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Geology and ore genesis of the Slate Creek area Custer County Idaho

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GEOLOGY AND ORE GENESIS OF THE SLATE CREEK AREA,

CUSTER COUNTY, IDAHO

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ABSTRACT

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Geology and Ore Genesis of the Slate Creek Area, Custer County, Idaho

Director: Ian M. Lange

The Slate Creek area is located on the north flank of the White Cloud Range approximately 45 kilometers southwest of Challis, Idaho. Siliceous and carbonaceous argillites of the Devonian Milligen Formation exposed in the area were deposited within a stable shale basin. Early-Mississippian Antler tectonism disrupted the basin and resulted in fine-grained sandstone and siltstone of the Copper Basin Group being deposited over the shale sequence. The strata are affected by Mesozoic(?) regional metamorphism (greenschist facies) and late-Cretaceous to early-Tertiary thermal metamorphism (hornblende hornfels facies) related to intrusion of the Idaho Batholith and White Cloud Stock. East-west-trending isoclinal to open folds in the sedimentary rocks developed during metamorphism(?) and subsequent intrusion.

Previous workers have concluded mineralization in the area is late-Cretaceous to early-Tertiary hydrothermal replacement of structurally prepared rocks along thrust faults. The present study concludes that late-Devonian syngenetic, sedimentary exhalative activity resulted in stratiform lead-zinc-silver sulfide and barite deposits hosted by carbonaceous and chert-rich strata. Remobilization of a portion of the stratiform mineralization into epigenetic veins occurred during metamorphism. Intrusion of a Tertiary rhyolite dike into the ore-bearing strata at the Livingston Mine remobilized and incorporated metals from the Devonian orebody.

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CHAPTER I

INTRODUCTION

Numerous lead-zinc-silver mines and prospects are located in middle-Paleozoic carbonaceous shales in central Idaho. The Slate Creek area has many of these base and precious metal occurrences and was selected for geologic research based on adequate outcrop over limited areal extent (approximately 50 km^2) and abundant accessible underground exposure. The purpose of this work was to study the stratigraphy and orebodies in order to develop a genetic model of mineralization.

Location and Access

The Slate Creek area lies on the north flank of the White Cloud Mountains in central Idaho (Figure 1). Access to the area is via Idaho State Highway 75 which parallels the Salmon River south and west of Challis. A U.S. Forest Service maintained dirt road follows Slate Creek up to the Hoodoo Mine. Four-wheel drive roads allow access to much of the study area; the rest is accessible only on foot.

Previous Work

Among the studies of Paleozoic rocks in central Idaho, those dealing specifically with rocks in the Slate Creek area include: Ross (1937), Kiilsgaard (1949), Thomasson (1959), Kern (1972, 1974), Hobbs, (1973), Tschanz and others (1974), Hobbs and others (1975), Gruber (1975), Thompson (1977), and Skipp and others (1979).

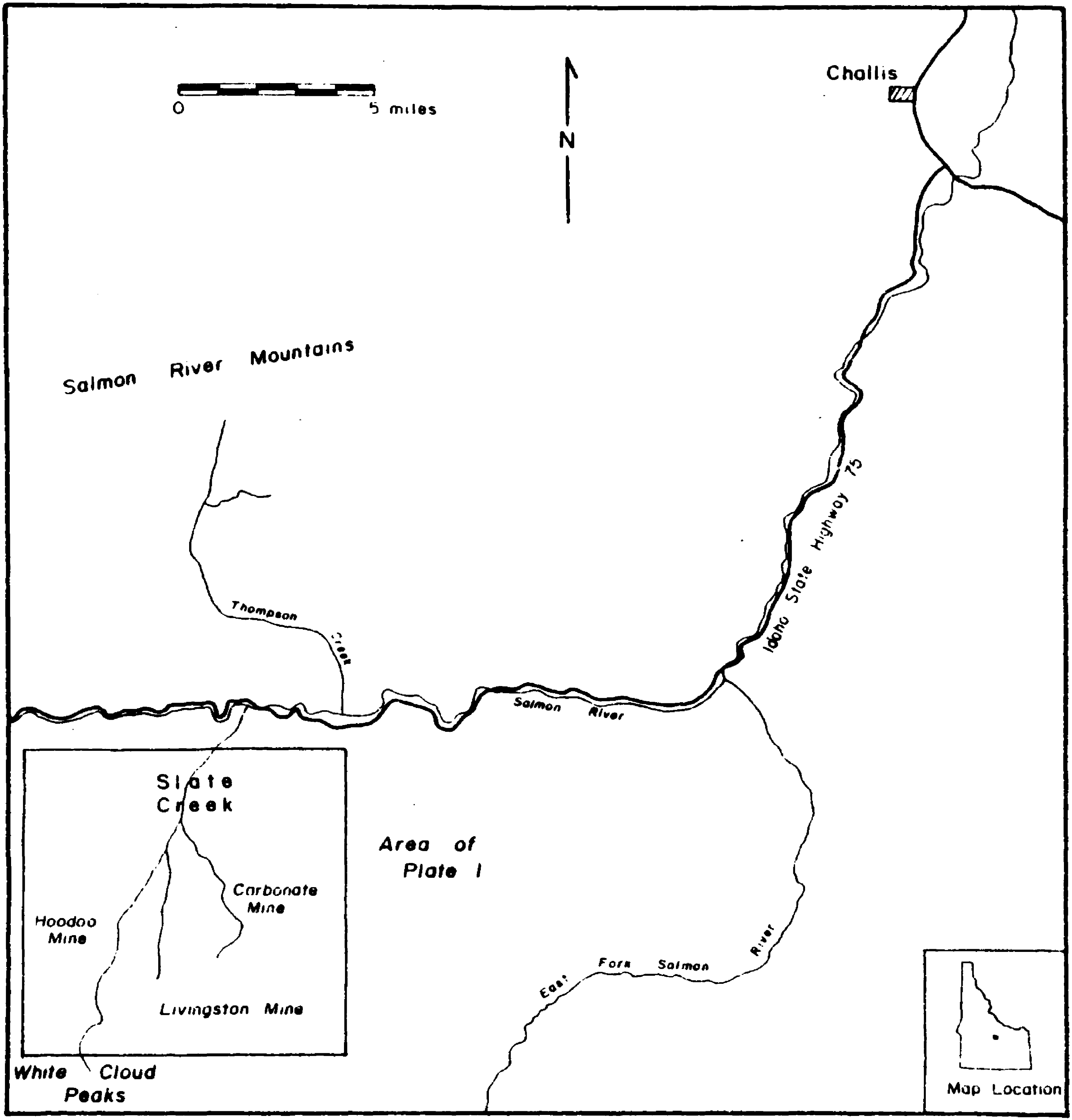


Figure I. Location Map of the Slate Creek area, Custer County, Idaho.

Ross (1937) originally mapped the region and proposed a stratigraphic succession for Paleozoic rocks exposed in central Idaho. Later workers concentrated on refining the stratigraphic column and interpreting depositional and tectonic environments. Most recent authors agree sedimentary rocks exposed in the Slate Creek area belong to the Mississippian Copper Basin Formation of Ross (1962) and to the Pennsylvanian Wood River Formation of Umpleby and others (1930). However, Gruber (1975) suggests some Devonian Milligen Formation rocks may be present in the Slate Creek area. Ross (1937), Kiilsgaard (1949), Kern (1972, 1974), and Tschanz and others (1974) review the mineralization in the Slate Creek area. All conclude the deposits are epigenetic hydrothermal replacement along thrust faults and are related to Cretaceous- to early-Tertiary-age plutonism.

Present Work

During the summer of 1982, I mapped, at a scale of 1:12,000 (Plate 1), and examined all mines and prospects in the study area. In the fall of 1982 I analyzed 72 standard and polished thin sections.

CHAPTER II

GEOLOGIC HISTORY AND REGIONAL GEOLOGY

Lower- to middle-Paleozoic sedimentary rocks exposed in east-central Idaho represent carbonate shelf, slope, and basinal sedimentation along the edge of the northwest-trending craton platform (Skipp and others, 1979). These rocks were deposited under relatively stable conditions from early-Cambrian to upper-Devonian time (Stewart and Suczek, 1978 and Poole and others, 1978). In late-Devonian to early-Mississippian time, the margin was disrupted by the Antler orogeny which resulted in uplift, faulting, and associated flysch sedimentation (Poole, 1974; Skip and others, 1979; Nilsen, 1978; and others). Pennsylvanian and Permian sedimentary rocks were later deposited in the area. Sediments of these rocks were eroded from Mississippian (Skipp and Hall, 1975) or pre-Mississippian (Shefchik, 1977) rocks uplifted during the latest stages of the Antler orogeny.

Eastward and northeastward thrusting of the Paleozoic rocks in east-central Idaho occurred during multiple events from late-Permian to late-Cretaceous time (Dover, 1980). These sedimentary rocks were metamorphosed and deformed prior to and coincident with intrusion of late-Cretaceous to early-Tertiary igneous rocks of the Idaho Batholith and related satellite intrusions (Ross, 1937 and Tschanz and others, 1974).

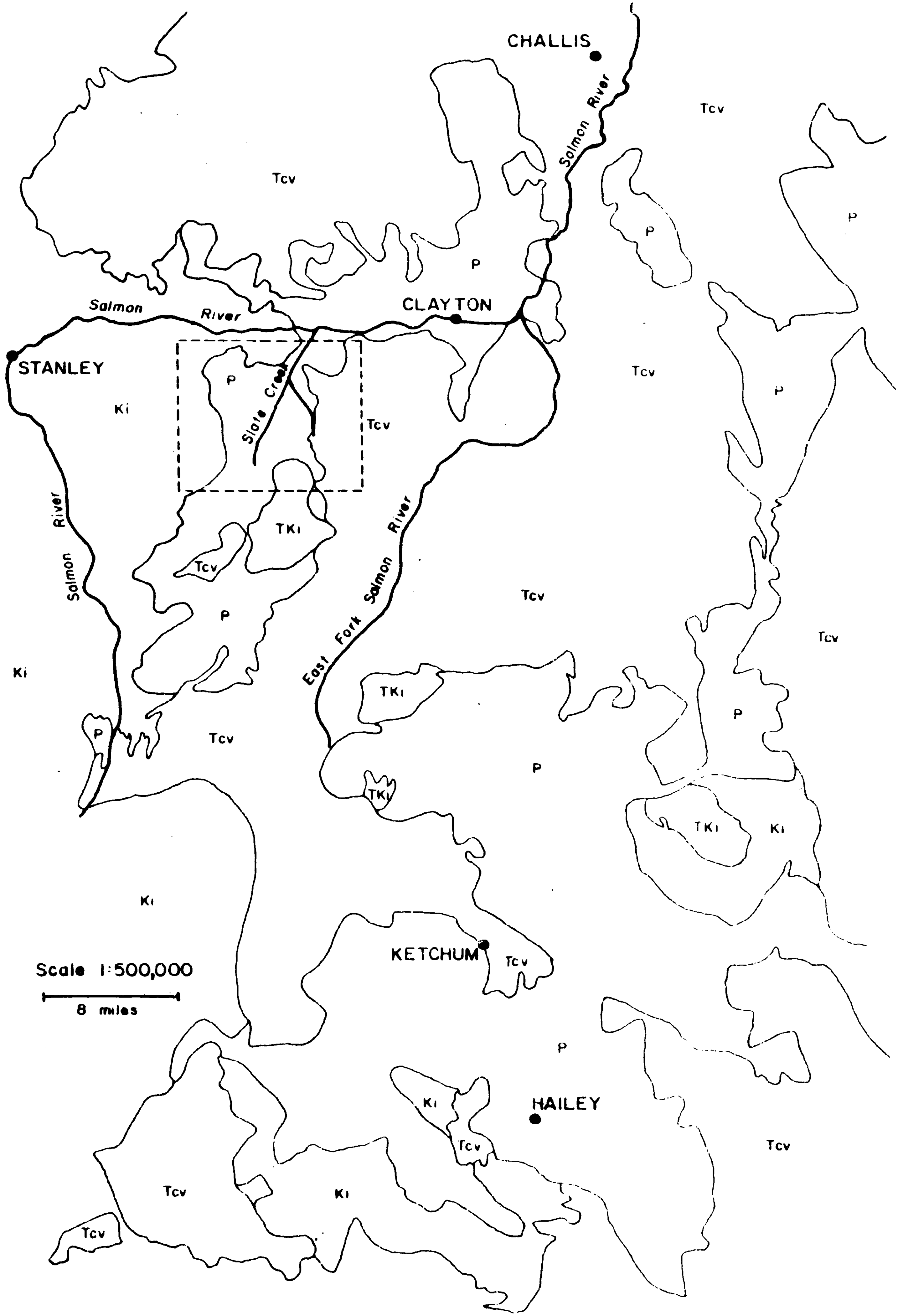
Uplift and erosion of central Idaho during early-Tertiary time produced an area of high relief which was subsequently buried by lava, pyroclastic, and sedimentary rocks of the Eocene Challis Volcanics (Ross, 1961; 1962). Post-Challis normal faulting created Basin-and-Range style topography throughout east-central Idaho (Baldwin, 1951). Fluvial and glacial erosion has locally removed the volcanic cover to expose the Paleozoic sedimentary and Cretaceous igneous rocks.

The Slate Creek area lies in an exposure of middle-Paleozoic basinal-shale rocks. Idaho Batholith and related rocks surround the area on the north and south. A thrust sheet of Pennsylvanian rocks borders the area on the west and Challis volcanics bury the middle-Paleozoic rocks to the east. The regional geology of the study area is presented on Figure 2.

EXPLANATION

Tcv	*Tertiary Challis volcanic rocks*
TKi	*Tertiary-Cretaceous plutonic rocks*
Ki	*Idaho Batholith and related rocks*
P	*Paleozoic sedimentary and metasedimentary rocks*
(dashed box)	*Thesis area*

Figure 2. Generalized regional geologic map (modified from Ross and Forrester, 1959).



CHALLIS
Salmon River
Tcv
Ki
Tcv
P
P
P
Salmon
River
CLAYTON
STANLEY
P
Slate Creek
Ki
Tcv
Tcv
P
River
Salmon
TKi
Tcv
Tcv
River
East Fork Salmon
P
Tcv
Ki
TKi
P
P
Tcv
TKi
P
TKi
Ki
Ki
KETCHUM
Tcv
Scale 1:500,000
8 miles
P
Ki
HAILEY
Tcv
Tcv
Tcv
Ki
Tcv

CHAPTER III

GEOLOGY OF THE SLATE CREEK AREA

Stratigraphy and Correlation

The Slate Creek area contains thick sequences of carbonaceous, fine-clastic debris and thinner intervals of carbonate and coarser-clastic sediments. The stratigraphy is dominated by siltstone and shale with minor limestone, chert, and quartzite. Coarser-grained sedimentary rocks are mostly confined to the upper portion of the exposed section. Since the section contains only subtle variation, lithologies present in minor quantities were emphasized in delineating mappable units and in determining stratigraphic relationships. Stratigraphic columns for the area are presented with a bedrock geology map on Plate 1. A fence diagram is shown on Plate 2.

The bulk of the stratigraphy consists of fine-clastic and carbonaceous rocks which, based on lithologic similarity to other described exposures in east-central Idaho, is thought to belong to the Devonian Milligen Formation (Sandburg and others, 1975; Gruber, 1975; Ross, 1937; Umpleby and others, 1930; and others). Overlying coarser-grained rocks are believed to be part of the Mississippian Copper Basin Group exposed in east-central Idaho. Paull and Gruber (1977) and Paull and others (1972) describe the Copper Basin Group lithologies south of the study area in the Pioneer Mountains.

Following a brief summary of the major lithologic components of the Devonian section, distinctive characteristics of the map units will be presented. Describing the dominate lithologies of the Devonian stratigraphy here will avoid repetition and allow for concentration on features unique to each unit. Additional hand-sample and thin-section characteristics of the various lithologies collected from each unit are tabulated in the Appendix.

Silicic siltstone and shale, now indurated to argillite, dominates most Devonian units. The silicic argillite is gray and consists of thinly-laminated to massive beds. This rock type is characterized in the field by its silver sheen on weathered surfaces and its platy cleavage. Carbon is typically present in minor amounts. Where the abundance of carbon is greater than a few percent, and the beds are large enough, the rock has been mapped as a separate unit (Dca). Carbon-rich argillite commonly forms distinct lenticular beds up to a few meters thick and hosts most sulfide occurrences. Unique situations in which the carbonaceous argillite unit is present in greater than the usual abundances is discussed under "Carbonaceous Argillite (Dca)".

The stratigraphic column is divided into lower, middle, and upper facies. The term facies is utilized to define intertonguing rock masses of differing lithologic components which occur within a stratigraphic section. Intervals with distinct lithologic characteristics are subdivided into units. Lower and middle facies rocks are assigned to the Devonian Milligen Formation and upper facies rocks represent the basal section of the Mississippian Copper Basin Group.

Lower Facies A (Dlfa)

A quartzite-, limestone-, and chert-bearing argillite restricted to the northwest and southern portions of the map area comprises the lower facies A unit. This unit consists of interbedded siliceous and carbonaceous argillite with interbeds and lenses of the other rock types. The quartzite and limestone are distinctive of this unit as the two lithologies are not present together in any other unit.

Massive quartzite occurs locally in the section as lenses up to five meters thick. Graphite in the quartzite imparts a gray color. This lithology weathers dark gray and has distinctive blocky jointing. Limestone forms lenticular beds up to seven meters thick that are internally massive, gray, locally dolomitic, and weather to brownish-gray masses with rounded surfaces. Chert-rich argillite is the least abundant rock type in the unit. Light- to dark-gray color and millimeter- to centimeter-scale laminations are typical of this lithology. Chert-rich argillite occurs as localized, lenticular beds which commonly display intense, chaotic, soft-sediment folds.

Lower Facies B (Dlfb)

Argillite and limestone beds of the lower facies B unit are in fault contact with underlying lower facies A rocks. Siliceous argillite comprises most of the section, and carbonaceous argillite and limestone form lenses. In addition, slump(?) breccia deposits form a minor portion of the section. The presence of limestone without quartzite is distinctive of this unit.

Limestone in this section is light gray, massive, and forms beds up to a few meters thick. Multi-lithologic breccias with sub-rounded to rounded clasts occur locally. These breccia deposits are conformable to the enclosing strata and contain fragments of the siltstone and shale set in a shaly, silicic matrix.

Middle Facies A (Dmfa)

Gradationally overlying lower facies B are siliceous and carbonaceous argillites and bedded cherts of middle facies A. Limestone forms a very minor portion of the section and crops out only in the southern part of the map area. Abundance of bedded chert commonly associated with carbonaceous argillite is characteristic of this unit.

Chert forms beds up to four centimeters thick and varies from buff to black. Bedded chert-rich strata can be traced along strike up to 250 meters and are up to 10 meters thick. These lenticular pods commonly display soft-sediment folding. Limestone in the unit is light gray, massively bedded, and forms lenticular beds up to 10 meters thick.

Middle Facies B (Dmfb)

Pronounced increase in carbon and silica content marks a lateral facies transition from middle facies A rocks to middle facies B in the southwestern portion of the study area. The middle facies B unit is composed of siliceous and carbonaceous argillites in subequal amounts with lesser bedded chert and limestone.

Argillite in this section contains a higher proportion of carbon and microcrystalline quartz disseminated throughout the rock than other middle facies units. The higher proportion of carbon in the rocks would allow for their being included in the carbonaceous unit (Dca), however, the presence of microcrystalline-quartz cement yields a resistant rock outcrop distinctive of the middle facies B unit. These argillite beds contain up to one percent euhedral pyrite grains which upon weathering impart a characteristic rusty appearance to the rock. This lithology is massively bedded and blocky jointed.

Dark-gray to black bedded chert with laminae up to three centimeters thick form lenticular pods up to one meter thick and less than 20 meters long. Bedded chert forms a very minor proportion of the unit. Limestone in the section is massive and forms discontinuous beds up to five meters thick. The limestone is dark gray due to the presence of graphite, and it locally contains up to one percent disseminated pyrite cubes.

A massive barite bed is exposed in the Hoodoo Mine workings. Sulfur isotopes from the barite suggest a seawater source and thus a syngenetic origin of the barite (W. Hall, pers. comm., 1982). The barite has a sugary texture and is commonly massively bedded. However, locally millimeter- to centimeter-scale bedding is in part defined by very fine-grained pyrite and sphalerite. Soft-sediment folding is also common within the barite bed (Figure 3).

Middle Facies C (Dmfc)

Siliceous and carbonaceous argillite, chert, and quartzite beds south of the Hoodoo Mine comprise the middle facies C unit. These rocks grade laterally into the middle facies B. This facies transition is marked north to south by a loss of limestone, appearance of quartzite,

Figure 3: Soft-sediment folding of laminated barite ore. Hoodoo Mine. Laminations in part defined by fine-grained pyrite and sphalerite.

and a gradual reduction in carbon content. The presence of quartzite without limestone in the section characterizes the middle facies C.

Quartzite in this unit is dark gray due to the presence of graphite. The rock is massive and blocky jointed and forms beds up to two meters thick. Dark-gray to black bedded chert forms lenticular beds up to one meter thick with individual laminae up to three centimeters thick.

Carbonaceous Argillite (Dca)

Carbonaceous argillite occurs throughout the lower and middle facies sections as distinct lenses mostly up to a few meters thick and a few hundred meters long. However, near the stratigraphic top of the middle facies section, large accumulations of carbonaceous argillite host most of the mines and prospects in the study area.

Carbonaceous argillite near the top of the middle facies section forms large lenticular beds up to 800(?) meters thick which are traceable for up to 4,000 meters along strike. Individual beds are very thin (< 1 centimeter) to massive (>1 meter). In the southern part of the map area, near the Livingston and Little Livingston Mines, light- to dark-gray, carbonaceous, massive limestone forms beds up to 10 meters thick.

Middle to Upper Facies Transition (stipling)

In the east and central portions of the map area the fine-clastic rocks grade upward to interbedded fine- and slightly coarser-clastic rocks. These transition strata are characterized by coarser grain size, minor graphite, local carbonate, and a distinctive platey to fissile parting.

East of Silver Rule Creek the transition zone is characterized by siliceous argillite and fine-grained sandstone interbeds up to 10 centimeters thick. These sandstone beds are buff and locally graded. West and south of Silver Rule Creek, in particular above the Tango Mine, the interval is marked by siliceous argillite interbedded with five-centimeter-thick beds of light gray to buff, carbon-free siltstone.

Upper Facies (Mufl, Muf2, Muf3)

Upper facies rocks are part of the Mississippian Copper Basin Group and crop out in the eastern and central portions of the map area. Lithologies include interbedded siltstone, calcareous siltstone, and fine-grained sandstone (Mufl); fine- to medium-grained sandstone (Muf2); and intercalated siltstone and shale (Muf3). Exposure of Mufl is restricted to east and north of Silver Rule Creek; Muf2 crops out in the extreme northeast; and Muf3 is exposed in the central portion of the study area. All upper facies units are characterized by their tan to buff color, fissile to platy parting, and millimeter- to centimeter-scale bedding. Detrital tourmaline grains occur in the majority of upper facies rocks examined.

Wood River Formation (Pwr)

A thrust sheet of Pennsylvanian- to Permian-age Wood River Formation rocks overlies the Devonian and Mississippian section and forms the western boundary of the study area. The Wood River Formation is composed of voluminous tan quartzite beds and gray limestone with minor dark-gray argillite. Conglomerate and tectonic breccia locally form the sole of the thrust sheet. Since these rocks are not within the scope of this study, the reader is referred to Bostwick (1955) and Thomasson (1959) for further lithologic description.

Idaho Batholith and Related Rocks (Tki)

Intrusive rocks of the late-Cretaceous to early-Tertiary Idaho Batholith and White Cloud Stock border the study area on the north and south. Compositions of the main intrusive bodies range from quartz monzonite to quartz diorite. Both intrusions are medium-grained and equigranular. Tertiary-age, porphyritic rhyolite dikes cut the region (Tschanz and others, 1974), and one is exposed in the Livingston Mine. Additional information on the igneous history of the area can be gathered from Tschanz and others (1974).

Challis Volcanics (Tc)

Intercalated lavas, ash-flow tuff, airfall tuff, and epiclastic rocks of the Eocene Challis Volcanics border the study area on the east. The volcanic stratigraphy lies unconformably on a surface of medium relief of at least a few hundred meters developed on the Devonian- to Mississippian-age strata. More information on Challis stratigraphy and petrology/petrography can be obtained from Ross (1961, 1962) and Leavitt (1980).

Metamorphism

Rocks in the study area have undergone at least two periods of metamorphism. The first period consists of Mesozoic(?)-age regional metamorphism to the greenschist facies. The second is a superimposed thermal metamorphism induced by intrusion of the Idaho Batholith and White Cloud Stock. Effects of the first event are documented in middle-Paleozoic pelitic rocks and consist of the development of slatey cleavage parallel to bedding and, the formation of a greenschist mineral assemblage. The presence of muscovite, chlorite, actinolite, albite, calcite, epidote, and locally biotite suggests conditions of the chlorite and biotite zones of the greenschist facies were attained during this metamorphic period (Hyndman, 1972).

Thermal metamorphism related to intrusions in the Slate Creek area produced different mineral assemblages and hornfelsic textures which are superimposed on schistosity developed during the previous regional event. Effects of the thermal metamorphism are present in all rocks exposed in the area, and are best developed adjacent to the intrusions. Local skarns are present adjacent to the White Cloud Stock. The skarns are characterized by coarse grain size (up to 5 millimeters), random mineral orientation, and an interlocking habit of mineral constituents. Metamorphic grade in the skarns is the hornblende hornfels facies based on the presence of calcite, diopside-hedenburgite, orthoclase, and muscovite (Hyndman, 1972). Other rocks in the middle-Paleozoic section exposed in the area display a hornfelsic texture. The texture is defined by randomly-oriented grains of scapolite, andalusite, tremolite-actinolite, diopside, muscovite, and biotite. These minerals, superimposed on textures developed during regional metamorphism, are typically coarser-grained than the regional assemblage. These minerals indicate the rocks belong to both the albite-epidote hornfels and hornblende hornfels facies (Hyndman, 1972).

Structure

Soft-sediment folds, developed during deposition and diagenesis, is common in chert- and barite-rich strata in the area. This folding displays no consistent orientation and is very limited in extent. Commonly this deformation style can be traced along strike or up section for less than a few meters. Figure 3 shows soft-sediment folding in barite from the Hoodoo Mine. Folds in bedded chert in the hanging wall of the Livingston Mine are well displayed in the 2,000 level portal.

Major structural deformation of middle-Paleozoic rocks in the area formed by metamorphism and compressional stress related to the late-Cretaceous to early-Tertiary age emplacement of the Idaho Batholith to the north and the White Cloud Stock to the south. Intrusion of the two magmas apparently created a prominent east-west fold system. Folds in the north and south portions of the area are isoclinal and locally overturned to almost recumbent in nature. These folds are best developed in lower facies A rocks adjacent to the White Cloud Stock (Figure 4). Fold wave lengths typically range up to a few tens of meters. However, in the central portion of the area near the Tango Mine, larger open folds with wave lengths up to 650 meters are present. Here, transition and upper facies rocks are preserved in a synclinal trough.

The east-west fold system has been warped in the vicinity of the White Cloud Stock. Original fold axes in upper Slate Creek trend northeast, those between upper Slate Creek and Crater Lake trend

Figure 4: Isoclinal folds in Dlfa adjacent to White Cloud Stock.

east-west, and those from Crater Lake to the Livingston Mine trend northwest. A few kilometers north of the White Cloud Stock fold axes do not display any second generation warping and all trend approximately east-west.

Emplacement of the White Cloud Stock created a concentric, high-angle normal fault which juxtaposes lower facies A rocks with rocks high in the middle facies. Normal faulting and uplift of lower facies A rocks are also evident adjacent to the northern intrusive body. These uplift events resulted in the development of an intervening graben within which the remainder of the middle-Paleozoic section is preserved (see Fence Diagram, Plate 2).

Bedding plane slippage, breccias, and small-scale thrusts are common throughout the section and make thickness estimates difficult (Figure 5). However, based on structural interpretation and topographic relief, a minimum of 1,600 to 2,300 meters (5,000 to 7,000 feet) of Devonian and Mississippian stratigraphy is exposed in the Slate Creek area.

Most workers who have studied the middle-Paleozoic section in the area have suggested very complex structural history (Ross, 1937; Kiilsgaard, 1949; Kern, 1972; Tschanz and others, 1974; and Thompson, 1977). Structure does appear complex when viewed at outcrop scale due to the combination of east-west folding and chaotic soft-sediment deformation. However, regionally the middle-Paleozoic strata north of the White Cloud Stock dips gently north.

Figure 5: Bedding-plane deformation and thrusting in Dmfa. Hammer handle is approximately 90 centimeters long.

Mineralization

All significant lead-zinc-silver sulfide mineralization occurs in the carbonaceous argillite unit (Dca) at the top of the middle facies section or in carbonaceous members near the stratigraphic top(?) of Dmfb. Minor base- and precious-metal deposits are located lower in the Devonian section and most of these are also hosted by carbonaceous argillite.

Seven textural types of mineralization are recognized in the Slate Creek area (Table 1). Following are descriptions of the textural types based on field relationships and hand-sample and microscopic analysis.

Textural Type I

Textural type I consists of laminated iron, zinc, and lead sulfides hosted by carbonaceous argillite. Pyrite and sphalerite best display the bedded nature of the sulfides (Figures 6, 7, and 8). Galena and jamesonite locally are bedded, but typically the minerals have a streaky appearance (Figure 9). Individual sulfide laminae in type I ores range from millimeter- (Figure 6) to centimeter-scale (Figure 9).

Chert is interbedded with base-metal sulfides in this textural type, but only locally present with the pyrite-rich stratigraphy. Average sulfide grain size for pyrite is 0.5 millimeter. Galena and/or jamesonite are present as grains (0.75 mm) and as larger annealed masses (average 2.5 mm). Accessory sulfide minerals in this textural type include chalcopyrite, covellite, tetrahedrite, and pyrrhotite. Chalcopyrite occurs as individual grains and as exsolution lamallae in sphalerite (Figure 10). Covellite of probable secondary origin has only been seen in hand sample where it forms a blue tarnish on

TABLE 1: ORE TEXTURAL TYPES

Ore Textural Type	Texture	Host Rocks	Stratigraphic Relationships	Dominant Sulfide/Sulfate Species	Accessory Sulfide Species	Gangue Mineralogy	Grain Size - Dominant Sulfide Species	Mines Present
I	Stratiform	Carbonaceous Argillite	Conformable	Pyrite Sphalerite Galena Jamesonite	Chalcopyrite Covellite Tetrahedrite Pyrrhotite	Chert	.5 to .75 mm	Carbonate Hermit Tango Livingston
II	Breccia	Carbonaceous Argillite	Conformable	Pyrite Sphalerite Jamesonite Galena Pyrrhotite	Chalcopyrite Covellite Tetrahedrite Arsenopyrite Native Silver(?)	Chert	.025 mm, .5 mm Pyrite Porphyro- blasts	Carbonate Livingston Little Livingston
IIa	Breccia	Carbonaceous Argillite	Conformable	Sphalerite Pyrite	Galena Chalcopyrite	Chert	Sphalerite in Coarse- Grained Aggregates- 5 mm; Pyrite- .5 mm	Hoodoo
III	Breccia	Carbonaceous Argillite	Cross-Cutting	Pyrite Sphalerite Galena Pyrrhotite	Chalcopyrite Covellite Tetrahedrite Arsenopyrite Native Silver(?)	Chert	.025 mm, .5 mm Pyrite Porphyro- blasts	Carbonate
IIIa	Breccia	Carbonaceous Argillite	Cross-Cutting	Splaherite Pyrite	Galena Chalcopyrite	Chert	Splalerite in Coarse- Grained Aggregates- 5 mm; Pyrite- .5 mm	Hoodoo

TABLE 1: ORE TEXTURAL TYPES (Continued)

Ore Textural Type	Texture	Host Rocks	Stratigraphic Relationships	Dominant Sulfide/Sulfate Species	Accessory Sulfide Species	Gangue Mineralogy	Grain Size - Dominant Sulfide Species	Mines Present
IV	Laminated to Massive Soft Sediment Folds	Carbonaceous Argillite	Conformable	Barite Pyrite Sphalerite Jamesonite	Smithsonite as Oxidation Product	Calcite	Barite-.75 mm Sulfides-.5 mm	Hoodoo
V	Massive Sulfides in Aggregates	Carbonaceous Argillite	Conformable	Barite Pyrite Sphalerite Jamesonite	Smithsonite as Oxidation Product	Calcite	Barite-.75 mm Sulfide Aggregates-5 mm	Hoodoo
VI	Massive	Carbonaceous and Siliceous Argillite	Cross-Cutting	Pyrite Sphalerite Galena	---	Quartz Siderite	2.5 mm	All
VII	Disseminated and Fracture-Coating	Rhyolite	Conformable and Cross-Cutting	Pyrite Sphalerite Jamesonite	---	---	1 mm	Livingston

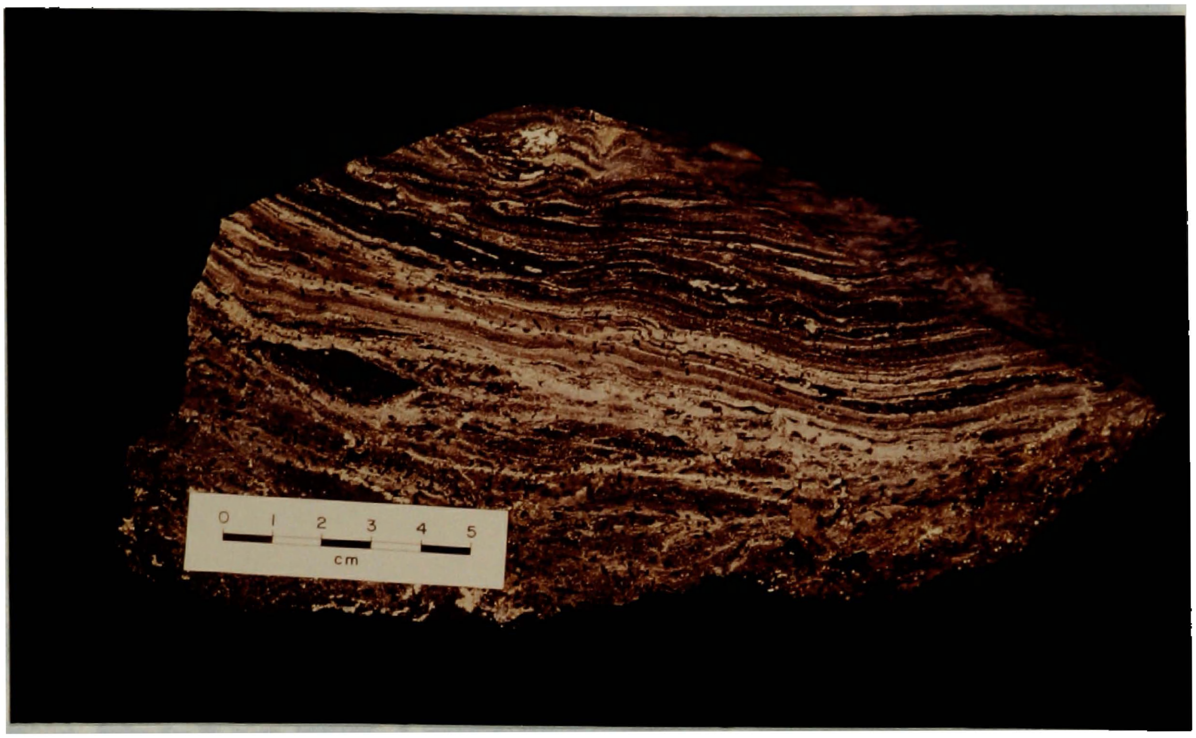


Figure 6: Textural Type I. Laminated pyrite and carbonaceous argillite. Livingston Mine. Note randomly-oriented amphibole grains.

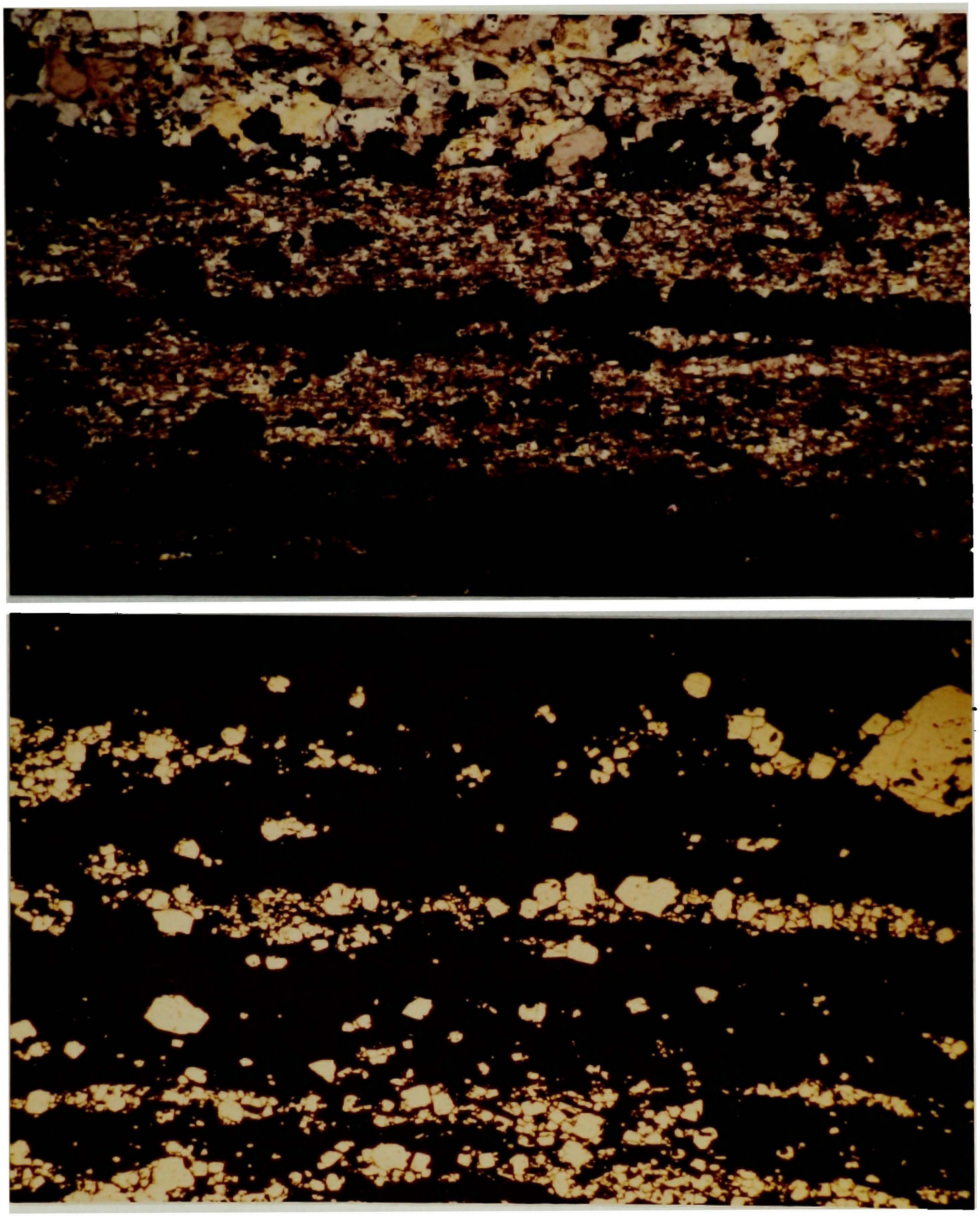


Figure 7: Textural Type I. Photomicrograph of bedded pyrite and carbonaceous argillite. Livingston Mine. Transmitted light with crossed nicols at top, reflected light at bottom. Horizontal field of view approximately 1 cm.

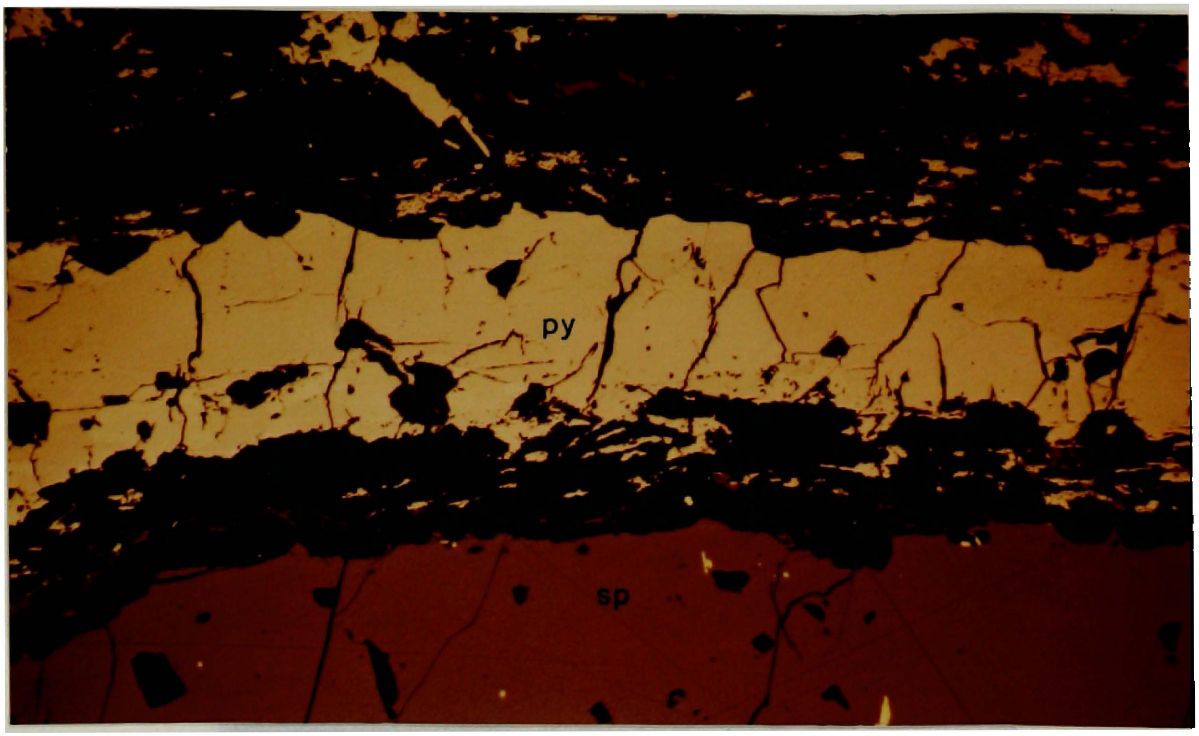


Figure 8: Textural Type I. Photomicrograph of bedded pyrite (py), sphalerite (sp), and carbonaceous argillite. Livingston Mine. Reflected light. Horizontal field of view approximately 0.65 cm.

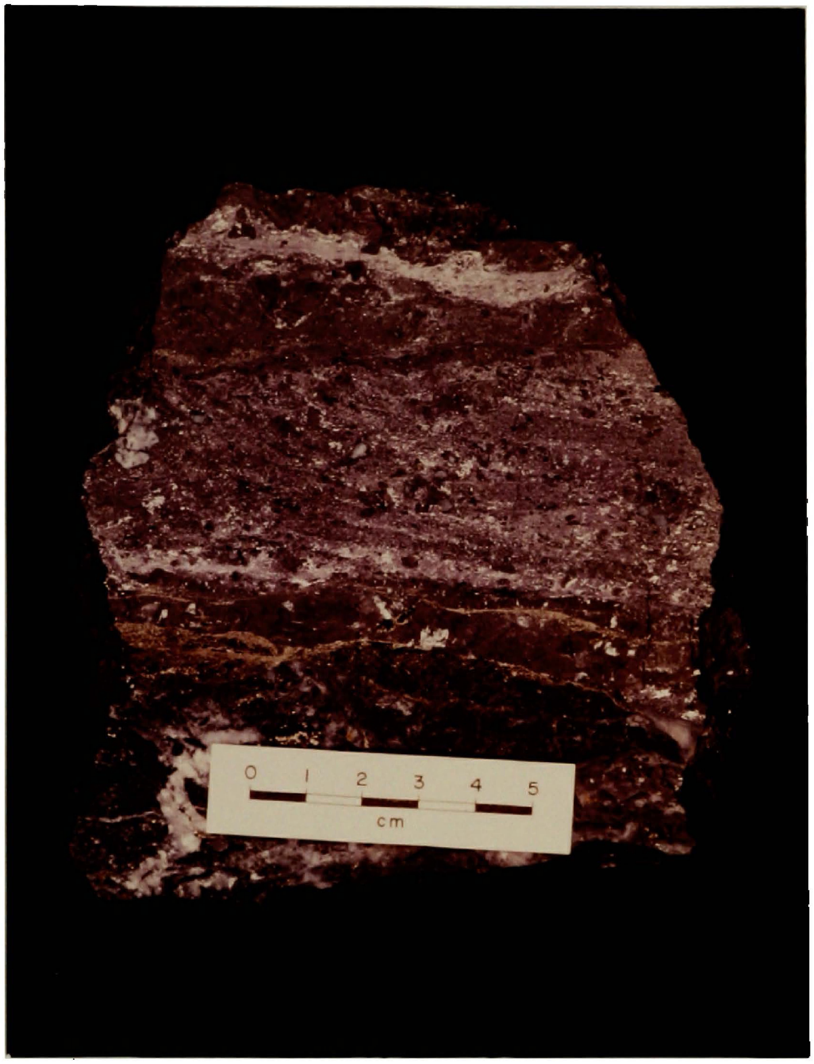


Figure 9: Textural Type I. Sphalerite (dark bands) displays bedded nature. Galena (light-gray zone) displays wispy and semi-brecciated texture. Breccia clasts are chert. Carbonate Mine.

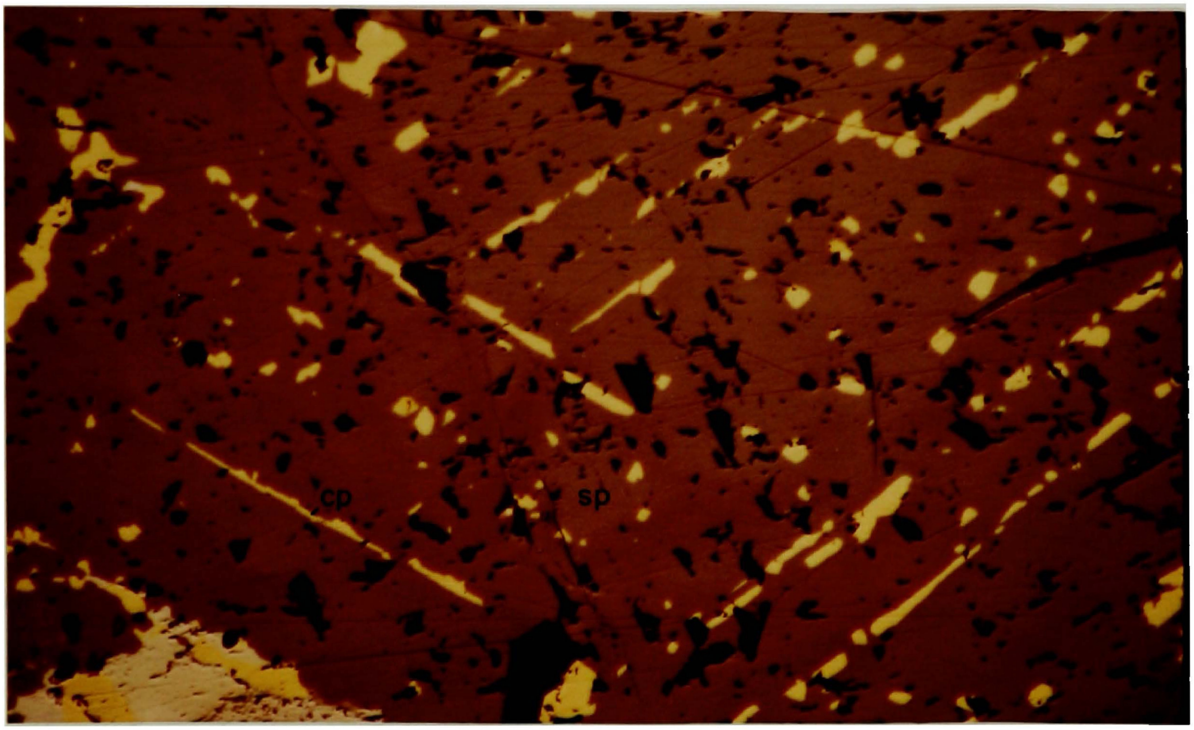


Figure 10: Photomicrograph of chalcopyrite (cp) exsolution lamallae in sphalerite (sp). Little Livingston Mine. Reflected light. Horizontal field of view approximately 3.5 mm.

chalcopyrite-rich sphalerite. Tetrahedrite occurs as small blebs along the common boundaries of sphalerite and galena (Figures 11 and 12). Pyrrhotite has only been recognized with pyrite in iron-rich ores such as shown in Figure 6. Textural type I ore is exposed in the Carbonate, Hermit, Tango, and Livingston Mines.

Textural Type II

Textural type II ores are breccias of predominately lead sulfides and chert. These breccias are characterized by 30 percent well rounded chert and subangular to rounded carbonaceous wall-rock fragments set in a chaotic matrix of sulfides and gangue quartz (Figure 13). Type II ores are conformable to the enclosing host rocks. This texture is typical of most lead-rich zones of the orebodies in the Slate Creek area. Fragments of chert and carbonaceous argillite wall rock in the breccias vary from less than one centimeter up to three centimeters in diameter. Base-metal sulfides in type II ores all average 0.025 millimeter in diameter. Pyrite is coarser and averages 0.5 millimeter. Sulfide minerals in this textural type include pyrite, sphalerite, jamesonite, galena, and pyrrhotite. Chalcopyrite, covellite, tetrahedrite, arsenopyrite, and native silver(?) are accessory minerals. These accessory minerals form distinct random grains or are present with the dominant sulfide species as exsolution lamallae, enclosed grains, or along grain boundaries. Textural type II ores are exposed in the Carbonate, Livingston, and Little Livingston Mines.

Textural type IIa is similar in character to type II ores, however, sphalerite is the dominant sulfide species. Chert is less abundant in

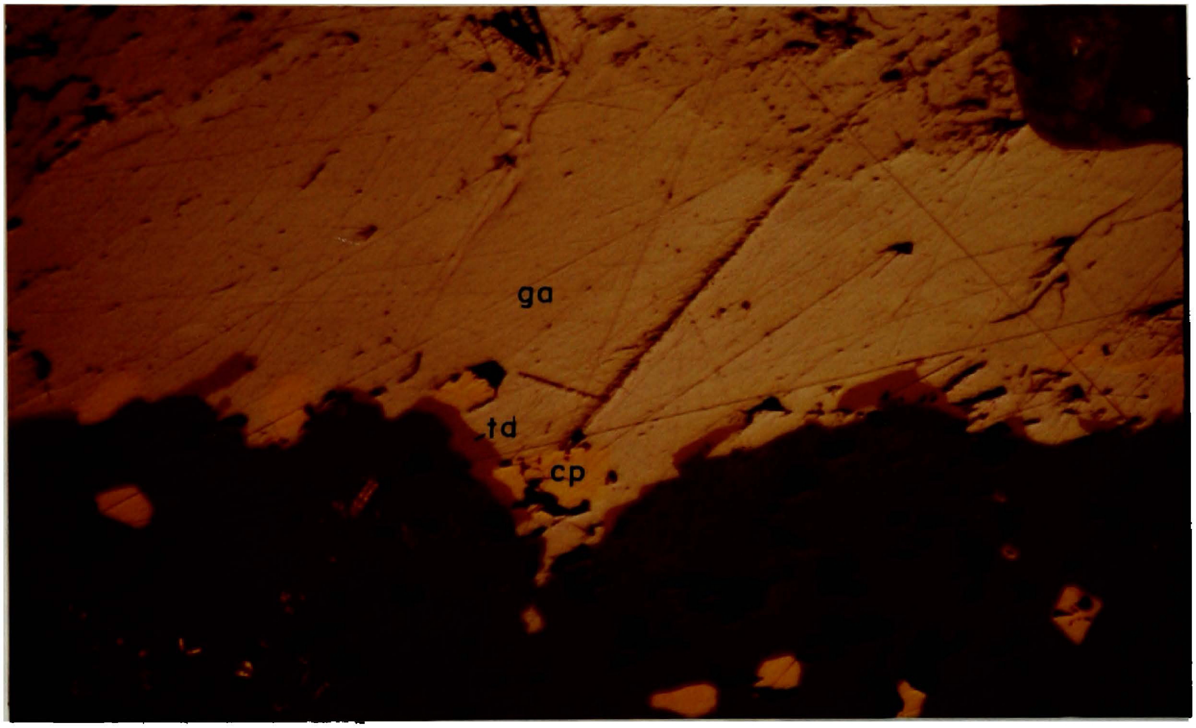


Figure 11: Photomicrograph of galena (ga), sphalerite (sp), chalcopyrite (cp), and tetrahedrite (td). Note tetrahedrite only occurs along common grain boundaries of galena and sphalerite. Little Livingston Mine. Reflected light. Horizontal field of view approximately 2 mm.

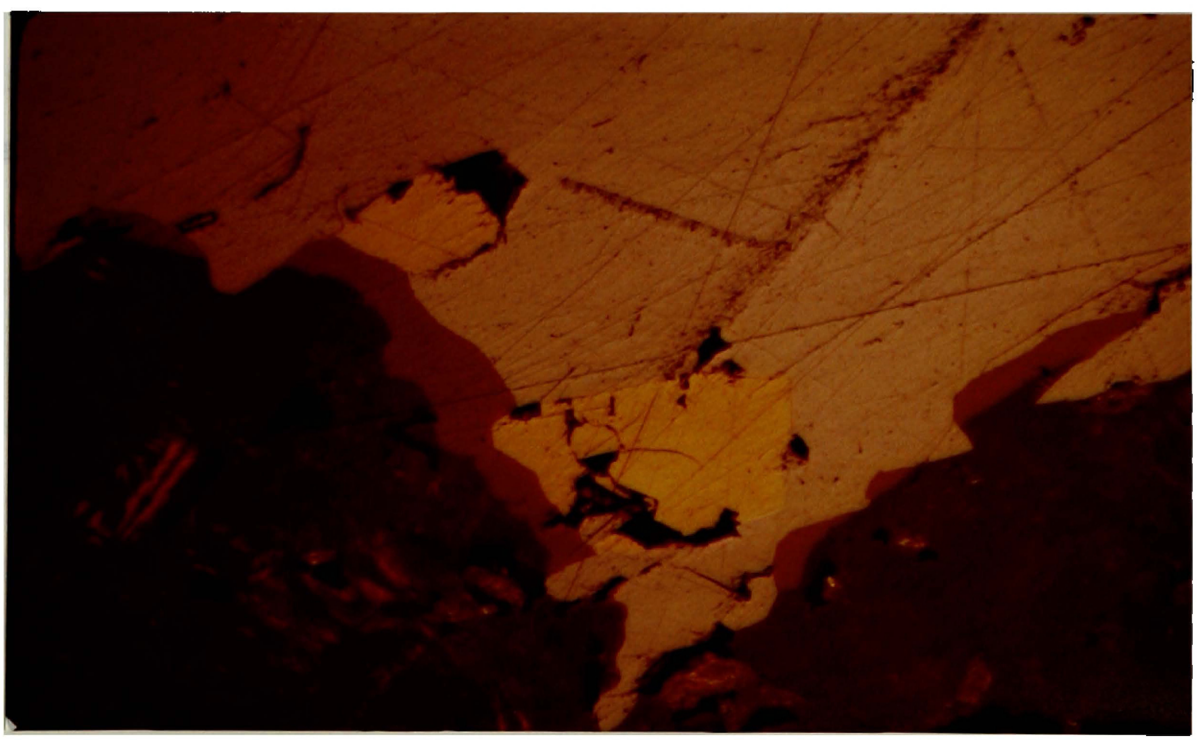


Figure 12: Close-up of Figure 11 above. Reflected light. Horizontal field of view approximately 0.8 mm.

Figure 13: Textural Type II. Massive lead-rich breccia from Livingston Mine.

type IIa ores. Sphalerite forms crystal aggregates up to five millimeters in diameter. Type IIa ore is present only at the Hoodoo Mine.

Textural Type III

Type III ores are similar in internal structure to type II, however, they occur in cross-cutting vein structures (Figure 14). Grain size of the matrix and clasts, sulfides, accessory sulfides, and the gangue minerals are the same as in type II ores. Type III ore was only noted in the Carbonate Mine. A sphalerite-rich variety (type IIIa) was observed in the Hoodoo Mine (Figure 15), and is similar to type IIa ores.

Textural Type IV

Textural type IV ores consist of both massive barite and calcite (Figure 16), and laminated barite, calcite, pyrite, sphalerite, and rarely jamesonite (Figure 17). Massive ore of this textural type has a sugary texture produced by grains which average 0.75 millimeter in size (Figure 18). The massive form is the most common of type IV ores. Laminated varieties have millimeter- to centimeter-scale banding defined by sulfide minerals (Figure 17). Sulfide grains average 0.5 millimeter in diameter. Textural type IV ores are present only at the Hoodoo Mine.

Very localized soft-sediment folds occur in this ore type (Figure 3). Sphalerite is commonly altered to smithsonite. The smithsonite occurs as fine, pale yellow crystals which surround sphalerite in oxidized portions of the ore. The yellowish color is

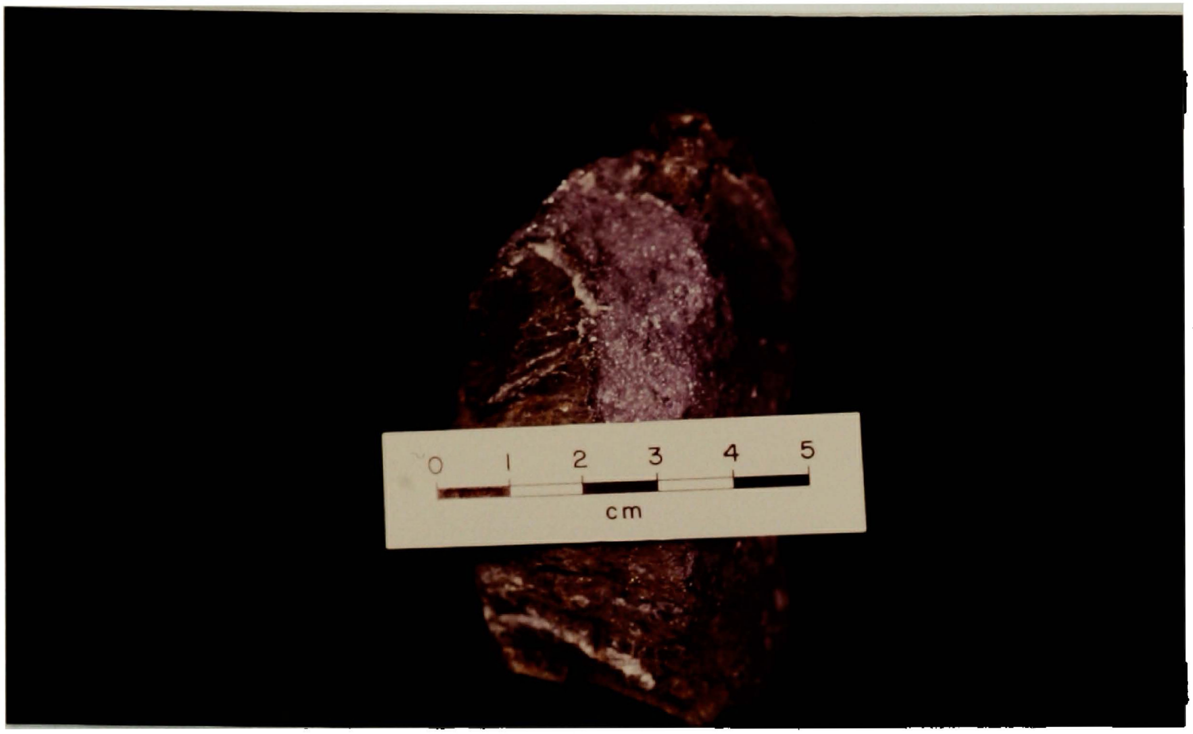


Figure 14: Textural Type III. Cross-cutting massive sulfide vein. Carbonate Mine.

Figure 15: Textural Type IIIa. Massive sphalerite with minor carbonaceous wall-rock fragments. From cross-cutting vein structure. Hoodoo Mine.

Figure 16: Textural Type IV. Massive calcite-barite. Hoodoo Mine.

Figure 17: Textural Type IV. Laminated calcite, barite, and sulfides. Sulfides include pyrite, sphalerite, and jamesonite. Hoodoo Mine.

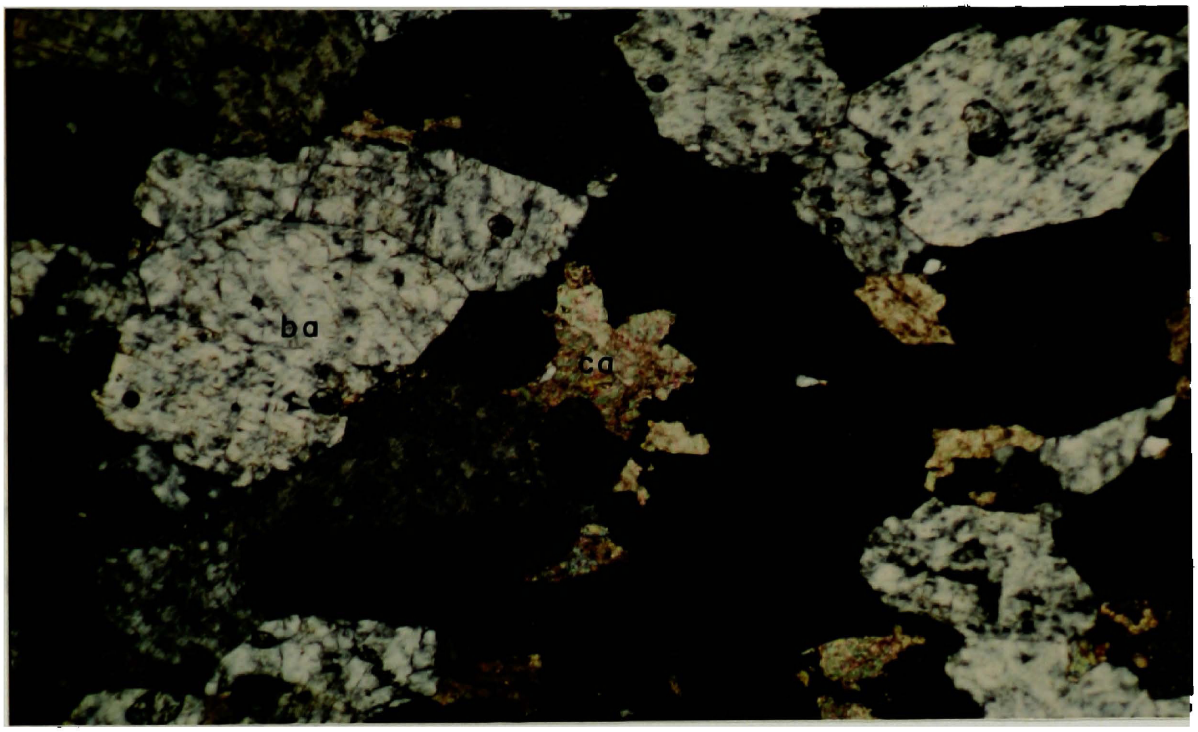


Figure 18: Textural Type IV. Photomicrograph of barite (ba) and calcite (ca). Hoodoo Mine. Crossed nicols. Horizontal field of view approximately 1 cm.

imparted by cadmium (Prinz and others, 1977) which has been detected at the Hoodoo Mine by Tschanz and others (1974).

Textural Type V

Type V ores consist of barite, calcite, and sulfide minerals similar to type IV, however, the sulfides are concentrated in pods set in massive sulfate and carbonate rock (Figure 19). These pods range up to eight centimeters in diameter. Sulfides include sphalerite, jamesonite, and pyrite. Grain size in the host barite and carbonate rock averages 0.75 millimeter and sulfide aggregates average five millimeters. As in type IV ores, smithsonite is the common secondary mineral (Figure 19). Type V is only exposed at the Hoodoo Mine.

Textural Type VI

Sulfide- and carbonate-bearing bull-quartz veins which cross-cut strata comprise textural type VI. These veins occur throughout the Devonian rocks and some extend through the Mississippian rocks. These veins at least in part originate in carbonaceous argillite units as at the Carbonate (Figure 20), Tango, and Livingston Mines. As a general rule, sulfide grain size in the veins is much coarser than in textural types I through IV. Sulfides average 2.5 millimeters (Figure 21) and occur as clusters and disseminated grains in the veins. Minerals observed include pyrite, sphalerite, and galena. Siderite is also a common constituent of the veins (Figure 20).

These veins were mined for base and precious metals by early prospectors. Upon following the veins down dip, many of these early-day

Figure 19: Textural Type V. Sulfide pod in calcite and barite. Sulfides include sphalerite and jamesonite. Note yellow smithsonite in upper-right corner. Hoodoo Mine.

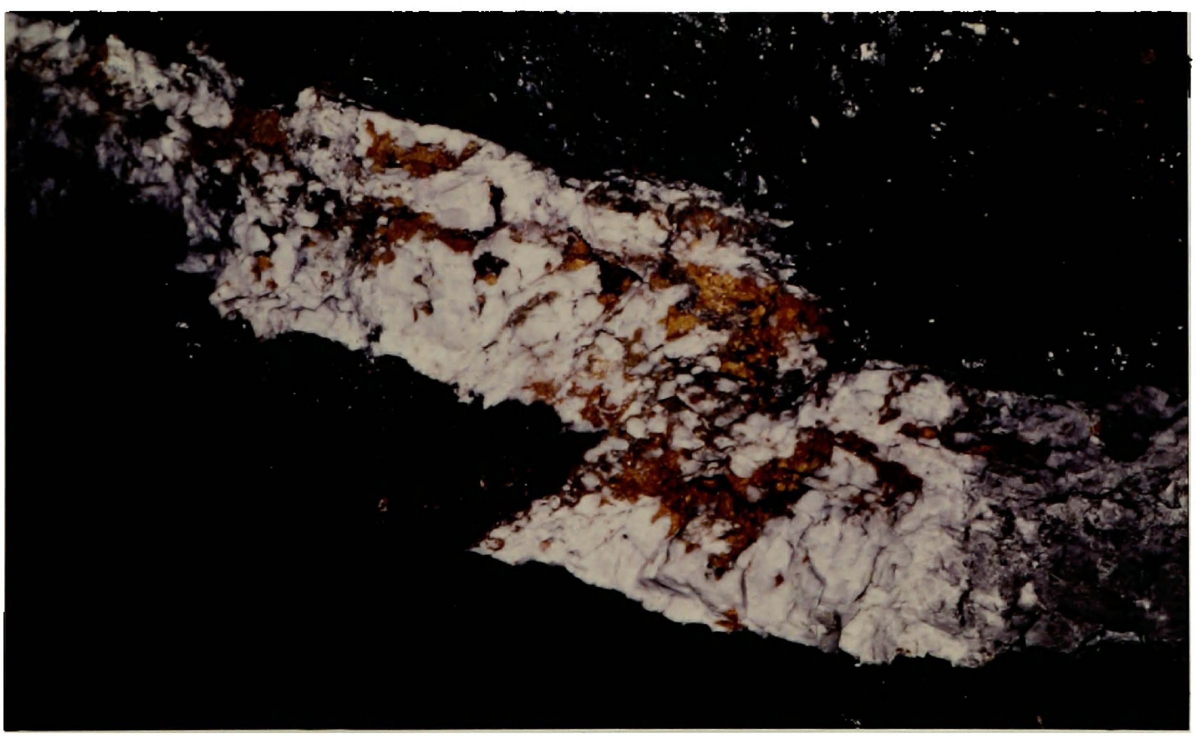


Figure 20: Textural Type VI. Quartz vein in carbonaceous argillite. Contains siderite, pyrite, and sphalerite. Carbonate Mine. Vein is approximately 20 cm thick.

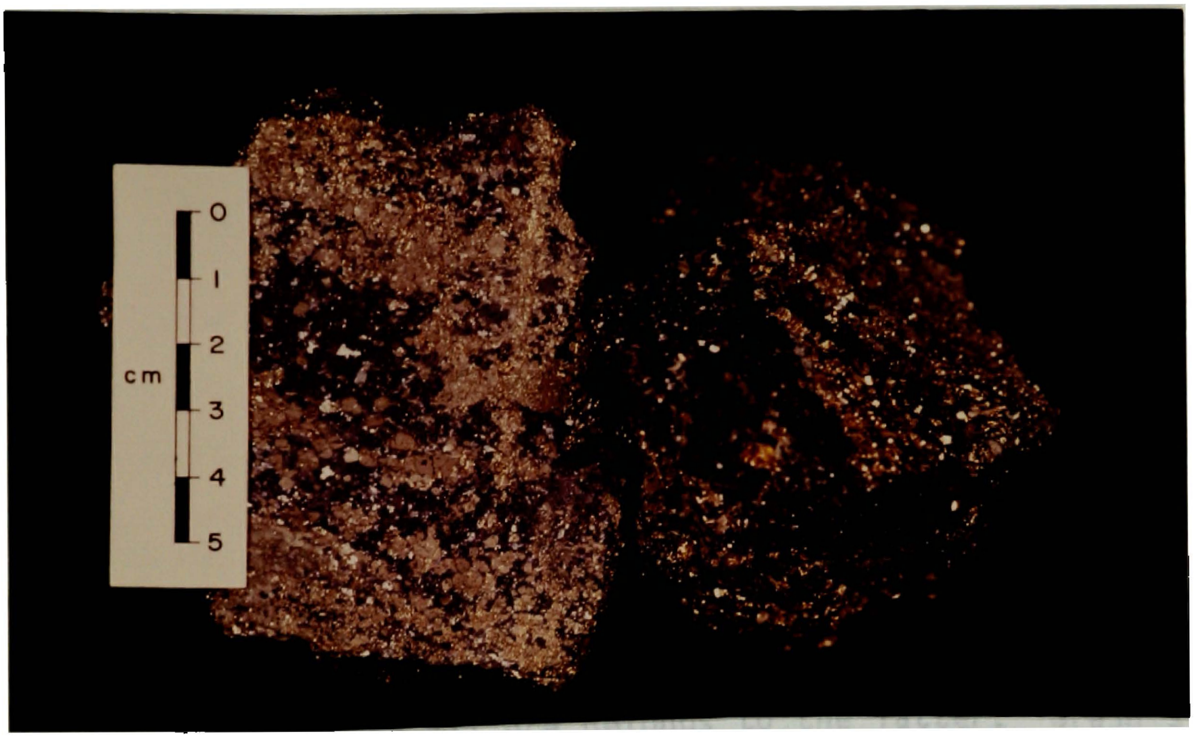


Figure 21: Textural Type VI. Massive sulfide pod from quartz vein. Sulfides include pyrite, galena, and sphalerite. Tango Mine.

miners intercepted ore of textural types I through III at depth. Lodes of the Silver Rule, Carbonate, Tango, and Hermit Mines were found in this manner (F. Fisher, pers. comm., 1982). The Copper prospect is an example of a textural type VI vein which cuts Mississippian rocks. This vein system is currently being explored for a potential "bonanza" type lode.

Textural Type VII

A rhyolite dike with disseminated and fracture-coating sulfide minerals is exposed in the Livingston Mine and is the only example of textural type VII ore in the Slate Creek area. The rhyolite parallels textural type II ore in the mine and contains pyrite, sphalerite, and jamesonite. In general, pyrite and sphalerite are disseminated in the dike rock while jamesonite is concentrated along fractures (Figures 22 and 23). Predominate type VII ore belongs to the latter. Grain size of the sulfides in the rhyolite is much coarser than in the adjacent textural type II. Average sulfide grain size is one millimeter in the dike rock and 0.025 millimeter in the type II ore.

The bulk of the highest-grade ore at the Livingston Mine was found by miners who explored the rhyolite dike and found textural types I and II at depth. Locally the rhyolite contained enough mineralization to warrant mining and consequently a large tonnage of this ore type has been milled (E. Swanson, pers. comm., 1982).

Carbonaceous rocks of Dca and Dmfb host textural types I through V exclusively and commonly contain portions of type VI. Host rocks directly adjacent to conformable mineralization display distinctive sequences. Barren carbonaceous argillite has a sharp upper contact with

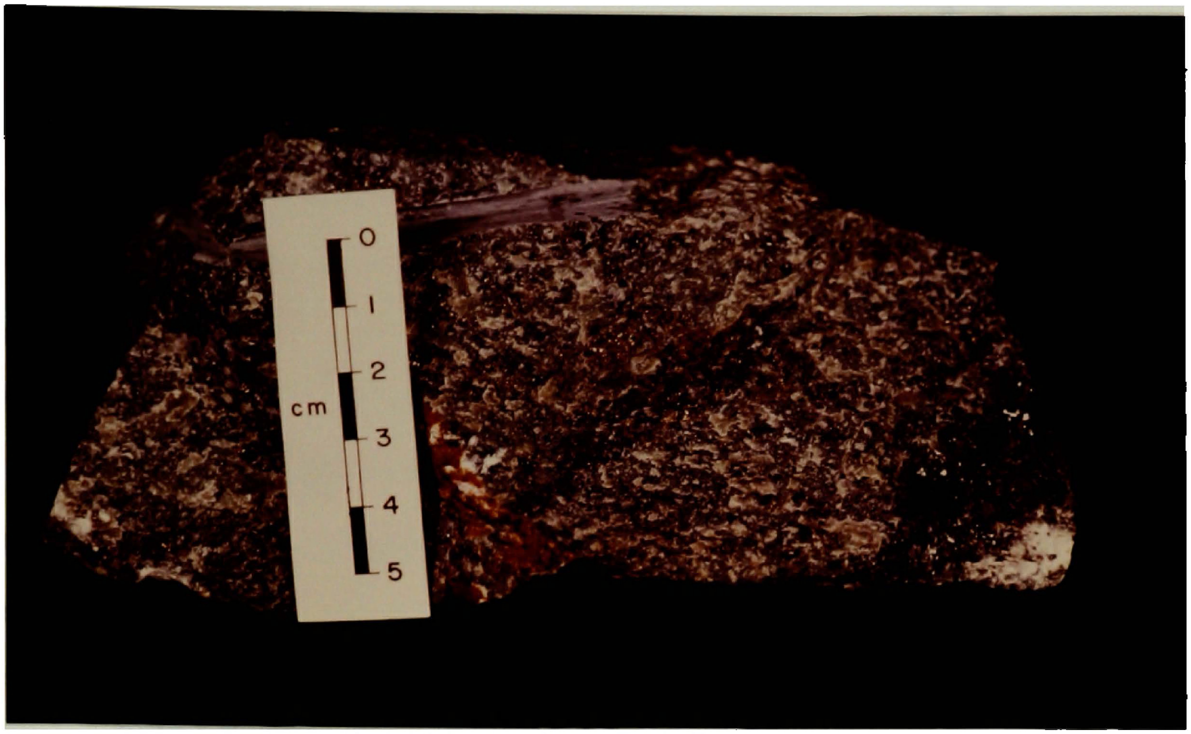


Figure 22: Textural Type VII. Disseminated pyrite and sphalerite in rhyolite. Livingston Mine.

Figure 23: Textural Type VII. Jamesonite on fracture in rhyolite. Livingston Mine.

siliceous, carbonaceous, and sulfide-rich rocks. The mineralized and chert-rich strata have a gradational upper contact with barren, pyritic carbonaceous argillite. The pyritic strata in turn grades upward to carbonaceous argillite similar to that located beneath the mineralized sequence. Figure 24 shows this stratigraphic interval exposed in Fox Gulch.

A zonation model of lead-zinc-silver mineralization of textural types I and II exposed in the Slate Creek area was developed by detailed examination of mineralogy and grade data from the Livingston and Carbonate Mines. A lead-iron-copper-silver core is flanked by lead-zinc-iron, which is in turn surrounded by a zinc-iron zone. An idealized cross-section of the Livingston orebody showing metal distribution and mine geology is presented on Figure 25. A similar zonation sequence was briefly mentioned by Ross (1937). Ross recognized that the highest-grade ore is restricted to the lead-rich core and that ". . . there is a tendency for the sphalerite to be relatively abundant on the borders of the orebody."

Lead-, iron-, copper-, and silver-bearing sulfide minerals of textural type II form the core of the Livingston orebody. Only a minor amount of chert is present within the core zone (Figure 13). Type II ores consisting of lead, zinc, and iron sulfides and up to 85 percent chert gangue surround the core zone. Minor carbonaceous argillite is present in this outer zone. Disseminated grains of sphalerite and pyrite in carbonaceous argillite and minor chert form a distinct halo around the inner two zones. Banded pyrite of type I in carbonaceous argillite (Figure 6) forms a distinct stratigraphic interval surrounding the

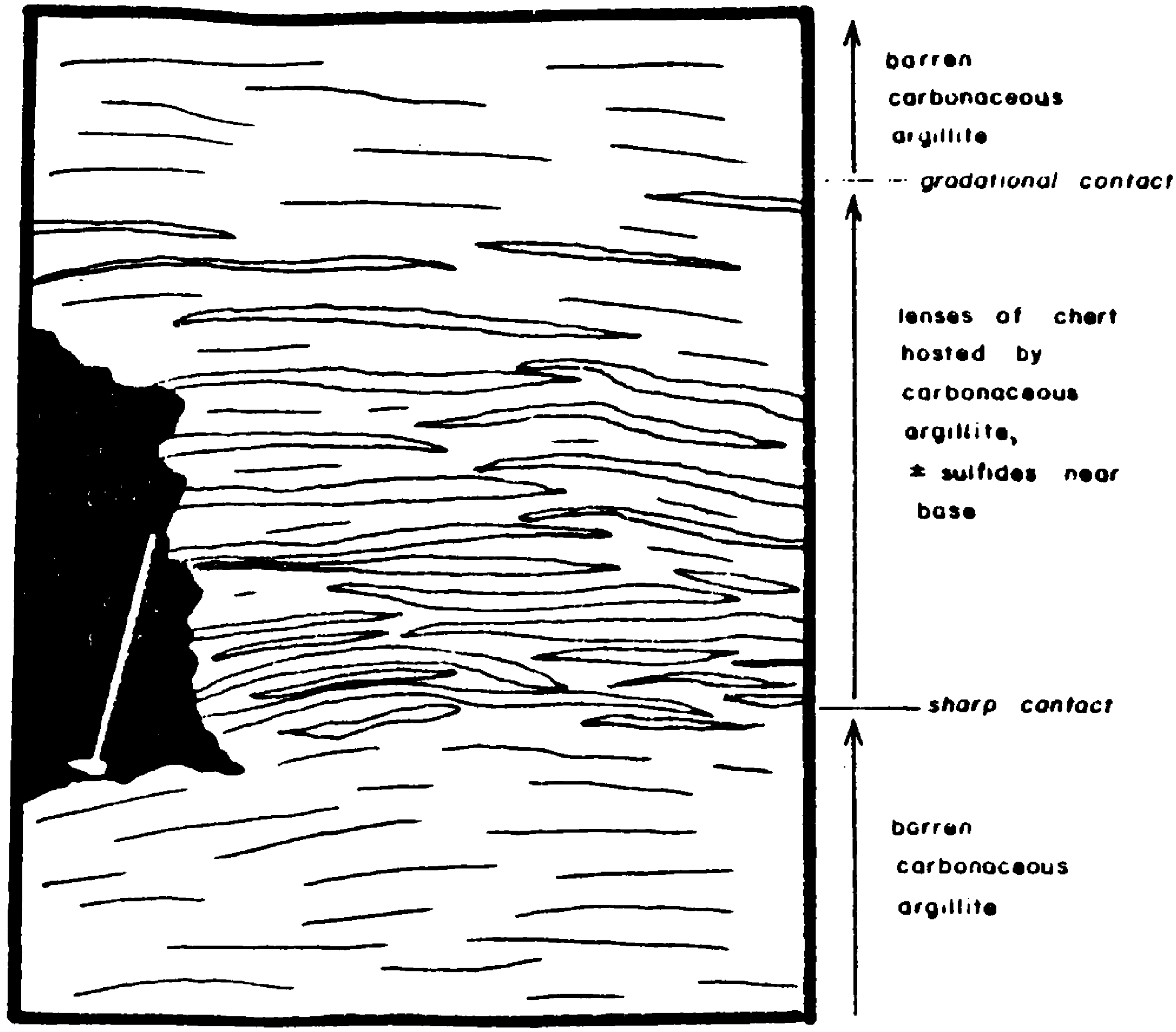


Figure 24. Ore stratigraphy – Fox Gulch area. Sketched from photo. Ore textural types I and II are hosted by similar stratigraphic sequences at Livingston, Tango, Hermit, and Carbonate Mines. Thickness of the sequences varies for each mine. Hammer handle is 90 cm long.

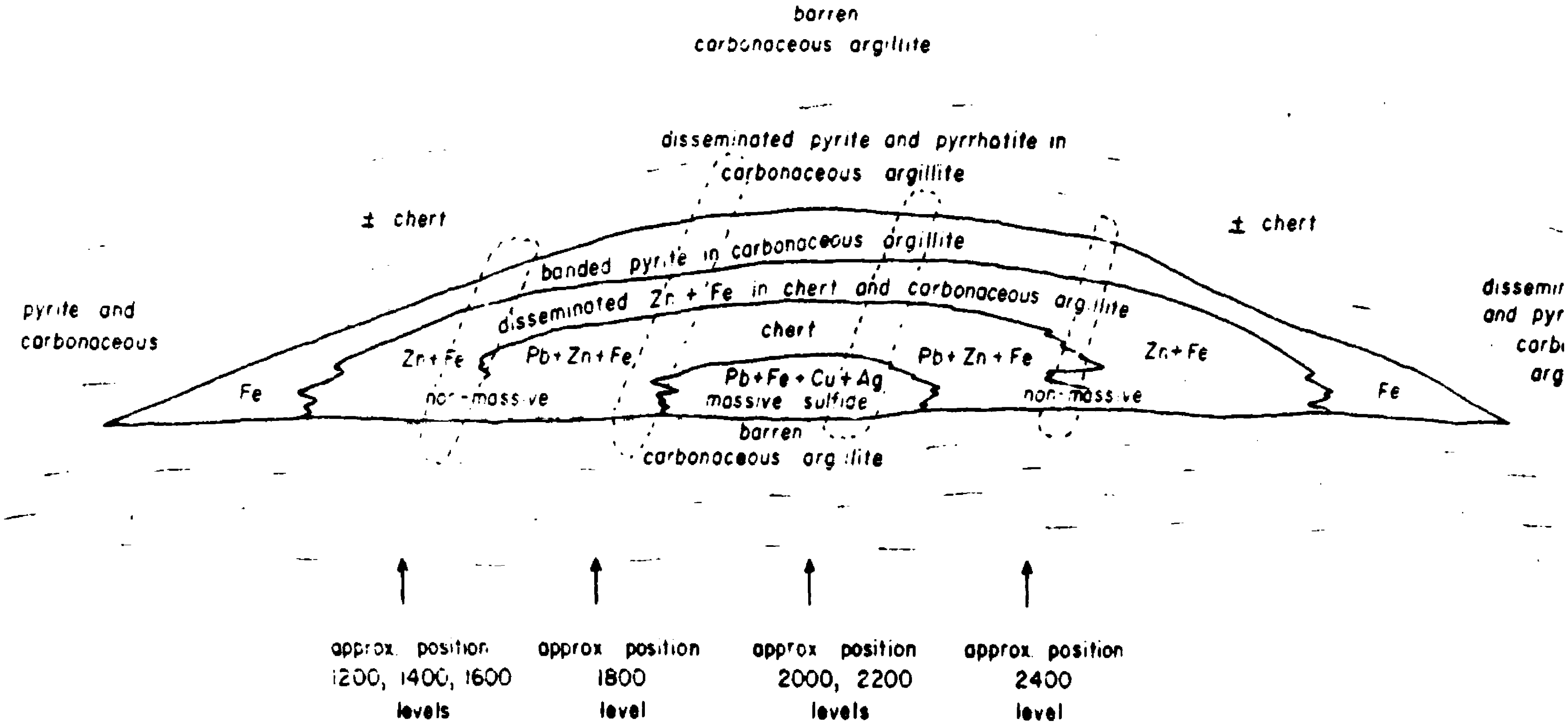


Figure 25: Cross-section of metal zonation model of the Livingston Mine orebody, 1200-2400 levels. Arrows project to metals and sulfide type exposed on the indicated levels (dashed lines). Orebody is elongate N-S and now dips NE. Exagerated vertical scale.

orebody. Disseminated pyrite and locally pyrrhotite form a halo around the ore-bearing stratigraphy and percentages of the sulfides diminish laterally and upsection. Chert becomes less abundant distally as well. Figure 26 shows the bedded chert from the Livingston Mine hanging wall strata.

Special textures in the ore stratigraphy are particularly well developed adjacent to textural types I and II. Carbonaceous argillite directly below sulfide zones is typically well laminated and displays minor deformation. Rocks immediately overlying the ore zones are commonly intensely deformed. Finely laminated rocks overlie sulfide zones within a few meters.

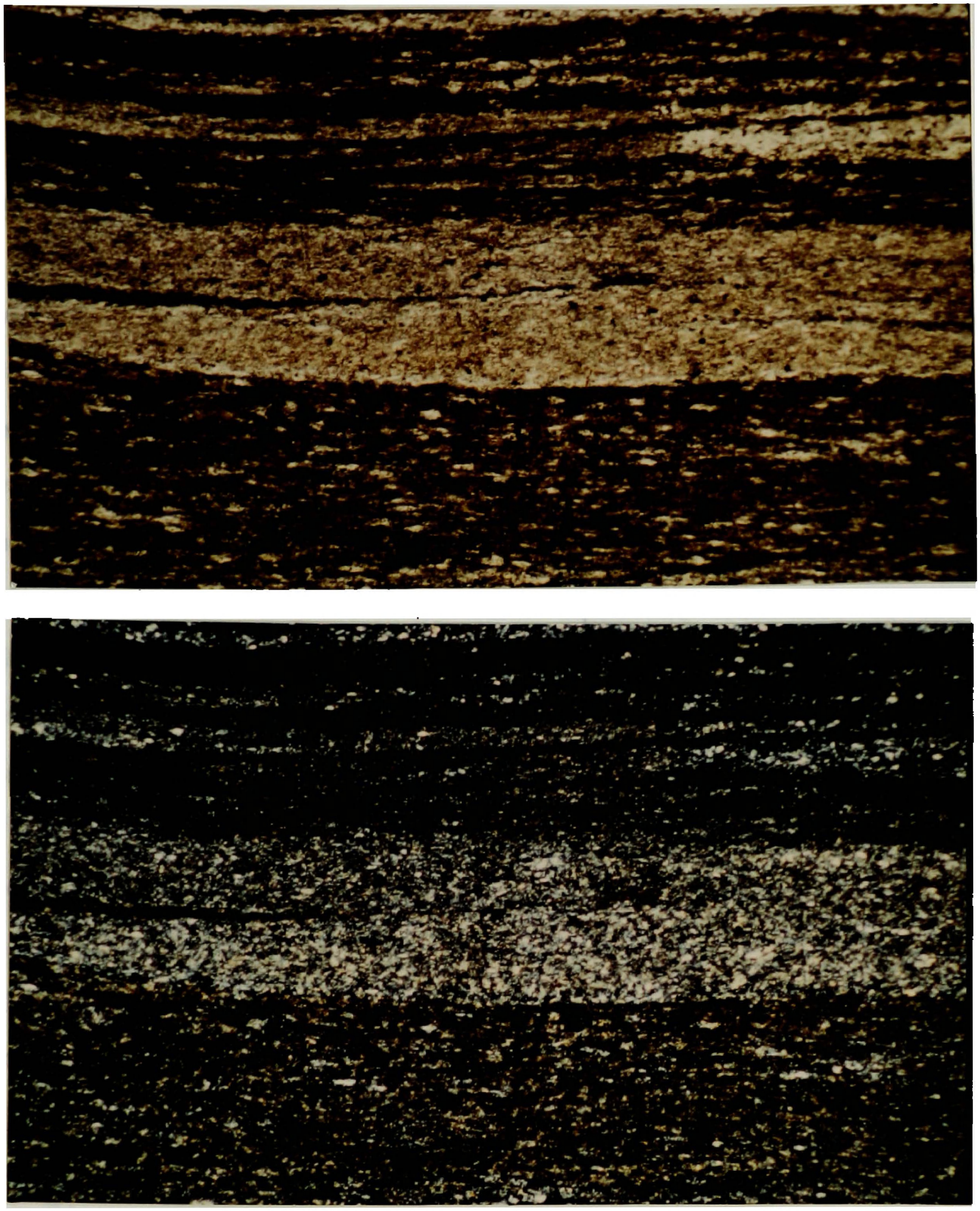


Figure 26: Bedded chert with minor micaceous and carbonaceous debris. Hanging wall Livingston Mine. Transmitted light at top, crossed nicols at bottom. Horizontal field of view approximately 1 cm.

CHAPTER IV

DISCUSSION

Sedimentation and Tectonic History

Stable depositional environments existed from at least middle-Ordovician through Devonian time in the region, and consisted of the development of an extensive carbonate platform and an adjacent shale basin (Churkin, 1962; Figures 27 and 28). Tectonism associated with the early- Mississippian Antler orogeny disrupted the stable conditions of sedimentation and resulted in an influx of coarse-clastic sediments into the shale basin. Predominant sediment input was from west to east from the Antler Highland (Skipp and others, 1979) (Figure 29). However, some tectonic activity to the east, perhaps affecting the shale basin or the carbonate shelf and shale basin margin, resulted in coarser clastics being shed westward as well. The westward transport direction is defined in the Slate Creek area by the westward fining of transition zone and upper facies rocks. The facies transition of medium- to fine-grained sandstones to siltstones and shales seen in this stratigraphic interval reflects distal sedimentation. This sedimentation may be record deposition of a submarine fan developed adjacent to a fault block created during Antler tectonic events, or may reflect a greater distance of westward transport of clastics from the shelf margin to the east. This increased transport distance may have been caused by change in basin morphology by Antler tectonism.

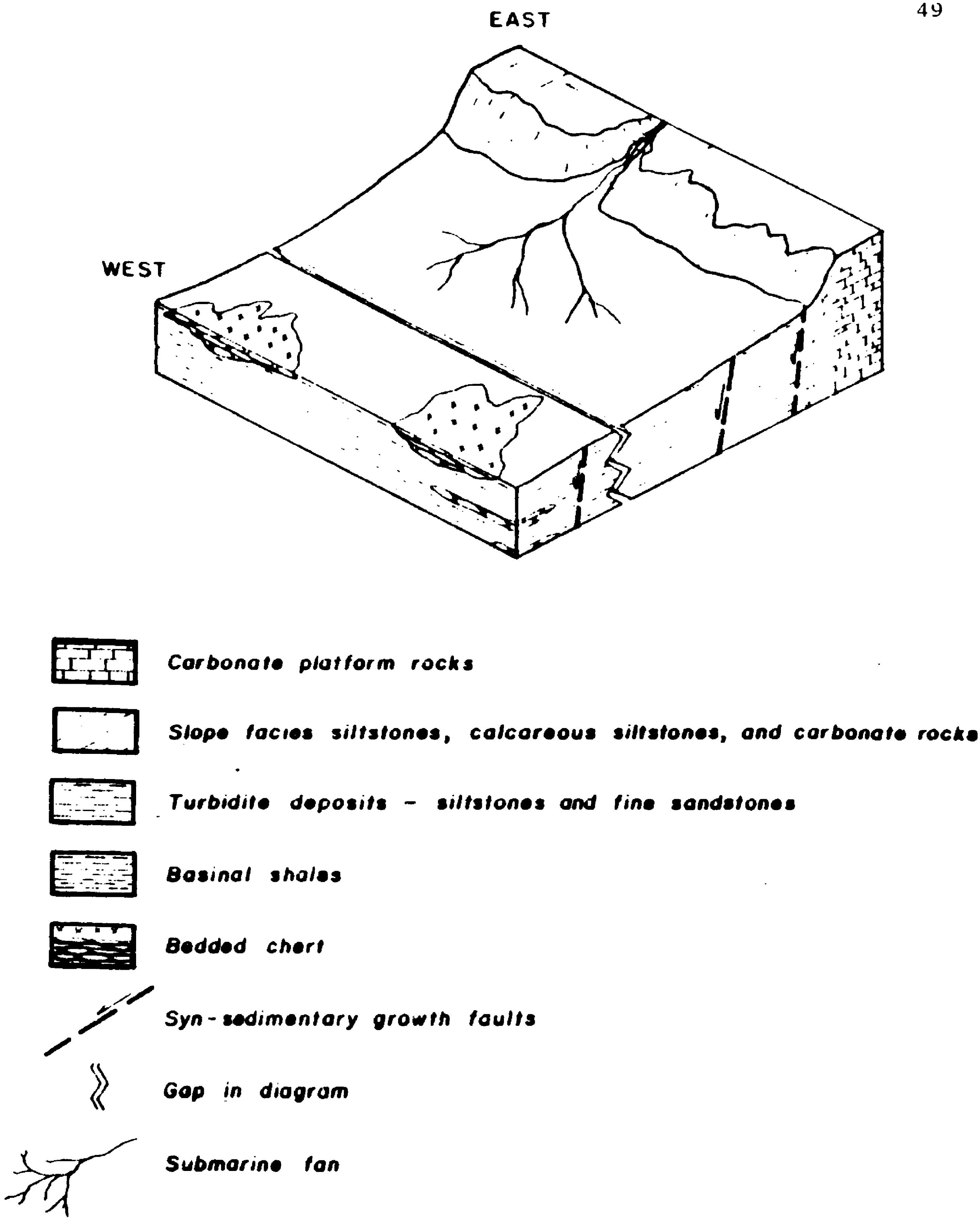


Figure 27. Idealized middle-Ordovician to late-Devonian time basin geometry across east-central Idaho.

EXPLANATION

B — *Middle-Paleozoic basinal rocks*

S — *Middle-Paleozoic carbonate shelf rocks*

? ...... ? — *Approximate boundary between carbonate shelf rocks to the east and shale basin rocks to the west*

Thesis area

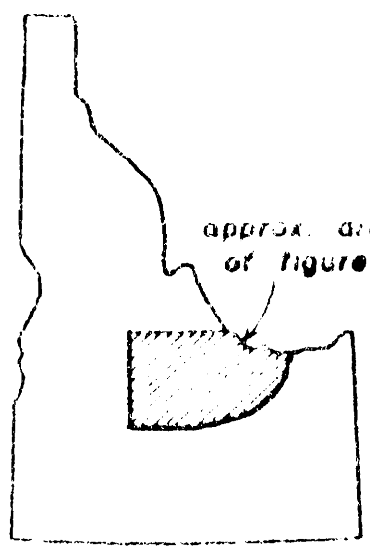
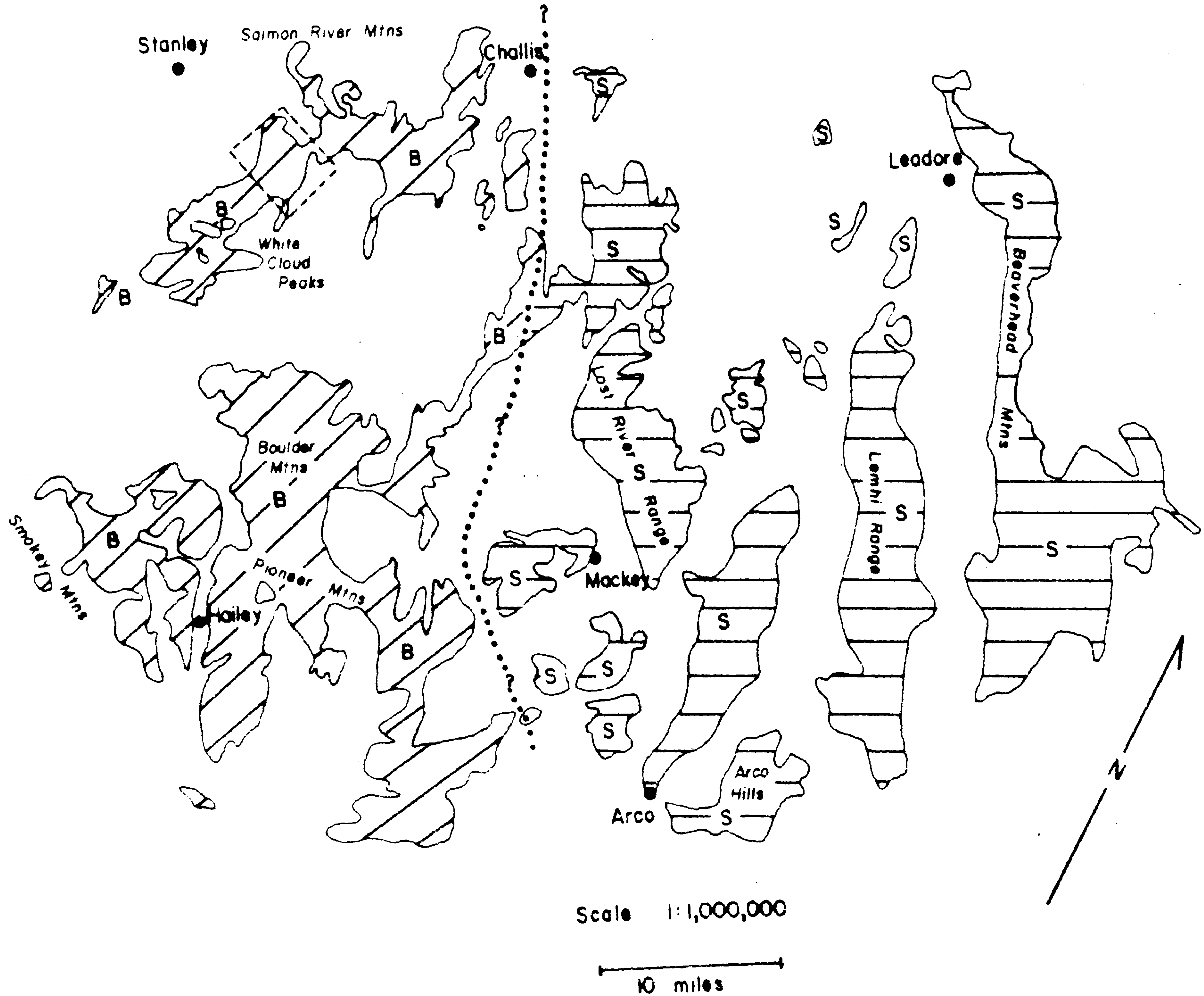


Figure 28. Generalized regional distribution of middle-Paleozoic sedimentary rocks in east-central Idaho. Figure shows approximate boundary between predomanently carbonate shelf rocks to the east and shale basin rocks to the west. (Modified from Ross and Forrester, 1959)


Stanley
Salmon River Mtns
Challis
?
S
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Leadore
B
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White
Cloud
Peaks
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Beaverhead
Mtns
Lost
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Range
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Boulder
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Lemhi
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Smokey
Mtns
Pioneer Mtns
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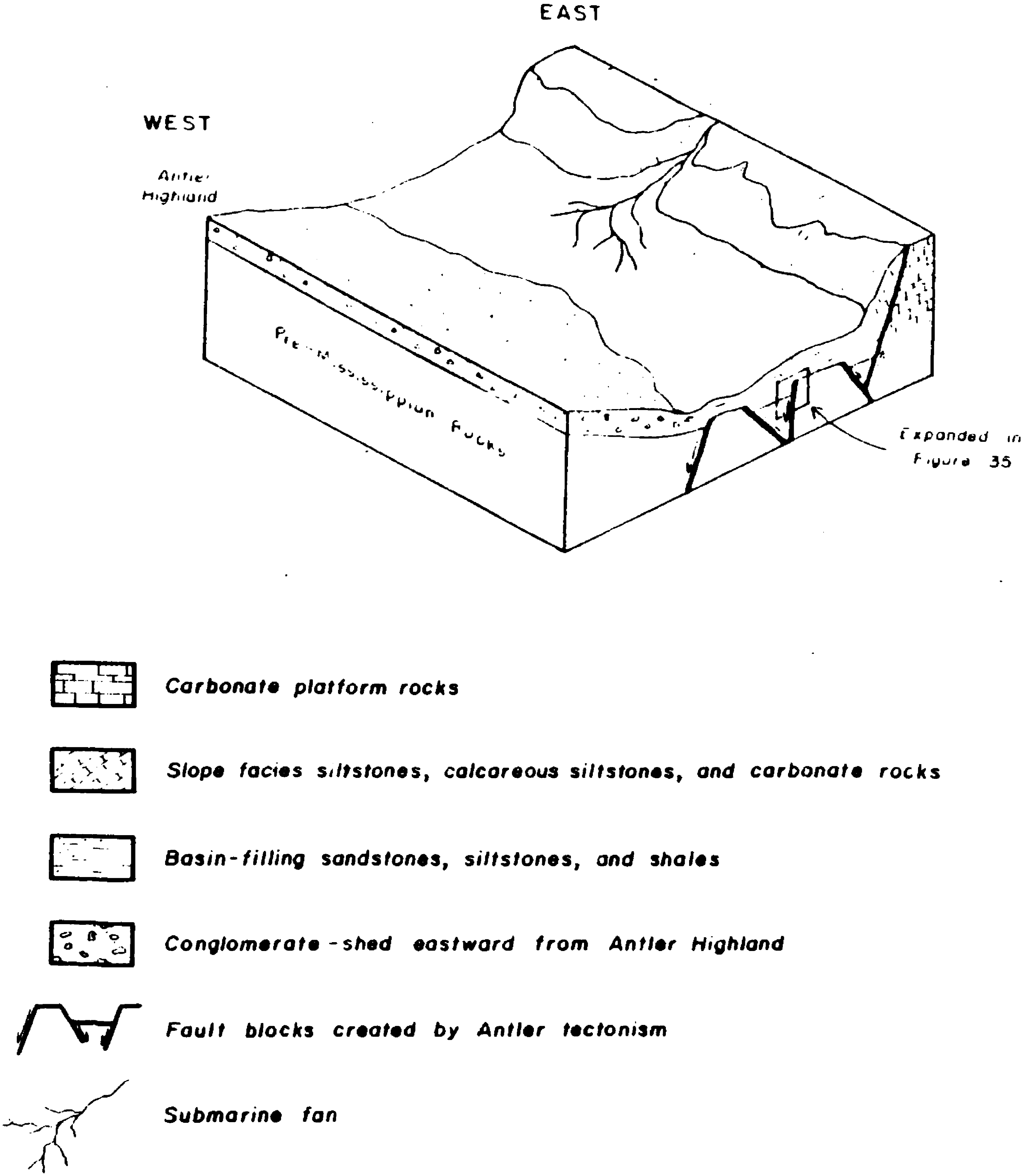

Figure 29. Idealized Early-Mississippian time basin geometry across east-central Idaho (modified from Nelson and Kulm, 1975).

Plate 3 displays a stratigraphic cross-section across the basin and shelf for middle-Ordovician to Mississippian rocks exposed in central Idaho. The stratigraphic interval which crops out at Slate Creek includes a portion of the Devonian Milligen Formation and a minor section from the overlying Mississippian Copper Basin Group deposited near the top of the basinal assemblage of Plate 3.

No volcanic component of the rocks exposed in the Slate Creek area was documented by the current study. Perhaps the presence of chert in the stratigraphy suggests exhalative activity (Russell and others, 1981). The minor carbon content found in lower and middle facies rocks is probably detrital and rained down as pelagic sediment. Dúring Devonian to Mississippian time the western coast of North America was subjected to equatorial climates (Dietz and Holden, 1970) which are known to produce high organic carbon deposition (Lisitzin, 1972). The carbon would be preserved in oxygen-deficient or completely anoxic environments (Ibach, 1982).

Ore Stratigraphy

Early authors who dealt with the lead-zinc-silver mineralization in the Slate Creek area concluded the deposits were hydrothermal replacement of structurally prepared rocks along thrust faults (Ross, 1937 and Kiilsgaard, 1949). Later workers (Kern, 1972; 1974 and Tschanz and others, 1974) agreed with this hypothesis. All came to this conclusion based on the abundant faulting in the area and the deposits' relative proximity to intrusions.

Ross (1937) describes the deposits in the area as having formed by replacement along shear planes which have an approximate or parallel strike to the bedding. He states that the mineralizing solutions were " . . . so tenuous that they did not require profound shearing or large openings for their passage." He also observed that much of the ore is disseminated in the country rock without evidence of any pre-mineralization shearing.

Kiilsgaard (1949) also suggests the ore deposits formed by replacement of shear zones. He calls on solutions permeating along shear planes to produce laminated ore in which thin layers of ore minerals are interbedded with the host argillite. Although he offers no evidence, Kiilsgaard concludes the deposits formed under " . . . mesothermal or moderately deep-seated conditions."

Kern (1972) again proposed hydrothermal replacement and pointed out that the Milligen Formation hosts most ore deposits in the area because it was the first unit encountered by ascending mineralizing solutions. Kern plotted ratios of the most abundant ore minerals from the mines in the area and found a zoning pattern. He relates this zoning to a buried plutonic source located in the central part of the area. Kern admits many problems are inherent to his study including lack of data points and probable sampling bias. He recognized that there is no supportive evidence for a buried pluton in the area. Kern suggested the intrusion must be so deep that it did not affect the presently exposed rocks. Kern cites Lindgren (1933) and others in stating the ore deposits are mesothermal.

Tschanz and others (1974) call on geophysical evidence to dispell the hypothesis of a buried intrusion existing under the central portion of the Slate Creek area. He does not agree with Kern's zonation model and states that the zoning present may be related to a regional vertical zonation or to overlapping zoning patterns from different sources. Tschanz and others (1974) briefly mention structural control of the orebodies. The study also suggests a replacement origin of the mineralization, but concentrated on ore mineral and geochemical zoning. Their zoning studies follow that of Ovchinnikov and Grigoryan (1971). Lead-silver, lead-zinc, zinc, and zinc-iron zones were all documented at the Livingston Mine. Tschanz states that the order of zonation is from lead-silver to zinc-iron indicating increasing temperature and/or proximity to source at the zinc-iron end. This pattern contradicts that noted during the present study and does not account for the symmetry or character of mineralogic zones. He also notes a zoning of the Hoodoo Mine with sphalerite grading to sphalerite-pyrite with an increase in temperature, depth, or closeness to source. Again this proposed pattern seems to ignore the geologic relationships of the geometry of the orebody. The main Hoodoo orebody has a central zinc-rich core surrounded by disseminated sphalerite and pyrite. The dissemination of the peripheral mineralization would seem to imply distance and not proximity to a fluid source.

Although hydrothermal replacement cannot be totally refuted by the current study, its application here is rejected. It is true that abundant faulting and shearing are present in the rocks and that the ore deposits lie within a few kilometers of intrusions. However, other characteristics common to hydrothermal replacement by hot magmatic or meteoric waters are not present or recognized in the study area. Alteration haloes typically envelope hydrothermal veins (Rose and Burt, 1979 and others). No alteration is found in the Slate Creek rocks in the vicinity of the ore deposits. Kern (1972) suggests calcite has altered to tremolite and some silicification is present. However, both of these processes may be related to metamorphism and not to a mineralizing event. No silicification of country rocks was noted during this study. Zoning in hydrothermal "vein-type" deposits commonly displays mineral distribution associated with individual metal and solution chemistries. The chemistries typically dictate a paragenetic sequence of precipitation, and, thus, zoning away from a source (Barnes, 1975). Mineral deposits in the Slate Creek area do not show a "one-directional" zonation, but rather a crude symmetry of mineral distribution. In addition, zoning sequences seen in the study area do not follow those proposed by Barnes (1975) for hydrothermal vein systems.

Geologic, mineralogic, and isotopic data (Hall, pers. comm., 1982) from the study area all support a syngenetic sedimentary-exhalative model rather than hydrothermal replacement for the genesis of the mineralization. Early attempts to describe the genesis of the ore deposits in the area were hampered by a lack of understanding of the development of syngenetic, lead-zinc-silver-barium deposits in clastic sedimentary rocks. The recent advancement of understanding and recognition of these deposits suggests a possible re-interpretation of the genesis of the orebodies in the Slate Creek area is warranted.

Sedimentary exhalative deposits have many differing features such as age, geologic environment, relative amounts of contained metals, or the presence or absence of associated stratiform barite. However, all deposits formed within the basinal shale environment have some similar characteristics such as conformity to enclosing strata, typical lenticular shape, usual absence of associated volcanic or plutonic rocks, and common association with carbonaceous rocks (Morganti, 1979). In addition, ores found in metamorphic terrains display textures indicative of metamorphism (Morganti, 1979). Examples of similar recognized orebodies which have all or some of the characteristics mentioned above include: Howards Pass and Sullivan, Canada; McArthur River and Mt. Isa, Australia; and Meggen, Germany. Discussion of these occurrences or sedimentary-exhalative deposits in general is not within the scope of this paper. For further documentation the reader is referred to summary papers by Morganti (1981) and Russell and others (1981).

Many of the orebodies exposed in the Slate Creek area contain the following characteristics indicative of syngenetic, sedimentary-exhalative mode of formation:

- Orebodies occur in carbonaceous rocks deposited within a long-lived shale basin.
- All major mines and prospects are located at one stratigraphic interval.
- Textural types I and II are conformable to enclosing strata.
- Host stratigraphy is barren in the footwall, has a sharp lower contact with chert-rich and mineralized rocks, and has a gradational upper contact with barren hanging wall rocks (Figure 24).

- Stratiform barite with sulfide laminations yields S isotope ratios suggestive of a seawater source (Hall, pers. comm., 1982).

- Growth of late, randomly-oriented amphibole grains superimposed on laminated sulfides (Figure 6) implies the sulfides must have pre-dated metamorphism. Other evidence such as coarsening of grain size in the area by metamorphism also suggests mineralization must have occurred prior to thermal event(s).

- Textural type I and II ores display sedimentary textures interpreted to be de-watering structures (Figure 30).

- Symmetry of metal zonation not supportive of a replacement vein origin. Zoning pattern is similar to that reported in other sedimentary-exhalative deposits (Gustafson and Williams, 1981; Large, 1981).

- Probable sedimentary origin of laminated and and disseminated sulfides (Lange and others, 1981) (Figure 6).

This evidence supports arguments for a syngenetic, sedimentary-exhalative origin of the ore deposits in the Slate Creek area. Replacement deposits typically do not have laminated sulfide beds, nor are syngenetic sedimentary textures such as soft-sediment folds or water escape structures found in replacement ores.

All mineralized strata of textural types I through V is thought to be very proximal to its source vent due to the presence of copper and precious metals or barite. These criteria suggest moderately high temperature and/or proximity to the vent (Morgenti, 1981 and Carne, 1979). Unfortunately, no accessible underground workings penetrate the footwall strata. No feeder structures were recognized in the area. However, distribution of mines and prospects, and carbonaceous argillite in the Slate Creek area suggest two, and possibly three, roughly

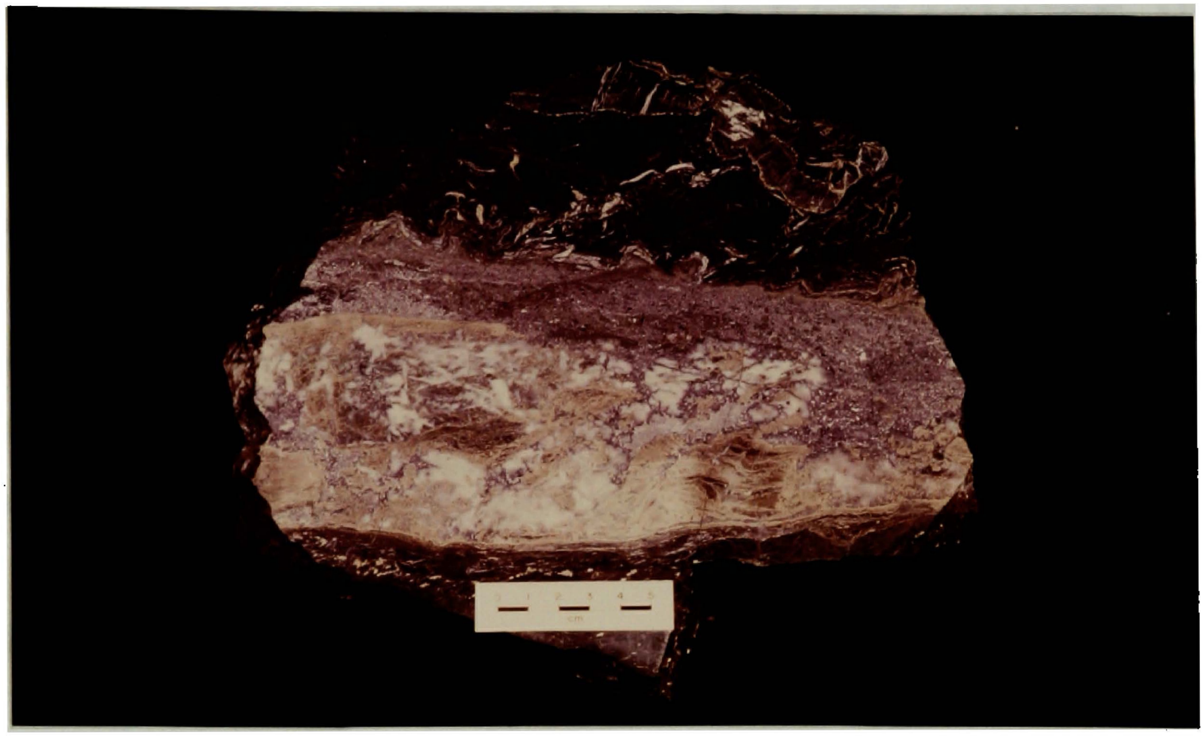

Figure 30: Dewatering features. Carbonate Mine. Note water-escape structures at the top of the sulfide zone.

north-south linear zones which may represent possible locations of feeder structures (Figure 31). This north-south trend roughly parallels the known shelf margin to the east. Kern (1972) also recognized this linear pattern to the mines and prospects. He envisioned replacement along north-south-trending Laramide normal and reverse faults defined by shearing and brecciation to account for this trend. Shearing and brecciation of the stratigraphy is common throughout the middle-Paleozoic section in the Slate Creek area (Figure 5) and does not appear to be restricted to continuous linear zones which could be interpreted as high-angle structures. In addition, no apparent offset of units can be documented along the structures proposed by Kern.

Textural classification of ore type further refines and aids in interpreting the genetic model. Textural type I consists of laminated iron, zinc, and rarely lead sulfides and is thought to display primary depositional characteristics (Figures 6, 7, and 8). Textural type II is most common and usually is characteristic of lead-rich zones. This type is thoroughly brecciated, but concordant to the enclosing stratigraphy (Figure 13). It most likely formed during diagenesis or by slumping and mass transport of an inherently unstable lead sulfide and silica gel on the sea floor. The mass transport could have been caused by deposition on a slope or by local topographic change related to differential loading of underlying water-saturated sediments. Craig and Vaughn (1981) interpret this texture as possibly being metamorphic. Textural type III is similar in appearance to type II; however, it occurs in cross-cutting veins (Figure 14). These veins probably formed during diagenesis due to differential loading, de-watering (Figure 30), or during metamorphism.

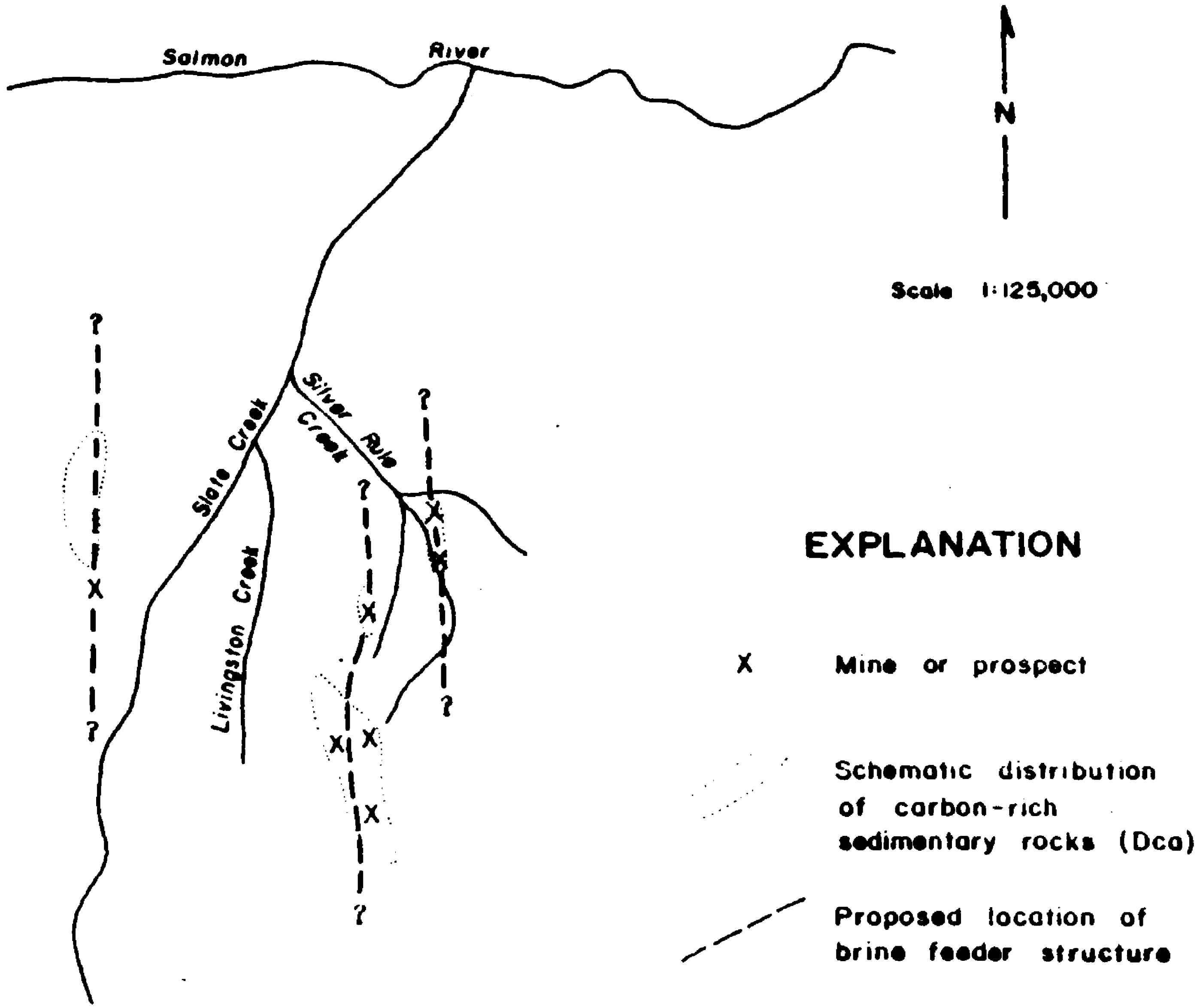

Figure 31. Hypothetical locations of brine feeder structures.

Textural type IV includes massive calcite and barite in addition to zinc and lead sulfides hosted by calcite and barite (Figures 16 and 17). Type IV, which occurs in a structurally complex area at the Hoodoo Mine, appears to represent a barite cap over underlying sulfide zones of textural types IIa and IIIa. Similar barite zones occur at some major sedimentary-exhalative deposits (Lange and others, 1981; Carne, 1979; Morgenti, 1979; and Winn and others, 1981). Textural type IV contains local soft-sediment deformation (Figure 3). The presence of sulfate and sulfide species in this ore type suggests: 1) chemical conditions were close to a reducing and oxidizing phase boundary at the time of formation; 2) incomplete fluid mixing; or 3) changing chemical conditions through time (Lange, pers. comm., 1982).

Textural types V and VI may result from metamorphism. Type V represents remobilization and recrystallization of type IV ores. Textural type VI is epigenetic quartz/carbonate/sulfide veins which contain base and precious metals, possibly remobilized from stratiform mineralization at depth or derived from their host stratigraphy. Figure 20 shows one of the veins at the Carbonate Mine which contains sulfides apparently remobilized from the adjacent stratiform mineralization.

Tertiary intrusion of felsic dikes in the vicinity of the White Cloud Stock created textural type VII. Post-mineralization faulting(?) adjacent to the Livingston orebody provided the structural avenue for the ascending rhyolite magma. This faulting is thought to have occurred at the margin of the Livingston orebody due to differences in deformational mechanics of the sulfide mass and the enclosing carbonaceous stratigraphy. Intrusion of the magma and associated thermal and hydrothermal fluid activity remobilized metals from the Livingston orebody and incorporated some of them in the rhyolitic magma. This explanation is supported by textural evidence of type VII ores. While some sulfide minerals are disseminated in the rhyolite, most coat fractures. This suggests the bulk of sulfides were transported after crystallization of the magma and probably by hydrothermal fluids related to the cooling of the rhyolite. Although the presence of the rhyolite at the Livingston Mine could suggest a genetic relationship, the lack of igneous or volcanic rocks at any other orebody or prospect in the area would imply the rhyolite at the Livingston is coincidental.

In addition to producing textural types V and VI, metamorphism has affected all ores present in the area. Effects include coarsening of grain size and partial destruction of primary depositional features. Microscopic analysis of ores shows annealing (Figure 32) and the development of 120° triple junctions at grain boundaries (Figure 33) which also imply metamorphism (Craig and Vaughn, 1981). Exsolution of chalcopyrite lamallae from sphalerite growth boundaries is also present (Figure 10). Craig and Vaughn (1981) state that this exsolution could not occur at low temperatures. However, temperatures involved with greenschist metamorphism (approximately 500° C, Hyndman, 1972) could allow enough copper to be adsorbed into the sphalerite crystal lattice (Craig and Vaughn, 1981). This copper would subsequently be exsolved as chalcopyrite upon cooling. The growth of pyrite porphyroblasts (Figure 34) is also an annealing texture suggestive of metamorphism and slow cooling (Craig and Vaughn, 1981).

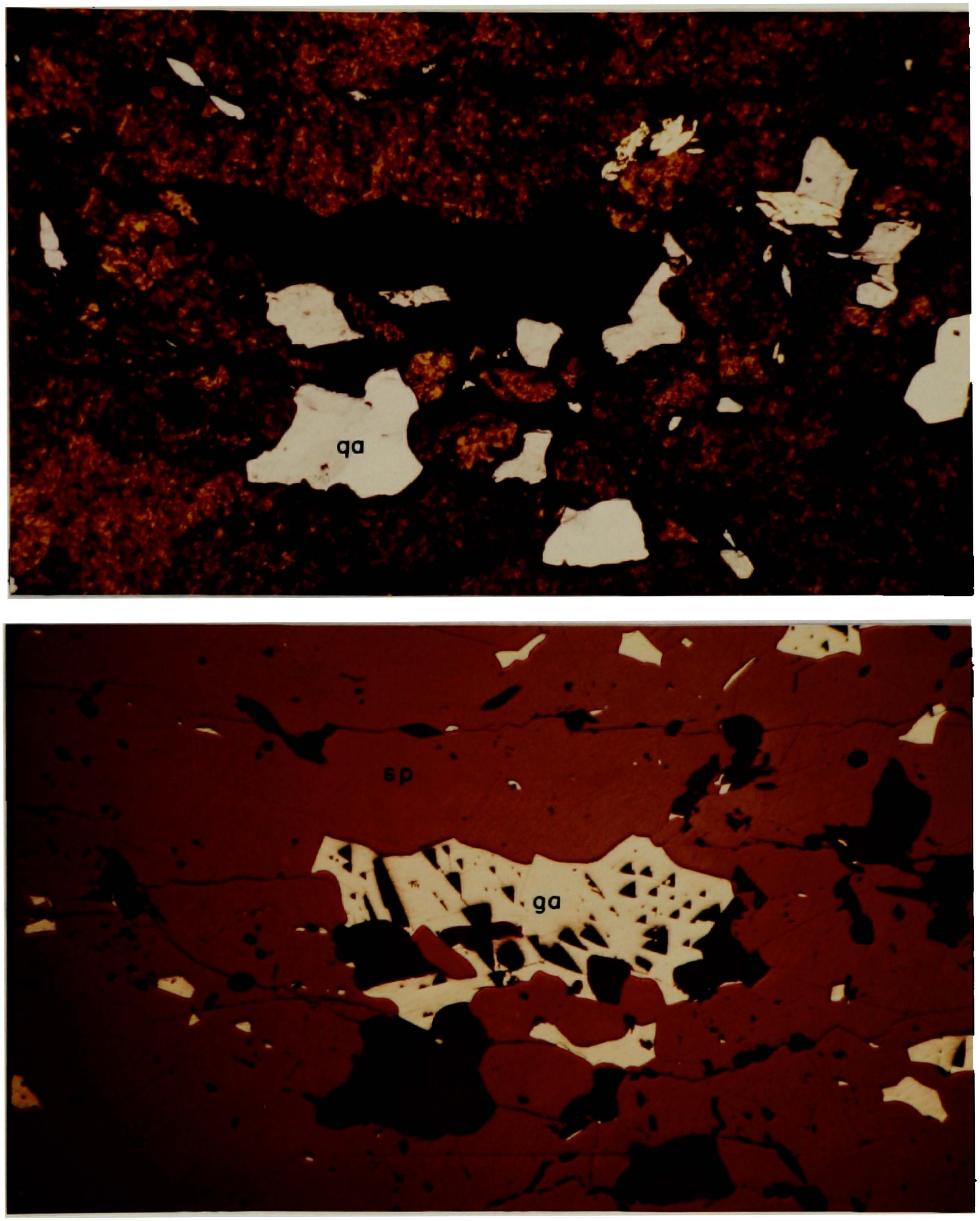

Figure 32: Photomicrograph of annealed sphalerite (sp) surrounding galena (ga). Quartz (qa) gangue. Hoodoo Mine. Transmitted light at top, reflected light at bottom. Horizontal field of view approximately 6.5 mm.

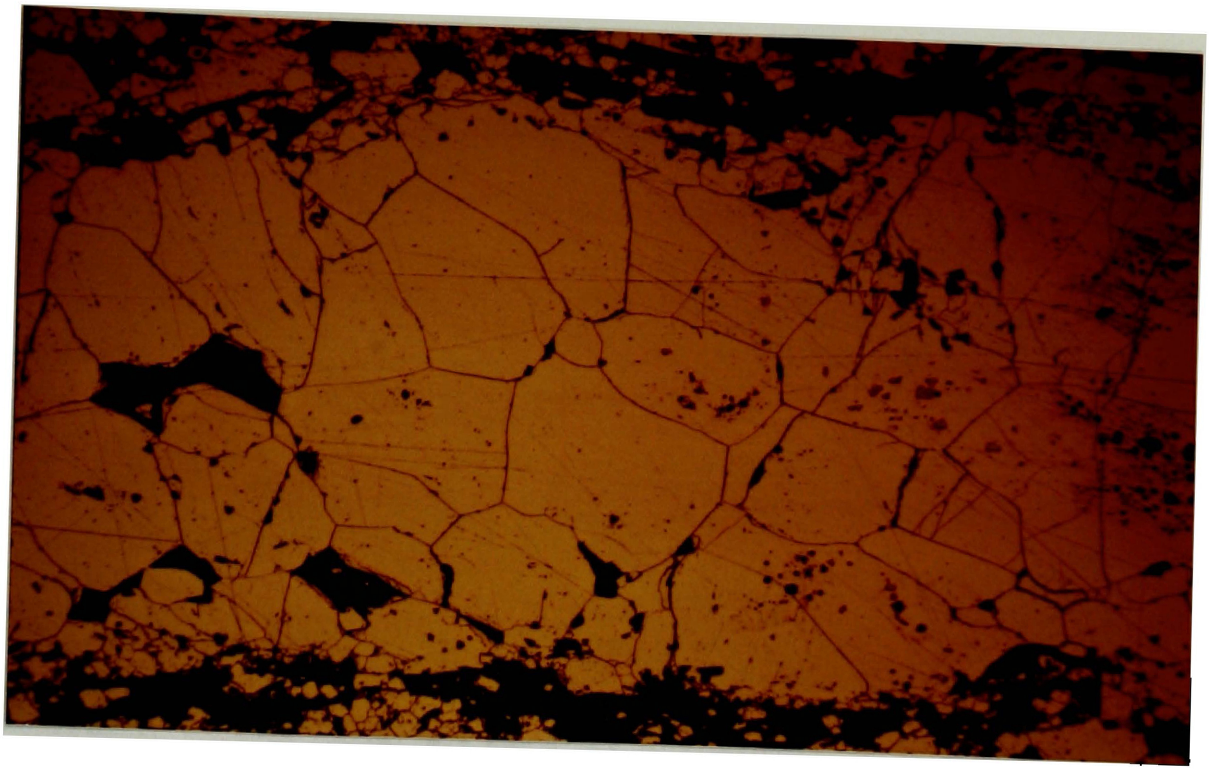

Figure 33: Photomicrograph of 120° grain boundaries within pyrite laminae. Livingston Mine. Reflected light. Horizontal field of view approximately 6.5 mm.

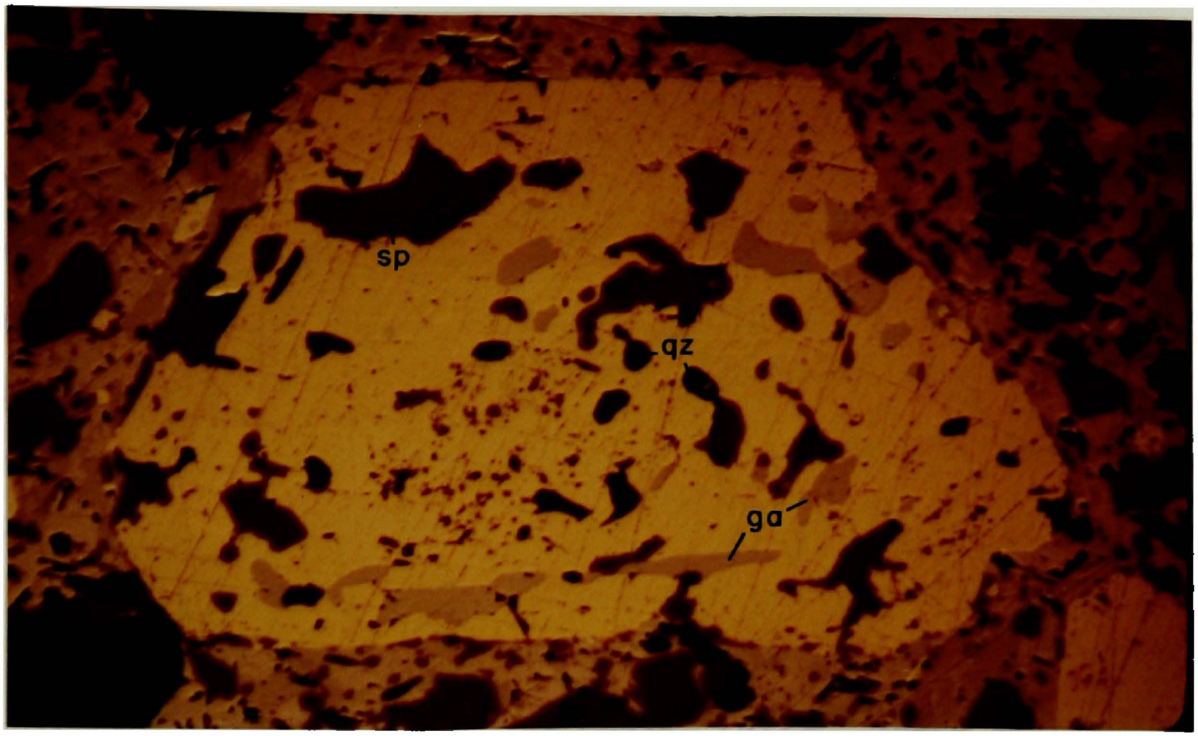

Figure 34: Photomicrograph of pyrite porphyroblast surrounding irregular blebs of galena (ga), sphalerite (sp), and quartz (qz). Livingston Mine. Reflected light. Horizontal field of view approximately 3.5 mm.

Genetic Model

Late in the history of the lower-Paleozoic basin early-Mississippian Antler tectonism created new or re-opened pre-existing high-angle faults. Tectonic disruption of the basin allowed for migration of large volumes of hot, metal-rich diagenetic brines to these structures. The faults guided the fluids to sites of venting and sulfide and sulfate precipitated on the sea floor (Figure 35). These events were probably geologically rapid as documented by the general lack of clastic dilution within ore zones. Non-ore-producing thermal springs probably continued for some time as evidenced by the gradual reduction in iron sulfides upsection.

In addition to the generation of sulfides and sulfates, these brines were probably silica-saturated which during pressure release venting precipitated as chert (Ochler and Logan, 1977). These venting hot fluids would also provide nutrients which created conditions favorable to abundant organic growth. This organic environment was similar to those noted along submarine rift zones (Fyfe and Lonsdale, 1981) and created a stratigraphic package rich in carbonaceous material. In the geologic record these areas are preserved as lenticular beds of carbonaceous and chert-bearing stratigraphy. Beds of this character host all major sulfide occurrences in the Slate Creek area.

Minor lenses of highly carbonaceous, siliceous, and sulfide-bearing argillite lower in the stratigraphic section likely formed in a similar manner. However, these zones were created during low volume, relatively rapid exhalations of metal-rich brines. These periodic fluid discharges may be related to leakage along recurrently activated syn-sedimentary

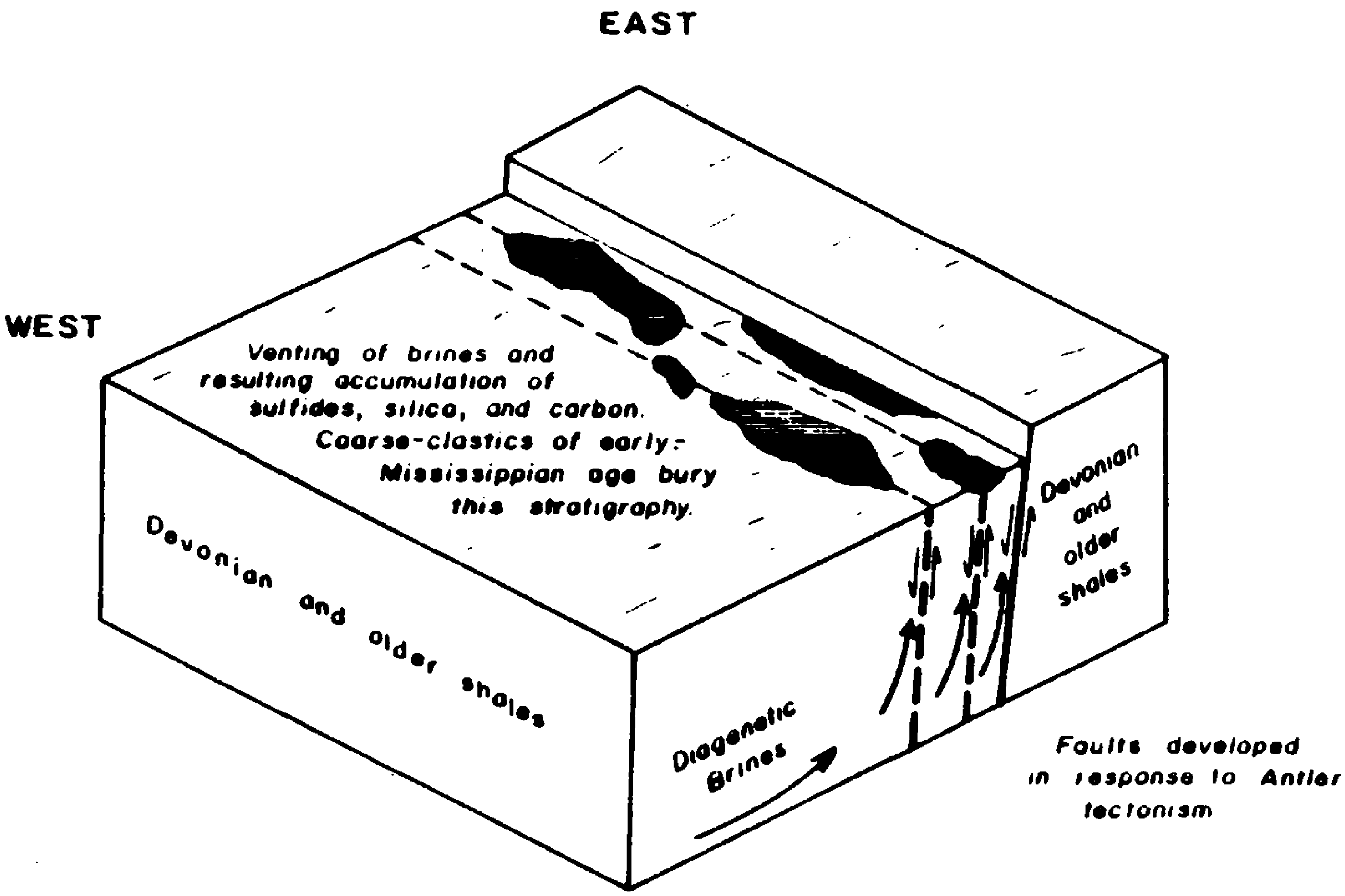

Figure 35. Ore stratigraphy genetic model during late Devonian time for the Slate Creek area of central Idaho.

growth faults. Not until early-Mississippian time and the advent of Antler tectonism were major, deep-seated structures opened which allowed for the large volumes of diagenetic brines to be vented to the sea floor. This tectonism and exhalative activity resulted in the large accumulation of carbonaceous, siliceous, and sulfide-rich strata at the top of the Devonian section. The tectonism also influenced coarser-grained sedimentation which directly overlies this mineralized stratigraphic interval.

Mesozoic regional metamorphism and thermal metamorphism associated with late-Cretaceous to early-Tertiary igneous activity altered the original characteristics of the syngenetic sedimentary-exhalative ores and produced many of the textures and types of ore present today.

CHAPTER V

SUMMARY

Devonian-age sedimentary rocks exposed in the Slate Creek area of central Idaho were deposited within a stable shale basin along the western margin of North America. Early-Mississippian Antler tectonism disrupted the stable conditions and resulted in flysch being deposited over the shale sequence.

Mineralization in the area occurred during three separate and distinct time periods. The first is the most important and includes deposition of lead-zinc-silver sulfides and barite during sedimentary-exhalative events during upper-Devonian time. Mesozoic regional metamorphism and thermal metamorphism associated with the late-Cretaceous or early-Tertiary emplacement of the Idaho Batholith and related satellite intrusions altered original textures and redistributed a portion of the pre-existing mineralization in epigenetic veins. The third and least important mineralizing event occurred during the Tertiary when rhyolite magmas intruded the Paleozoic section in the vicinity of the White Cloud Stock. One of these rhyolite bodies intruded the ore-bearing strata at the Livingston Mine and remobilized and incorporated metals from the orebody.

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APPENDIX

ROCK DESCRIPTIONS

1. Lower Facies A Quartzite

Mineralogy and texture: 98% rounded to sub-rounded quartz grains (0.25 mm); occasional larger quartz grain (1.5 mm); quartz cement; few interlocking grain boundaries, minor carbon, muscovite, and Fe oxide.

Color: dark gray to brownish.

Comments: This rock type distinguishes the lower facies A unit.

2. Lower Facies A Carbonate

Mineralogy and texture: subequal calcite and quartz; minor carbon, pyrite, Fe oxide, muscovite; quartz grains (0.05 mm), angular to sub-rounded and typically interlocking; calcite occurs as amorphous cement and coarser-grained veinlets; quartz grain concentration defines weak bedding.

Color: light to dark gray.

Comments: This rock type forms only a minor portion of the unit.

3. Lower Facies A Siliceous Argillite

Mineralogy and texture: predominantly 0.05 mm grains of rounded, annealed quartz; minor muscovite, $\pm$ albite, pyrite, tremolite, carbon, and apatite; microfractures offset beds on mm-scale; epidote(?) and chlorite alteration products of tremolite; bedding displayed by carbon concentrations.

Color: gray to silvery gray.

Comments: Predominant rock type in lower facies A unit.

4. Lower Facies A Calc-Silicate Adjacent to White Cloud Stock

Mineralogy and texture: roughly subequal calcite as large anhedral grains (1 mm) and an alteration of diopside/hedenbergite and large 3mm radiating aggregates of fibrous diopside/hedenbergite; minor muscovite, orthoclase, quartz, sphene, and apatite; minor calcite veining.

Color: buff to white.

Comments: Probable hornblende hornfels facies metamorphism. Highest grade specimen found in study area. Probably reflects "wet" intrusion.

5. Lower Facies A Layered Calc-Silicate near White Cloud Stock

Mineralogy and texture: tremolite in 1 mm radiating aggregates defines layering; abundant biotite and calcite in subequal amounts; minor quartz, apatite, muscovite, $\pm$ albite; carbonate is in part an alteration product of tremolite.

Color: buff and light tan bands.

Comments: Very common rock type in the vicinity of the stock.

6. Lower Facies A Calcareous Quartzite near the White Cloud Stock

Mineralogy and texture: subequal calcite (0.6 mm) and quartz (0.025 mm); minor carbon and tremolite; calcite forms star-shaped splotches which give the rock a spotted-hornfels-like appearance.

Color: gray.

Comments: This rock type forms only a very minor portion of the unit.

7. Lower Facies A Silicic Argillite Adjacent to White Could Stock

Mineralogy and texture: predominantly 0.1 mm anhedral interlocking quartz grains; minor calcite, carbon, tremolite/actinolite, epidote, and apatite; carbon concentrations define bedding; minor quartz veining.

Color: light gray with dark gray bands.

Comments: Similar to #3 but slightly coarser-grained due to proximity to intrusion(?).

8. Lower Facies A Calc-Silicate Adjacent to Idaho Batholith

Mineralogy and texture: calcite pseudomorphs after amphiboles(?) or pyroxenes(?) in fine radiating aggregates (0.5 mm); minor quartz and scapolite.

Color: light gray.

Comments: Looks like #4 but is finer-grained and alteration and replacement of ferromagnesian minerals is complete; finer grain size may be related to dryer intrusion.

9. Lower Facies A Argillite Adjacent to Idaho Batholith

Mineralogy and texture: 0.1 mm annealed quartz grains with minor calcite, tremolite, muscovite, carbon, and pyrite; very faint banding defined by carbon.

Color: gray with dark carbon-rich streaks.

Comments: Similar to argillite sample from near the White Cloud Stock (#7).

10. Lower Facies B Carbonaceous Argillite

Mineralogy and texture: subequal quartz (0.025 mm) and very fine carbon; carbon and quartz layers display definite kink banding and shearing; numerous very fine quartz veinlets.

Color: black.

Comments: This rock is typical of carbon-rich lenses located throughout the Devonian strata.

11. Lower Facies B Siliceous Argillite

Mineralogy and texture: predominantly 0.025 mm interlocking quartz grains; minor carbon, biotite, and apatite; kinky and wavy bedding; abundant quartz veining (0.1 mm in veins).

Color: light gray with dark carbon-rich bands.

Comments: Unique growth banding defined by mica(?) or fine carbonate(?) of a quartz grain in a vein.

12. Lower Facies B Dolomite

Mineralogy and texture: fine rounded grains (<0.01 mm) of dolomite; 0.5 mm grains of muscovite which display a crude alignment; small (0.05 mm) grains of quartz along microfractures.

Color: dark gray.

Comments: Dolomite is found locally within the lower facies B unit.

13. Lower Facies B Carbonate Hornfels

Mineralogy and texture: predominantly fine-calcite grains (<0.01 mm); calcite is a bit coarser in veins (0.2 mm); 0.025 mm quartz grains in veins; random scapolite grains (0.4 mm) define hornfelsic texture; minor muscovite, pyrite, and carbon.

Color: medium to dark gray.

Comments: Hornfelsic textures occur locally and commonly in carbonate rocks.

14. Lower Facies B Laminated Calcareous Argillite

Mineralogy and texture: majority of rock is recrystallized and annealed quartz grains (0.05 mm); calcite forms 0.1 mm aggregates; quartz-calcite veining; layering defined by grain size and carbon; minor pyrite, muscovite, apatite, and carbon; Fe oxides form partial alteration product of pyrite.

Color: laminated light gray and dark gray.

Comments: Similar to silicic argillites but contains 30% calcite.

15. Middle Facies A Silicic Argillite

Mineralogy and texture: mainly 0.03 mm quartz grains; calcite form 0.05 to 0.1 mm aggregates; quartz veining; layering defined by carbon abundance variation; minor carbon, muscovite, Fe oxides, biotite, and apatite.

Color: laminated light gray and dark gray.

Comments: Predominant rock type in Slate Creek area.

16. Middle Facies A Carbonate

Mineralogy and texture: predominantly <0.01 mm calcite grains with minor carbon, Fe oxides, and muscovite; calcite veins.

Color: medium gray.

Comments: Found only in the southern portion of the area.

17. Middle Facies A Carbonaceous Argillite

Mineralogy and texture: mostly <0.03 mm grains of quartz but up to 0.1 mm in veins; abundant carbon, minor epidote, muscovite, microcline, and Fe oxides; epidote occurs in quartz veins as aggregates up to 1 mm.

Color: very dark gray or black.

Comments: Minor sulfide occurrences are located in lenses of this lithology.

18. Middle Facies A Skarn

Mineralogy and texture: abundant tremolite aggregates in radiating masses up to 3.5 mm; also abundant 0.15 mm muscovite; remainder of the rock is quartz, carbon, and calcite.

Color: medium gray.

Comments: Relatively rare rock type in this unit.

19. Middle Facies A Bedded Argillite and Chert

Mineralogy and texture: mostly very fine-grained quartz (<0.01 mm); some quartz grains up to 0.05 mm and 0.5 mm in veins; also very fine muscovite (<0.01 mm); alignment of optical axes in both quartz and muscovite; banding defined by coarser and finer quartz grains; quartz vein display kinking; micro-dewatering features.

Color: brownish to medium gray.

Comments: This lithology is distinctive of the middle facies A unit.

20. Middle Facies C Quartzite

Mineralogy and texture: assorted grains of annealed quartz up to 0.75 mm; minor calcite as random grains 0.1 mm and as fine aggregates; tremolite/actinolite as 0.75 mm aggregates; minor carbon, epidote, Fe oxides, and apatite; epidote as fine dusty aggregates; some calcite and epidote associated with tremolite/actinolite.

Color: dark gray.

Comments: Distinguishing rock type of the middle facies C unit.

21. Middle Facies C Calc-Silicate

Mineralogy and texture: majority of the rock is 0.025 mm quartz grains; quartz veins with 0.1 mm grains; abundant diopsite (1 mm); calcite as distinct grains (<0.02 mm) and alteration aggregates associated with diopside, minor sphene and Fe oxide.

Color: light gray.

Comments: This rock type occurs only in the extreme southwestern portion of the area along Slate Creek. Intrusive rocks crop out locally a bit further south.

22. Middle Facies C Silicic Argillite

Mineralogy and texture: mainly 0.07 mm grains of quartz and 0.15 mm in coarser layers; 0.5 mm quartz grains in veins; oriented quartz grains; tremolite in veins (1 mm) and as random grains (0.1 to 0.5 mm); minor subequal carbon and muscovite; also pyrite and calcite in trace amounts.

Color: dark gray.

Comments: Most common rock type in middle facies C section.

23. Middle Facies C Carbonaceous Argillite

Mineralogy and texture: mainly quartz (0.03 mm) as grains and abundant veins with up to 1 mm veins; abundant carbon; muscovite and biotite occur as random grains and in veins; minor calcite, tremolite, and scapolite; intense deformation.

Color: black with white veins.

Comments: Some sulfides associated.

24. Middle Facies B Silicic Argillite and Chert

Mineralogy and texture: predominantly 0.01 mm or finer quartz; in veins, quartz is up to 0.25 mm; muscovite concentrations define layering; minor carbon and apatite.

Color: light gray and splotchy darker portions.

Comments: Chert forms a minor portion of the unit.

25. Middle Facies B Carbonaceous Argillite

Mineralogy and texture: mainly quartz and carbon; minor amounts of epidote as fuzzy masses; also minor muscovite, apatite, diopside, and tremolite; less deformation than typical of other carbonaceous rocks.

Color: black.

Comments: Locally up to a few percent pyrite.

26. Middle Facies B Calc-Silicate

Mineralogy and texture: mostly coarse-grained calcite (0.5 mm); tremolite as large masses (0.6 mm) in radiating aggregates; scapolite (0.75 mm average); also minor muscovite (0.15 mm), quartz (0.15 mm), and andalusite (0.2 mm average).

Color: medium gray to black.

Comments: Relatively rare lithology usually found in limestone beds.

27. Middle Facies B "Reaction Skarn"

Mineralogy and texture: mainly large tremolite grains (1.5 to 2 mm); also calcite in large intergrain masses up to 6 mm across; individual calcite grains average 1.5 mm; minor carbon and coarse muscovite (0.5 mm).

Color: dark gray to black.

Comments: Occurs locally along contacts of limestone and carbonaceous argillite beds. Forms third lithology from constituents of the two. Found as discontinuous lenses.

28. Middle Facies B Pyritic Limestone

Mineralogy and texture: mostly 0.15 mm calcite grains; also abundant quartz and carbon; minor muscovite, apatite, scapolite, and tremolite(?).

Color: dark gray.

Comments: Section cut did not intercept any pyrite which forms one percent random euhedral cubes (0.5 mm).

29. Carbonaceous Argillite Unit Banded Carbonaceous Argillite

Mineralogy and texture: subequal quartz (0.05 mm) and calcite (0.05 mm); carbon present helps define layering; minor pyrite and muscovite; quartz and calcite veining.

Color: dark gray.

Comments: Relatively carbon-deficient rock located within very carbonaceous stratigraphy.

30. Carbonaceous Argillite Unit Graphitic Carbonaceous Argillite

Mineralogy and texture: mostly quartz (0.03 mm) and carbon in a massive texture; minor calcite, muscovite, sphene, and apatite; quartz and calcite veining.

Color: black.

Comments: Ore stratigraphy from Carbonate Mine.

31. Carbonaceous Argillite Unit Carbonaceous Argillite with Quartz Veins and Pyrite

Mineralogy and texture: predominantly quartz (0.01 mm) and carbon;

quartz in veins is up to 0.2 mm; aligned quartz in rock not apparent in veins; minor calcite, muscovite, pyrite, and apatite; calcite also present in veins.

Color: black with white veins.

32. Middle to Upper Facies Transition (Eastern Portion) Laminated Argillite and Fine Sandstone

Mineralogy and texture: two distinct grain size populations are present and they display the laminated nature of the rock; coarse layers include quartz (0.1 mm), calcite (up to 0.5 mm), plagioclase (0.1 mm), and tremolite (0.5 mm). Fine layers consist of the same mineralogy, however, grain size averages <0.01 mm; minor apatite, sphene, and carbon; carbon is concentrated in the fine layers.

Color: medium gray with tan laminae.

Comments: First appearance of carbon deficient sediment.

33. Middle to Upper Facies Transition (Central Portion) Laminated Siltstone and Shale

Mineralogy and texture: very fine-grained quartz (<0.01 mm) and minor muscovite, carbon, apatite, and pyrite; very subtle grains size variations define laminations; quartz veinlets.

Color: light gray and medium gray in layers.

Comments: Possibly more distal to a sediment source than #32. This rock also has carbon deficient layers.

34. Upper Facies 1 Laminated Dolomitic Siltstone

Mineralogy and texture: mainly quartz (0.05 mm) and dolomite (0.03 mm); minor apatite, carbon, pyrite, muscovite, Fe oxides, and plagioclase; dolomite tends to form aggregates; carbon is present but in very minor quantities; very weak bedding defined by the carbon and Fe oxides.

Color: tan to brownish-gray laminae.

Comments: Carbon very minor component. A bit coarser rock.

35. Upper Facies 2 Sandstone

Mineralogy and texture: mainly 0.1 mm grains of quartz; Fe oxides from splotches disseminated through the rock; minor muscovite, apatite, and tourmaline.

Color: reddish brown.

Comments: First appearance of detrital tourmaline.

36. Upper Facies 1 Laminated Siltstone and Sandstone

Mineralogy and texture: mostly 0.15 mm quartz grains; minor muscovite, tourmaline, apatite, and Fe oxides; layering displayed by accumulation of finer-grained quartz and muscovite; minor quartz veining of much less frequency than seen in rocks lower in the stratigraphy.

Color: light gray and brown laminae.

Comments: Most common lithology in upper facies rocks east of Silver Rule Creek.

37. Upper Facies 1 Sandy Carbonate

Mineralogy and texture: mainly calcite (0.1 mm) and quartz (0.1 mm); minor microcline, muscovite, pyrite, Fe oxides, and tourmaline; tourmaline forms good rounded detrital grains.

Color: buff to dark tan.

Comments: Common as thicker beds within #36 east of Silver Rule Creek. All grains look detrital. Little evidence of metamorphism.

38. Upper Facies 1 Massive Siltstone

Mineralogy and texture: predominantly quartz grains which range in size from <0.01 to 0.075 mm; minor muscovite, Fe oxides, and apatite; massive.

Color: tan.

Comments: Fairly common lithology east of Silver Rule Creek.

39. Upper Facies 1 Laminated Sandy Calcareous Siltstone

Mineralogy and texture: mostly calcite as 0.02 mm grains; calcite also present in veins (0.3 mm); quartz 0.02 to 0.05 mm grains and 0.5 mm in veins; minor biotite (0.25 mm) in a vein; accessory pyrite and muscovite.

Color: light gray.

Comments: Relatively rare lithology in upper facies 1 rocks.

40. Upper Facies 3 Laminated Siltstone and Shale

Mineralogy and texture: quartz 0.05 mm in coarse layers and 0.02 mm or less in fine layers; abundant muscovite (0.02 to 0.05 mm in coarse layers); minor Fe oxides.

Color: laminated light gray and tan.

Comments: Typical lithology in upper facies 3 rocks.

41. Upper Facies 3 Thin Bedded Carbonaceous Siltstone and Shale

Mineralogy and texture: predominantly quartz (0.05 mm and smaller); muscovite (0.025 mm) in coarser-grained layers; chlorite (0.025 mm) in finer-grained layers; minor carbon, epidote, apatite, and Fe oxides; millimeter-scale offset of beds.

Color: light to dark gray.

Comments: Approximately as common as #40.

42. Upper Facies 3 Massive Siltstone

Mineralogy and texture: mainly quartz (<0.01 mm); some quartz grains up to 0.1 mm; most muscovite is <0.01 mm but some up to 0.03 mm; variation of muscovite size defines faint layering; minor epidote and apatite.

Color: medium gray.

Comments: Forms thicker lenses (up to 0.25 m) in central portion of the area.

43. Upper Facies 3 Thin Bedded Siltstone and Shale

Mineralogy and texture: variable quartz grain size from 0.02 to 0.1 mm; this variation defines bedding; minor epidote, Fe oxides, muscovite, apatite, and spinel(?).

Color: dark gray.

Comments: Common lithology in upper facies 3 unit.

44. Banded Barite and Limestone

Mineralogy and texture: mainly calcite and barite which both average 0.5 mm and display annealed textures; minor quartz and pyrite.

Color: white with very light gray bands.

Comments: In hand sample, pyrite and sphalerite define banding but no concentrations of sulfides were intersected by the thin-section cut.

45. Barite Ore

Mineralogy and texture: predominantly barite (1 mm) set in a calcite matrix (0.6 mm); minor pyrite and quartz.

Color: light gray.

Comments: Sugary, granular texture.