibolites are present; the former are meta-diabase sills for the most part, whereas the latter are probably meta-morphosed calcareous and dolomitic shales. The percentage of each type is difficult to establish, but approximately 50% are believed to be of igneous parentage and 25% of sedimentary parentage. The origin of the remaining 25% could not be determined.

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PART III - SKARN DEPOSITS

INTRODUCTION

Metalliferous deposits in Precambrian metamorphic rocks have been found in several localities in south-central Colorado (Figure 22). As a result of the detailed examination of a number of these deposits (Bever, 1954; Heinrich and Salotti, 1959; Tweto, 1960; Shappirio, 1962; Boyer, 1963; Salotti, 1965; and Pierce, 1970), it is apparent that they constitute a distinct type of mineralization that can be characterized as follows:

1) they are partly metasomatic in origin;
2) they occur in medium- to high-grade regionally metamorphosed rocks of Precambrian age;
3) they do not occur directly along intrusive contacts, although they may be closely associated with granitic rocks;
4) they typically show evidence of both structural and lithologic control;
5) they contain either copper-zinc or tungsten as ore metals;
6) they commonly appear to have been developed in four distinct stages: a) recrystallization or pegmatoid stage, b) oxide stage, c) sulfide stage, and d) retrograde silicate stage.

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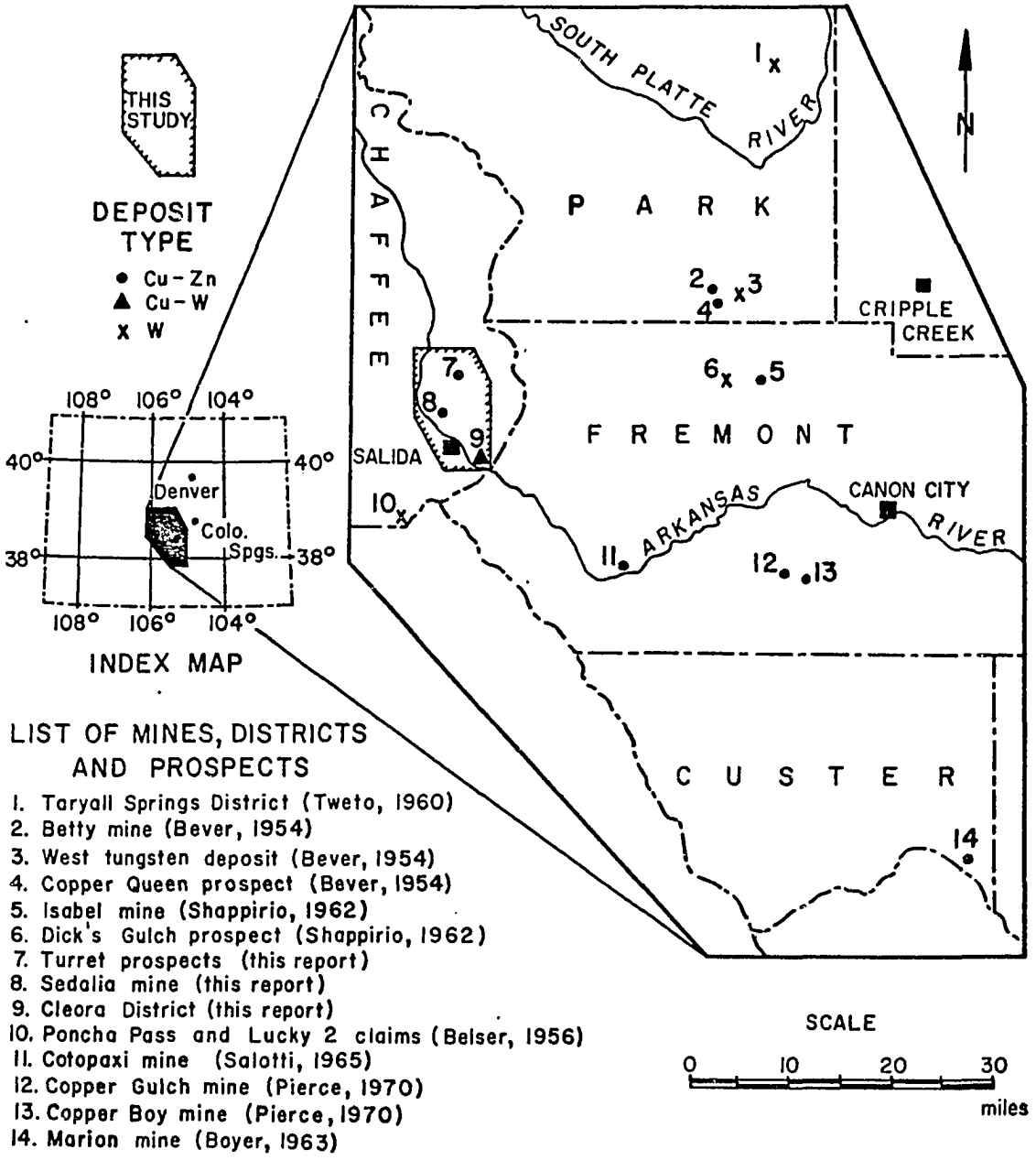

Figure 22. Location map of the Cu-Zn, Cu-W, and W skarn deposits of south-central Colorado (modified from Pierce, 1970).

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The term skarn has been used by Heinrich and Salotti (1959) in reference to these deposits because of their similarity to the classic Precambrian calc-silicate skarn deposits such as Langban and Bastnäs, Sweden. The term skarn is used similarly in this report. Skarns, therefore, are distinguished from tactites, or true contact metamorphic deposits, which are generally younger and most commonly form in previously unmetamorphosed carbonate rocks.

The skarns of south-central Colorado, as noted above, form copper-zinc deposits and tungsten deposits. The more common copper-zinc skarns occur in non-carbonate rocks such as amphibolite, biotite gneiss, sillimanite gneiss, and cordierite gneiss. In contrast, tungsten skarns are characteristically confined to lenses of calc-silicate gneiss.

In the Salida area, copper-zinc skarns are abundant throughout the strongly-foliated group of metamorphic rocks between the Sedalia mine and Turret (Plate I). No deposits of the strictly tungsten type have been found, but the Cleora District, near the Arkansas River in the southern end of the area, contains copper-tungsten skarns in amphibolite.

SEDALIA-TURRET DISTRICT

The Sedalia-Turret District contains dozens of copper-zinc deposits, but only a few have been prospected extensively and only one, at the Sedalia mine (NW $\frac{1}{4}$ sec. 18, T.50N., R.9E.), was ever commercially important.

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SEDALIA MINE

Introduction

The Sedalia copper-zinc deposit is by far the largest and best known of the skarn deposits in the Salida area. The mine workings cover the west side of an 800-foot hill facing the Arkansas River valley (Plate 3). The only published account of the geology and mineralogy of the mine is a brief summary by Lindgren (1908). A number of exploration companies have evaluated the mine in recent years, but their reports were concerned principally with grade and tonnages of ore rather than with the geology and mineralogy of the deposit.

General Geology

Country Rocks

The skarn mineralization is confined to a series of Precambrian rocks that have been regionally metamorphosed to the amphibolite facies. The metamorphic units trend northeast and dip from 40^{o} to 80^{o} southeast. From north to south the main rock units are: 1) fine-grained quartz-feldspar-mica schists $\pm$ andalusite, 2) the skarn rocks, which are mostly recrystallized and metasomatized pelitic metasediments and amphibolites, 3) fine-grained quartz-feldspar-mica schist $\pm$ andalusite (same as Unit 1), and 4) quartzite. The entire series is cut by steeply dipping granitic pegmatite dikes.

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Quartz-Feldspar-Mica Schists (Units 1 and 3)

These units are very similar, with Unit 1 forming the footwall and Unit 3 the hanging wall of the skarn. In outcrop, the rock is medium to light gray, strongly-foliated, and uniformly fine-grained, except for local andalusite-bearing zones that give the rock a "knotty" appearance.

The schists contain essential quartz and biotite. Microcline, oligoclase,and andalusite (as poikiloblasts up to 1 cm in diameter) are locally essential. Muscovite is a ubiquitous accessory mineral, and zircon and magnetite are present in trace quantities. Cordierite porphyroblasts occur adjacent to the skarn unit.

Skarn Rocks (Unit 2)

The rocks of this unit have been affected to varying degrees by recrystallization and metasomatism. Thus, it is commonly difficult to distinguish between primary metamorphic species and later minerals. The pre-skarn parent rock types appear to have been amphibolite or hornblende gneiss and micaceous schists and gneisses. The petrology of the skarn rocks is considered in detail below.

Quartzite (Unit 4)

The quartzite unit lies above Unit 3 and extends for several hundred feet southeast of the mine area. It is a medium brown, dense, fine-grained rock. Present are quartz, microcline, and plagioclase with minor biotite and muscovite.

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Structure

There is no evidence of folding at the Sedalia mine and the only surface indication of faulting is the wedging-out of the skarn unit to the northeast and the local intensification of foliation. Shear and fracture planes are exposed in only a few open cuts, pits, and portals of tunnels. However, Watcher (1969) delineates several major and minor faults on the basis of considerable underground mapping. He recognizes two major faults that bound the skarn unit both to the north and south. The intersection of these faults to the northeast marks the eastern limit of significant mineralization. Both faults dip steeply southeast, and the trace of their intersection plunges steeply northeast. Although the mineralization is confined to the wedge between the faults and is most intense at the surface near the convergence of these faults, Watcher (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.

Other structural intersections have been mineralized at several places in the mine.

The pegmatite dikes that cut the country rocks also appear to cut the skarn unit and have not been visibly mineralized or altered in any way by the skarns. In addition, there is not any apparent offset of the pegmatites by the bounding faults. The age of the pegmatites with

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respect to skarn mineralization is discussed below.

Petrology of the Skarn Rocks

Several rock types are present in the skarn unit. Most are medium- to coarse-grained and granoblastic. Dense quartz-biotite rocks with variable amounts of sillimanite, garnet, andalusite, and cordierite constitute the bulk of the unit. Most of the remaining skarn rocks are amphibole-rich and contain combinations such as actinolite-talc-chlorite; gedrite-garnet-cordierite-quartz; anthophyllite-cordierite-quartz-biotite; tremolite-thulite; and hornblende-epidote-plagioclase-(garnet). In addition, chloritite, generally with garnet and magnetite, occurs locally.

Quartz-Biotite Skarn Rocks

These rocks constitute most of the skarn unit. They have been recrystallized, but mineralization appears to be less extensive than in the amphibolitic rocks. They are dense, dark gray, and poorly-foliated.

The only minerals that are essential in all of the variants of this rock type are fine- to medium-grained quartz and biotite, which together constitute up to 80% of the rock. Coarser garnet (up to 1 cm), andalusite, and sillimanite commonly are present in essential amounts. Andalusite is extremely poikiloblastic with included quartz making up as much as 75% of the individual grains. Garnet is only slightly poikiloblastic and in one thin section was confined to a narrow "veinlet" that cuts the rock.

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Sillimanite normally is fibrolitic and the textural relationships indicate that it replaced both biotite and andalusite. A narrow sillimanite rim around garnet was observed in one thin section (Figure 23). Cordierite was identified as a major phase in two samples by means of x-ray diffraction, but was not present in the rocks examined in thin section.

Accessory minerals are zircon, as inclusions in biotite, and euhedral to anhedral magnetite grains throughout the matrix. Retrograde alteration is minor, being restricted to hematite and chlorite after biotite and hematite after magnetite.

Amphibole-bearing Skarn Rocks

The amphibole-rich skarn rocks are concentrated along the bounding faults particularly near their intersection. In addition, the amount of recrystallization and metasomatism that they have undergone appears to have been much greater than in the quartz-biotite-rich rocks. The various types of amphibole-bearing skarn rocks can be grouped as follows on the basis of the species of amphibole present: 1) anthophyllite-gedrite, 2) actinolite, 3) tremolite, and 4) hornblende.

Anthophyllite/gedrite-bearing rocks

Anthophyllite-gedrite skarn rocks are common. They vary in color from medium greenish-gray to nearly black, are dense, nonfoliated, and medium- to coarse-grained. In addition to the orthoamphiboles, cordierite, quartz, and locally garnet and biotite are essential minerals. Zircon, rutile, gahnite, and an opaque mineral

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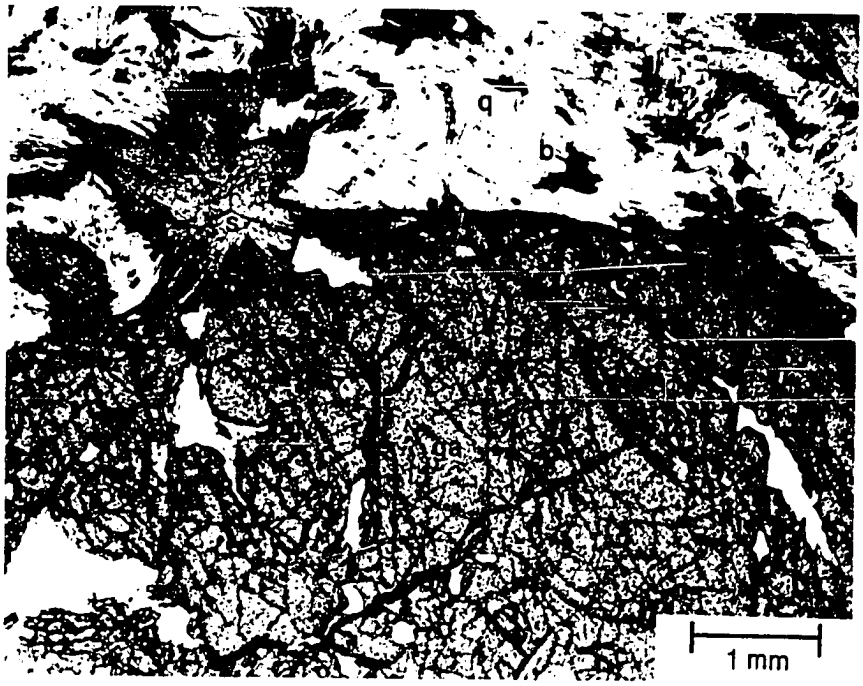

Figure 23. Photomicrograph showing fibrous sillimanite (s) rimming garnet (ga). Groundmass is quartz (q) and biotite (b). From Sedalia mine. Ordinary light.

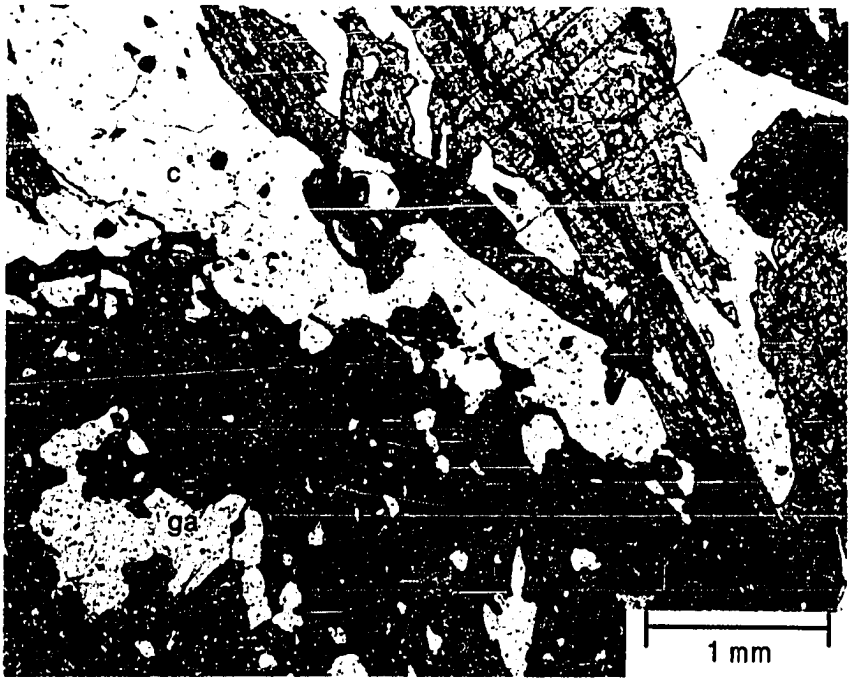

Figure 24. Photomicrograph of garnet (ga), gedrite (ge), and cordierite (c). From Sedalia mine. Ordinary light.

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(magnetite or ilmenite) are the accessories.

Anthophyllite and gedrite do not appear to occur together. Gedrite is present as discrete, randomly oriented blades (< 8 mm long), whereas the anthophyllite forms radiating aggregates (< 1 cm long). The gedrite is highly pleochroic in shades of tan, pale green, and greenish-gray and occurs with coarser, anhedral, poikiloblastic garnet (Figure 24); the anthophyllite is colorless and is associated with biotite, which is only slightly pleochroic in shades of brown. Medium- to coarse-grained cordierite with poikiloblastically included quartz is present in abundance in both associations. Quartz also occurs separately in fine-grained aggregates.

Zircon forms inclusions in biotite, but the other accessory minerals appear to be randomly distributed throughout the rock. Retrograde alteration is confined to chloritization of biotite, anthophyllite, and gedrite.

Actinolite-bearing rocks

These rocks are among the most intensely altered in the mine area. They are particularly abundant near the intersection of the bounding faults. When fresh, the rock is dark green and consists almost entirely of a coarse matte of actinolite blades. Commonly, however, talc has replaced the actinolite to a large degree, and the rock appears pale green or white in outcrop.

In thin section the rock appears as a mass of intergrown actinolite blades and tablets that commonly are longer than 1 cm. Minor

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epidote occurs interstitially and trace sphene, zircon, and apatite also are present. Some alteration of actinolite to talc is visible. In addition, a late-stage veinlet containing chlorite and fluorite cuts the rock and has included actinolite fragments within it. Iron staining along grain boundaries and fractures is prominent.

Tremolite-bearing rocks

A coarse-grained, dense, tremolite-thulite rock crops out along the southern contact of the skarn unit at elevations above 7800 feet. It has a mottled pink and pale green color with tremolite occurring typically as radiating blades up to 2 cm in length. The rock is tabular in shape, with a maximum thickness of about 2 feet.

Tremolite and thulite are the only essential minerals. Sphene, in aggregates as coarse as 3 mm, is a common accessory. Both tremolite and thulite are partly altered to talc.

Hornblende-bearing rocks

A nodular hornblende-epidote rock also crops out along the same fault contact as the tremolite-thulite rock, but occurs within the quartz-feldspar-mica schist. The nodules, which are as much as a foot in diameter, appear to be restricted to a zone only a few feet wide. They vary from nearly spherical to highly lensoid in shape and in places appear to have undergone considerable plastic deformation. In outcrop the nodules appear well-zoned (Figure 25), with an interior consisting principally of epidote. Hornblende constitutes the cores of some nodules and disseminated, fine-grained garnet was found in one specimen.

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Surrounding the core of the nodule there normally are two to four concentric zones rich in uniformly fine- to medium-grained epidote, hornblende, or quartz-plagioclase. Grading into the country rock is a zone containing medium-grained acicular hornblende in a quartz-plagioclase matrix. These elongated hornblende grains are oriented in "flow" patterns around the nodule.

The only minerals present in nodules examined in thin section are epidote, hornblende, quartz, plagioclase, and very minor biotite. The interior contains fine-grained aggregates of either epidote-quartz or hornblende-quartz, but rarely all three minerals. The outer zones are rich in plagioclase, but contain only minor epidote, suggesting that the epidote has formed at the expense of plagioclase. Hornblende is poikiloblastic and coarser grained (up to 5 mm) in the outer zones than in the core. Biotite is rare, occurring in the outer zones in association with hornblende.

The secondary origin of these nodules is indicated by the formation of epidote at the expense of plagioclase. They must have been formed before the end of metamorphism, as many of the nodules have been deformed plastically to a high degree and the surrounding metamorphic minerals "flow" around them. The spatial association of the nodules with the southern bounding fault suggests that they formed during or after faulting. Fragments of country rock produced at the onset of faulting when the rocks were still brittle may have been the nuclei about which the nodules formed, and movement along the fault

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zone during metamorphism could have been responsible for the deformation of the nodules.

Chloritite Rock

A chlorite body, about 25 x 125 feet in size, crops out in the central part of the skarn unit. The rock consists almost entirely of medium- to coarse-grained chlorite (< 2 cm) containing euhedra of magnetite (< 1 cm) and garnet (< 12 cm). The garnet, which is almandite (Penfield and Spring, 1896), has been largely chloritized and constitutes locally as much as 60% of the schist. Magnetite is not present in quantities greater than 10%. The garnet from this unit has made the Sedalia mine a famous collecting locality for many years.

Copper-Zinc Mineralization

Primary sulfide minerals are not preserved in the skarn rocks at the surface. The only evidence of mineralization is the distinctive and widespread occurrence of copper staining, principally malachite and chrysocolla, particularly along fractures and cracks in the talc-actinolite rocks. According to old mine reports, the oxidized zone extends to a depth of about 300 feet, below which sulfides predominate.

Sulfide mineralogy was determined by polished section examination of samples collected from the dumps. Owing to the limited number of specimens found containing primary ore minerals, it is probable that some species were missed.

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Ore minerals occur as disseminations in both the quartz-rich and amphibole-rich skarn rocks. In all cases the sulfides appear to be later than the skarn silicates, as they are confined to interstitial areas and locally fill cracks and fractures in the gangue minerals. Identified are chalcopyrite, pyrite, marcasite, sphalerite, magnetite-ilmenite, and covellite.

Textural relationships among the primary sulfides suggest that chalcopyrite, pyrite, and most sphalerite formed contemporaneously. Marcasite appears to have formed somewhat later at the expense of chalcopyrite. Small veinlets of sphalerite cut the marcasite and represent either a later period of zinc deposition or the preservation of early sphalerite during the replacement of chalcopyrite by marcasite. Covellite, a supergene mineral, replaces chalcopyrite along grain margins and fractures. Gahnite and rutile (?), where present, are disseminated throughout the gangue. Magnetite and associated ilmenite form euhedra (< 2 mm) in one polished section of mineralized anthophyllite rock. Associated chalcopyrite and pyrite are clearly younger as they fill fractures in and form rims around the magnetite (Figure 26). Galena is reported (Lindgren, 1908) to occur in minor quantities, but no mention is made of its association with other minerals. It was not found in any samples examined in this study.

It appears that the original skarn mineralization, including sulfide deposition, was controlled both by structure (the bounding faults) and lithology (amphibolites and pelitic metasediments). In addition,

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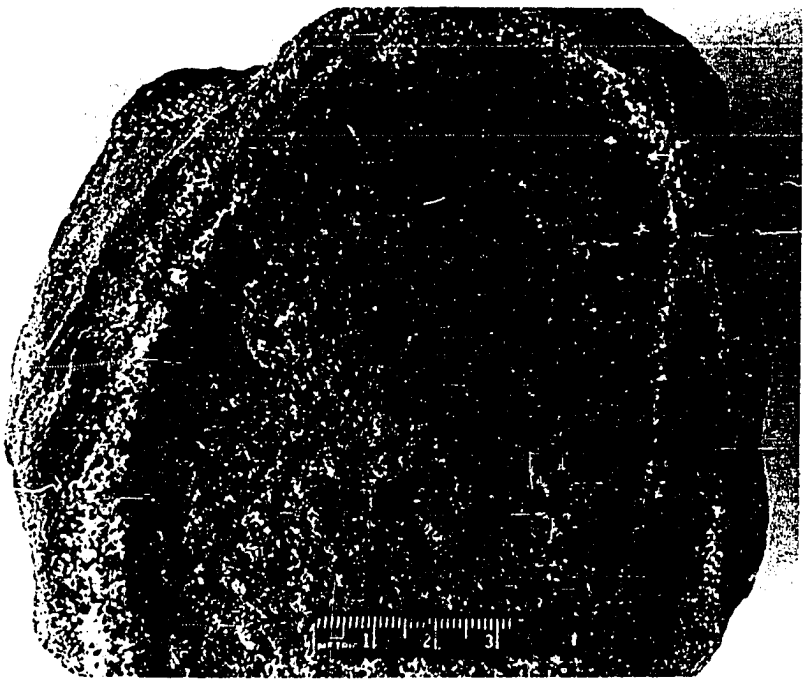

Figure 25. Epidote-hornblende nodule from the Sedalia mine.

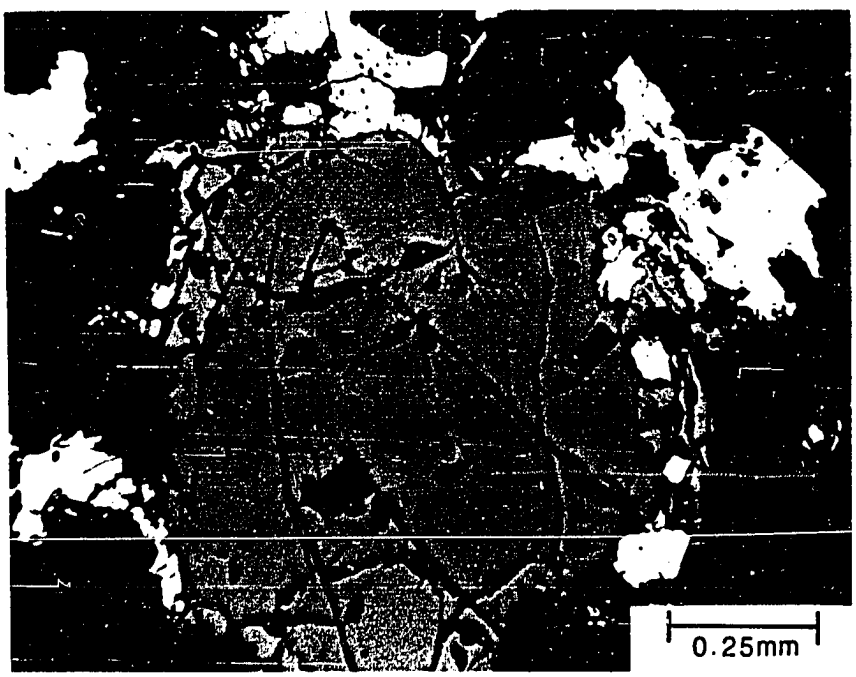

Figure 26. Photomicrograph of chalcopyrite (white) rimming magnetite (gray). Sample from Sedalia mine. Reflected light.

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structure and lithology played a major role in the formation of the secondary ores, from which virtually all production has come. The highest grade ore was concentrated by supergene processes at the intersections of faults and fractures, particularly within the amphibolitic rocks, which are most susceptible to weathering.

TURRET SKARN DEPOSIT

Introduction

Numerous prospect pits, trenches, and short adits have been developed in a Cu-Zn skarn deposit located about $\frac{1}{4}$ mile south of Turret (SE $\frac{1}{4}$ sec. 29, T.51N., R.9E. and NE $\frac{1}{4}$ sec. 32, T.51N., R.9E.). The skarn rocks crop out over an area of about 700 x 300 feet along the crest of a NW-trending hill (Plate 4). Country rocks consist of mica schists and gneisses, amphibolites, and quartz-feldspar gneisses and granitic pegmatite. The contact with the quartz monzonite, which crops out 100-200 yards east of the deposit, trends north-northwest. Metamorphic foliation parallels the contact and dips from 30^{o} to 80^{o} northeast. Minor pyrite and chalcopyrite are the only sulfide minerals found at the Turret skarn deposit, but copper carbonate staining is evident along most of the shear zones exposed in the workings. As at the Sedalia mine, mineralization appears to be controlled both by faults and the type of country rock. All of the major workings are located on shear zones that, in general, conform to the foliation and are developed in amphibolitic rocks or altered amphibolite. In most respects the

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mineralogy and petrology of the Turret and Sedalia skarns are similar.

Petrology of the Skarn Rocks

Quartz-Cordierite-Garnet Skarn Rocks

Within the micaceous schists and gneisses, skarn rocks containing quartz, cordierite, biotite, and garnet as major species have formed. For the most part these rocks are medium to dark gray, poorly-foliated, dense, and unaltered. Coarse garnet (up to 2 cm) occurs in a groundmass of fine-grained anhedral quartz, cordierite, and biotite. Quartz and minor biotite and ilmenite are poikiloblastically included in the garnet. Ilmenite, gahnite, and apatite are disseminated throughout the matrix as accessories.

The only extensive alteration is the pinitization of cordierate. A small percentage of biotite has been chloritized and ilmenite has been partially altered to leucoxene.

Anthophyllite/Gedrite-Cordierite Skarn Rocks

Lenses of ortho-amphibole-cordierite rocks up to 120 feet long occur in several places in the skarn. They are medium- to coarse-grained, normally poorly-foliated and range in composition from nearly 100% amphibole to 100% cordierite. As at the Sedalia mine, the two amphiboles do not occur together. Both amphiboles are bladed in form, but the gedrite is strongly pleochroic, whereas the anthophyllite is colorless. Cordierite, generally as anhedral grains less than 6 mm in size, is pinitized along grain boundaries and cracks. Slightly

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poikiloblastic garnet (< 1.5 cm) is associated with gedrite, but apparently not with the anthophyllite. Accessory minerals are ilmenite, allanite, gahnite, and apatite. Pinitization of cordierite ranges from minor to nearly complete and chloritization commonly is extensive.

Chloritite Skarn Rocks

A large percentage of the skarn rocks are chloritites which form irregular lensoid bodies up to 250 feet long and 60 feet wide. Medium- to coarse-grained chlorite and rarely corundum, tourmaline, and gahnite are the essential species. Zircon, rutile, and hoegbomite are the accessory minerals. The tourmaline occurs as black, trigonal prisms up to 4 cm long (Figure 27) and the corundum as gray, slightly barrel-shaped hexagonal crystals up to 3 cm long (Figure 28). Both are confined to the eastern margin of the large chloritite body in the southeastern end of the skarn. These minerals must have formed at considerably higher temperatures than the chlorite, either prior to mineralization or during an early skarn stage in an area particularly rich in mineralizing fluids. The chloritite grades into the amphibole-bearing skarn rocks in many places and is believed to have been formed by the retrograde alteration of the latter.

INDEPENDENCE MINE

Located $\frac{1}{2}$ mile west-northwest of Turret (NE $\frac{1}{4}$, NW $\frac{1}{4}$ sec. 32, T.51N., R.9E.), the Independence mine consists of several shafts in a copper-zinc skarn. Dumps up to 25 feet high are present, indicating

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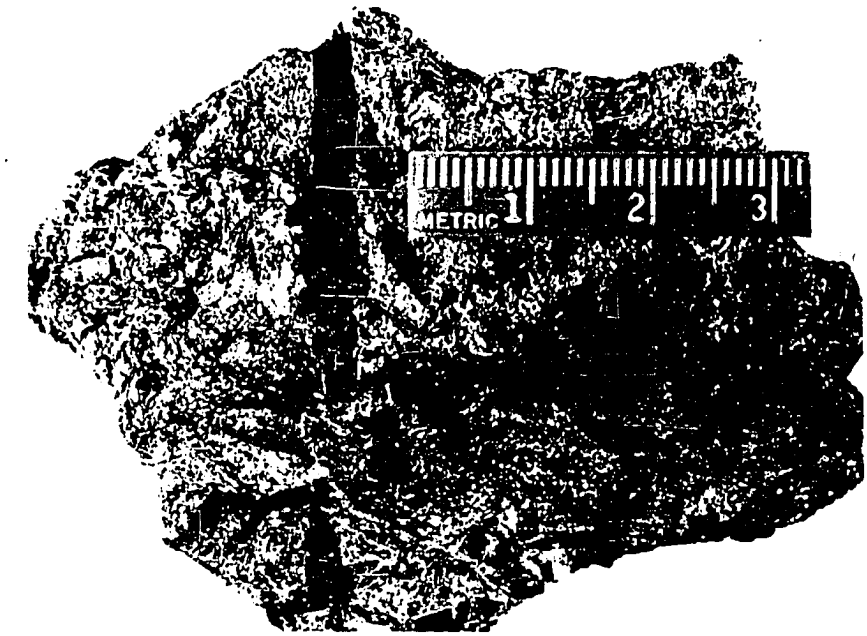

Figure 27. Tourmaline crystals (black) in chloritite skarn rock from Turret deposit.

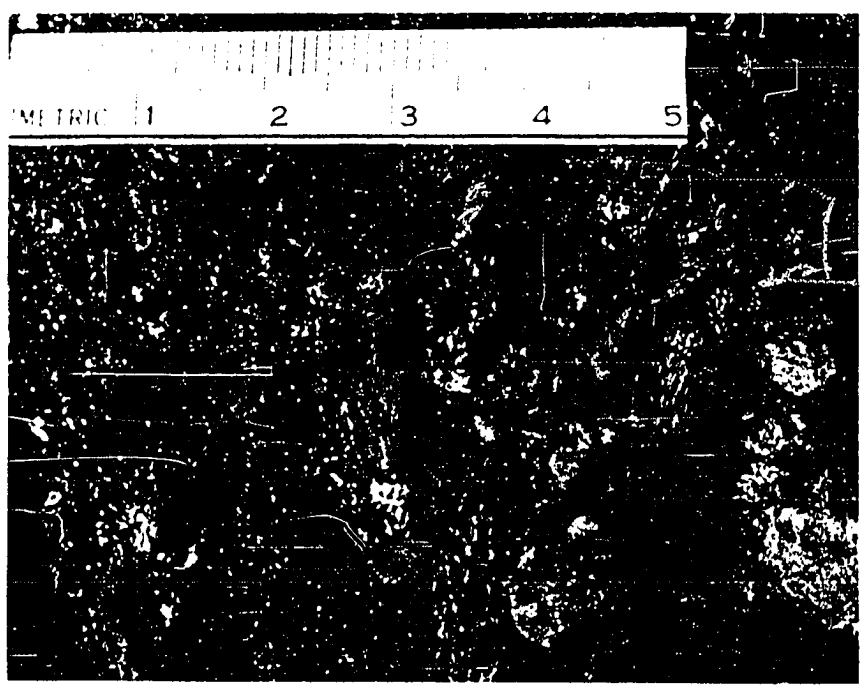

Figure 28. Corundum crystals in chloritite skarn rock from Turret deposit.

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considerable underground working of the deposit. The country rocks are principally mica schists and gneisses with minor granitic, pegmatitic, and amphibolitic units. Foliation, which is strongly developed, trends N 70°W and dips 60° NE.

The skarn is localized along a major fault, which trends N 35°W and dips about 45°NE. The rocks within and immediately adjacent to the fault have been recrystallized and metasomatized over a maximum width of about 25 feet. The workings extend for approximately 400 feet along strike. The main fault, which is exposed in a 20-foot wide pit, is characterized by intense shearing, breakage, and contortion of the rocks and conspicuous copper carbonate staining.

Coarse-grained minerals, formed by recrystallization of the country rocks, include garnet, biotite, quartz, cordierite, and actinolite. Most of the minerals that are of probable metasomatic origin (molybdenite, magnetite, pyrite, chalcopyrite and gahnite) occur principally in the highly altered amphibole skarn rocks.

A brief description of the Independence mine is given by Lindgren (1908, p. 166) who states:

> ...The schists here consist of a coarse brown "augen" gneiss; there is also some quartz-biotite-garnet schist like that at the Sedalia camp. Streaks of very coarse amphibolite embedded in this gneiss or schist contain partly oxidized chalcopyrite. The explorations have been carried down 200 feet along the dip. The mine was not entered, but the owner, Mr. P. S. Plympton, states that the width of the ore body is 30 feet, with a richer streak 5 feet wide. Molybdenite is stated to occur in this deposit. 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.

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ACE HIGH AND JACKPOT PROSPECT

Van Alstine (1969) examined the Ace High and Jackpot Prospect (NW $\frac{1}{4}$ sec. 32, T.51N., R.9E.) which is about a mile southwest of Turret. The following account is a summary of Van Alstine's description.

The deposit consists of a narrow quartz-chalcopyrite vein in a metasomatized amphibolite that has been localized between two north-trending faults. The vein dips 85°W, and the foliation of the unaltered hornblende gneiss country rock dips gently toward the east. Workings consist of an incline and a shaft with underground development of unknown extent.

The hornblende gneiss has been coarsely recrystallized and metasomatized, now containing actinolite, anthophyllite, apatite, biotite, calcite, chlorite, cummingtonite, gahnite, phlogopite, quartz, sphene, talc, tremolite, and zoisite. Locally, magnetite and chalcopyrite occur as disseminations or fracture fillings in the skarn rocks. Magnetite is altered to limonite and chalcopyrite to malachite and minor chalcocite, azurite, chrysocolla, brochantite, and chalcanthite. The quartz–chalcopyrite veinlets have been "brecciated, cut by malachite veinlets, and then coated by botryoidal clusters of calcite and opal."

OTHER DEPOSITS

Dozens of smaller copper-zinc skarn deposits are located throughout the strongly-foliated group of metamorphic rocks. The great

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majority are localized along faults and within rocks of amphibolitic composition. Country rocks typically are coarsely recrystallized and mineralization occurs both as disseminations in the skarn rocks and within narrow quartz veins. Chalcopyrite and pyrite commonly are present, but in many prospects, the only evidence of mineralization is copper carbonate staining. Brecciation of the veinlets, indicating post-ore faulting, is common. Relatively large prospects, other than those discussed above, include a shaft at least 200 feet deep about 3/4 mile south-southeast of Turret (west-central sec. 33, T.51N., R.9E.), several caved shafts about $1\frac{1}{2}$ miles west of the fork in the Longs Gulch road (central sec. 6, T.50N., R.9E.) and a north-dipping inclined shaft, $\frac{1}{2}$ mile southwest of the same fork in the Longs Gulch road (NE $\frac{1}{4}$ sec. 8, T.50N., R.9E.).

MINERALOGY AND PARAGENESIS

The minerals found in the copper-zinc skarns are listed in Table 8. Textural evidence indicates that there were four main stages in their development (Table 9):

1) Early silicate-oxide stage
2) Sulfide stage
3) Retrograde silicate stage
4) Supergene stage

In contrast to other skarn deposits of south-central Colorado, a discrete oxide stage was not recognizable, most of the oxides being

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Table 8. Mineralogy of the Cu-Zn Skarns.

Mineral	Sedalia mine	Turret skarn prospects	Independence mine	Ace High and Jackpot prospect
Actinolite	x		x	x
Allanite		x		
Andalusite	x			
Anthophyllite-gedrite	x	x		x
Apatite	x	x		x*
Biotite	x	x	x	x
Calcite	x	x		x
Chalcopyrite	x	x	x	x
Chlorite	x	x	x	x
Cordierite	x	x	x	
Corundum	x*	x		
Cummingtonite				x*
Epidote	x			
Gahnite	x	x	x	x
Galena	x*			
Garnet (Almandite)	x	x	x	
Hematite	x			
Hoegbomite		x		
Hornblende	x			
Ilmenite	x	x		
Magnetite	x		x	x*
Marcasite	x			
Molybdenite			x	
Phlogopite				x*
Pyrite	x	x	x	
Quartz	x	x	x	x
Rutite	x	x		
Sericite	x	x		
Sillimanite	x	x	x	
Sphalerite	x			
Sphene	x			x*
Talc	x			x
Thulite	x			
Tourmaline		x		
Tremolite	x		x	x
Zircon	x	x		
Zoisite				x*

x - Identified in this study
x* - Reported from previous studies

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intimately associated with the early silicate minerals. This is, however, the same paragenesis recognized at the Cotopaxi mine by Salotti (1965).

In order to determine what the original, pre-skarn, metamorphic rocks were, it is helpful to consider the two principal varieties of skarn rocks: those rich in quartz and containing variable and locally abundant amounts of biotite, andalusite (sillimanite), almandite, and cordierite; and those rich in magnesium and aluminum minerals such as anthophyllite-gedrite, cordierite, chlorite, and gahnite. The quartz-rich rocks appear to have been originally pelitic metasedimentary rocks that have undergone considerable recrystallization, but comparatively little metasomatism. The Mg-Al-rich rocks, on the other hand, pose a more difficult problem, as they have no common igneous or sedimentary analogues that could have served as parent rocks. Furthermore, the absence of rocks of this composition everywhere in the area except in association with the skarns, makes it highly unlikely that a compositionally equivalent progenitor ever existed. The problem of the origin of cordierite-anthophyllite rocks is considered by Grant (1968, p. 908) who states:

> The origin of cordierite-anthophyllite-bearing rocks is commonly difficult to explain in that they do not have chemical counterparts among common sedimentary or igneous rocks. Hence, mechanisms which, in particular, may concentrate Mg and Fe, have been proposed as important in their formation from a variety of protoliths.

The methods mentioned by Grant are metasomatism, leaching of lime

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and alkalis, weathering prior to metamorphism, and structural movements during early stages of metamorphism. Grant proposes that in high-grade regional terranes, this assemblage can be generated by partial melting and filter pressing of various types of parent materials. Which of these processes, if any, has produced the Mg-Al-rich skarn rocks cannot be determined, but it is apparent that they have not formed by isochemical metamorphism. Within the country rocks surrounding the skarns, amphibolites and hornblende gneisses are common, locally grading into the skarn rocks, indicating that they may have been the unaltered parents. If this is the case, calcium and sodium must have been removed from the amphibolites.

Early Silicate-Oxide Stage

The minerals formed in the quartz-rich rocks during this stage are difficult to distinguish from primary metamorphic minerals. For the most part the rocks appear to have undergone recrystallization with only minor metasomatism to form gahnite and possibly other accessory species. Garnet commonly formed non- to slightly-poikiloblastic grains and locally is confined to veinlets or thin lenses. At the Sedalia mine, sillimanite replaces poikiloblastic andalusite and locally is "plastered" around garnet grains. Quartz, biotite, and cordierite, where present, form an anhedral granular matrix, slightly coarser and more poorly-foliated than in adjacent non-skarn rocks. The accessory minerals, gahnite, magnetite, ilmenite, and apatite are disseminated throughout the

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rocks, and appear to be contemporaneous with the silicate minerals.

Within the amphibole-rich units there is evidence that the early silicate-oxide stage extended over a wide temperature interval. The assemblages, cordierite-anthophyllite, cordierite-almandite, and almandite-sillimanite are restricted to upper amphibolite and higher grade metamorphic rocks (Grant, 1968; Wynne-Edwards, 1963), whereas the tremolite-thulite association and the actinolite units form at lower temperatures. Oxide minerals such as gahnite, magnetite, ilmenite, sphene,and rutile are more abundant than in the quartz-rich skarn rocks, but they occur similarly, generally as disseminated accessories.

Sulfide Stage

The primary sulfide minerals typically are present as disseminations throughout the silicate skarn rocks, filling cracks and fractures in garnet, anthophyllite/gedrite, and magnetite as well as along grain boundaries of the gangue minerals. Sphalerite also forms massive veinlets and veins up to 8 feet thick (Watcher, 1969). These textural relationships indicate that the sulfides were deposited at a later time. Within the sulfide stage, however, paragenetic relationships are not well defined. Chalcopyrite and pyrite appear to be contemporaneous. Sphalerite (containing exolved chalcopyrite) locally fills fractures in chalcopyrite indicating that, at least in part, it is younger. Galena has been reported from the Sedalia mine (Lindgren, 1908), but nothing is known of its paragenesis. Molybdenite occurs disseminated in

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Table 9. Generalized paragenesis of the Cu-Zn skarns of the Salida area.

Early silicate-oxide stage (may contain original metamorphic minerals	Sulfide stage	Retrograde silicate stage	Supergene stage
Actinolite	Chalcopyrite	Calcite(?)	Chalcocite(?)
Allanite	Galena	Chlorite	Covellite
Anthophyllite/gedrite	Marcasite(?)	Fluorite	
Apatite	Molybdenite	Muscovite (Sericite)	
Biotite	Pyrite		
Cordierite	Quartz	Quartz(?)	
Corundum	Sphalerite	Talc	
Cummingtonite			
Epidote			
Gahnite			
Garnet			
Hematite(?)			
Hoegbomite			
Hornblende			
Ilmenite			
Magnetite			
Phlogopite			
Quartz			
Rutile			
Sillimanite			
Sphene			
Thulite			
Tourmaline			
Tremolite			
Zircon			
Zoisite			

actinolite-rich skarn rocks from the Independence mine, but was not found in polished section. In a few deposits, narrow sulfide-bearing quartz veinlets cut the skarn rocks. The presence of pyrite and chalcopyrite and the absence of any minerals characteristic of the early silicate-oxide stage suggests that these veins were formed during the main period of sulfide deposition. Marcasite occurs in close association with the

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other sulfides, generally as granular aggregates, but its paragenesis is not certain.

It is not known whether the sulfides were present during the early silicate-oxide stage or were introduced during a separate hydrothermal event. The latter case seems unlikely because of the close spatial association of the sulfides with the skarn silicates. If the sulfides were introduced independently they should occur along any favorable structure in the strongly-foliated metamorphic group, rather than only in the skarns. However, with the exception of sphalerite, which could have formed from early gahnite, there is no evidence to suggest where the metals were concentrated if they were present during the early silicate-oxide stage.

Retrograde Silicate Stage

The development of minerals such as chlorite, talc, and sericite by retrograde alteration of the early silicates is well established, as all stages in the alteration process are clearly represented in both thin section and hand specimen. Field relationships at the Turret deposit suggest that the chloritite bodies formed at the expense of amphibolite skarn rocks. The relationship between the retrograde and sulfide stages, however, is not so clear. Because no sulfides have been found in rocks that have undergone extensive retrograde alteration, it is likely that the sulfides were deposited prior to the retrograde stage and were removed during subsequent retrograde alteration. A post-

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retrograde age for the sulfides would require that they be selectively deposited in the unaltered skarn silicates and not in the retrograde skarn rocks, a restriction that is unlikely.

Supergene Alteration

Covellite and possibly chalcocite occur as supergene alterations of chalcopyrite at the Sedalia mine. Replacement textures are well developed, from the initial formation of the supergene minerals along grain boundaries and cracks to the complete elimination of chalcopyrite. The distribution of these supergene sulfides throughout the mine is not known, but Watcher states that they are minor.

Most of the copper minerals that constituted the ore at the Sedalia mine are late oxidation products of weathering, malachite, azurite, and chrysocolla. The azurite and chrysocolla predominate in the upper 250 feet of the ore body, often as heavy masses, veins, and impregnations, whereas malachite is the dominant oxidation product at depth (Watcher, 1969). In most prospects throughout the area, copper staining is the only evidence of metallic mineralization.

TEMPERATURE AND PRESSURE OF FORMATION

Formation of the copper-zinc skarns took place over a wide range of temperatures, but the total pressure was fairly constant during the early silicate-oxide stage and may not have changed significantly until the supergene stage. Figure 29 is a schematic representation of the variation in temperature during the early silicate-oxide stage. The

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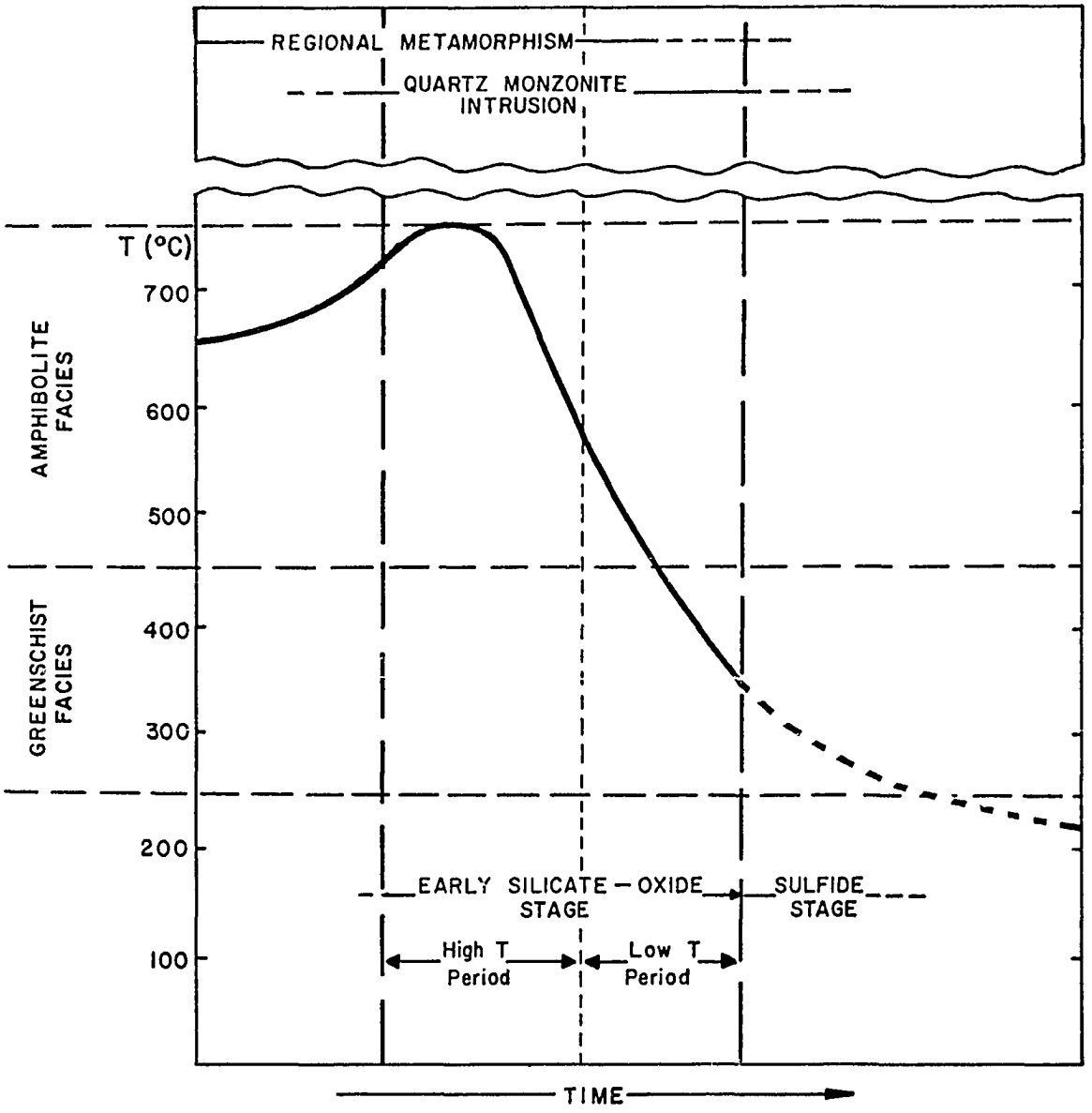

Figure 29. Schematic representation of the variation in temperature with time during the early silicate-oxide stage of copper-zinc mineralization. Total pressure is constant at about 5 kb. High T period characterized by sillimanite replacing andalusite, cordierite-anthophyllite, cordierite-almandite, and sillimanite-almandite. Low T period characterized by tremolite, actinolite, thulite, and epidote.

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assemblages sillimanite replacing andalusite, cordierite-almandite, and almandite-sillimanite represent the highest temperature skarn minerals. They were formed at about 600-750°C, which is within the upper amphibolite facies. Total pressures probably were the same as in the surrounding metamorphic rocks, about 4.5-5.5 kb. The later period of this stage, represented by tremolite, actinolite, thulite, and epidote, took place at considerably lower temperatures in the lower amphibolite to greenschist facies, probably between 300-500°C.

The assemblages present in the remaining sulfide, retrograde silicate, and supergene stages suggest that temperatures continued to decline during these later stages of mineralization. There is not enough information available, however, to establish the precise temperatures. Exsolution blebs of chalcopyrite in sphalerite, which are common at the Sedalia mine, have been considered to indicate a high temperature of crystallization. However, Kelly and Turneaure (1970) point out that there is considerable discrepancy in the reported temperatures at which exsolution takes place. For this reason, no conclusions regarding the temperature of sulfide deposition are made on the basis of this texture.

RELATIONSHIP TO THE QUARTZ MONZONITE

No direct connection has been found to link genetically the copper-zinc skarns to the quartz monzonite, but two observations strongly suggest that the intrusive played at least an indirect role in the development of the skarns. The first is the spatial association of the skarns

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with the quartz monzonite. They all are confined to the strongly-foliated group of metamorphic rocks which occurs within three miles of the quartz monzonite contact. Moreover, the local increase in metamorphic grade itself is considered to have been produced either by the intrusive or by the same thermal event that was responsible for the emplacement of the intrusive. The second observation is that the temperatures and pressures of formation of the early silicate-oxide skarn minerals closely approximate the grade of metamorphism in the surrounding country rocks, indicating that skarn formation was initiated during the peak of metamorphism, and therefore, during quartz monzonite intrusion. It is not possible to say whether the quartz monzonite actually provided any material for skarn development or merely the heat necessary to allow mobilization of the needed constituents from the country rocks.

The close temporal association between the early skarn stage and intrusion causes a problem with respect to the timing of the later skarn stages. At the Sedalia mine granitic pegmatites, which are related to the quartz monzonite, reportedly cut the deposit. The pegmatites were formed late in the intrusive-metamorphic development of the area, as indicated by the fact that they transect the metamorphic fabric, are not foliated, and generally have not been deformed. There is no evidence either of alteration of the skarn rocks by the pegmatites or of skarn mineralization within the pegmatites (with the possible exception of the presence of accessory pyrite). If the previous reports are correct, and the pegmatites are younger than the skarn mineralization, there

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must have been a very rapid drop in regional metamorphic temperatures following intrusion of the quartz monzonite, as the sulfide and retrograde minerals probably were deposited at temperatures considerably below 400°C. The only other possibility is that the pegmatites were intruded some time during skarn development, but were not visibly affected by subsequent skarn stages.

CLEORA DISTRICT

GEOLOGY

The Cleora District, located on the Arkansas River in the southern end of the area, contains several small skarn deposits that have been prospected for copper and tungsten. The amphibolite country rock forms a nearly horizontal unit several hundred feet thick in the poorly-foliated group of metamorphic rocks.

Moderate- to steeply-dipping fractures trending northeast to east have localized the mineralization, which consists of fracture fillings and marginal recrystallization of the amphibolite country rock. Individual veins rarely exceed 200 feet in length or 3 feet in width, but there has been widespread scapolitization of the amphibolite throughout the area. Belser (1956) and Tweto (1960) briefly describe several of the mines in the area.

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MINERALOGY

Two mineralogical associations are recognized in the deposits. The most widespread association, characterized by scapolite and sulfide minerals, displays a distinctly developed lateral zonation with respect to the veins (Figure 30). The zones are the 1) vein core, 2) vein margin, 3) selvage, 4) scapolitized amphibolite, and 5) unaltered amphibolite (Table 10). The vein core, for the most part, represents the actual fracture filling and the remaining zones contain predominantly recrystallized country rocks, introduced material becoming progressively less abundant away from the core. The second association, characterized by grossularite, vesuvianite, and scheelite, was found only in specimens from the dumps of the Stockton mine. Its relationship to the zonation of the district, therefore, is uncertain. One specimen, however, included a contact with coarse vein core (?) quartz, suggesting that the assemblage is a part of the vein margin zone. The zonation is discussed in greater detail following the description of the individual minerals.

a) Hornblende: Hornblende, an essential mineral in the amphibolite, is also abundant in the scapolitized amphibolite and selvage. Grain size increases from less than 5 mm in the country rock to about 1.5 cm in the selvage zone.

b) Plagioclase: The plagioclase of the country rock appears to have been the source material for scapolite. Relicts are present in the

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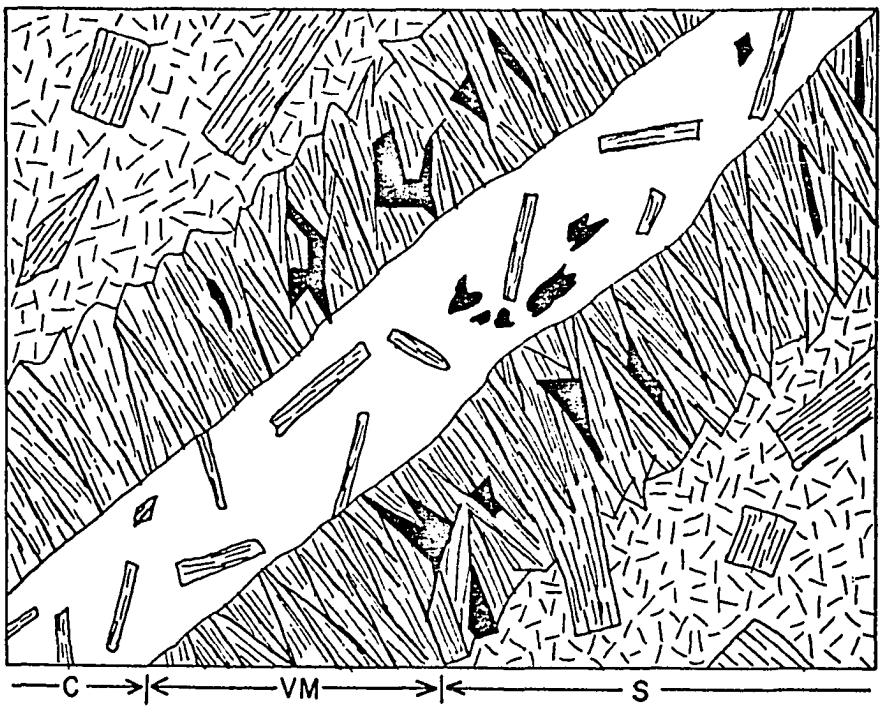

Figure 30. Diagrammatic representation of the zonation at the Cleora District. Core (C) contains quartz, calcite, and minor scapolite (laths) and sulfides (black). Vein margin (VM) contains scapolite and sulfides. Selvage (S) contains scapolite euhedra in matrix of hornblende and biotite.

Figure 31. Scapolitized amphibolite from the Cleora District.

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Table 10. Mineral zonation at the Cleora District.

Mineral	Association		Zone				
	Scapolite-Sulfide	Grossularite-Vesuvianite	1 Vein Core	2 Vein Margin	3 Selvage	4 Scapolitized Amphibolite	5 Unaltered Amphibolite
Chlorite	(x)		(x)				
Quartz	x	x	x	x	(x)		
Ilmenite	(x)			(x)			
Vesuvianite		x		x			
Grossularite		x		x			
Scheelite	(x)	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

scapolitized amphibolite, but do not occur within the selvage or the vein itself.

c) Biotite: Biotite, a fine-grained accessory in the country rock, becomes abundant in the scapolitized amphibolite, selvage, and vein margins. It generally is fine- to medium-grained in the outer zones and becomes coarser (up to 1 cm) toward the vein.

d) Scapolite: Minor scapolite is a widespread alteration product of plagioclase throughout the amphibolite country rock. Near the veins it becomes abundant, forming medium- to coarse-grained euhedra in the scapolitized amphibolite zone. Still closer to the veins, it becomes coarser and more elongated in form, attaining lengths in excess of 5 cm in the vein core and vein margin. Based on the average refractive index method of Shaw (1960) the scapolite has a composition of 50% meionite, containing, therefore, roughly equal amounts of calcium and sodium. This is compatible with its formation by recrystallization of the plagioclase in the amphibolite; as the composition of the plagioclase is about An_{50}.

e) Epidote: Epidote is an accessory mineral in the amphibolite. It becomes somewhat more abundant in the skarn, but never exceeds about 15%. The typical occurrence is as anhedral grains in both the scapolite-sulfide and grossularite-vesuvianite-scheelite associations. Locally, it forms late-stage fracture fillings.

f) Diopside: Diopside, as medium- to coarse-grained aggregates, occurs with the grossularite-vesuvianite-scheelite association in amounts

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up to about 10%.

g) Sphene: Euhedral sphene crystals up to 7 mm long were found in one specimen from the vein margin zone in association with scapolite and biotite.

h) Apatite: In a few places, euhedral green apatite crystals as much as 1 cm in diameter were found in the vein margin and selvage zones intergrown with calcite, scapolite, and biotite.

i) Calcite: Calcite is common in the vein margins, but decreases in abundance both toward and away from the vein. It is an accessory mineral in the scapolitized amphibolite and selvage zones. In the vein margins it forms coarse-grained masses several centimeters long and commonly is the matrix for scapolite, quartz, and biotite. Calcite also forms as a late mineral, filling intergranular spaces and fractures.

j & k) Pyrite and chalcopyrite: These minerals are everywhere closely associated as disseminations in the selvage, vein margin, and core zones. They are particularly abundant in the vein margins where they fill the spaces between scapolite crystals and locally constitute as much as 25% of some specimens. Pyrite rarely forms euhedra (1-3 mm). No pyrite or chalcopyrite has been found in the grossularite-vesuvianite-scheelite association.

l) Scheelite: With the exception of one specimen of scheelite with scapolite and hornblende from the selvage zone, scheelite has only been found in the grossularite-vesuvianite-scheelite association. Other minerals that occur intergrown with the scheelite are diopside, quartz,

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calcite, and epidote. Grain size ranges from less than 1 mm to 1 cm. The distinctly yellow fluorescence of the scheelite indicates that it contains considerable powellite (Tweto, 1960).

m) Grossularite: Orange-red grossularite is the most abundant mineral in the grossularite-vesuvianite-scheelite association. The skarn rock formed by this assemblage contains numerous vugs that are lined with euhedra of garnet and vesuvianite.

n) Vesuvianite: Vesuvianite is intergrown with the other minerals of the grossularite-vesuvianite-scheelite association. Grains normally are anhedral, but euhedra up to 3 mm long line cavities in the rock.

o) Ilmenite: Ilmenite is a rare constituent of the vein margin zone. It occurs as subhedral crystals up to 5 mm long associated with scapolite and biotite.

p) Quartz: Quartz is the main mineral of the vein core, becoming less abundant in the vein margins and uncommon in the selvage. It typically is white and massive, and most closely associated with scapolite, calcite, grossularite, scheelite, and epidote. The sulfide minerals are not commonly found in contact with quartz. In a few places the quartz appears to fill in around coarse scapolite euhedra.

q) Chlorite: Strongly pleochroic chlorite, possibly an alteration product of biotite, is a rare core mineral, filling fractures and spaces between scapolite grains.

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ZONATION

Core

The vein core, which normally is less than a foot wide, consists principally of massive quartz and coarse euhedral scapolite. Calcite, chlorite, and sulfide minerals are subordinate. Post-depositional movement along fractures has brecciated the core zone locally. Carbonate, quartz, iron oxides, and rarely epidote have been deposited between breccia fragments.

Vein Margin

Scapolite is the most abundant mineral in the vein margin. The coarse euhedra commonly are oriented perpendicular to the vein and appear to have grown outward, away from the vein core. Intergrown with and commonly interstitial to the scapolite are calcite, biotite, and less abundant sulfides, quartz, and epidote. The core-vein margin contact generally is sharp, but the vein margin-selvage contact is gradational.

The grossularite-vesuvianite-scheelite association is placed in this zone because of the apparent contact with the core found in one specimen.

Selvage

The selvage is distinguished from the typical vein margin by the reduction in quartz, calcite, and sulfides and the presence of abundant

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hornblende. Scapolite appears to be slightly less euhedral and somewhat less abundant. A maximum width of about 1½ feet was observed for this zone.

Scapolitized Amphibolite

Scapolite is present in minor amounts in most of the amphibolite country rock. However, in the immediate vicinity of the veins, it commonly becomes abundant and the rock takes on a spotted appearance (Figure 31). The zone of visible scapolitization normally is less than 6 feet wide.

Unaltered Amphibolite

The unaltered amphibolite is described in the section on the petrology of the metamorphic rocks.

PARAGENESIS

The problem of establishing the relative ages of alteration zones in ore deposits is considered by Meyer and Hemley (1967) who conclude that "the simple geometry of the banded pattern is unobligingly ambiguous." In the copper-tungsten skarns there is no evidence that the various zones represent separate stages of mineralization. Rather, the differences between the zones appear to be a function of a progressive decrease in the degree of alteration away from the vein. The reason for this decrease in alteration is not known.

Sulfide deposition is believed to have taken place relatively late

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because the pyrite and chalcopyrite commonly occur as infillings among coarse euhedral scapolite grains. Also minor late-stage quartz and calcite was deposited along cracks and fractures and between scapolite grains in the vein core and margin.

CHEMISTRY OF THE CU-W SKARNS

The minerals present in the Cleora skarns represent a typical calc-silicate assemblage. In view of the close chemical similarity between the skarn minerals and the amphibolite, and the confinement of the skarns almost entirely to amphibolite, it is believed that mineralization involved principally the chemical reorganization and coarse recrystallization of the country rock with relatively minor addition of material. The only components not easily accounted for are W, Cu, S, CO_2, and SiO_2, which were probably derived metasomatically from hydrothermal fluids of unknown origin traveling through the fractures.

TEMPERATURE AND PRESSURE OF FORMATION

It is unlikely that pressures during skarn deposition exceeded those that existed at the peak of regional metamorphism in the southern part of the area. A maximum pressure of about 4 kb can therefore be established for mineralization. Relatively low pressures are also indicated by the vuggy nature of some of the skarn rocks, particularly those of the grossularite-vesuvianite-scheelite association. Because many of the assemblages represented in the skarns are sensitive to the relative

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P_{H_2O} and P_{CO_2}, the determination of these variables, in addition to T and P_T, is critical to the accurate determination of the conditions during deposition. Storre (1970) has experimentally determined the stability fields of grossularite-bearing assemblages in the system $CaO-Al_2O_3-SiO_2-CO_2-H_2O$. His results are summarized in Figure 34. The co-existence of grossularite-calcite-quartz in the Cleora skarns establishes an upper temperature limit of 630°C and a molar fraction of CO_2 of 0.3 at 2 kb total fluid pressure. At 4 kb the invariant point would be at about 725°C and 0.4 CO_2.

According to Turner (1968), at 2 kb P_f ($P_{H_2O} = P_{CO_2}$), the reaction

Tremolite + 3 Calcite + 2 Quartz $\rightleftharpoons$ 5 Diopside + $3CO_2$ + H_2O

takes place at 540°C. With a decrease in the molar fraction of CO_2 to 0.3, the temperature of the reaction would be depressed only slightly. At 1 kb P_f ($P_{H_2O} = P_{CO_2}$) the temperature of the reaction is only lowered to 525°C.

Based on these reactions, the estimated P-T conditions of formation, at least of the non-metallic minerals, are:

Pressure: 1-4 kb

Temperature: 500-725°C

Mole fraction CO_2: 0.1-0.4

The conditions of sulfide deposition are not known.

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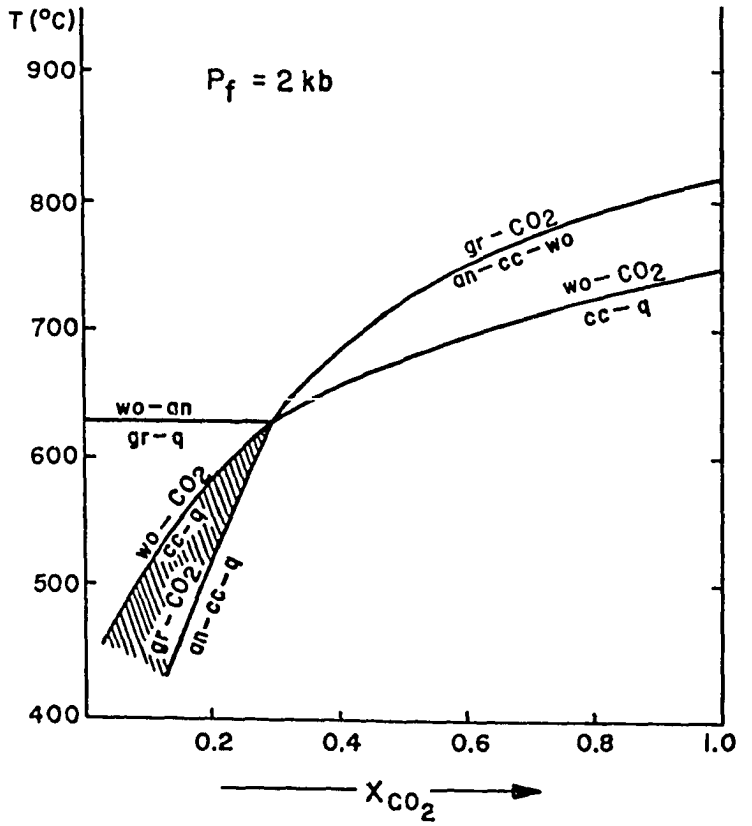

Figure 32. T-X_{CO_2} diagram at 2 kb for the system CaO-Al_2O_3-SiO_2-CO_2-H_2O. Shaded area is region in which grossularite, quartz, and calcite coexist. An - anorthite, cc - calcite, gr - grossularite, q - quartz, wo - wollastonite (Storre, 1970).

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RELATIONSHIP BETWEEN THE Cu-Zn AND Cu-W SKARNS

A comparative summary of the characteristics of the two skarn types in the area is given in Table 11. The main similarities between them are the structural and lithologic localization of mineralization and the presence of copper. In most respects, however, the two types differ markedly. Their general chemical character, in particular, suggests that the mineralizing solutions were considerably different. Both types favor amphibolitic country rocks, but the Cu-Zn skarns have been highly metasomatized and are Mg-Al-rich, whereas the Cu-W skarns appear to have involved little metasomatism and are Ca-rich. Because there is no evidence of the source of the mineralizing solutions that formed the Cleora deposits, it is not possible to determine whether the copper-zinc and copper-tungsten skarn types are consanguineous.

Table 11. Comparison of major features of the Cu-Zn and the Cu-W skarns of the Salida area.

	Sedalia-Turret District	Cleora District
Principal metals	Cu, Zn	Cu, W
Original country rock type	strongly-foliated amphibolite (?) and pelitic metasediments	poorly-foliated amphibolite
Kind of deposit	metasomatic replacement and recrystallization of country rocks; minor veins	veins with considerable marginal recrystallization and minor metasomatism of country rock
Structural controls	localized along and between faults	localized along faults

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Table 11 (Continued)

Chemical character	Mg-Al-rich	Ca-rich (calc-silicate assemblage)
Characteristic minerals		
Silicates and carbonates	actinolite, andalusite, anthophyllite-gedrite, biotite, chlorite, cordierite, garnet (almandite), sillimanite, talc, tremolite, sphene	biotite, calcite, diopside, epidote, grossularite, hornblende, quartz, scapolite, sphene, vesuvianite
Oxides	corundum, gahnite, hoegbomite, ilmenite, magnetite, rutile	ilmenite, scheelite
Sulfides	chalcopyrite, galena, marcasite, pyrite, sphalerite	chalcopyrite, pyrite
Paragenesis	several distinct stages: a) silicate-oxide, b) sulfide, c) retrograde, d) supergene	indistinct; mostly simultaneous deposition; sulfides probably late
Zoning	none	well developed around veins: a) vein core, b) vein margin, c) selvage, d) scapolitized amphibolite, e) unaltered amphibolite
Temperature during mineralization	initially 600-750°C; later stages possibly below 200°C	500-725°C (probably lower for later sulfides)
Total pressure during mineralization	initially 4.5-5.5 kb; unknown for later stages	less than 4 kb
Source of mineralizing solutions	quartz monzonite or country rock	unknown

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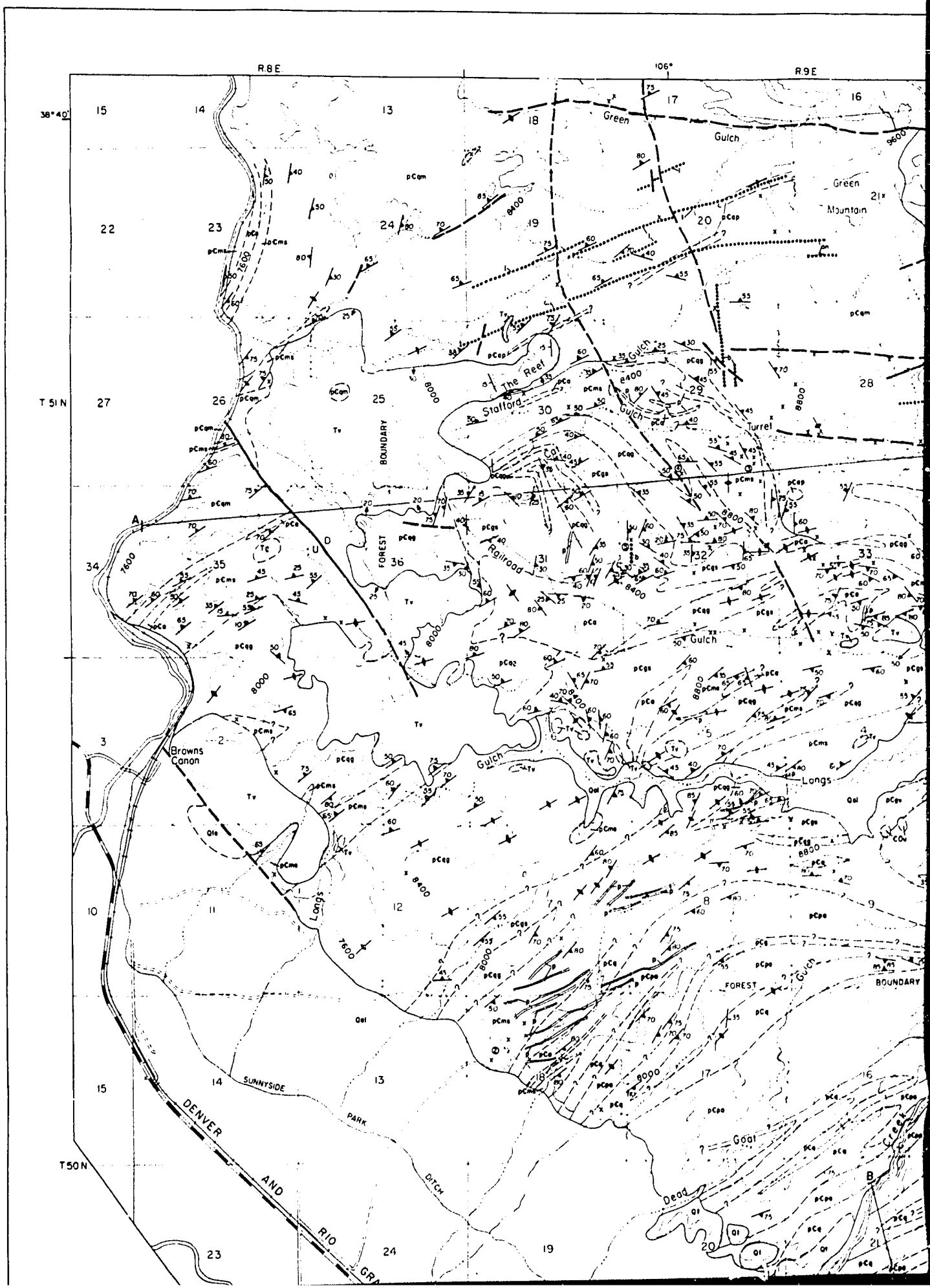

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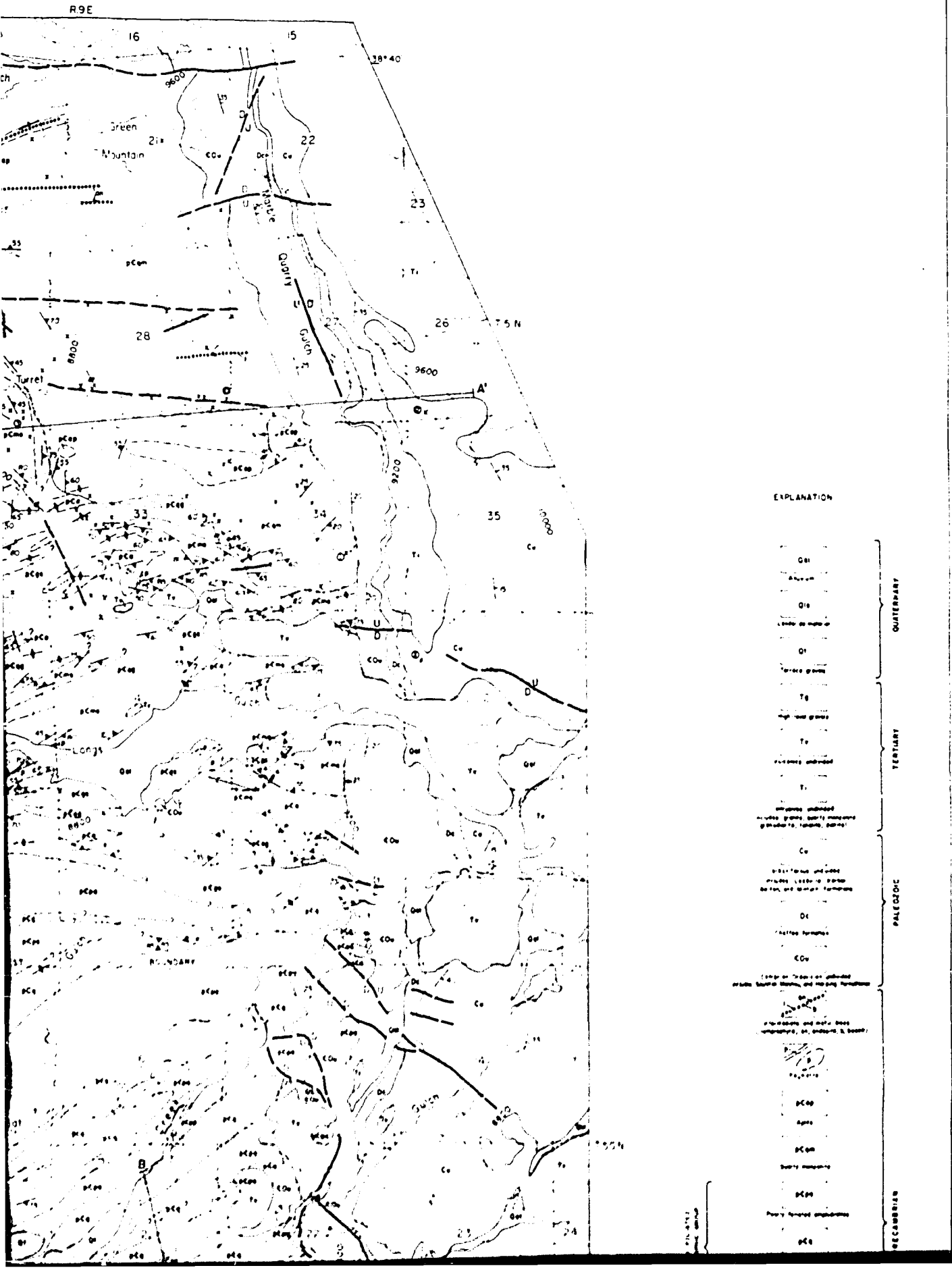
PLATE I



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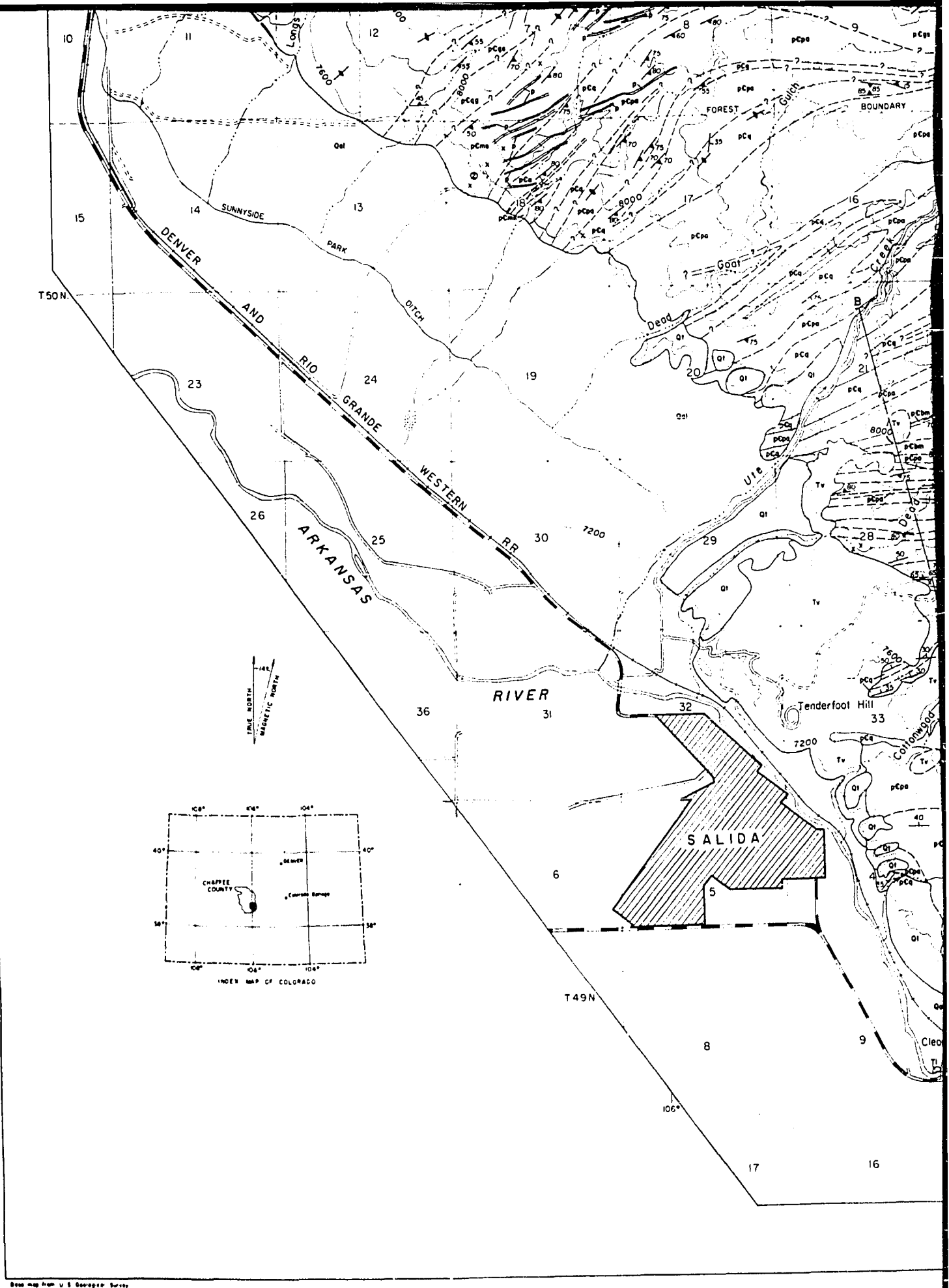

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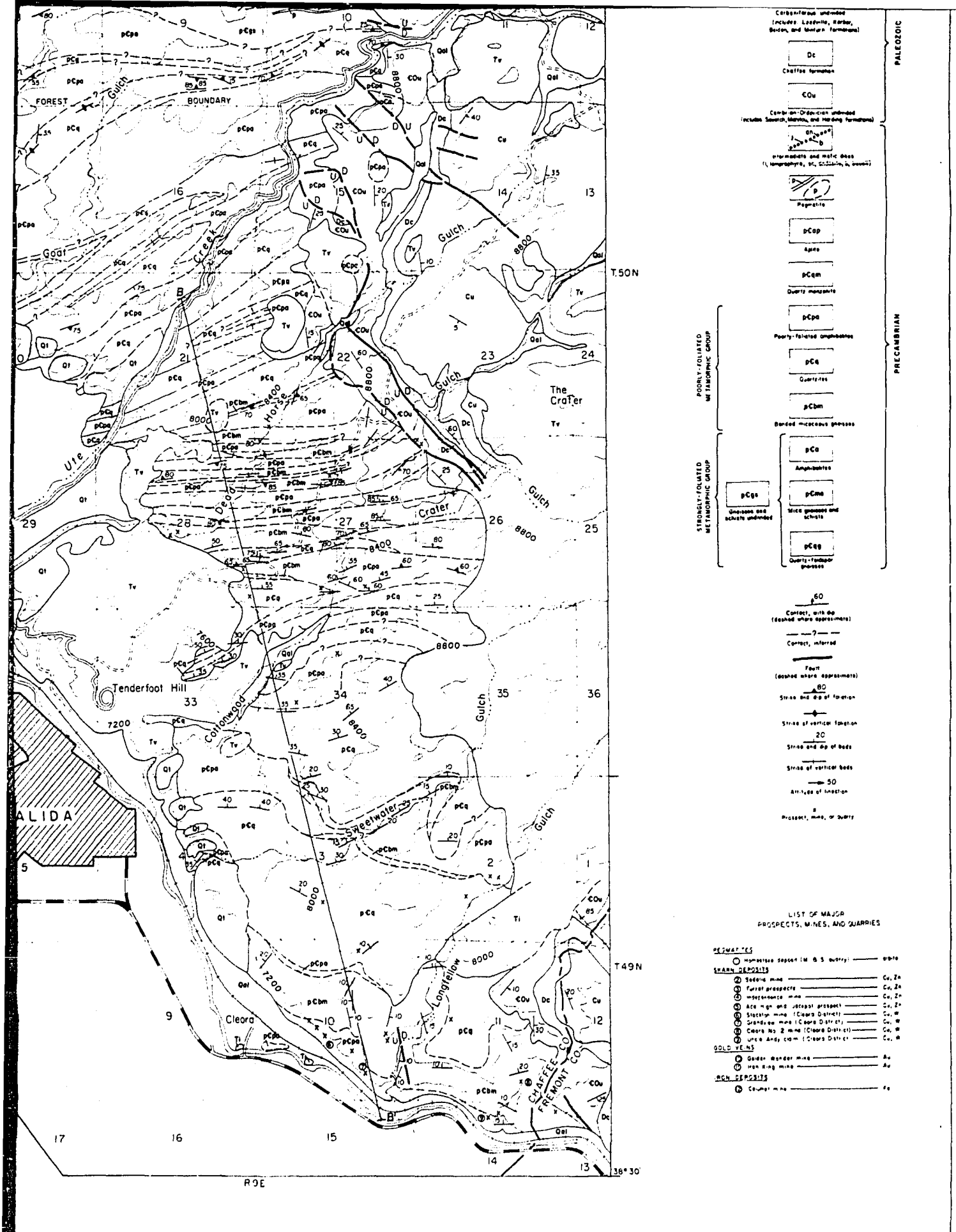

E SALIDA AREA, CHAFFEE COUNTY, COLORADO

Scale

1/2 1 1 1/2 2 Miles

CONTOUR INTERVAL 400 FEET

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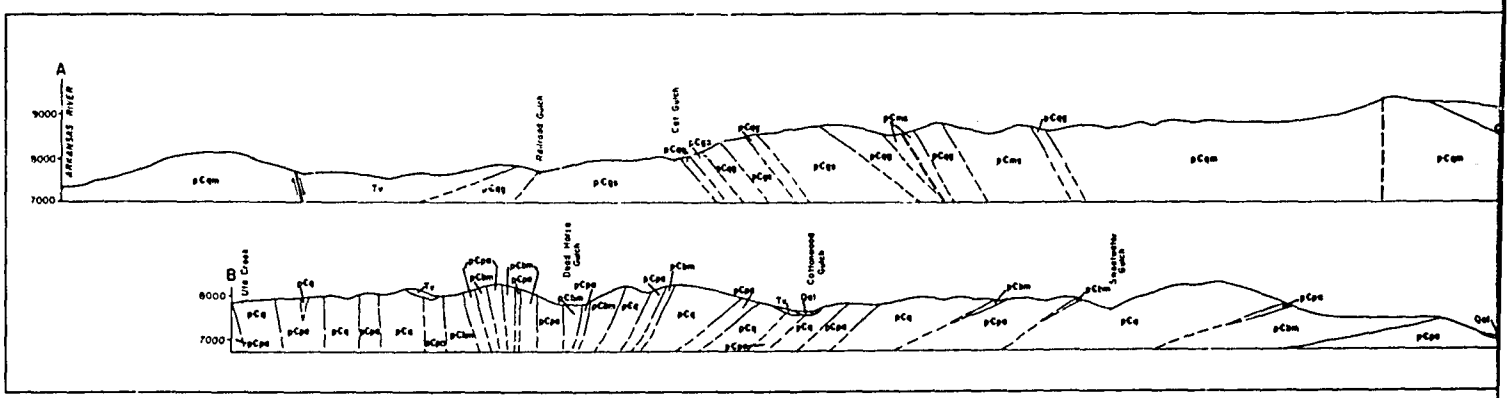

GEOLOGICAL CROSS SECTIONS OF THE SALIDA AREA, CHAFFEE COUNTY, COLORADO

SCALE

1/2 1/4 0 1/4 1/2 3/4 MILES

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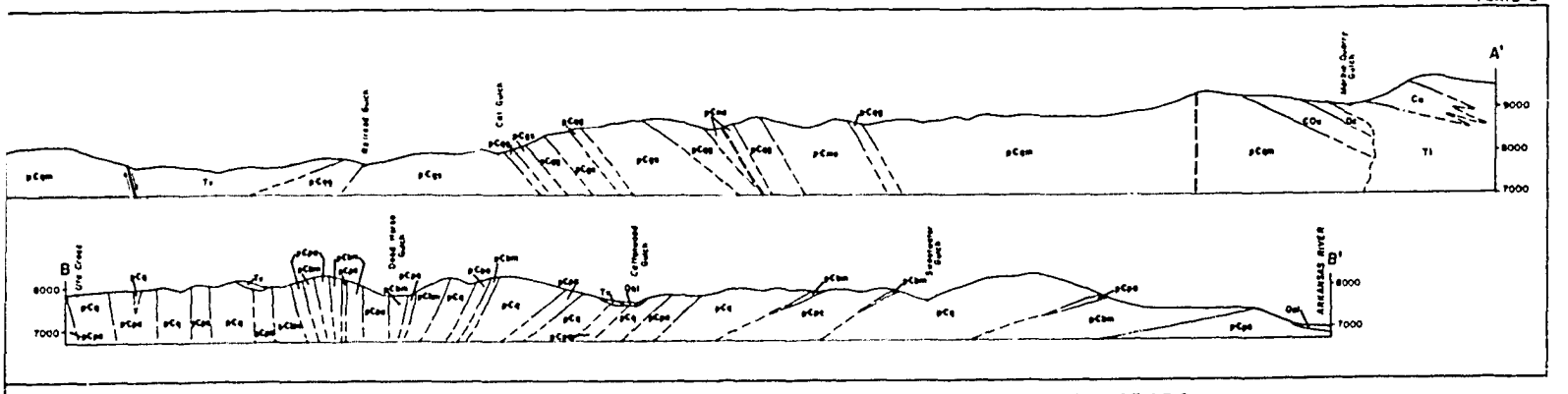
PLATE 2



GEOLOGICAL CROSS SECTIONS OF THE SALIDA AREA, CHAFFEE COUNTY, COLORADO

SCALE

1/2 1/4 0 1/4 1/2 3/4 MILES

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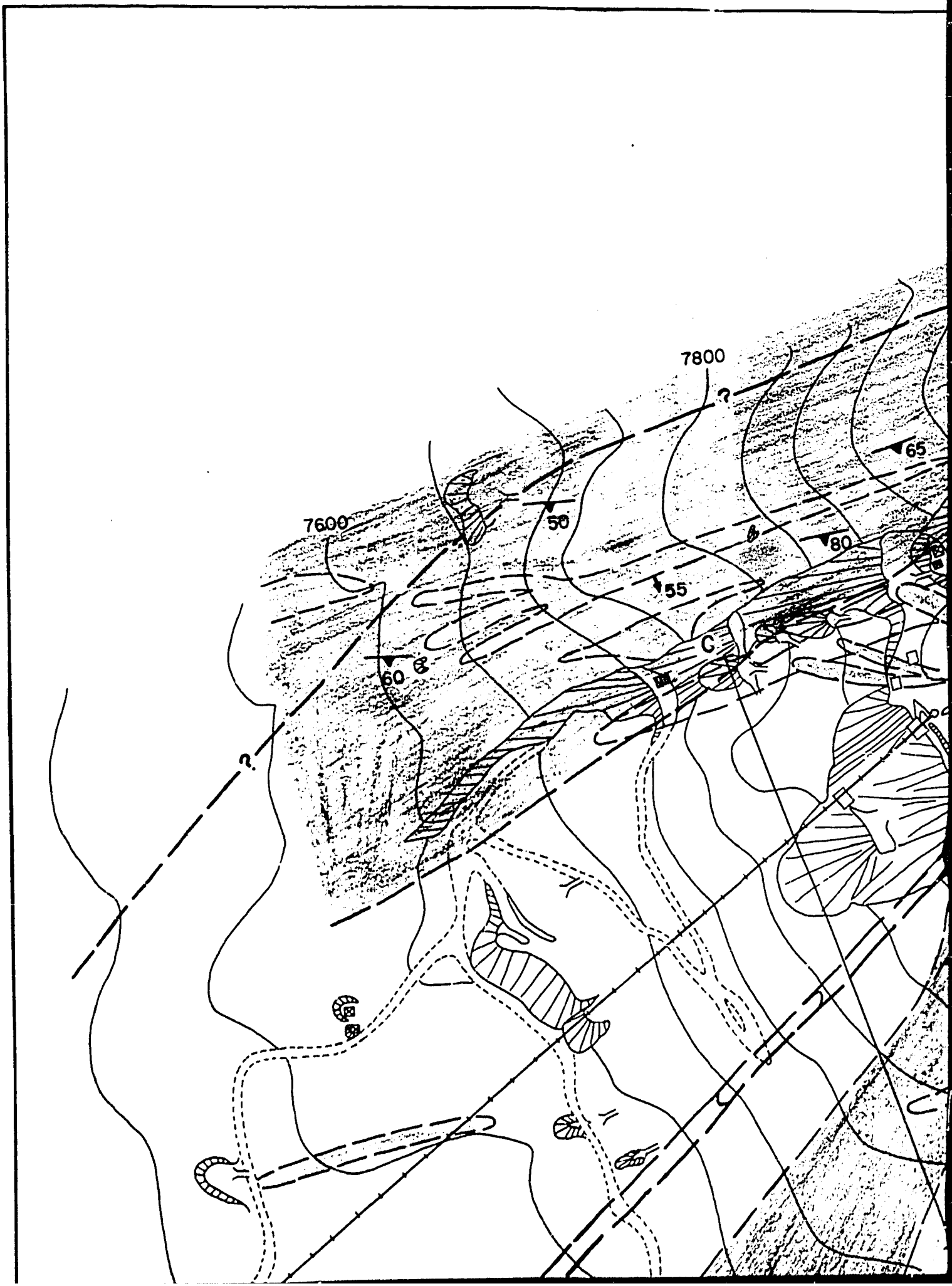

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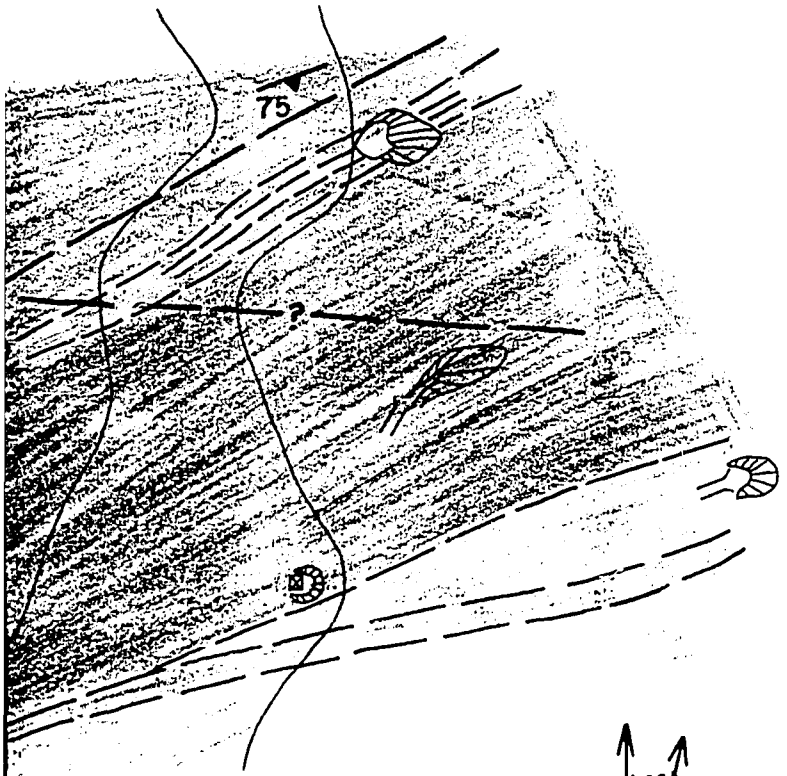
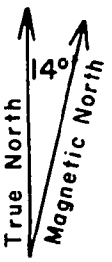
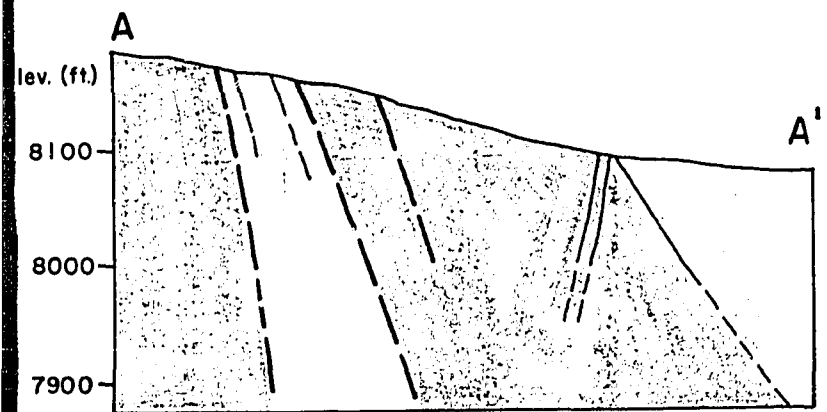
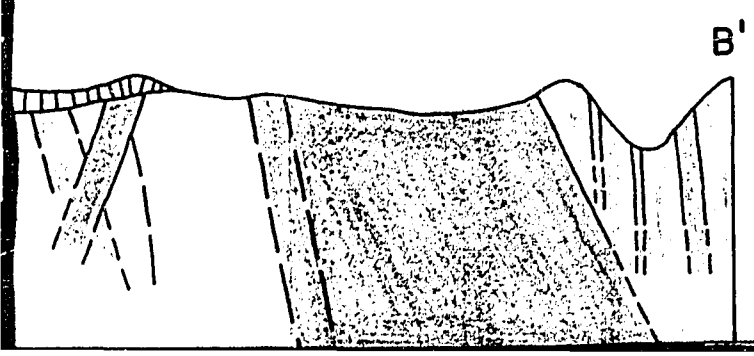
PLATE 3









EXPLANATION

Pegmatite dikes
(showing dip of contact)

SKARN ROCKS

Cu – Zn ores

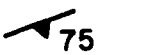
Recrystallized & Metasomatized Amphibolite

Quartzose biotite, garnet, andalusite and cordierite gneisses

Ortho – amphibolite dike

Quartzite

Mica schist



Attitude of foliation

Fault

Adit

Shaft

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GEOLOGIC MAP AND SECTIONS

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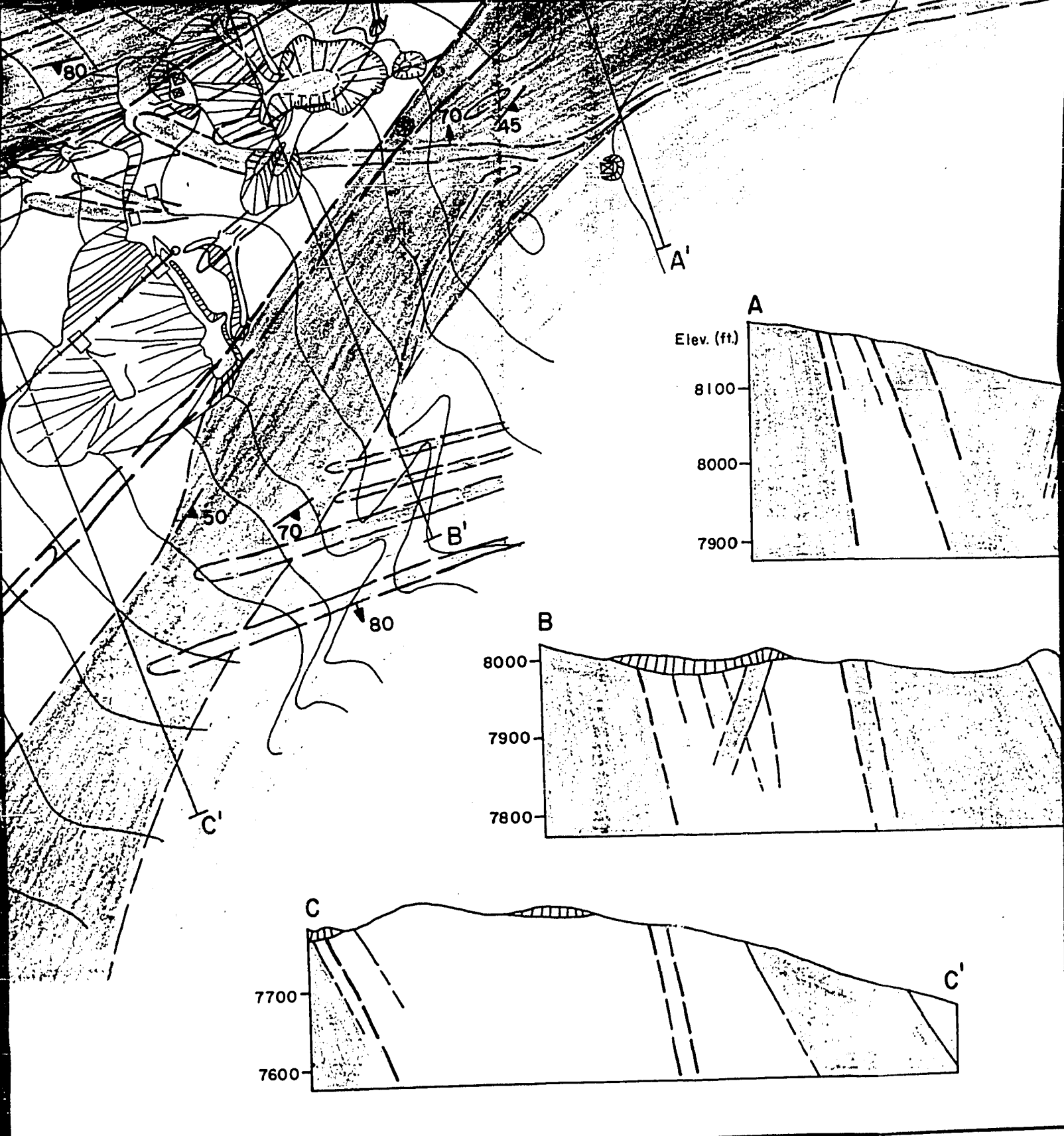

SCALE

0 100 200 300 400 Feet

CONTOUR INTERVAL: 50 Feet

SECTIONS OF THE SEDALIA MINE, CHAFFEE COUNTY, C

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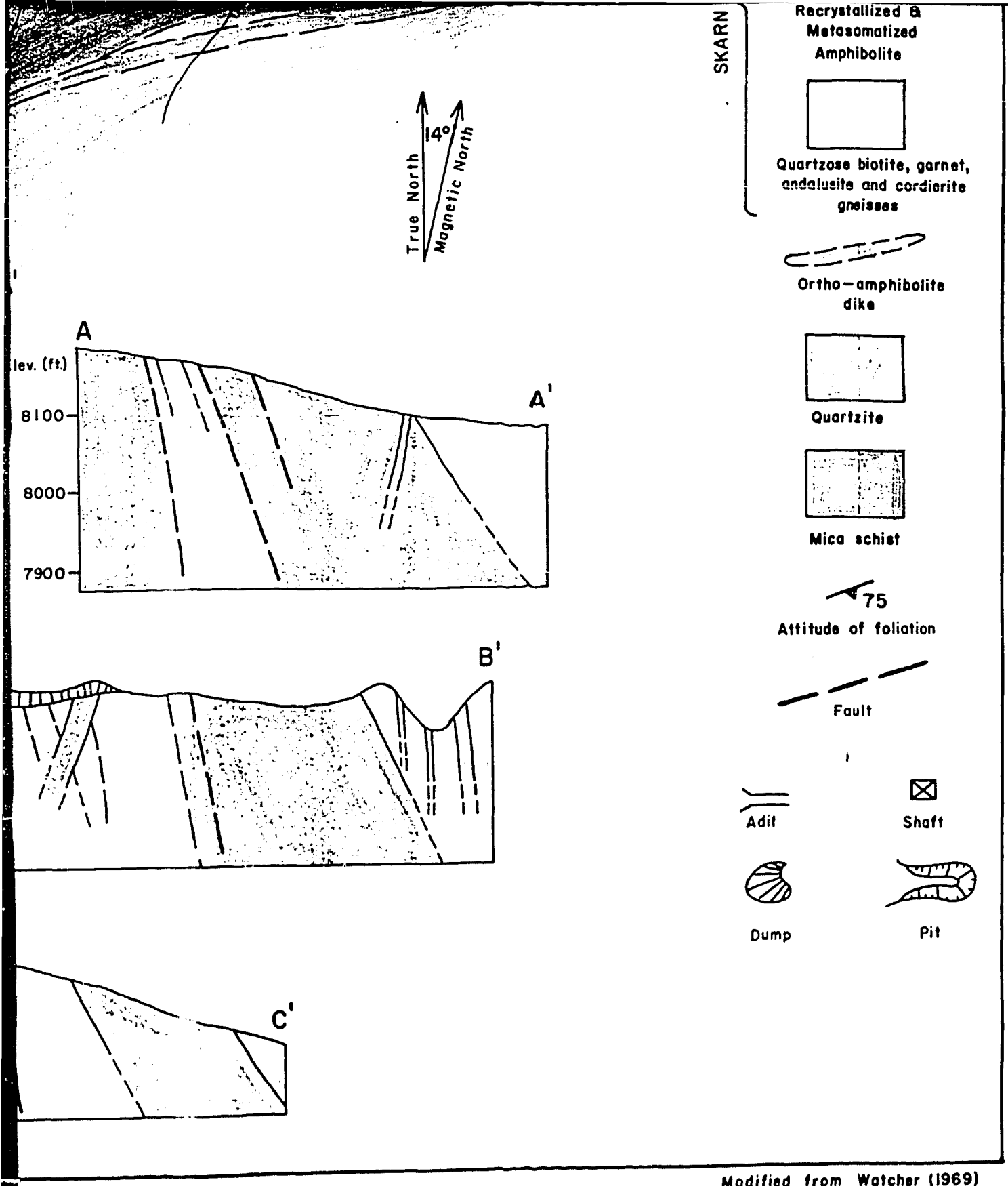

Modified from Watcher (1969)

CHAFFEE COUNTY, COLORADO

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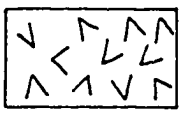
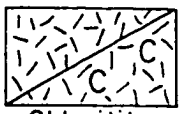
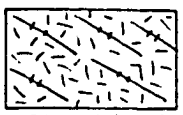
EXPLANATION


Granitic Pegmatite



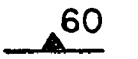
Chloritite
(Locally corundum-bearing)


Chloritized Amphibolite

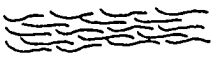
Quartz-feldspar Gneiss
(Locally sillimanite-bearing)

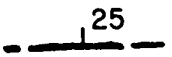
Amphibolite

Mica Gneiss



Attitude of Foliation


Shear Zone



Vein (with dip)

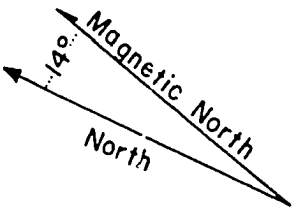
Prospect Pit

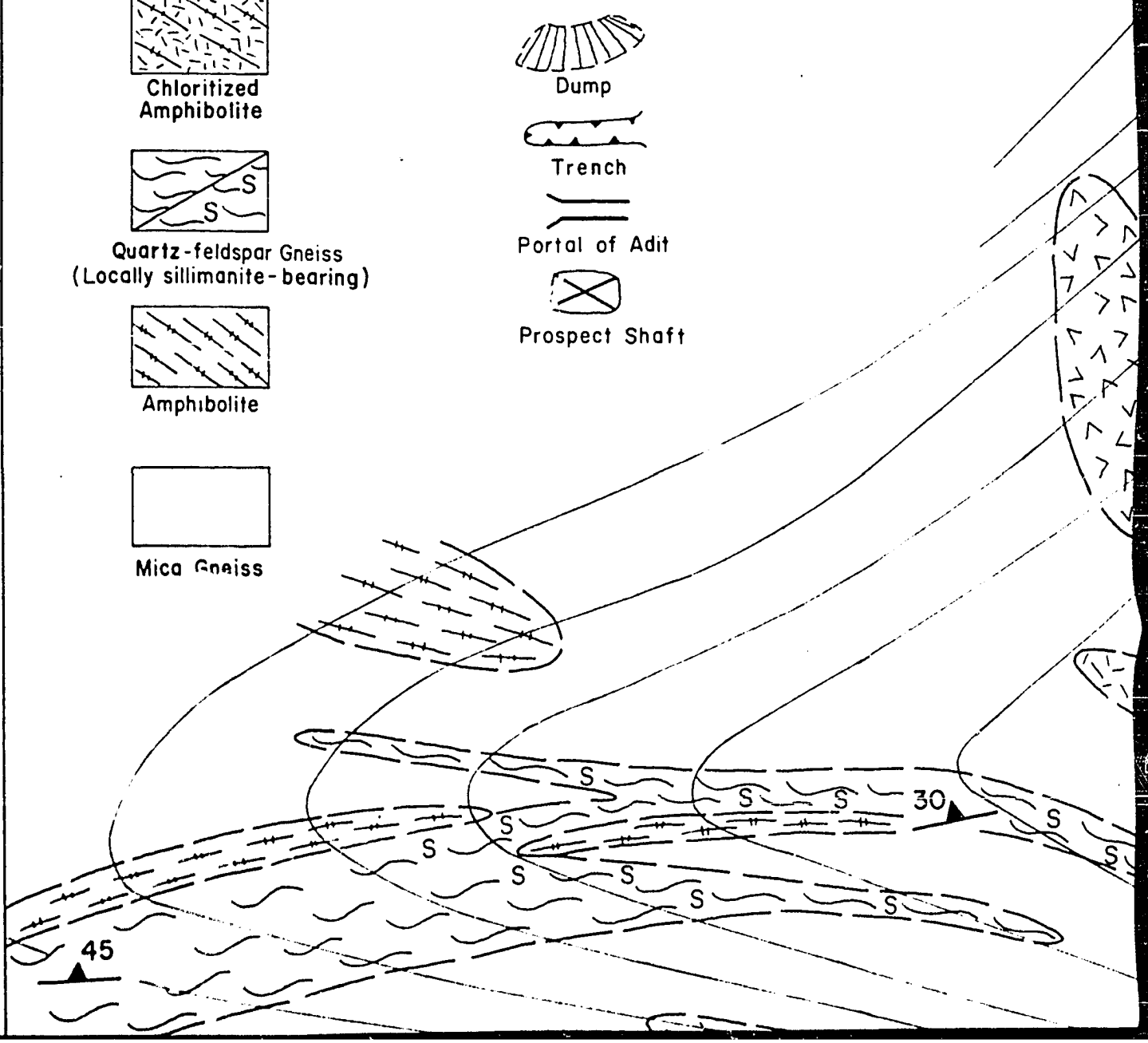
Dump

Trench

Portal of Adit

Prospect Shaft





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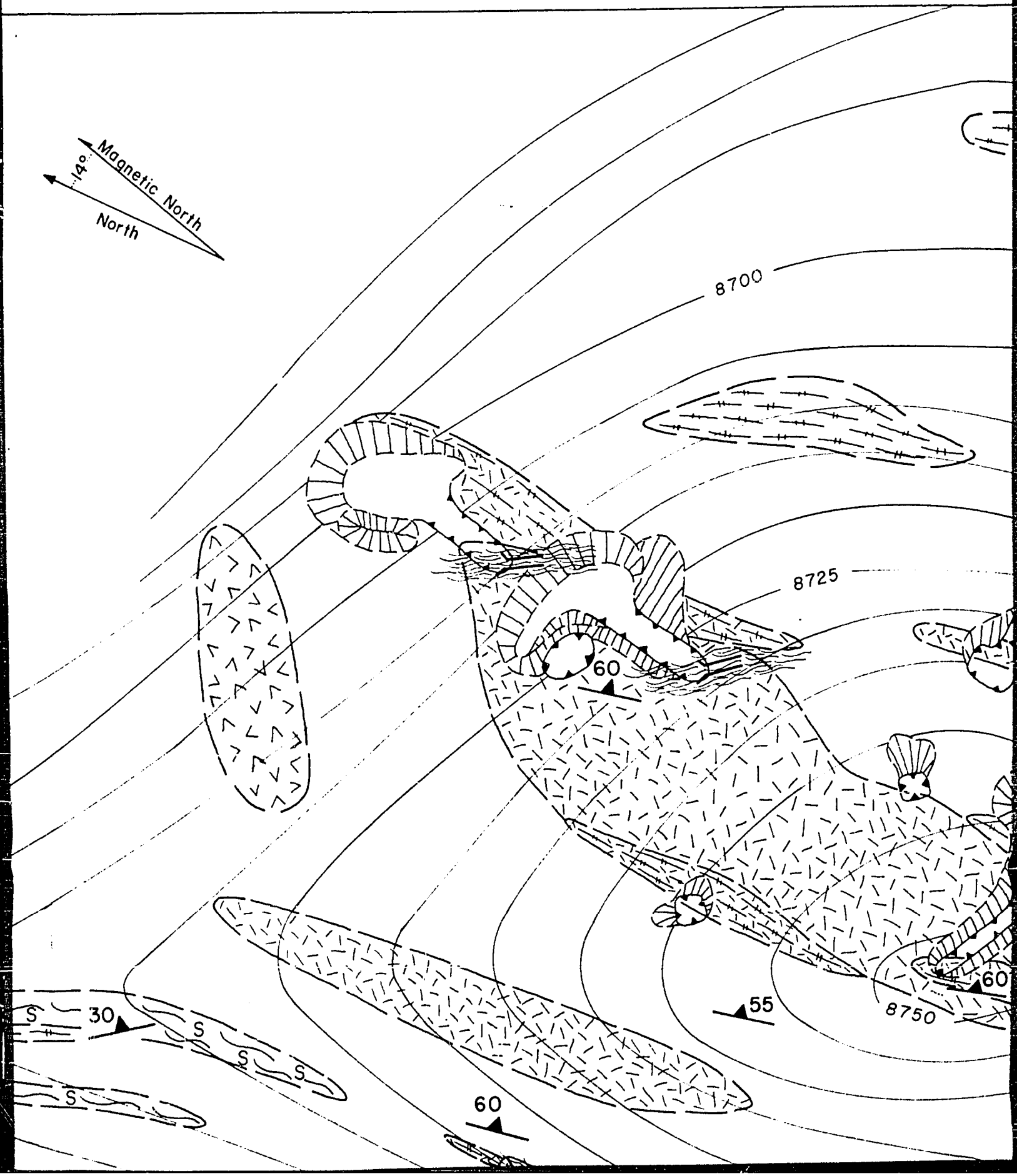

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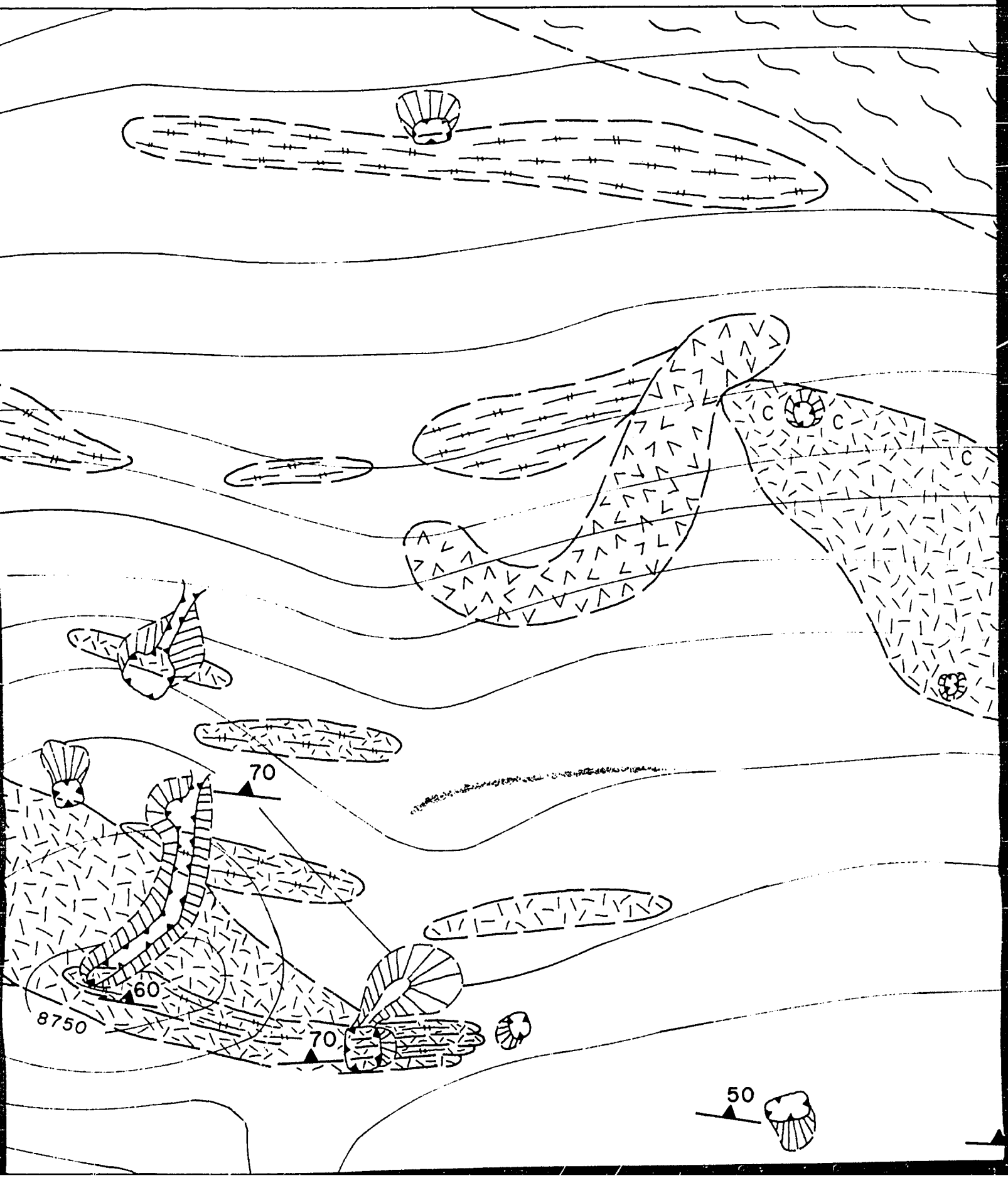

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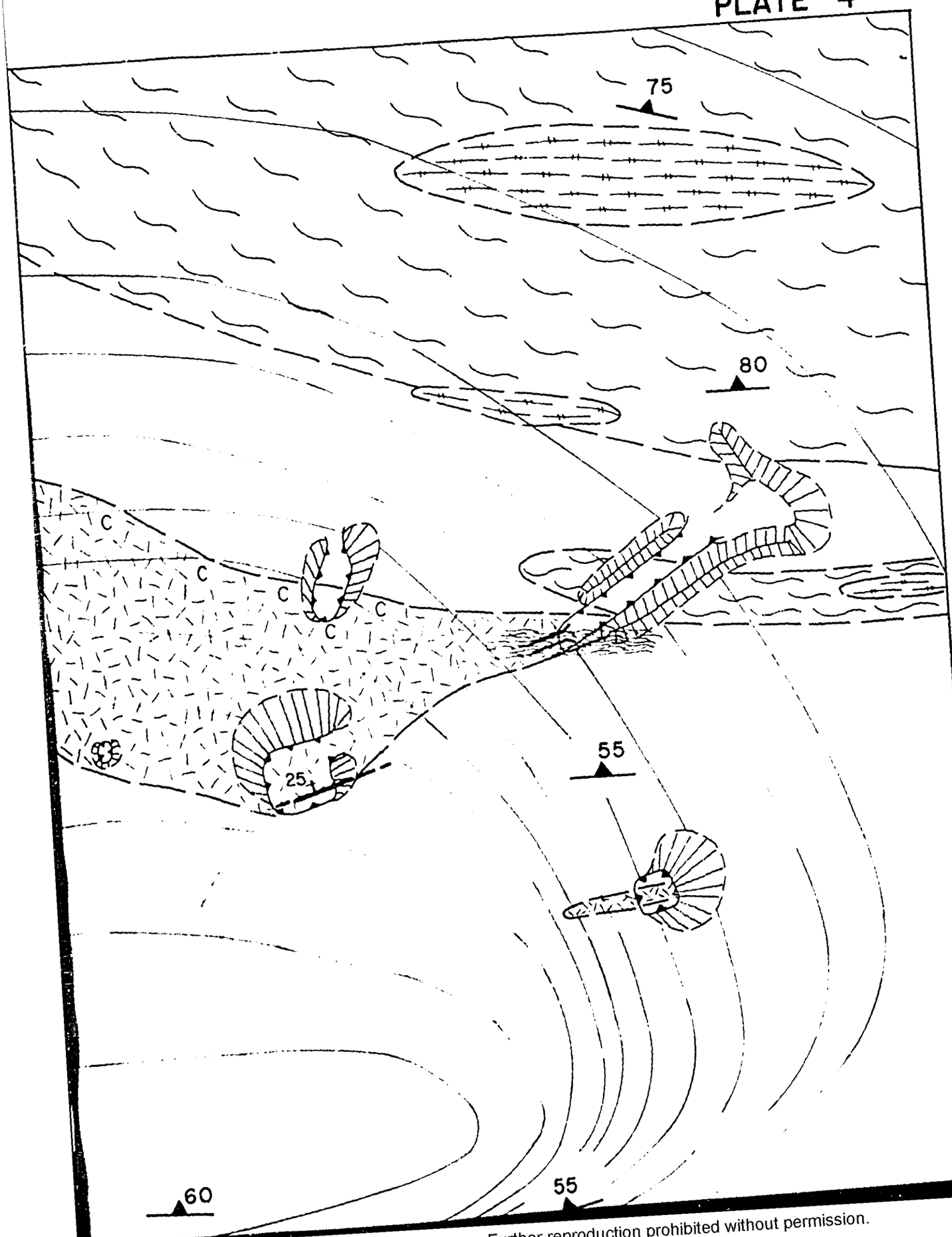
PLATE 4



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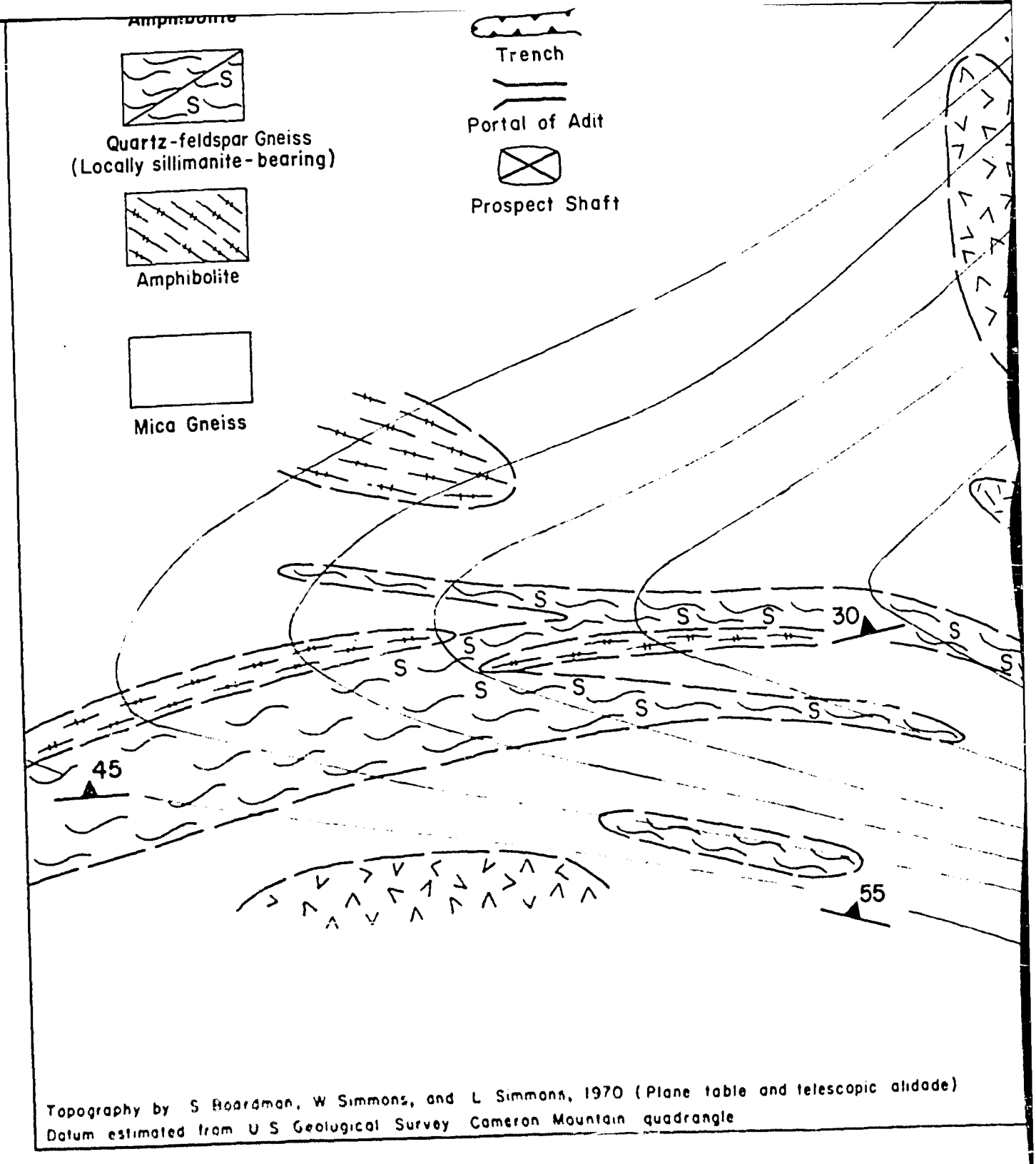

Topography by S Boardman, W Simmons, and L Simmons, 1970 (Plane table and telescopic alidade)
Datum estimated from U S Geological Survey Cameron Mountain quadrangle

GEOLOG

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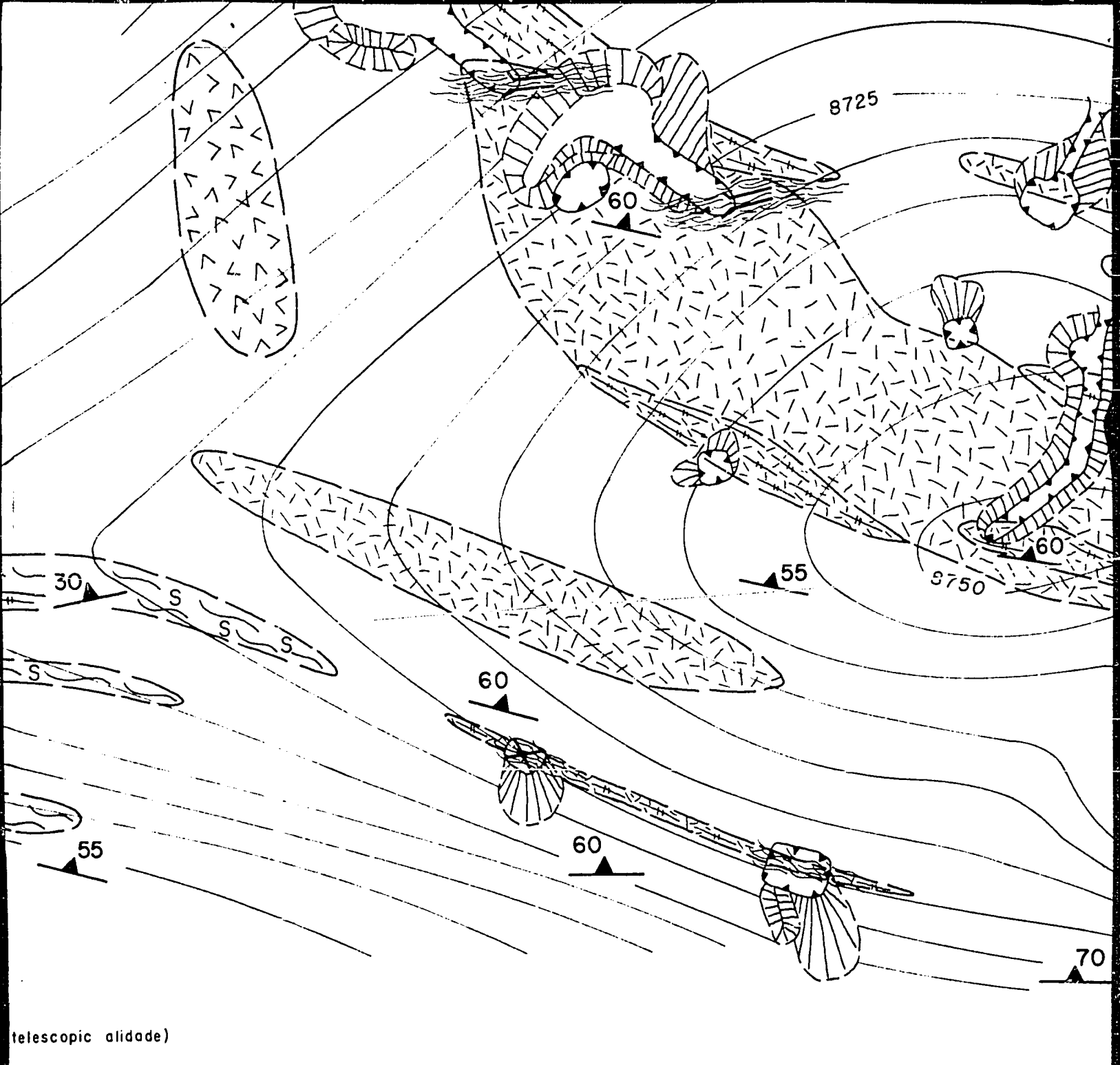

telescopic alidade)

GEOLOGIC MAP OF THE TURRET SKARN DE

Scale

30 0 3

Contour interval 5

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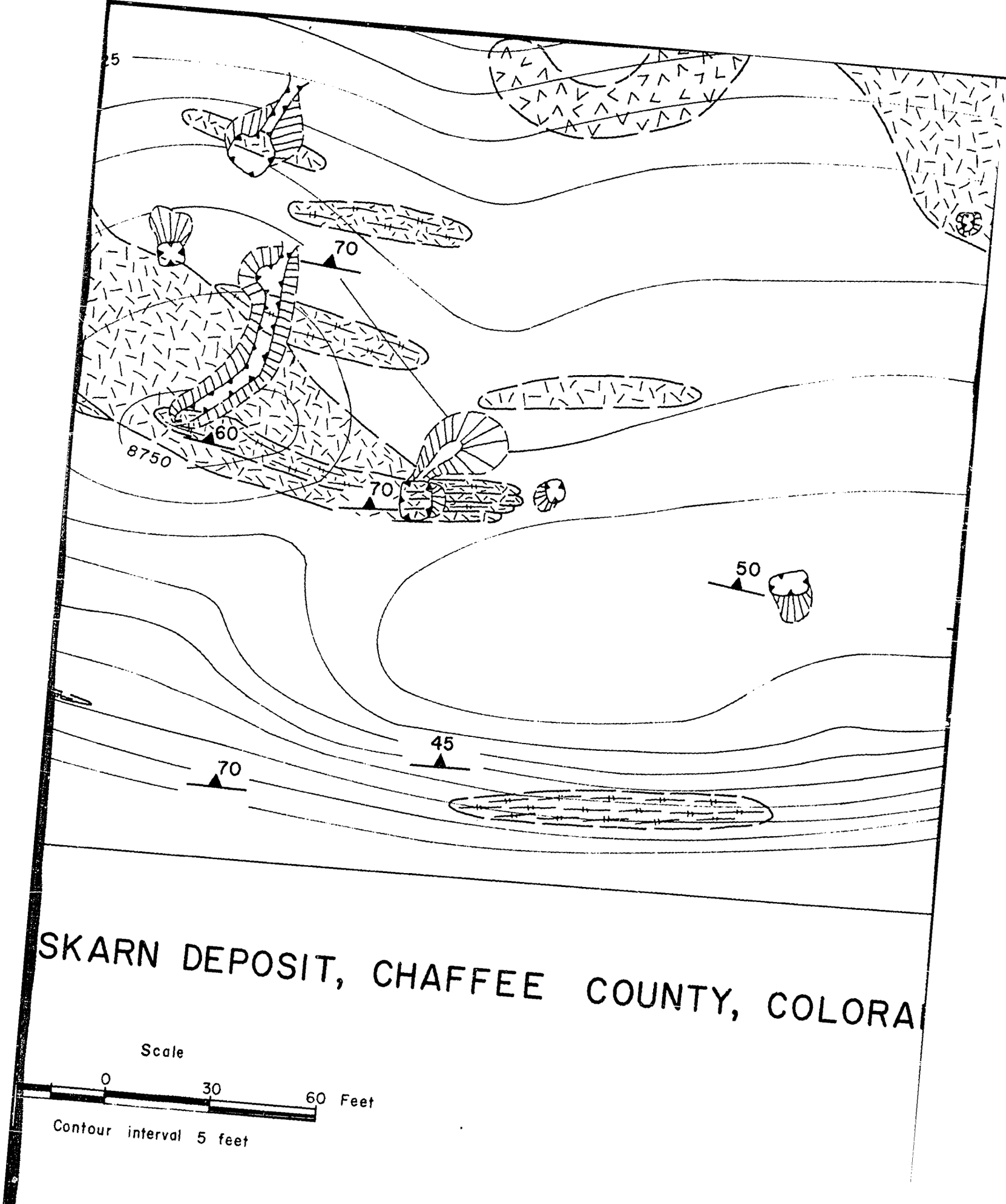

SKARN DEPOSIT, CHAFFEE COUNTY, COLORA

Scale

0 30 60 Feet

Contour interval 5 feet

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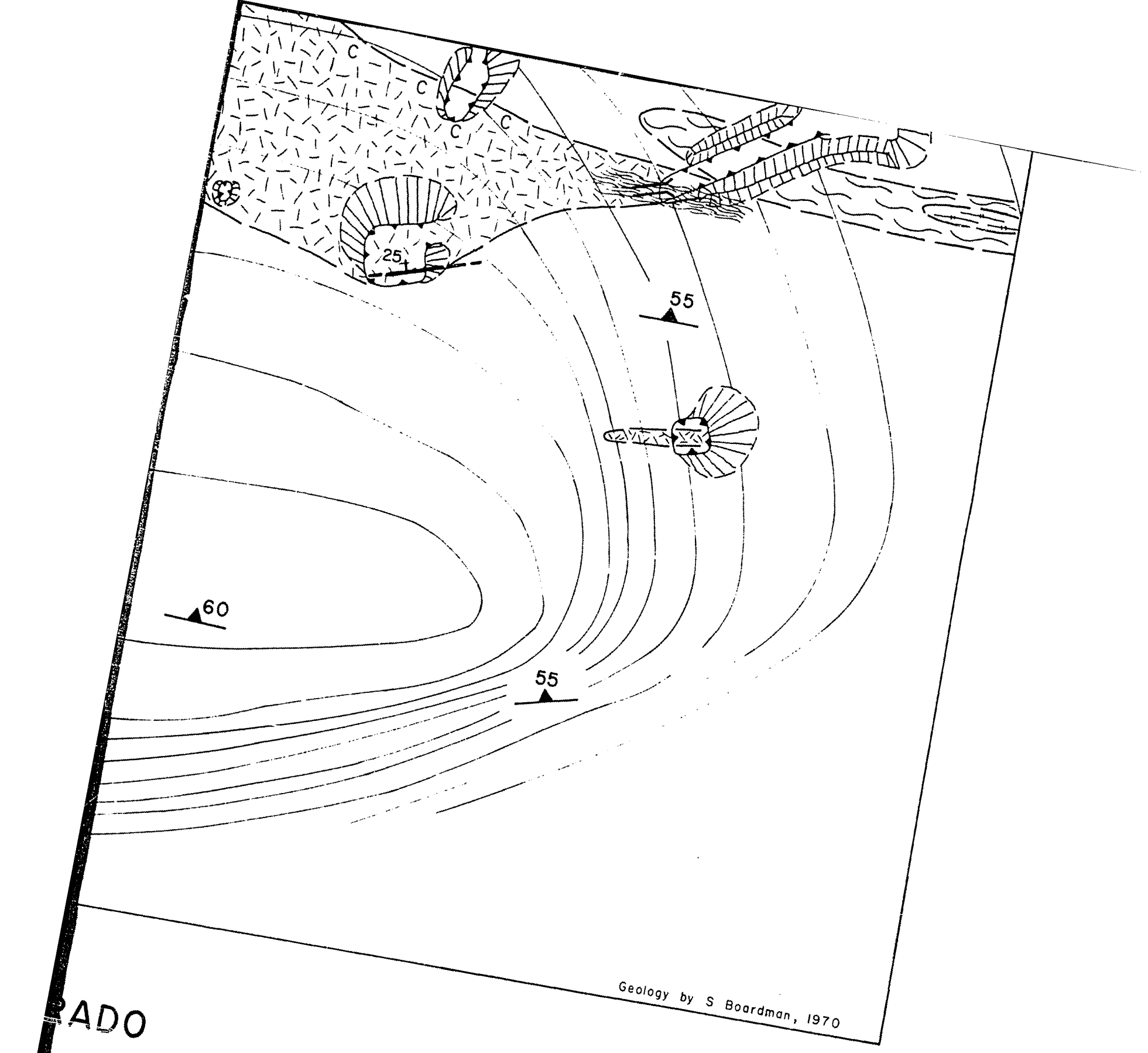

RADO

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