Discovery of the Silver Creek molybdenum deposit, Rico, Colorado

D.E. Cameron, L.F. Barrett, and J.C. Wilson

Abstract — *Exploration by Anaconda Minerals Co. in the Rico area from 1978 through 1983 resulted in discovery of the Silver Creek molybdenum deposit. The drill-indicated resource is 40 Mt (44 million st) of 0.31% Mo, and projections suggest that the deposit may exceed 182 Mt (200 million st). No source intrusion has been intersected by drilling, but its presence is sugested by intramineral silicic alkali-alaskite porphyry dikes observed at the surface and in drill holes.*

Age dates and fluid inclusion studies indicate that the deposit was formed 5.2 ± 0.2 m.y. ago and that more than 1200 (3937 ft) of cover has since been removed by erosion.

The deposit is hosted by Precambrian quartzite and greenstone, and Paleozoic sediments. Three prominent faults intersect in the vicinity of the molybdenum deposit, and one of these, the Last Chance fault, strongly influenced the shape and location of the deposit. The juxtaposition of host rocks across the Last Chance fault reflects significant offset spanning at least three different periods.

Wallrock alteration associated with the deposit includes potassic, phyllic, and propylitic zones in noncalcareous rocks and garnet and anhydrite-diopside zones in the carbonates. All +0.2% Mo mineralization is within the potassic and garnet zones.

Premineral faults that intersect the deposit contain the only surface molybdenum, tungsten, and fluorine anomalies. Dispersion halos of the indicator elements were defined by drilling in the discovery phase of exploration, and are particularly well-developed in the hanging wall of the Last Chance fault.

Introduction

Rico is an historic lead-zinc silver mining district located in the San Juan Mountains of southwestern Colorado at elevations ranging from 2700 to 3800 m (8860 to 12,500 ft) (Fig. 1). Mining from veins and from replacement deposits in calcareous sediments produced 76,064 t of lead, 75,039 t of zinc, 5,114 t of copper, 14,513,288 troy oz of silver, and 83,045 oz of gold from 1879 through 1968 (McKnight, 1974, p.6). Production ceased in 1971 with the closure of the Blaine mine, which directly overlies the Silver Creek molybdenum deposit.

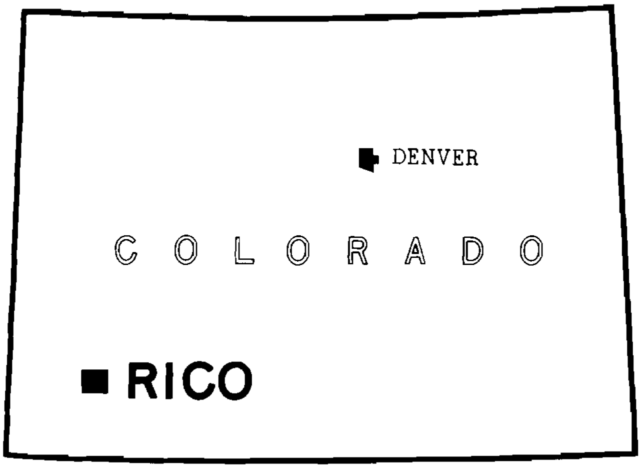
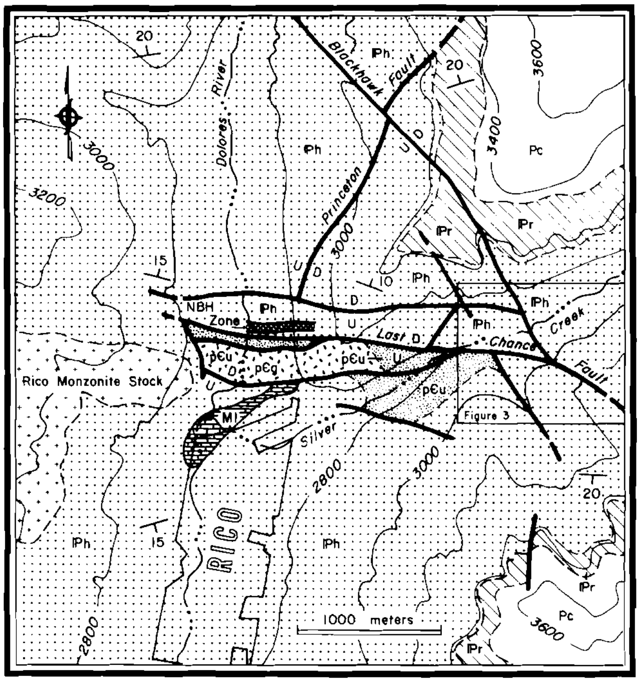


Fig. 1 — Location of the Rico mining district

Anaconda acquired an exploration option in the district in 1978 from Crystal Oil Co. and explored for porphyry and replacement deposits through early 1983. These efforts culminated in the discovery of the Silver Creek molybdenum deposit.

History of the Silver Creek discovery



modified from · McKnight (1974) and Rushing (1979).

Fig. 2 — Rico district geology

The discovery of the Silver Creek molybdenum deposit resulted from application of the Henderson molybdenum porphyry model (e.g., Wallace et al., 1978) to a structurally complex, sediment-dominated host environment. In 1978, an exploration team evaluated a recent discovery by Crystal Oil, the NBH zone copper-silver-gold replacement deposit (Fig. 2). The team also recognized

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the potential for a molybdenum porphyry deposit in the district based on reconnaissance mapping and outcrop sampling. In 1979, several existing drill holes were analyzed for molybdenum, tungsten, and fluorine. One of these, a 529-m (1736-ft) hole in Silver Creek showed increases in tungsten and flourine with depth. This hole was correctly inferred to have intersected the periphery of a porphyry molybdenum system and this interpretation was the basis for locating Anaconda's first completed drill hole, C-25 (Fig. 3). C-25 was collared west of the intersection of the Last Chance and Blackhawk faults to test the assumed extensions of the NBH zone and a porphyry center from which the replacement deposit was thought to be laterally zoned. C-25 intersected very strong fluorine and tungsten gradients and significant molybdenum [15 m (49 ft) of 0.064% Mo] that were correlated with data from the outer margin of the Henderson deposit (Ranta et al., 1976; Wallace et al., 1978).

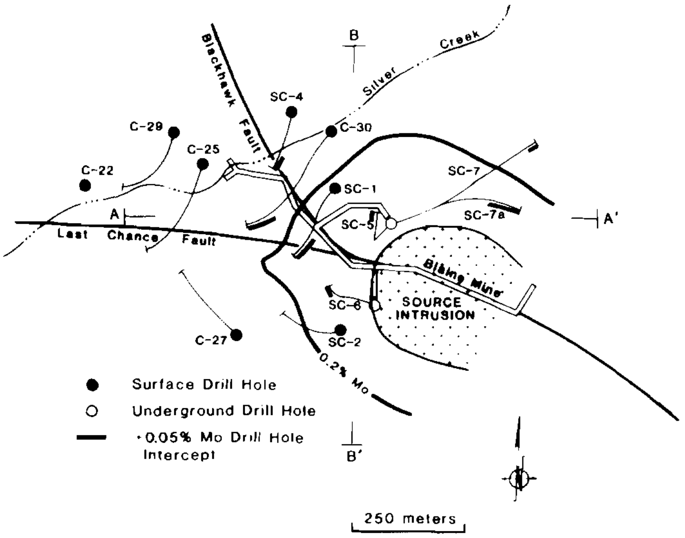

Fig. 3 — Silver Creek area drill hole location map

Less successful step-out drilling followed the completion of hole C-25, but the seventh hole, C-30, intersected 226 m (741 ft) of 0.106% Mo in 1981 and encouraged further drilling. Drill hole SC-1 intersected better mineralization late in 1981 and indicated that the center of the system might underlie the old Blaine mine. The adit level of the Blaine was rehabilitated and all subsequent drilling was done underground. Hole SC-5 intersected 194 m (636 ft) of 0.334% Mo, at a 0.2% Mo cutoff, the best intercept obtained to date.

The encouraging results obtained from SC-5 prompted a development feasibility study in 1982, but the study indicated that development was not warranted under anticipated market conditions. Before abandoning exploration, drill hole SC-7a was deflected southeast from SC-5 to demonstrate that the deposit was both large and highgrade. The hole direction was chosen based on an intensified effort to integrate the accumulated drill hole and surface geology and geochemistry on a set of sections and level plans. SC-7a succeded in indicating size potential, but like previous holes it failed to locate the center of the system. SC-7a intersected 87m (285 ft) of 0.29% Mo (0.2% Mo cutoff), and significantly expanded the drill-indicated tonnage of the deposit. The exploration program at Rico was discontinued in February 1983.

Geology of the Silver Creek area

The Rico mining district is centered on the Rico dome, a Laramide uplift cored by Precambrian rocks and flanked by a thick section of Paleozoic sediments (Fig. 2). The Silver Creek molybdenum system is probably the center of mineralization of the district. A thermal center lies within the Silver Creek system and was recognized independently by Naeser et al. (1979). Those authors used progressively reset fission track ages on mineral separates from Laramide intrusions to establish locations of major late-Tertiary heat sources.

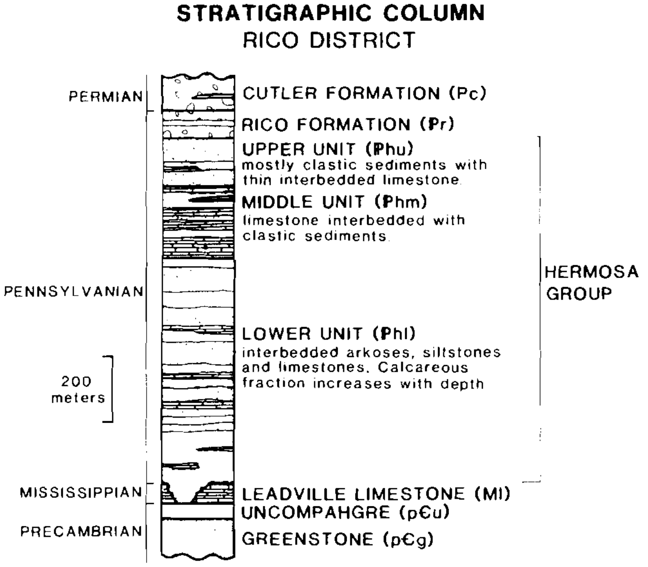

Fig. 4 — Stratigraphic column for the Rico district

Stratigraphy

The Precambrian section (Fig. 4, 5, and 6) consists of a phyllitic Proterozoic greenstone unit comprising flows and intrusions that is unconformably overlain by orthoquartzites of the Uncompahgre Formation. The orthoquartzites are generally white and massive, but locally contain intercalated argillaceous layers. The Precambrian rocks are the principal hosts of higher-grade molybdenum mineralization.

Mississippian Leadville limestone, locally absent in the district, but locally as thick as 75 m (246 ft), unconformably overlies the Uncompahgre Formation. Karst features and erosional alteration recognized within the Leadville indicate that it was exposed to erosion prior to deposition of the Hermosa Group. The Leadville hosts the NBH replacement deposit and near-surface historic lead-zinc-silver deposits in the western portion of the district.

The Pennsylvanian Hermosa Group is a thick sequence of clastic and calcareous sediments that in the Rico district has three members (Cross and Spencer, 1900). The lower member displays tremendous variation within the district both in thickness and lithology, but is dominated by fine- to coarse-grained marine clastics. The lower member unconformably overlies the Uncompahgre Formation locally. The Pennsylvanian Molas Formation may be present locally at the base of the Hermosa Group, but is included in the lower member of the Hermosa for illustrative purposes. Distinctive limestones of the middle member host most of the district's known lead-zinc-silver mineralization. Clastics compose the upper Hermosa member.

The Hermosa Group is overlain on the fringes of the district by redbeds of the Pennsylvanian Rico and Permian Cutler Formations. These formations are not significantly mineralized and may have been too high in the section to have been reached by ascending mineralizing fluids.

Intrusive rocks include the Rico monzonite stock (78 m.y.; Naeser et al., 1979), exposed in the western part of the district; abundant dikes and sills of hornblende latite porphyry (59.9-64.9 m.y., Naeser et al., 1979); and rare dikes of silicic alkali-alaskite porphyry (3.4-3.9 m.y., Naeser et al., 1979). One of several alaskite dikes intersected by drill hole SC-1 was analyzed (Table 1) and age-dated by the authors at 5.2 ± 0.2 m.y. (K-Ar whole rock). This dike is clearly intramineral and is probably a differentiate of the source stock.

Table 1 — Analysis of Silicic Alkali-Alaskite

Oxide	Wt %
SiO_2	78.50
TiO_2	0.10
Al_2O_3	11.00
Fe_2O_3	0.70
FeO	—
MnO	0.01
MgO	0.20
CaO	0.65
Na_2O	2.20
K_2O	5.10
P_2O_5	0.12
	98.58

The very young age of the Silver Creek intrusion may account for elevated geothermal gradients noted in the district (Medlin, E., 1983, personal communication). Gradients in the Silver Creek area average about 3.8 °C per 100 m (328 ft) of depth.

Structure

The Last Chance fault is the dominant structure recognized in the vicinity of Silver Creek (Figs. 5 and 6), and has a complex history as follows:

- The north block was *upthrown* prior to Pennsylvanian time causing the Leadville limestone to be removed, and the Uncompahgre to be drastically thinned.
- The north block was *downthrown* during the Pennsylvanian, causing deposition of a thick clastic wedge in the lower member of the Hermosa Group.
- The south block was *upthrown* during Laramide doming.

The offset implied during the first stage is at least 1000 m (3281 ft), and during the second stage is at least 600 m (1969 ft). The thick clastic wedge is characterized by discontinuous lenses of coarse arkoses, siltstones, and anhydrite lenses. A period of inactivity followed the second stage of offset on the fault and permitted uniform deposition of the middle member Hermosa Group carbonates. The last stage of offset is not bracketed in time by lithologic evidence, but probably occurred during the doming associated with widespread intrusion of sills and the Rico monzonite stock in the period 80 to 60 m.y. ago. The Last Chance fault now shows an apparent displacement of about 1000 m (3281 ft), north side down, on the Paleozoic-Precambrian unconformity. Baars, (1983) suggests that the Last Chance fault is one of a series of Precambrian wrench faults with northwest strikes that localized uplifts from Paleozoic through Laramide time. Baars and Stevenson (1981) also suggest that east-west flexures along these faults localized intrusions.

The Last Chance fault bends westward in Silver Creek near the inferred location of the source intrusion and appears to break up into a horsetail zone having many individual fault strands. The Blackhawk fault strikes

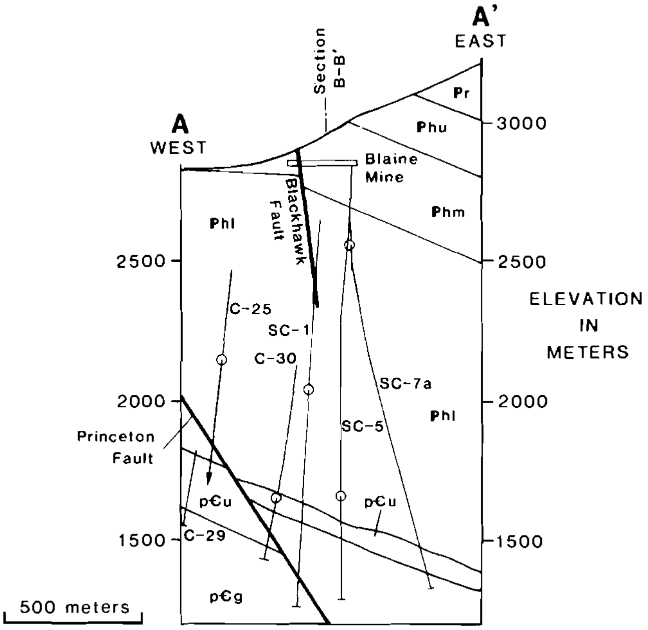

Fig. 5 — East-west geologic section of Silver Creek area

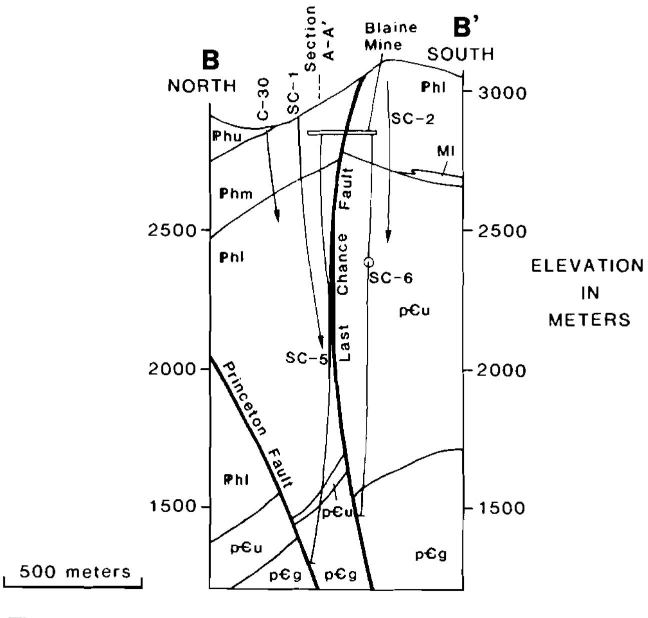

Fig. 6 — North-south geologic section of Silver Creek area

northwest from the bend. The Blackhawk fault can be traced for about 5 km (3 miles), but shows only 15 m (49 ft) of displacement. Both the Last Chance and Blackhawk faults localized near-surface lead-zinc-silver mineralization. The Allyn Gulch fault, another northwest-striking structure located 300m (984 ft) southwest of the Last Chance fault, may have significant offset because Leadville limestone has not been intersected in drill holes east of the fault, and the lower member of the Hermosa Group is much thicker east of the fault.

The Princeton fault is a premineral, northeast-striking, moderate-angle normal fault that steepens near its intersection with the Last Chance fault. It has approximately 750 m (2461 ft) of apparent dip-slip displacement near the surface, but at depth where it cuts the basal formations the offset is not known.

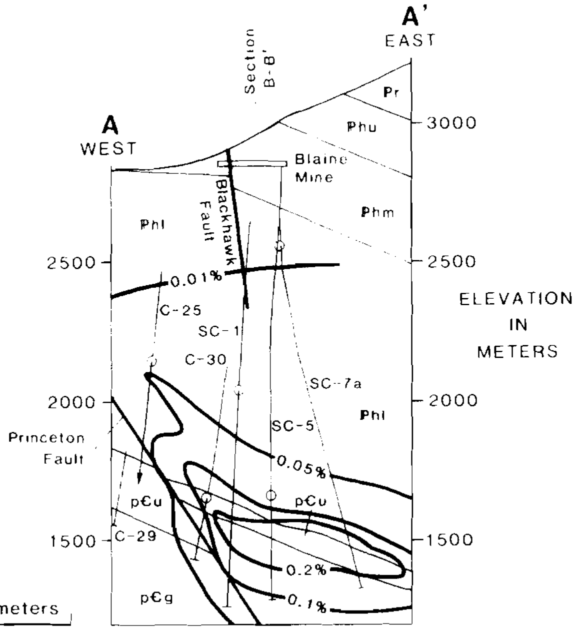

Fig. 7 — East-west section of Silver Creek area showing molybdenum grades

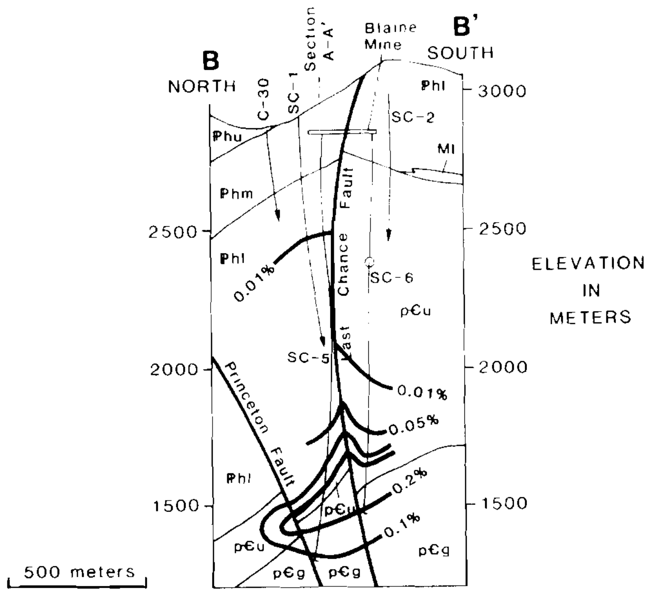

Fig. 8 — North-south section of Silver Creek area showing molybdenum grades

Mineralization

Mineralization in Silver Creek is elongated parallel to the Last Chance fault. The contacts between the greenstone and Uncompahgre Formation and between the Uncompahgre and the Hermosa Group also appear to have been important conduits for mineralization. In the four drill holes with thick +0.2% Mo intercepts (SC-1, SC-5, SC-6, and SC-7a), the highest grade intervals occur adjacent to one or both of these contacts (Figs. 7 and 8). The best molybdenum intercept [40 m (131 ft) of 0.5% Mo in drill hole SC-5] overlaps the Uncompahgre/greenstone contact.

Mineralization appears to thicken from west to east, and dips to the northeast. The top of the known mineralization at the 0.2% Mo cutoff is at an elevation of 1615 m (5299 ft), and the deepest known extent is to an elevation of 1380 m (4528 ft), a vertical range of 235 m (771 ft). The polygonal resource estimation from the four well-mineralized drill holes is 40 Mt (44 million st) of 0.33% Mo at the 0.2% Mo cutoff.

Molybdenite and pyrite are the predominant sulfide minerals and occur together in a multistage quartz vein stockwork, with minor amounts of scheelite, magnetite, specularite, chalcopyrite, galena, and sphalerite. The minor minerals occur mostly in veins that both predate and postdate deposition of the molybdenite. The best tungsten mineralization generally occurs as disseminations within garnetites and greenstones in association with 0.05% Mo. Little or no tungsten mineralization occurs in the Uncompahgre Formation regardless of molybdenum grades.

Homogenization temperatures from 350° to 500°C have been recorded from fluid inclusions in vein quartz associated with molybdenum mineralization. Five liquid-rich and three vapor-rich primary inclusions in drill core from a depth of 784 m (2572 ft) in drill hole C-25 homogenized in the range of 362° to 367°C, and indicate that boiling occurred over that temperature range. Salinities calculated from freezing of the liquid-rich inclusions were consistently less than 1 wt % NaCl equivalent. The minimum pressure required to maintain boiling of such dilute solutions at 360°C is 184 bars which implies a depth of formation of 2000 m (6562 ft) assuming hydrostatic pressure. These data suggest that approximately 1200 m (3937 ft) of overburden have been eroded from atop the deposit in the 5 m.y. since mineralization formed.

Wallrock alteration

Alteration zoning (Figs. 9 and 10) around the molybdenum deposit is controlled by the original host rock compositions and distance from the source intrusion. Alteration in noncalcareous rocks range from a potassic core to distal phyllic and propylitic assemblages. In calcareous rocks, a garnet (-diopside) skarn is flanked by a zone characterized by massive diopside and/or massive anhydrite. A pervasive quartz vein stockwork is present in the strongly altered rocks

The potassic alteration assemblage is orthoclase and biotite with minor cholrite, anhydrite, epidote, and magnetitie. The biotite occurs as vein selvages and wall-rock flooding. The anhydrite is ubiquitous and locally abundant, occurring with orthoclase in the quartz veins. Sericite is ubiquitous in the potassic zone as apparent late

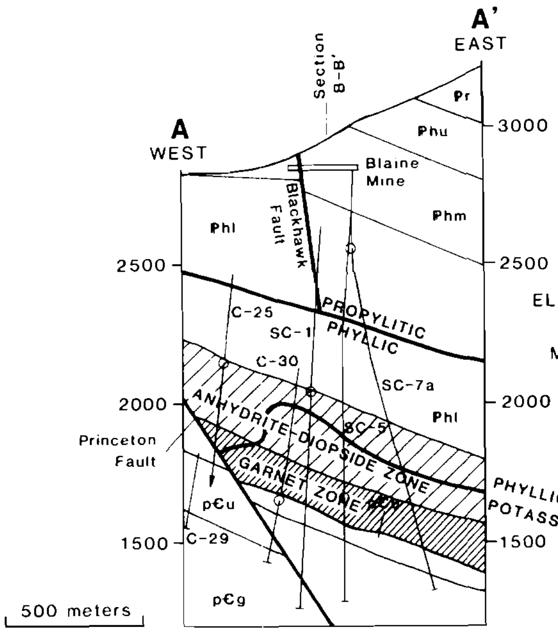

Fig. 9 — East-west section of Silver Creek area showing alteration zones.

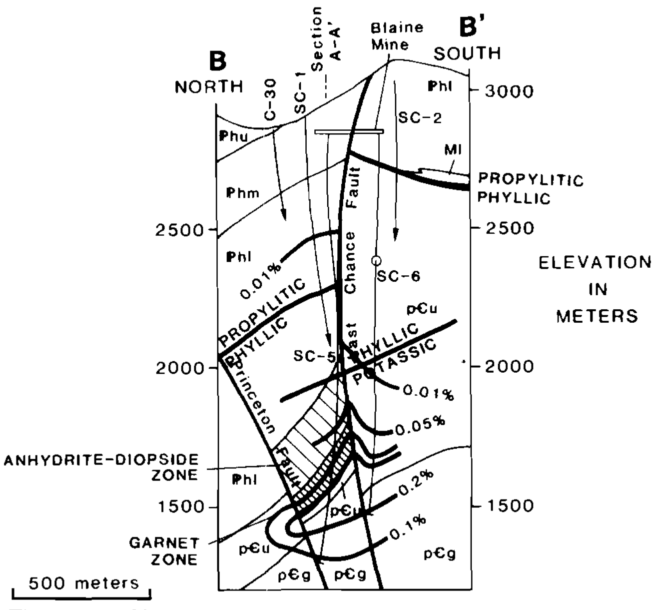

Fig. 10 — North-south section of Silver Creek area showing alteration zones

stage or remnant disseminations. The siltstones of the Hermosa Group and Precambrian greenstone are hornfelsed and bleached in the potassic zone, whereas the arkose and quartzite are not significantly altered. Most of the +0.2% Mo mineralization occurs within the potassic zone.

The phyllic zone lies above the potassic zone and is characterized by an assemblage of sericite, biotite, and chlorite with trace clinozoisite. Sphene and chlorite replace primary mafic minerals in hornblende latite porphyry sills, whereas secondary sericite, chlorite, and/or biotite are present in Hermosa Group arkoses. Siltstones and greenstone are bleached and somewhat hornfelsed. Minor orthoclase in quartz veins and biotite in vein salvages, apparent potassic zone minerals, occur throughout the phyllic zone. Phyllic alteration is present as narrow halos around the major structures in the Blaine mine and for several thousand meters to the west along the Last Chance fault. The boundary between the potassic zone and the phyllic zone is gradational and corresponds to an upward decrease in quartz veining near the 0.05% Mo grade contour. The upper phyllic zone boundary coincides with the disappearance of pervasive quartz veining.

Propylitic alteration is recognized in near-surface arkoses and porphyry sills, and is characterized by partial sericitization of feldspars and replacement of mafic minerals by chlorite and epidote.

The garnet zone is confined to the basal 100 m (328 ft) of the Hermosa section, which was originally calcareous. Garnet skarns contain most of the tungsten mineralization but have lower values of molybdenum than do interbedded lenses of siltstone. Isolated pods of garnet skarn have been found in the Blaine mine.

Massive diopside and massive anhydrite replacements of carbonate rocks compose the anhydrite-diopside zone that extends above the garnet zone approximately 250 m (820 ft). Lenses of garnetite occur at the base of the zone. Textural evidence suggests that the anhydrite replacements occurred before the formation of the calc-silicates.

The quartz vein stockwork is also present in calcareous rocks. Magnetite and orthoclase occur within quartz-molybdentite veins and vein selvages at the base of the garnet zone. Vein selvages in the upper garnet zone and in diopside hornfels of the anhydrite-diopside zone comprise biotite that grades both laterally and distally to actinolite.

Anhydrite veins occur within the Precambrian rocks but are more abundant in the Hermosa sediments. They commonly contain specularite and minor base metal sulfides and occur later in the paragenetic sequence than both the massive anhydrite and the quartz-molybdenite veins.

The origin of the sulfate in the anhydrite replacements is enigmatic. The Hermosa Group a few kilometers west of Rico includes the Paradox Formation, a sequence of interbedded limestones and evaporites. Similar quantities of evaporite have not been recognized in the near-surface section in the Rico area, but may have existed in the structurally isolated section that was massively garnetized. Replacement of limestones above the garnet zone may have required only minor remobilization of syngenetic anhydrite. Carbon dioxide bubbles observed in fluid inclusions in the massive anhydrite suggest that substantial pressure corrections are required on homogenization temperatures that range from 75° to 150°C. The carbon dioxide probably evolved by hydrothermal alteration of calcite to anhydrite (Reynolds, 1981).

Geochemistry

Pervasive dispersion halos of molybdenum, tungsten, and fluorine occur above the Silver Creek deposit and are especially well-developed and extensive in the Hermosa Group. Tin, thallium, rubidium, strontium, and columbium show sporadic anomalies.

Molybdenum increases gradually with depth to within a few hundred meters of +0.2% Mo where a very rapid increase is observed (Figs. 7 and 8). Near-surface samples very rarely exceed 1 ppm except along major structures.

Tungsten forms a relatively confined halo immediately

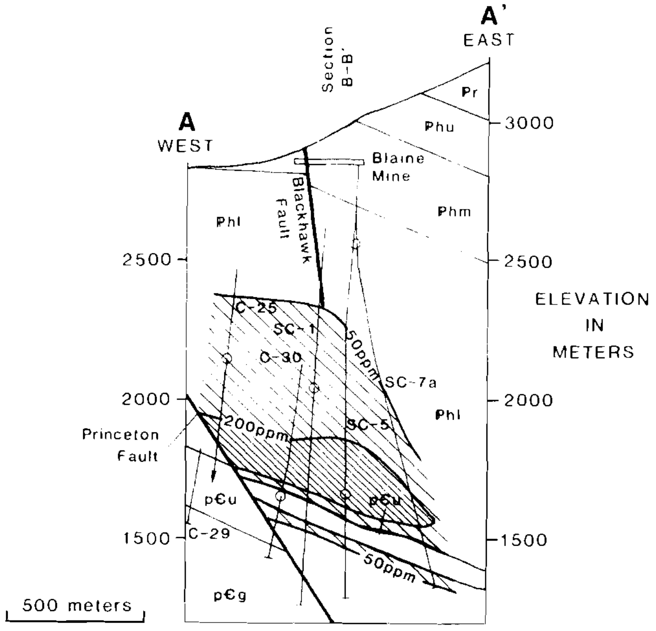

Fig. 11 — East-west section of Silver Creek area showing tungsten dispersion

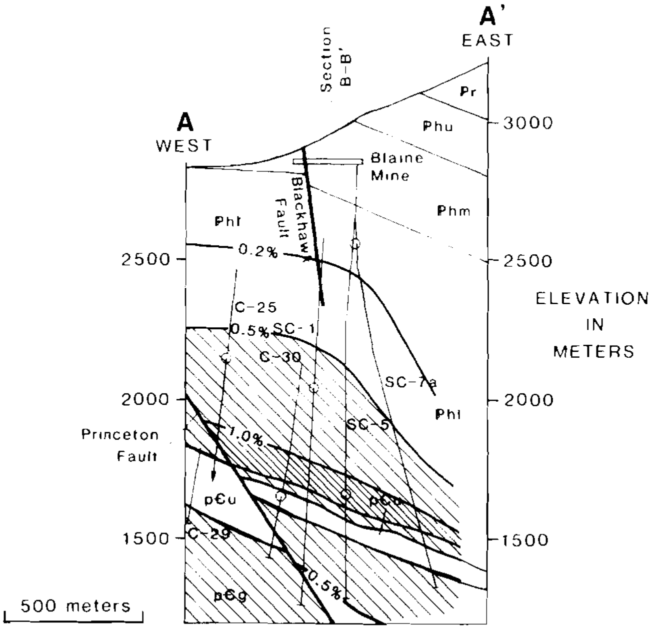

Fig. 13 — East-west section of Silver Creek area showing fluorine dispersion

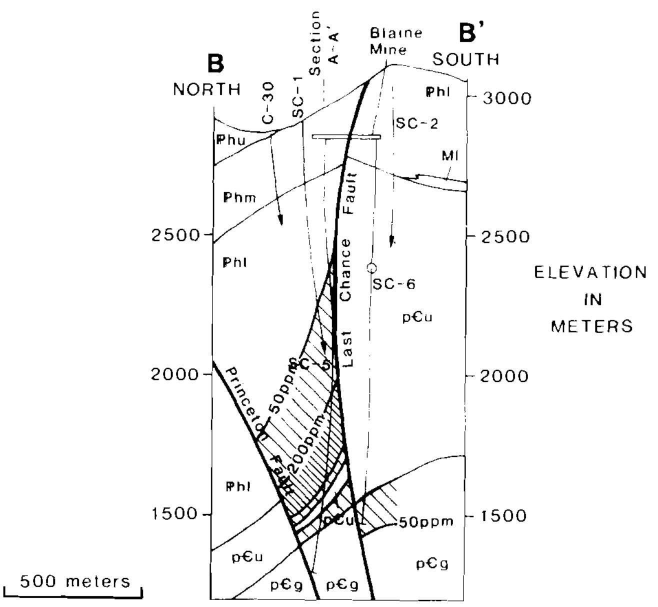

Fig. 12 — North-south section of Silver Creek area showing tungsten dispersion

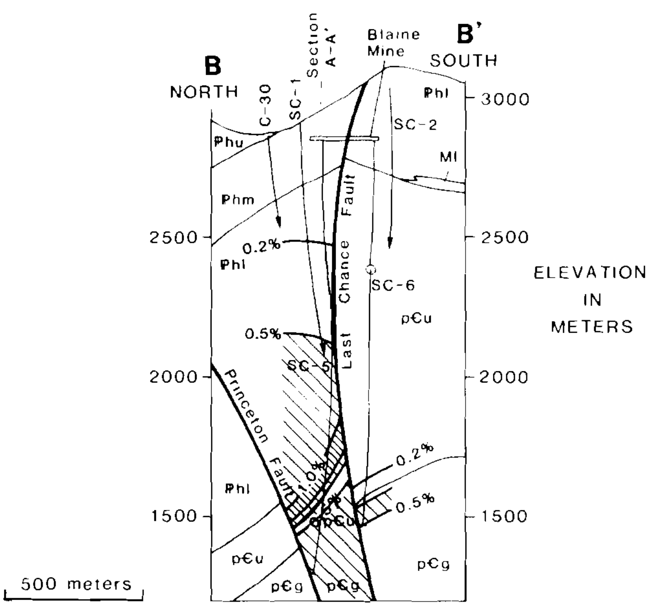

Fig. 14 — North-south section of Silver Creek area showing fluorine dispersion

above the 0.2% Mo contour (Figs. 11 and 12), where it coincides with the occurrence of skarn alteration in the lower member of the Hermosa. Scheelite and powellite are the principal tungsten minerals.

Fluorine forms the most extensive trace element halo and increases steadily from about 1000 ppm at the surface to several percent at the upper 0.2% Mo grade contour (Figs. 13 and 14). Sericite and/or garnet are inferred to contain most of the anomalous fluorine, since only traces of fluorite have been identified in the Silver Creek area.

The drilled portion of the Silver Creek deposit lies beneath the Blaine mine, and proximal to the near-surface intersection of the Blackhawk and Last Chance faults. These faults are exposed in the workings of the Blaine mine as locally gougy quartz and calcite veins that are strongly anomalous in tungsten, fluorine, and molybdenum. Sampling of the faults both underground and at the surface yielded information that helped locate the deposit.

Phyllic alteration, in association with lenses of pyrite and perhaps remnant magnetite, projects nearly to the surface adjacent to the major structures. Lead-zinc-silver and copper-iron mineralization associated with the Silver Creek deposit occurs peripheral to the phyllic halos above an elevation of 2400 m (7874 ft), and extends several thousand meters laterally from the surface projection of the molybdenum resource.

Conclusions

Application of the Henderson deposit genetic model was essential to the discovery of the Silver Creek molybdenum deposit. Dispersion halos of fluorine, molybdenum, and tungsten were key elements used to direct the exploration drilling program. Timely encouragement from drill hole intercepts kept exploration active long after molybdenum market conditions had deteriorated.

Although the Silver Creek deposit has been only partially defined by drilling, it appears to be very large and high grade. The known resource from drilling is estimated to be approximately 40 Mt (44 million st) of 0.31% Mo mineralization at a 0.2% Mo cutoff. Projections of the outline of +0.2% Mo indicate that the deposit may exceed 182 Mt (200 million st). Two factors suggest that the grade may increase with additional drilling: (1) the geologic center (source intrusion) of the deposit has not been located, and (2) the structural control of the Last Chance fault suggests that a high grade keel may occur in an untested area to the southeast where the fault intersects the mineralized zone.

Analysis of the surface and drill hole geology shows that the Silver Creek deposit is located in an area with a very complex structural history. The close association of interleaved skarns, massive anhydrite, and potassic zone siltstones above the deposit is unique and provides an opportunity for future study of the relations of different alteration zones and the evolution of the deposit.■

Acknowledgments

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Geology and production of humate and weathered coal in New Mexico

G.H. Roybal and J.M. Barker

Abstract – *Humate mining in New Mexico is a small industry [455 m^3 (16,079 cu yd) valued at $395,894 for 1983] with three mines active in 1985. Either humate (carbonaceous claystones rich in organic matter) or weathered coal ("leonardite") high in humic acid are mined. The humic acid content needed to meet consumer specifications determines which type is mined. The humate and "leonardite" now mined in New Mexico are used primarily as soil conditioners or as drilling mud additives. The potential resource for both are very extensive within the coal-bearing formations of the San Juan Basin in northwest New Mexico.*

Introduction

Humic acid-rich deposits exist in Arkansas, Florida, Louisiana, New York, North Dakota, Michigan, Minnesota, Texas, and Wyoming (Burdick, 1965) and New Mexico (Shomaker and Hiss, 1974). New Mexico humic deposits are associated with coal in the northwestern part of the state where humate and weathered coal are presently mined. Discussion of the humic acid industry in New Mexico requires an understanding of complex terminology and coal geology.

Terminology

Humic material is not a pure substance so an ambiguous and complex terminology is in use by geologists, chemists, soil scientists, agronomists, and producers. Material mined for its humic acid content is an extremely variable mixture of base-soluble humic, fulvic, and ulvic acids and their salts, formed during partial or complete decay of organic matter. This decay releases a high-molecular-weight organic material that is darkly colored, partly colloidal, and weakly acidic.

The use of the term "humic acid" varies between geology and chemistry with geological humic acid including additional smaller molecules and having greater acidity than chemical humic acid as derived in the laboratory (Krauskopf, 1967, p. 289). Humic acids have an average molecular weight between 5,000 and 50,000, are amorphous with poorly defined X-ray patterns, and have a large cation exchange capacity (CEC) ranging from 200 to 500 meq/100 gm at pH 7 (Senn and Kingman, 1973). This CEC may explain the acidity variation between humic acid and humate (chemical) because a molecule with hydrogen-filled exchange sites yields humic acid with a lower, but still modest, pH than one filled with other cations that yield chemical humate (Senn and Kingman, 1973). Figure 1 shows the relationships among

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