THE MINING HISTORY AND ENVIRONMENTAL CLEAN-UP AT THE SUMMITVILLE MINE

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INTRODUCTION

(1) At 9:00 pm on December 1, 1992, Galactic Resources Limited (GRL) of Vancouver, Canada notified the State of Colorado of their intent to declare bankruptcy and abandon operation of the Summitville mine effective December 16.

The fluid level in the cyanide heap leach pad at that time stood just five feet below the emergency spillway and normal winter precipitation would have caused it to overtop the spillway. Had that happened, cyanide and metal-bearing processing fluid would have overflowed by February of the next year. Within hours of a power outage or mechanical failure, water pumps would have shut down, leaving acidic cyanide water in the heap leach underdrain effluent to overflow the underdrain sump. Effluent from the underdrain would have discharged directly into Cropsy Creek, then Wightman Fork, a tributary to the Alamosa River.

(2) On December 4, with no capability to deal with an emergency of this character, the State requested emergency response assistance from Region VIII of the U.S. Environmental Protection Agency (EPA).

(3) The EPA sent emergency response personnel and contractors to the site to assess the situation. Most of GRL's staff were retained by the EPA's contractors, the U.S. Bureau of Reclamation and Environmental Chemical Corporation, to facilitate the transition. Steps were taken to assure that necessary water circulation and water treatment systems remained operable. Thus, the immediate threat of a direct contaminant release from the site was averted. A technical team comprised of EPA, DMG, and CDPHE personnel and emergency response personnel began assessing longer term consequences of GRL's operations.

For nearly eighteen months prior to bankruptcy, GRL and its daughter company Summitville Consolidated Mining Company Inc. (SCMCI) had been under constant State agency enforcement mandates to evaluate contaminant releases from the site and develop remedial measures to resolve the problems and reclaim the site. Also, state and federal agencies with varying regulatory responsibilities had been monitoring the mine site and its surroundings. As a result, though inadequate to answer the challenge, considerable environmental monitoring data were available with which to evaluate the Summitville Mine and its environmental impacts.

In the six months following GRL's abandonment of the site, a broad selection of environmental characterization, monitoring and clean-up projects were initiated. This paper describes the Summitville site, provides a history of the mining activities, and a description of the environmental clean-up approach.

BACKGROUND

A general explanation of the physical situation, history, construction of the mine site, and on-site contaminant generation problems is provided in this section.

Site Location and Description

The Summitville mining district is located about 25 miles south of Del Norte, Colorado, in Rio Grande County.

Occurring at an average elevation of 11,500 feet in the San Juan Mountain Range, the mine site is located two miles east of the Continental Divide. The mine pit occupies the northeastern flank of South Mountain (Figure 1). The permit area occupied by the State's Mined Land Reclamation permit covered 1440 acres, of which approximately 550 acres have been disturbed.

The Site is located in the Rio Grande Drainage Basin near the headwaters of the Alamosa River. The northern part of the Site is bounded by the deserted townsite of Summitville - last occupied in the mid-1930s - and by the Wightman Fork of the Alamosa River. Cropsy Creek, a tributary to Wightman Fork, bounds the site on the east. The confluence of Cropsy Creek and Wightman Fork is located near the northeastern perimeter of the site at the downstream boundary of the site. Wightman Fork enters the Alamosa River approximately 5 miles below its confluence with Cropsy Creek.

Climate

The climate of the Summitville mine site is characterized by long cold winters and short cool summers. Snowfall is heavy (commonly 400 inches) and thunderstorms are common in the summer, particularly during the monsoonal season in August. Temperatures range from about 70°F to 17°F in summer and 40°F to -15°F in winter. Annual precipitation averages 55 inches, mostly as snowfall between November and April with annual evaporation of approximately 24 inches.

Topography

South Mountain, the prominent topographic feature of the site, is a relatively steep-faced, faceted surface hosting sparse vegetation in the upper surfaces grading to a gently sloping alpine valley that forms the headwaters of the Wightman Fork. The oversteepened rock faces on South Mountain bear evidence partly of alpine glaciation and of rapidly eroding clay-rich rocks that break down readily in the local climate.

Before 1870, when gold was first mined from the Wightman Fork, the Site consisted of upland surfaces, wetlands and the peak of South Mountain. The predominant ground cover was alpine tundra at the higher elevations with coniferous forest and subalpine meadow in the lower elevations. Since then, mining has altered grossly the local topography. From 1870 through 1873 limited placer mining was conducted in the alluvial deposits of Cropsy Creek and Wightman Fork. Following that was limited open cut mining in several outcrops of gold-bearing quartz veins. From 1873 through 1940 the northeastern flank of South Mountain was mined extensively during several underground mining campaigns. To access the underground, the surface became laced with road cuts and was disturbed by deposition of waste rock in downslope piles near adit portals.

Several mills were constructed at the mine site, including stamp mills and a flotation-cyanidation mill in 1934. Tailings were deposited downslope of each mill. In the late 1960's Wightman Fork was diverted to the north side of the stream valley to accommodate construction of a large tailings pond. Mill tailings at that time were deposited largely on what was to be called later the Beaver Mud Dump, just upslope of the tailings pond, and fine "slimes" were discharged to the pond (Figure 1).

Starting in 1984, SCMCI significantly altered and enlarged the pre-existing disturbed surface over most of the mine site. Waste rock and ore were excavated to form an open pit on the northeastern flank of South Mountain and were dumped into waste rock piles or placed onto a pad for heap leaching. Waste rock from the pit and other locations was used to construct the extensive road system, various building pads, parking lots, sediment ponds, and the earthen embankment that now contains the valley-fill heap leach pad (Dike 1). Cropsy Creek was diverted into a constructed channel upslope of the heap leach pad along the southeastern valley wall of the Cropsy Creek valley. Waste rock and fines were deposited on the Cropsy Waste Pile, the North Waste Pile, the Beaver Mud Dump and the Clay Ore Stockpile.

Several deviations from the original mining plan caused disturbances that might have been avoided. The original mining plan called for the processing of two separate types of ore: clay ore and vuggy silica ore. A separate crusher and conveyor system was installed for each of these ores. The clay ore was to have been agglomerated and leached on a pad upslope of the main heap leach pad, on what is now the Cropsy waste rock dump. However, agglomeration was abandoned, the experimental clay "ore" stockpile remains on the site, and the clay ore crusher and conveyor went virtually unused.

Geology

The Summitville mining district is located near the margin of the Platoro-Summitville caldera complex. Ore-bearing rocks in the immediate area of the mine site consist of the South Mountain Quartz Latite Porphyry (Steven and Ratte, 1960). The porphyry is underlain and surrounded by the Summitville Andesite. The contact between the latite and andesite is intrusive, faulted in some areas, and nearly vertical. The contact on the northern margin of the latite intrusive is marked by the Missionary Fault. South Mountain is bounded on the southwest by the South Mountain Fault, a large northwest trending regional fault. The South Mountain Quartz Latite Porphyry is bounded to the west, on both sides of the South Mountain Fault, by the slightly older Park Creek Rhyodacite. The latite is overlain at higher elevations in nearby erosional remnants by the Cropsy Mountain Rhyolite.

Emplacement of the South Mountain volcanic dome, hydrothermal alteration, and mineralization occurred in rapid succession approximately 22.5 million years ago (Rye and others, 1990). Stoffregen (1987) concluded that magmatic, hot and highly acidic, sulfate-laden water that suffused from the quartz latite magmas caused extensive alteration of the quartz latite. Hydrothermal alteration consists of four zones, generally occurring in sequence: vuggy silica, quartz-alunite zone, quartz-kaolinite zone, and the clay alteration zone. The vuggy silica zone generally is a porous unit from which most major elements except silica and iron were leached by acidic solutions and replaced in places by excess silica. This zone is comprised of irregular pipes and lenticular pods that generally show greater vertical than lateral continuity. The next outwardly occurring zone, the quartz-alunite zone, contains feldspars of the quartz latite porphyry which have been replaced by alunite. This zone grades outward to a thin quartz-kaolinite zone, which is not always present, and then into an illite-montmorillonite-chlorite zone in which feldspar and biotite crystals were replaced by illite and quartz, with lesser kaolinite and montmorillonite. The quartz-alunite and clay alteration zones are the most volumetrically significant. Fine-grained pyrite is disseminated through the groundmass in all zones (Rye, et.al., 1990). Overall, the alteration mineralogy at Summitville is most similar to alteration near the crest of Cropsy Peak, a lava-capped peak southeast of South Mountain.

Summitville mineralization is an example of acid-sulfate epithermal Au-Ag-Cu mineralization associated with advanced argillic alteration (see Plumlee and others, 1995). Magmatic water (derived from the magma) mixed with the less acidic and more reducing meteoric water (derived from snowmelt and rainfall), and deposited metal sulfides at relatively shallow depths (less than 1 kilometer). Mineralization is associated mostly with the porous vuggy silica zone, and occurs as covellite + luzonite + native gold changing with depth to covellite + tennanite (see Plumlee and others this volume for an explanation of these minerals). Gold also occurs in a near-surface barite + goethite + jarosite assemblage that crosscuts the vuggy silica zone (Stoffregen, 1987). Numerous minerals comprised of secondary metal salts occur throughout the fractures and groundmass (Plumlee and others, 1995).

Post-volcanic geologic processes have been largely erosional, in part glacial. The two major streams that drain the site, Cropsy Creek and Wightman Fork, tend to follow the quartz latite/andesite contact. Numerous springs and seeps issue along this junction between the fractured quartz latite porphyry aquifer and the underlying dense andesite aquitard. Discharges of iron-rich waters from these springs and seeps, when mixed with air, form ferricrete bogs, concrete-like deposits of iron oxides and iron hydroxides that cement together whatever lies in the path of the mineral water including rock, vegetation, and rarely, wildlife. Site cover material consists of topsoil, silt, clay, and gravel.

Hydrogeology

Ground water at the Summitville mine site is present in several local, shallow, discontinuous perched aquifers. Shallow ground water occurs in surficial deposits consisting of colluvium, "slope wash" alluvium and/or glacial ground moraine, and weathered and fractured portions of the Summitville Andesite. These shallow systems discharge to surface water seasonally. The upper perched aquifer system also contributes to the ground water recharge of the fractured bedrock system. Both the quartz latite and andesite bedrock throughout the mine site are fractured extensively. Several local highly productive wells were installed apparently in zones of high fracture density, and are coincident with surface lineaments. Numerous springs and seeps occur throughout the mine site, the greatest number near the contact zone between the productive, upgradient quartz latite and the surrounding less permeable andesite. Most of these discharge in direct response to the annual precipitation cycle, with high and low flows corresponding to the surface water flows in the area. Rainstorm related discharges, particularly in August, occur at some seeps.

Surface Water Hydrology and Human Occupation

Surface water from the Summitville Site flows past the town of Jasper into Terrace Reservoir, approximately 17 miles downstream from the confluence of the Wightman Fork with the Alamosa River. Below the Terrace Reservoir, the river flows into the western side of the San Luis Valley, past the town of Capulin. Throughout this drainage area, homes, farmsteads and ranches depend on alluvial and bedrock wells or river water for potable and agricultural water production. Additionally, the Alamosa River is used for surface irrigation on lands within a small portion of the Alamosa River Wildlife Refuge. Part of the Alamosa River is diverted through the Empire Canal into La Jara Creek. La Jara Creek stream flow and irrigation return water reach the Rio Grande River during several times of year. However, because of irrigation diversion and recharge loss to the alluvial aquifer, the Alamosa River channel rarely has in-channel flow east of U.S. Highway 287, so it does not flow into the Rio Grande at their historic confluence. In places the historic Alamosa River channel has been plowed.

Present Surrounding Land Use

The Summitville Mine occurs mostly on private (patented) land, and is surrounded by lands of the Rio Grande National Forest. Within the mine site are 22 acres of Forest Service land. The Forest Service lands are highly desirable for outdoor sports and recreation, both in winter and summer. Additionally, logging is conducted adjacent to the site and the main access roads. Cattle and sheep are grazed in the surrounding area during summer and autumn the area is heavily hunted.

Production of the Summitville Gold Resource

Placer gold was first discovered in the alluvium of the Wightman Fork of the Alamosa River by J. L. Wightman in 1870. In 1873 the first lode gold deposits were located and claimed on South Mountain. Like many mining communities in the west that are now ghost towns, Summitville materialized overnight to accommodate the miners who worked the mines and mills on South Mountain. Between 1873 and 1949, Summitville yielded approximately 240,000 troy ounces of Gold, worth approximately $7 million at the time of production. Between 1950 and 1984, activities at Summitville were limited largely to exploration. Between 1984 and 1992, SCMCI produced approximately 249,000 troy ounces of Gold. Based on an average price of $325 per ounce, this production represents a value of approximately $81 million. (The price of gold fluctuated during mining operations and what SCMCI recovered in value is not known.)

GRL's Operating Problems

In 1984, GRL acquired the property, completed additional drilling, and proceeded to obtain a permit for a "limited impact" test pit and heap leach. (A limited impact operation, in terms of the Mined Land Reclamation Board, covers less than 10 acres of disturbance and can disturb no more than 70,000 tons of rock per year.) The test project was completed in the summer and fall of 1984 and pronounced a success. GRL formed a local subsidiary, Summitville Consolidated Mining Company Inc. (SCMCI), in early 1984. SCMCI was a wholly-owned subsidiary of Galactic Resources, Inc. (GRI), of Idaho, which was in turn a wholly-owned subsidiary of Galactic Resources, Limited (GRL) of Canada. For simplicity hereafter, we will refer to GRL, the parent corporation, when referring to any of the three corporate entities.

GRL obtained a mine permit for the full scale open pit and heap leach operation in October 1984. However, the depressed gold price during 1985 apparently prolonged the raising of investment capital. Construction commenced in 1985, continued through the winter of 1985, and was completed during the summer of 1986. Considerable difficulty was encountered during construction, due to the extreme winter conditions at the site, and this resulted in extensive avalanche damage to the heap leach liner system.

Even though SCMCI produced a reported 249,000 troy ounces of gold, the company's December 4, 1992 U.S. bankruptcy petition reported a net operating loss of approximately $85 million. Complemented by equally unprofitable involvements in the Ridgeway (South Carolina) and Ivanhoe (Nevada) gold mines, Galactic Resources Limited of Vancouver, Canada, SCMCI's parent, reported a combined net operating loss of $297 million in its January 21, 1993 Canadian bankruptcy petition.

SCMCI notified the State of its intention to file for Chapter VII bankruptcy petition by facsimile delivery of a draft press release at 9:00 pm on December 1, 1992. The press release stated that SCMCI intended to seek protection of bankruptcy because it lacked the financial ability to continue operations at the Summitville Mine after December 15, 1992. On the previous day, SCMCI had delivered a revision to their mined land reclamation plan that had been required by the Division of Minerals and Geology (the Division) and the Mined Land Reclamation Board (the Board). This revision application included cost estimates covering several amended reclamation plans; these ranged from $20.6 and $38.6 million. Upon completion of a technical adequacy review, the Division, as statutorily mandated, would have required the operator to submit additional warranty, increasing the bond to an amount equal to the projected reclamation cost. SCMCI filed its petition with the federal bankruptcy court in Denver on the afternoon of December 3, 1992.

ON-SITE CONTAMINANT SOURCES

The Heap Leach

Crushed ore was first deposited in the heap leach, and cyanide solution application commenced in June of 1986. During the first month of processing, cyanide-bearing fluids were detected in the leak detection layer between the primary fabric liner and the secondary compacted clay layer and in the underdrain installed beneath the secondary compacted clay liner. The Division of Minerals and Geology (the Division) reported the loss of containment to the Mined Land Reclamation Board (the Board). GRL and its consultants attributed both occurrences to sloppy application of solution which allowed overspray outside the partially lined basin. In addition, GRL presented the rationale that the leak detection system is also an interceptor system because no 45-acre heap could be constructed with zero leakage. The company was allowed to construct a sump (the French drain sump) to capture the contaminated leak detection and underdrain effluent and pump them back into the heap for containment.

The original permit application included a water balance assessment for the Summitville site that projected an excess of evaporation over precipitation. Had that been the case, water from Wightman Fork would have been needed to sustain operation of the heap leach. In fact, water rights covering this project were procured prior to operations. But the water balance projection was later determined to be in error. GRL's consultants contended that the sump fluid, which was pumped back to the heap, would not eliminate the projected water balance deficit within the heap. Additional water would still be required to compensate for evaporative loss.

Records from mid-1987 through the late fall of 1992 show that Summitville mine operations suffered a series of broken pump back pipelines and springs erupting from beneath the heap leach, resulting in releases of cyanide-contaminated fluids. One of the reasons that pumps failed is that acidic waters, which flowed beneath the heap leach pad into the French drain sump had to be neutralized prior to pumping. However, because lime was used to neutralize the acid, and because the solutions dissolved the metals in the pumps quickly, several pumps failed before the operator switched over to sodium hydroxide and stainless steel pumps for more stable operations.

Violations were issued and abatement actions ordered and completed only to encounter further setbacks. The NPDES/CDPS program's original assumption that the mine would be a "zero-discharge" facility was discarded, and GRL was required to install a treatment plant to treat and release the accumulating cyanide-contaminated heap solution. Discharge was essential because there was too much fluid in the heap leach pad and it was affecting recoveries, operations, and ultimate shutdown. But treatment was necessary because every industrial discharge had to meet water quality standards that were established for the discharge.

Throughout a prolonged sequence of events, the operator's attempts to perfect its water treatment plant met no success. During 1989 and 1990 GRL attempted land application to polish and dispose of partially treated effluent. However, the land application project resulted in overland flow due to over application and GRL was cited again for water quality violations. Had the land application water not flowed overland, there might not have been an "unregulated discharge" and application to groundwater might have continued. The volume of fluid inside the heap leach pad grew steadily, inundating the ore, compromising resource recovery, and increasing the eventual risk.

The Waste Rock

Much of the attention was focused on the heap leach pad, its water balance, land application, and related issues. However, as mining progressed, a significant additional environmental issue developed over acid drainage and metals contamination from the site's waste rock piles. There was a lack of adequate characterization of the overburden and waste rock during the permitting process. The original limited impact permit application stated that because the rocks of the ore body came from the "oxide" zone, they had no acid generating potential. This observation was grossly incorrect.

Like thousands of other deposits in the world, the gold at Summitville formed when hydrothermal solutions deposited sulfide-rich base metal veins. Originally, the gold was extremely finely disseminated within the sulfides and, if not for the process of weathering, probably would not have been technically feasible to mine. Yet, as the cover rock above these ore-bearing deposits eroded, and water and oxygen percolated into the veins, dissolved sulfide minerals, precipitated iron oxide minerals in their place, and in the process left behind higher concentrations of native gold. Native gold in an oxide deposit is eminently more recoverable than gold in sulfide minerals. In a deposit like this, gold grades are highest and most easily recoverable in the upper, near-surface parts of sulfide veins and diminish downward.

It is generally known that the contact between the upper oxide zone and the sulfide zone below is not a horizontal plane, but rather is an undulating, roughly planar surface which is more or less parallel to the ground surface. It is common to find pockets or pods of sulfide minerals above the water table, even though they reside in the "oxide" zone. Variations in rock permeability allows water and oxygen to reach parts of the veins and restricts them from others.

Because sulfide minerals are not good candidates for cyanide heap leach processing, high sulfide-bearing rock, normally, is disposed without processing. Even at Summitville, grade control was exercised in order to limit the amount of sulfide minerals that reported to the heap. The pit geologist, using visual clues and analytical information from drill hole analyses, decided whether each load of rock was to be ore or waste. Owing to this segregation, the waste rock contains a higher abundance of base metal sulfide minerals than the heap. Unfortunately, these now are being released to the ground and surface waters, due to weathering. GRL discarded extensive amounts of waste rock in several waste rock piles throughout the permit area. They carelessly placed at least one of these piles in a spring fed (groundwater fed) bog which magnified the volume of acid drainage and metallic contaminants released. Had GRL comprehensively evaluated the feasibility of this venture, mining might never have been pursued.

Based on recent water quality monitoring data, it appears that in terms of metal loading, approximately 45% of the mine site's copper metal load (as high as 8,000 pounds per day) comes from the combined French drain sump beneath the heap leach pad, the Cropsy waste pile, the beaver mud dump, and the north waste rock pile.

The Reynolds Adit

At some point in the development of practically every historical mining district in Colorado, there was constructed a dewatering tunnel that lowered the water table to avoid pumping costs and difficulties while mining the deeper levels. In Central City the dewatering tunnel is the ARGO Tunnel; in Cripple Creek, the Carlton Tunnel; in Leadville, the Yak Tunnel; and in Summitville, the Reynolds Adit. The Reynolds Adit, located near the base of South Mountain, was completed in 1897. Prior to plugging in 1994, the Adit flowed continuously, varying from a low of approximately 100 gallons per minute in the winter to an average high of approximately 400 gallons per minute during spring melt. Abnormally high undocumented snowmelt flows as high as 1,600 gallons per minute have been reported.

Because the Reynolds Adit drains the mineralized portion of South Mountain, historically it has evidenced relatively high metal discharges. Prior to 1988, copper concentrations typically reached 20 to 30 milligrams per liter (mg/L). Beginning in 1989, however, the metals content of the Reynolds Adit effluent began to increase (Golder Associates, Remedial Measures Plan, 1992). In 1992 copper in the effluent reached about 130 mg/L. Even though the mechanism is not completely understood, it appears that GRL's excavation of the open pit, which was not drained and which floored about 300 feet above the Reynolds Adit, stimulated the infiltration of surface water and promoted oxidation of the ore body. Of course, this man-induced activity resulted in an increased release of acid and metals to the Reynolds Adit, following natural processes of weathering. By 1989, the GRL open pit had become an undrained sump.

In June of 1993 the Reynolds Adit effluent reached a maximum documented concentration of 650 milligrams of copper per liter. The past ten years monitoring demonstrate that the highest metal concentrations coincide with the highest flow rates.

Based on recent water quality monitoring data it appears that, in terms of metal loading, as much metal flowed from the Reynolds Adit as from the remainder of the entire mine site, including the waste rock piles. Prior to its plugging in January of 1994, approximately 50% of the metals yield from the entire mine site (as high as 9,000 pounds of copper per day) issued from the Reynolds Adit.

PURPOSES OF CHARACTERIZATION

Rumor Control

An immediate concern voiced by local government officials, business representatives, environmental advocates and local citizens alike, was the need for factual information and the control of misinformation. The EPA and the State desired to disseminate factual and precise information concerning potential health and environmental risks. Testing of municipal and private water supplies was expedited. Representative agricultural produce and animal tissue from areas exposed to potentially contaminated Alamosa River water were analyzed to verify safety of the food supply and to quell potentially damaging food scare rumors. The initial preliminary determinations required thorough and expeditious verification. Most of the results are reported in this volume.

Risk Assessment

In accordance with CERCLA regulations and EPA procedure, complete human health and ecological risk assessments must be completed to define the nature and extent of the risks related to historic and potential contaminant releases from the Summitville mine site. Additional statutes such as the Migratory Bird Treaty and the Threatened and Endangered Species Act also require evaluation of ecological impacts. Both a human health risk assessment and an ecological risk assessment are in progress, and although preliminary indications show minimal risk to human health, aquatic life are severely at risk.

Feasibility Study

CERCLA statutes and EPA superfund regulations also require thorough evaluation of the relative feasibility of proposed emergency response "removal" actions and longer term superfund "remedial" actions. Primary among these feasibility evaluations is the ability of the proposed action to curtail the contaminant release and provide a remedy for the impacts of that release.

Determination of Background Environmental Conditions

CERCLA precludes cleaning up sites to conditions cleaner than those which preceded contaminant release. Provided background water quality and ecological conditions are documented, this can be a relatively straightforward determination. Yet in the case of the Summitville mine site, no comprehensive quantitative environmental monitoring data existed with which to characterize the environmental conditions prior to 1984.

The Summitville mine site is probably representative of the majority of historic mine sites in the western U.S. in its paucity of pre-disturbance background data. Many of the characterization projects conducted both on-site and off-site provide insight to deduce environmental conditions which existed prior to contaminant release.

Current methodologies preclude making model determinations about the quality of water prior to anthropogenic disturbances. Although the Clean Water Act provides that streams must consider natural or man-induced pollution caused prior to implementation of the act, such classifications do not consider potential impacts from mines that operated after the act was passed. Summitville, lacking acceptable environmental baseline information, was unable to distinguish pollution caused by their operations from that caused by previous ones, and by natural conditions.

Establishing the Remedial Targets

The majority of the early emergency response and remedial activities implemented at the Summitville mine site have concentrated on the prevention of contaminant release. However, as the remedial projects proceed, the yet-to-be determined pre-disturbance conditions will be approached as subsequent actions are implemented. In order to make efficient and cost-effective decisions between optional technologies and scales of activity, it will become increasingly important to comprehensively characterize the on-site and off-site environmental conditions and impacts of contaminant release. The preliminary results of characterization studies have been instrumental in establishing interim remedial targets for the Summitville mine site. As more comprehensive characterization data are assembled the interim remedial targets will be amended.

Currently, the interim goal is to restore the Terrace Reservoir to fishery status, and meet promulgated in-stream standards in the Alamosa River. The Alamosa is classified as a Class II cold-water fishery, with segments below the Wightman Fork confluence having a seasonal classification for copper.

OTHER ISSUES

Off Site Studies

Much of the information about Summitville pertains not to the site but rather to the off site areas. Studies of the off site areas, most of which are detailed in this volume, pertain to water quality in the Alamosa River, irrigation water, potential effects on crops, on livestock forage, and on crops. Wetlands in the western nether tip of the Alamosa National Wildlife Refuge were examined for potential impacts as well as several palustrine wetlands in the Alamosa River and La Jara Creek. The nature of these studies, though beyond the scope of this review, is impressive for its diversity and complexity. The studies covered disciplines in agronomy, agriculture, water quality, human health, aquatic life biology, aquatic chemistry, geology, geochemistry, limnology, bacteriology, process chemistry, civil engineering, hydrology, hydrological engineering, and terrestrial biology.

Other Contaminant Sources

In the Alamosa River basin are three major areas that have undergone extensive hydrothermal alteration. This alteration formed above and alongside the margins of molten intrusive igneous rocks that formed within a few million years of the Summitville mineralization. Regionally, they are part of the late-stage igneous rock suites that intruded the San Juan volcanic sequence.

The San Juan volcanic field hosts several major calderas where intrusive igneous rocks actually exploded through the overlying volcanic rocks. The extrusions spilled out onto the previously deposited rocks, leaving behind a nearly circular shaped depression that filled in part with other later forming rocks (see Bove and others, this volume, for a more detailed explanation). The Platoro caldera hosts two stocks, igneous intrusive bodies that intruded part way into the crust. These are the Alamosa River stock and the Jasper stock. These stocks are circumscribed in part by zones of hydrothermal alteration, and the altered zones contain anomalous concentrations of minerals, particularly iron sulfide. The hydrothermal alteration zone at Summitville, where the pluton lies at some depth below the surface, is less extensive but obviously well mineralized. Other stocks and hydrothermal alteration zones occur within and adjacent to the caldera (see Bove and others, this volume).

The hydrothermally altered areas are key to understanding the region, geologically, and some may have profound impacts on water quality. At a minimum, the altered areas contain pyrite (iron sulfide), which upon oxidation forms sulfuric acid. The acid, in turn, may dissolve other adjacent minerals, and the process can lead to environmental conditions that in the worst case will not support soil life and which pollutes local streams with acid and metals that were dissolved by the acid.

The rates of physical erosion is generally very high in these altered zones because of the lack of protective soil caps, acidity, and the self-disaggregating nature of some of the rocks. Extreme examples of physical erosion are evident especially in Alum Creek and Burnt Creek, but high erosion rates are also operative in Iron, Bitter, Wightman Fork and Burnt Creeks. The net effects of chemical and physical erosion in these areas has not been quantified.

Summitville and the Mining Law of 1872

Numerous accounts of the Summitville situation cite flaws in the 1872 mining law as part of the reason for the present situation. However, the problems at Summitville, environmental problems, are not covered by the 1872 Mining Law, which is a property law that applies to some federal land. Revisions in the royalties to be paid for use of these federal lands, changes in the patent law, or other property provisions would not have affected the problems at Summitville.

ENVIRONMENTAL RESPONSE ACTIONS

Immediately upon taking over the Site, plans were developed to control releases and reducing the potential for release of contaminants from the Site. Once open pit mining was initiated at Summitville, concentrations of toxic metals had been steadily increasing in the Alamosa River watershed. As a result of environmental clean-up actions, this trend had been reversed. By 1995, metal loadings released from the Site have been significantly reduced.

Contaminants of Concern

Contaminants of Concern (COC) were identified based on elevated concentration and potential toxicity of mobilized chemicals. These concentrations were compared to site-specific background levels, which were determined by standard statistical analysis (MK, 1994). Potential adverse effects on human health and the welfare of wildlife were preliminarily assessed (EPA, 1992). COC identified for the Site are copper, iron, cadmium, lead, silver, zinc, arsenic, aluminum, mercury and cyanide. Copper was found to be a reliable indicator of the contaminant loadings from the Site. All of these contaminants, except cyanide, are found at the Site in naturally occurring minerals and compounds. They are made soluble during a natural chemical process that results in acidic metals laden water called Acid Mine Drainage (AMD). This process accelerated by the mining activities which took place at the Site.

Acid Mine Drainage

Acid Mine Drainage (AMD) is the result of a natural occurring mineral oxidation process that can occur when these chemical ingredients are found together: oxygen, water, and sulfide minerals. Sulfide minerals oxidation by water derived from snowmelt and rainfall is a normal geologic process; however, it is markedly accelerated by increased exposure of sulfide minerals to water and oxygen which results of man-made excavations in sulfide-bearing, rock formations. Catalyzation of reactions by indigenous bacteria, Thiobacillas ferroxidans, often accompanies and significantly accelerates the reactions. Primary metallic sulfides and secondary sulfate minerals found at the Site are pyrite (FeS_2) and marcasite (FeS_2), pyrrhotite ($Fe_{1-x}S$), covellite (CuS), enargite (Cu_3AsS_4), alunite (hydrous potassium aluminum sulfate - $KAl_3(SO_4)_2(OH)_6$), and jarosite (hydrous potassium iron sulfate- $KFe_3(SO_4)_2(OH)_6$).

Pyrite and other sulfide minerals undergo weathering and produce acid solutions containing sulfate ions along with iron, copper, and other dissolved metals. These acid solutions usually have a pH of less than 4.0 and are responsible for degradation of water quality (Siwik and others, 1989).

At Summitville, mining activities resulted in additional sulfidic material surface area available for contact with oxygen and water. Air and water contact additional surface area provided by broken rock accelerates oxidation of minerals and creation of low pH drainage. This drainage water is high in acidity, sulfate (SO_4) ions and dissolved metals.

AMD contributes metal loading to Wightman Fork and Alamosa River. This creates adverse conditions preventing the growth and maintenance of a healthy aquatic ecosystem. These adverse effects have been noted in various studies of water quality of Wightman Fork and the Alamosa River (SCMCI, 1992).

Of the twelve areas identified on the Site as sources of AMD, the Cropsy Waste Pile, the Summitville Dam Impoundment, the Beaver Mud Dump, the Mine Pits, and the underground workings that are below the Mine Pits, are considered to be the most significant contributors to the generation of metal-laden acidic (low pH) water (Ecology & Environment, 1993; MK, 1994).

The Overall Clean-up Approach

The overall approach emphasizes the stabilization and control of on-site sources such that aquatic, agricultural, and drinking water uses in the Alamosa river watershed are restored and/or maintained with minimal active water treatment requirements. Although this approach results in high initial construction costs, effective source control will reduce annual water treatment costs. Thus, the overall project cost is reduced. Control of the sources of contamination is being accomplished by reducing the generation of AMD draining from the adits and waste rock piles, detoxification and capping of the heap leach pad, and active water treatment during remedy construction.

A two part plan was developed to control AMD from the most significant sources. The first part was initiated immediately to control AMD being released from the Site. This part focused on improving the efficiency of the water treatment facilities and controlling the AMD discharges from the mine drainage adits. The discharges from the adits was accomplished by plugging the Reynolds and Chandler adits.

The second part of the plan focused on reducing the AMD generated from mine waste piles and areas disturbed by mining. A lined and capped repository located in the mine pits for AMD generating waste rock and revegetation was determined to be the preferred alternative to address these sources of contamination.

The Remediation Plan - Part 1

The first part of the remediation plan was aimed at controlling AMD from being released from the Site. This part included improvements to the efficiency and capacity of the water treatment plants and plugging of the Chandler and Reynolds mine drainage adits. EPA found that the capacity of the water treatment plants at the site were greatly undersized. Initially, there were three treatment plants located at the Site with a combined treatment capacity of approximately 300 gpm. The discharge from the Reynolds adit alone was greater that 900 gpm during spring runoff. The cost of operating these facilities was as high as $1.5 million per month.

The water treatment facilities were improved by consolidating the operations into one facility and improving the efficiency of the treatment process. Once improvements are completed, the treatment capacity will be increased to 1,400 gpm. A 90 million gallon reservoir has been added to the water treatment system to store contaminated water during spring runoff when flows exceed the capacity of the water treatment plant. The storage reservoir will also be used to store contamination water during the winter months, enabling the site operations to be shut down during the winter months. Improvements to the water treatment facility have resulted in a reduction of cost from $18 million per year to $3.0 million per year while increasing the treatment capacity by more that 4.5 times.

Active water treatment is being used as an interim measure to control the release of AMD generated on the site until the stabilization of the sources of AMD is completed. Once the sources are stabilized, it is anticipated that the need for active water treatment will be significantly reduced.

In addition to controlling the release of AMD from the Site, water treatment was also used to remove the residual cyanide from the Heap Leach Pad. Water was pumped from the bottom of the Heap Leach Pad to the water treatment facilities where cyanide and metals were removed. The purified water was then applied to the top of the Heap Leach Pad. The rinsing process effectively reduced levels of cyanide in the Heap Leach Pad such it no longer presents an threat to the environment.

The Reynolds Adit was the major mine drainage facility constructed to provide a dewatering function for the Summitville Mine. This drainage was found to be the largest single source of AMD. The AMD was a result to water percolating through the sulfide-bearing rock in surrounding the underground workings.

It was determined that plugging the Reynolds adit would be an effective method to control this discharge. The plugging of the adits will significantly reduce the generation of AMD by limiting the oxygen available for oxidation of sulfides. Once the saturated condition is established, the groundwater is the only medium capable of carrying oxygen into the system. The low flux of oxygen through the groundwater will limit the oxidation of the sulfide minerals, reducing acid generation within the saturated ore zone. The reduction of acid generation will limit the leaching of the metals found in the rock.

Groundwater modeling indicated that, once the Reynolds adit was plugged, groundwater would rise to the elevation of the Chandler and then discharge to through the Chandler Adit. The Chandler adit was driven to connect and access the underground workings at the North end of the ore deposit. To further saturate the ore body, the Chandler Adit was also plugged.

The reduction in loading from the Reynolds adit due to plugging was substantial. Prior to plugging the average discharge was 80 gpm with copper concentrations of 140 ppm of copper. After plugging, the discharge from the Reynolds adit was reduced to an average of 7 gpm with concentrations of copper of 50 ppm. This represents a reduction in copper loading of 97 percent.

The Remediation Plan - Part 2

Mining wastes contained in the Cropsy Waste Pile, Beaver Mud Dump, and Summitville Dam Impoundment were found to be significant contributors to the metals loading in the Wrightman Fork. Upon investigation, it was found that the source of the water was not from precipitation, but from groundwater entering the waste piles from below. In the Summitville Dam Impoundment, a historic tailings pond, AMD was generated by the contact of surface water collected with the waste stored in the impoundment. It was estimated that 36,000 pounds of copper per year was transported from these source areas into the Wrightman Fork.

To address these sources of AMD, an engineering evaluation was completed. The results of this evaluation indicated that excavation and placement the mine waste in a lined and capped repository located in the mine pits was the most effective measure to control these sources of AMD. There were two major benefits to this response action. First, the waste was removed from the sources of water which was causing large volumes of AMD to be generated. The wastes were placed in a location which AMD generation could be controlled. The second benefit was the mine pits would be filled, capped, and graded such that the area would be free draining. The mine pits would no longer act as a catchment basin for precipitation. Thus, reducing the volume of water entering the ground and the underground workings resulting in a reduction in contaminate loadings.

Beginning in September 1993, waste rock from the Cropsy Waste pile, Beaver Mud dumps, and Summitville Dam Impoundment were beginning to be excavated and placed in the Mine Pits. In November 1995, all of the waste from these sources had been excavated and placed in the the Mine Pits.

The final stage of this part of the remediation plan is the reclamation of the 550 acres of disturbed area and the closure of the Heap Leach Pad. Reclamation will stabilize all exposed areas to reduce erosion. The revegetation will reduce the amount of moisture and oxygen available in the subsurface available for AMD generation.

Although the Heap Leach Pad is not a currently source of AMD, there is the potential that it could become a source of AMD in the future. To maintain the favorable conditions within the HLP, the HLP will be recontoured and capped to reduce the amount of water percolating through it.

CONCLUSION

By EPA using its emergency and long-term Superfund response authorities, a catastrophic release of contaminated water to the Alamosa river watershed was prevented and stabilization of AMD generating waste rock were quickly addressed. Remediation of the Summitville Mine is not yet complete. However, the amount of toxic metals released from the Site has already decreased. With completion of the environmental response actions, it is anticipated that the need for longterm active water treatment will be significantly reduced and possibly eliminated.

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