Chapter G

A GEOENVIRONMENTAL MINERAL DEPOSIT MODEL FOR THE NEW WORLD POLYMETALLIC REPLACEMENT/SKARN DEPOSIT

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INTRODUCTION

The historic New World mining district lies about 2.5 miles north of the town of Cooke City, Montana (about 3 miles east of the northeast corner of Yellowstone National Park). Minable reserves of Au-Cu-Ag mineralization in the New World district are contained in three, carbonate hosted (Cambrian Meagher Limestone), massive sulfide-iron oxide replacement deposits (Como, McLaren, and Miller Creek deposits) adjacent to high-angle contacts with hydrothermally altered porphyritic stocks. Mineralization also occurs in a geologically complex deposit zone within and adjacent to a phreatic explosion-collapse breccia pipe (Homestake deposit). Deep exploration drilling also led to the discovery of a "porphyry-type" copper-gold mineralized shell in a hydrothermal intrusion breccia within the porphyry stock, at depth, lying adjacent to the breccia pipe. Mining of the Miller Creek and Homestake deposits (7.9 MM tons averaging 0.261 opt gold, 0.74% copper, and 1.05 opt silver, totalling 2 million ounces of gold) was proposed by Crown Butte Mines between 1989 and 1996, until the proposal was withdrawn after a federal buyout. The entire New World District was subsequently withdrawn from future mineral entry. As part of its agreement with Crown Butte Mines, the United States government paid $22.5 million for closure of historic mining properties in the district. Efforts to control historic mining impacts through management of ARD in historic surface and underground mine facilities are ongoing, led by the USDA Forest Service Region 1 in consultation with a variety of other state and federal agencies and environmental interest groups.

The environmental hydrogeochemistry of the New World project was closely scrutinized during the mine permitting and NEPA review process and a significant body of hydrogeochemical data is available characterizing the mineralized portions of the deposits prior to mining operations. Historical mining operations also produced mixed lithologic wastes from different deposit types that have varied ARD and metal release potential. Hydrogeochemical data characterizing these mined wastes and related existing water quality impacts are also available. The New World ore deposits therefore provide an excellent opportunity to apply a geoenvironmental mineral deposit model to a polymetallic replacement/skarn deposit.

HYDROGEOCHEMICAL OVERVIEW OF THE NEW WORLD DEPOSIT GEOLOGY

The New World mining district is located in the south-central part of the Beartooth uplift, a fault bounded block of Precambrian crystalline rocks. Paleozoic sandstone, siltstone, shale, limestone, and dolomite, with associated Tertiary intrusive and volcanic rocks, overlie the Precambrian basement at New World (Lovering, 1929; Elliott, 1979; Elliott, Kirk, and Johnson, 1992; Johnson and Meinert, 1994). Intermediate to felsic calc-calkaline rocks, including diorite, andesite, trachyandesite, dacite, quartz latite, and rhyolite, occur as shallow stocks, laccoliths, and numerous sills and dikes. The intrusions are spatially related to alteration, mineralization, and location of breccia pipes in the district. The plutons, shown from north to south in Figure 1, are the Scotch Bonnet Diorite Stock, the Fisher Mountain dacite porphyry intrusive complex, the Homestake dacite porphyry stock, and the Lulu Pass dacite porphyry laccolith. Breccia pipes include the Homestake breccia, the Henderson Mountain Stock, and the Alice E. Breccia.

The New World Au-Cu-Ag deposit is actually comprised of 5 separate deposits, including the Como, Fisher Mountain, McLaren, Miller Creek and Homestake deposits. The ore deposits are developed in skarns and replacement zones at sedimentary-rock contacts with four intrusive complexes and in breccia complexes where entrained blocks of limestone have been selectively mineralized. The principal ore mineral is native gold, which occurs as inclusions within pyrite and chalcopyrite and as particles along fractures and grain boundaries, with associated magnetite and specularite mineralization.

Skarn-replacement deposits are located adjacent to steep contacts of the Fisher Mountain and Homestake intrusive contacts, along sill and dike margins; at upper and lower contacts of the Cambrian Meagher Limestone;

and along faults where these features served as conduits for mineralizing fluids. The skarn-replacement deposits wrap around the west margins of the intrusives, as shown in Figure 1, and include the McLaren, Como, and Fisher Mountain deposits. Another stratiform skarn and replacement deposit is located to the east of Miller Creek, in the

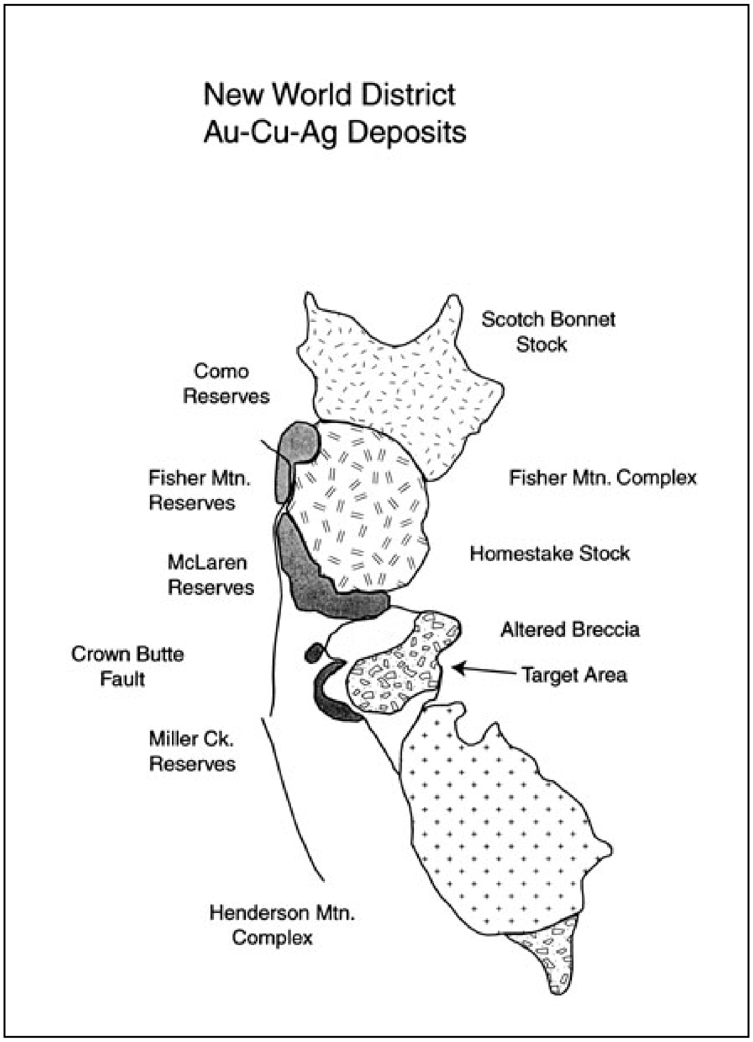

Figure 1. Geologic map of New World Ore deposits, showing intrusives and contact/replacement zones of mineralization (after Elliott et al, 1992)

Meagher formation to the west of Henderson Mountain as shown in Figure 1. Replacement mineralization also occurs in zone enriched in blocks of Paleozoic limestone entrained in the Homestake breccia.

HYDROLOGY

The New World district is located at an elevation that ranges from 7,380 feet to over 10,400 feet, sits at the headwaters of three watersheds; Daisy Creek, Fisher Creek, and Miller Creek. (Figure 2). Average annual precipitation exceeds 60 inches, and the site is snow covered much of the year. Groundwater recharge occurs primarily during seasonal snowmelt, when surface runoff peaks in all three drainages. Groundwater in the vicinity of Como basin is controlled by near vertical fractures, joints, and faults, with limited to moderate interconnectedness.

Water flows into the abandoned Glengarry adit, where oxygen interacts with sulfide rich mineralization to produce ARD that is discharged into the headwaters of Fisher Creek.

Groundwater is also impacted by recharge through the mine wastes and mineralized rock at the historic McLaren pit, with subsequent discharge to Daisy Creek. The cold climate and strongly variable surface water flows exert important controls on surface and groundwater impacts at New World. The conceptual hydrogeochemical model for the New World Closure is summarized in Figure 3.

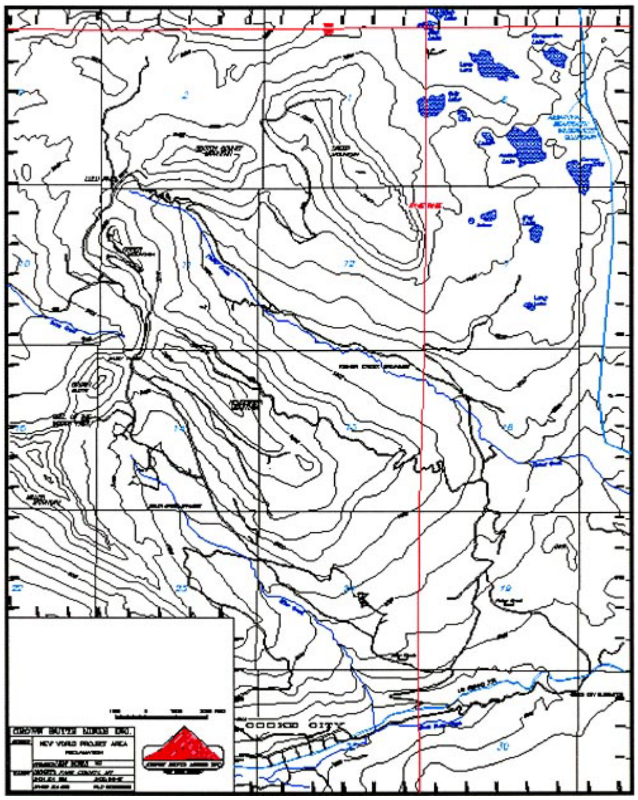

Figure 2. Map showing district location and surface water resources (Maxim, 1999).

GEOCHEMISTRY

Despite the fact that carbonate-hosted deposits as a group have some of the lowest probability for adverse environmental impact, the majority of rocks at New World are acid generating. The widespread and locally massive sulfide mineralization that is prevalent at New World produces acid generation potential throughout the district. Neutralization potential varies, however, with the result that some materials are more strongly acid generating than others. Sulfide mineralization in intrusive porphyry rocks and massive sulfide replacement deposits in limestones are strongly acid generating, but local portions of the limestone hosted replacement/skarn deposits are net neutralizing. Generally, the McLaren/Como/Fisher Mountain deposits are strongly acid generating, and historic ARD impacts are evident in both Daisy and Fisher Creeks. Water quality in the New World district is summarized using the USGS geoenvironmental models approach in Figure 4; virtually all analyses fall into the Cu-skarn category. The water quality measured in the Gold Dust adit, which is developed in Precambrian granodiorite and metasediments, and ends in the Homestake Breccia, is much different and falls into the pyrite-poor, carbonate hosted category. This portion of the ore deposit, although it does locally host some strong sulfide mineralization, also has significant acid neutralization potential. The metals that are associated with the New World deposit include Al, Fe, Cu, Pb, Cd, and Zn. The relative concentrations of each metal in receiving water vary between deposits in the district, as a function of flow and sediment load as well as the primary character of the ore in each deposit.

Natural deposits of ferricretes formed 8,800 years before present (Furniss and Hinman, 1998) occur at New World, indicating that acid rock drainage has occurred naturally in the district for thousands of years. Two springs at New World located upgradient of historic mine workings that are typical of background geoenvironmental conditions at New World were described by Runnells et al, 1992. The chemistry of these springs is shown in Figure 4 for comparison.

As is typical of carbonate hosted deposits, the metal ratios and pH of mine drainage attenuate fairly rapidly down gradient at New World. Dilution and mixing along gradient with bicarbonate rich, low-metal groundwater dramatically improves water quality in both Fisher Creek and Daisy Creek within a mile of the ARD impacts. From this standpoint, the carbonate-hosted character of the deposit serves to limit the geographic impact of ARD generated in the more heavily mineralized deposits.

STYLES OF MINERALIZATION IN THE NEW WORLD DEPOSIT

Three principal types of mineralization are recognized by Elliott et al, 1992. Each of these deposit types has a unique suite of mineralogic, alteration, and oxidation characteristics which must be incorporated into a meaningful environmental geochemistry analysis. Key factors include the distribution of pyrite and chalcopyrite, calcite, and calc-silicate mineralization. The three styles of mineralization are:

1) Stratiform retrograde skarn and replacement deposits hosted mostly by the Meagher formation (Como/Glengarry, McLaren, and Miller Creek deposits).

2) Replacement and vein deposits along high-angle faults (Fisher Mountain deposit).

3) Sulfide-and iron-oxide rich replacement of limestone blocks in diatreme and intrusion breccias of the Homestake breccia complex (Gold Dust adit/Homestake deposit).

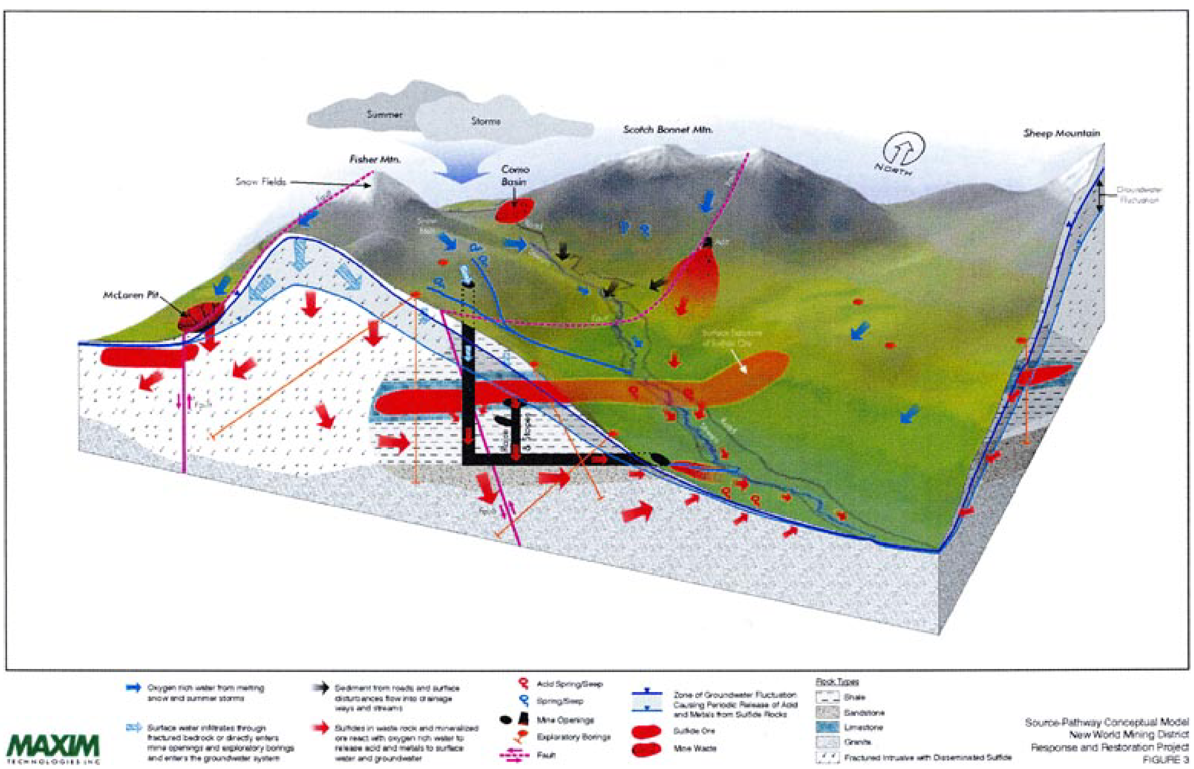

Figure 3. Source pathway conceptual model of New World district closure hydrogeochemistry

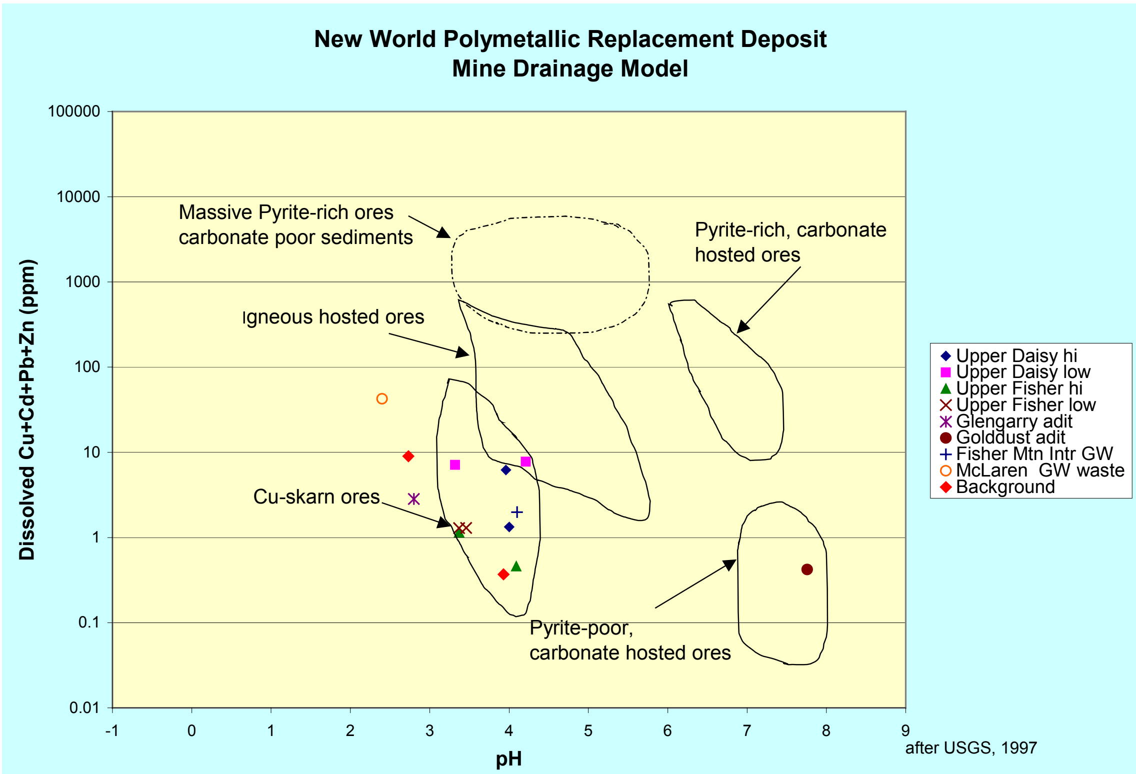

Figure 4. New World Polymetallic Replacement/Skarn deposit mine drainage model, based on USGS geoenvironmental model approach.

This case study focuses on the polymetallic replacement/skarn styles of mineralization, in the historically mined Como/Glengarry, Fisher Mountain, and McLaren ore deposits. Similar mineralization occurs in the Miller Creek Deposit, which was does not outcrop and was not mined historically at New World, and is therefore not considered further here. Sulfide-rich retrograde skarn and replacement deposits are hosted dominantly by the Cambrian Meagher limestone. Calc-silicate minerals that occur with both sulfide and iron oxide minerals indicate acidic and oxidizing hydrothermal fluids that were neutralized by reaction with the limestone host, thus forming the Au-Cu-Ag deposits. Minerals commonly occurring in these deposits include pyrite, magnetite, quartz, sericite, epidote, chlorite, biotite, muscovite, chalcopyrite, amphibole, clays, garnet and pyroxene.

In the Como/Glengarry Deposit, mineralization occurs where epidote-rich retrograde skarn and limestone replacement with massive pyrite and chalcopyrite were developed at the Meagher limestone- Fisher Mountain Intrusive contact . The geology of the Como Basin is dominated by the Fisher Mountain Intrusive Complex. Cambrian Park Shale, Meagher Limestone, and Wolsey Shale Formations are mineralized in the deposit.

Neutralization potential in rocks mined from this portion of the district is provided by calcite and calc-silicate mineralization in the Meagher limestone, and by feldspars and biotite in the Fisher Mountain Intrusive. Wastes produced from the Como portion of the ore deposit include Cambrian Meagher and Park shale lithologies, as well as Fisher Mountain Intrusive, which contain variable degrees of sulfide mineralization and show a large range in ARD potential, from –480 to 11 tons $CaCO_3$/ktons rock.

The Glengarry adit, located at the headwaters of Fisher Creek, was driven 1,500 feet northwest under Como Basin. The adit intercepted tertiary intrusive rocks along the Glengarry fault, as well as blocks of mineralized Meagher limestone in contact with the Fisher Mountain Intrusive complex. The adit is connected to the surface near the center of the main Como ore body, so that the adit receives continual recharge. The geochemistry of groundwater in the Fisher Mountain Intrusive Complex and of water flowing from the Glengarry adit are shown with surface water data for Fisher Creek (under low and high flow conditions) in Figure 4. Waters are acidic, but show relatively low concentrations of metal relative to igneous and massive sulfide polymetallic ore deposits.

Both source and migration control options are being evaluated for management of the Glengarry adit drainage. In 2000, an underground de-watering and mapping program will be undertaken to evaluate options for reducing flow of water into the adit and for reducing the solute load contributed by sulfide oxidation reactions.

In the McLaren deposit, stratiform replacement mineralization in the Meagher formation was mined in an historic open-pit operation. McLaren mineralization consists chiefly of epidote-rich retrograde skarn, quartz-pyrite replacement bodies, and magnetite-rich replacement bodies. (Johnson and Meinert, 1994). Mine wastes that exist in the historic McLaren pit include Cambrian Wolsey Shale, Meagher Limestone, and Park Shale as well as Fisher Mountain intrusive and zones of replaced Cambrian Pilgrim limestone. These varied lithologies exhibit variable sulfide and metal content, with trimodal distribution of acid generation risk based on static test ABA data that range from + 779 to –160 tons $CaCO_3$/kton. Wastes from this portion of the district are likely to range in acid generation potential, from slightly to strongly acid generating. The occurrence of strongly net neutralizing material is rare in this portion of the district.

Water quality data from groundwater monitored in McLaren pit mine wastes, as well as surface water data from upper Daisy Creek (immediately downgradient of the pit) under low and high flow conditions, are also presented in Figure 4. The Cu-skarn geoenvironmental signature dominates in these waters as well. The floor of the McLaren pit is rich in sulfide mineralization, so that acid generating waste removal may (paradoxically) expose bedrock with very high sulfide contents that is capable of further acid generation. Capping, waste removal, backfilling, and water management options are being considered for closure of the McLaren deposit. The smaller Fisher Mountain deposit, located between the Como and McLaren deposits, consists of quartz-pyrite replacement ore in the Pilgrim Limestone and sulfide-rich fracture fillings along the Crown Butte fault. Limited sampling data indicate that the waste from this deposit is acid generating.

GEOENVIRONMENTAL MODELS IN MINE CLOSURE

The New World deposit presents several challenges in mine closure, due to the sub-alpine setting; the geochemical variability of the mineralization and high ARD potential of mine wastes; the natural occurrence of near surface sulfide mineralization in the McLaren and Como pits; and the hydrologic complexity of groundwater recharge in the vicinity of the Glengarry adit. In any mine closure, a "big picture" understanding of closure goals, options, and limitations is needed to optimize environmental protection within economic constraints. Application of the geoenvironmental model at New World correctly identifies the Cu-skarn mineralized portions of the mining district as the primary goals for ARD management. Control of the McLaren pit and Glengarry adit point sources of ARD at New World will accomplish a significant portion of the possible improvement in water quality. Further, reference to the background water quality data plotted in Figure 4 indicates that the success of closure actions will be limited by the geoenvironmental nature of the unmined, naturally occurring mineralization throughout the New World district. Fortunately, the natural remediation offered by the carbonate-hosted deposit will serve to minimize any remaining ARD impacts in Fisher and Daisy Creeks.

REFERENCESCITED

Elliott, J.E., 1979, Geologic map of the southwest part of the Cooke City quadrangle, Montana and Wyoming: U.S. Geological Survey Miscellaneous Investigations Series Map I-1084, scale 1:24,000.

Elliot, J.E, Kirk, A.R. and Johnson, T.W., 1992, Field Guide Gold-Copper-Silver Deposits of the New World District, in Elliot, J.E. (ed), Guidebook for the Red Lodge-Beartooth Mountains-Stillwater area, Seventeenth annual field conference, Tobacco Root Geological Society, p. 1-19.

Furniss, G. and N.W. Hinman, 1998. Ferricrete provides record of natural acid drainage, New World District, Montana. Water Rock Interaction, Arehart and Hulston (eds). Rotterdam: Balkema, 1998, p. 973-976.

Johnson, T.W. and L.D. Meinert, 1994. Au-Cu-Ag Skarn and Replacement Mineralization in the McLaren Deposit, New World District, Park Country, Montana. Econ. Geology, Vol. 89, No. 5, August 1994, p. 969-993.

Lovering, T.S., 1929, The New World or Cooke City mining district, Park County, Montana: U.S. Geological Survey Bulletin 811, p. 1-87.

Maxim Technologies, Inc., 1999. Final Overall Project Work Plan: New World Mining District Response and Restoration Project. A report prepared for USDA Forest Service, Region 1, November 1999.

Maxim Technologies, Inc., 2000. Technical Memorandum: Data Summary McLaren Pit, Como Basin, and Glengarry and Goldust Adit Areas, New World Mining District. A report prepared for USDA Forest Service Region 1, February 2000.

Runnells, D.D, T. A. Shepherd, and E.E. Angino, 1992. Metals In Water: Determining Natural Background Concentrations in Mineralized Areas. Environ. Sci. Technol., Vol. 26, No. 12, p. 2316-2323.