HIGH ALTITUDE RECLAMATION
AT THE ANTAMINA MINE, PERU

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Abstract

The Antamina copper-zinc mine reached commercial production in late 2001 after a two-and-one-half year construction and startup window. The open pit mine, mined rock dumps, low-grade ore stockpiles, froth flotation concentrator, tailings impoundment, maintenance facilities and a 1,500 person camp are located at an altitude of 4,200 metres (13,800 feet) above sea level in the Peruvian Andes, 250 km north of Lima. Over the course of an operating life of at least 23 years, some 1,700 ha of land surface will be disturbed by project development, of which approximately 770 ha will be revegetated as part of the mine closure.

Although the project is not (yet) subject to regulatory requirements regarding closure and rehabilitation, these considerations have been addressed during project planning, design and execution. This is consistent with the requirements of the environmental policies of the project sponsors and is in part driven by the requirements of international lending agencies. Antamina's reclamation program was initiated in 1999 and includes a yearly campaign of progressive reclamation that, to date, has successfully reclaimed over 130 ha of land at the minesite and 270 ha along the mine access road. In addition, under the project's loan agreements, a series of revegetation trials has been initiated to establish criteria for successful post-closure reclamation.

A relatively mild climate, seasonally abundant rainfall and a plentiful supply of cheap labor facilitate reclamation activities that would be impossible in Canada at high altitudes; but reclamation in the high Andes is not without its challenges. This paper describes Antamina's reclamation programs and some of the successes and challenges to date.

The Project

Compañía Minera Antamina S.A. (CMA) operates the Antamina copper-zinc mine in the high Andes of north-central Peru. The project is owned jointly by Noranda Inc. (33.75%), BHP Billiton (33.75%), Teck Cominco Ltd. (22.5%) and Mitsubishi (10%). Project facilities were constructed over a two year period.
between 1999 and 2001, and the project reached commercial production in October, 2001. One of the largest greenfield mining projects to have been developed, Antamina is the seventh largest copper mine and third largest zinc mine in the world. The mine is expected to produce 720 million pounds of copper and 675 million pounds of zinc this year.

Major project facilities include an open pit mine, flotation concentrator, tailings impoundment, maintenance facilities and a 1,500 person camp at Yanacancha, 4,200 metres above sea level in the Peruvian Andes of the Department of Ancash, 250 km north of the national capital of Lima. (Figure 1). Concentrates of copper and zinc are transported to a concentrate storage facility and marine terminal near Huarmey on the Pacific coast, via a 302 km long slurry pipeline. The mine is accessed via a 120 km long surfaced road from the Conococha crossroads. In Huaraz, the major population and commercial center of Ancash, CM A has constructed a housing complex for staff and workers and their families.
Project Setting

The Yanacancha mine site, where most of the ongoing reclamation activities are focused, lies to the east of the continental divide in the upper Amazon watershed. The open pit is located in the headwaters of Quebrada (Qda) Antamina, which drains southwest toward Qda Pampa Moruna and the Rio Mosna valley. The tailings impoundment, concentrator, mine maintenance facilities and camp are located in Qda Huincush, to the southeast of the pit and draining northward to Qda Ayash and eventually to the Rio Mosna.

Average annual precipitation at the mine site is on the order of 1.5 metres, 80% of which falls between October and March. April and September are "shoulder" months, while the austral winter months of May to August are usually dry. Freezing conditions and snowfall can occur at any time of year but are relatively infrequent at the 4,200 metre elevation. Air temperature generally fluctuates between freezing and 15°C, rarely dropping below -2°C or exceeding 20°C.

Agricultural land capability on the eastern slopes of the Andes is controlled primarily by elevation and, at 4,200 metres, is limited. Prior to mine development, land use at Yanacancha was primarily cultivation of potatoes and pasture for livestock grazing, mainly cows and sheep. Remnant stands of native trees that grow at elevations up to 4,500 metres are found in the project area although not on CMA property. These trees were once widespread in the high Andes but have long since been cleared for firewood and to open lands for grazing; remaining stands are now confined mostly to sheltered locations in high, inaccessible valleys.

Surface soil (horizon A) in the mine area is generally described as black to dark brown silt, rich in organics, with a typical depth of 20 to 40 cm, and a maximum depth of approximately 1.3 metres. The B horizon, silty clay with gravel, pebbles and cobbles, averages about 40 cm in depth. Local vegetation flourishes with only a thin soil cover and root penetration seldom exceeds 30 cm.

Although agricultural land capability is limited at Yanacancha, the cool, rainy climate (not unlike Vancouver's) is ideal for growing grass, and facilitates revegetation.

Reclamation Programs

Antamina's reclamation programs, which are described below, address both short- and long-term issues, including:

1. Progressive reclamation of construction-related land disturbance, for slope stabilization, erosion control and water quality protection.
2. Topsoil recovery and management, and long-term reclamation planning.
3. Puerto Punto Lobitos forestation project.
Progressive Reclamation

Since 1999, CMA has conducted progressive reclamation of lands disturbed during construction activities. Most reclamation has been conducted at the Yanacancha mine site (131 ha to April 2002) and along the access road between Conococha and Yanacancha (272 ha).

Early in the construction phase, a series of informal revegetation trials were undertaken at the mine site. These early trials were used to establish appropriate seed mixes, seed and fertilizer application rates and to train local workers in seeding and transplanting native grasses and seedlings to reclaimed areas.

Most reclamation work at Antamina is carried out by hand, taking advantage of an abundant supply of local labor (Photo 1). Seed mixes consist mainly of commercially available imported grasses and legumes (there is no reliable commercial supply of Peruvian seeds) including *Dactylis glomerate* (orchard grass), *Festuca arundinacea* (tall fescue), *Lolium perenne* (rye grass), *Trifolium repens* (white clover) and *Trifolium pratense* (red clover). Most seeding is done by hand during the first months of the rainy season, between October and February. Seeds are broadcast by hand at application rates that generally vary from 75 to 150 kg/ha; this is near the upper end of the range that would be typical for most mines in B.C., and is necessary due to the difficulties in obtaining adequate coverage when hand broadcasting at lower application rates. A native grass called "ichu" (*Calamagrostis* sp.) is transplanted by hand and has been found to survive well and to spread once established. Straw mulch is applied to many reclaimed areas to provide some measure of erosion control as vegetative cover is established.

Even on thinly applied topsoil, good vegetative cover can be established on slopes and platforms within one rainy season. In fact, experience on angle-of-repose slopes has shown that localized failures of the soil cover are most likely to occur in areas where too much soil has been placed (Photo 2).

In addition to grass and legumes planted to control erosion, some 22,000 seedlings of the native Andean trees *Polylepis racemosa* ("quinual"), *Polylepis incana* ("queñua") and *Buddleja coriacea* ("colle") trees have been planted around the mine site. These evergreens have responded remarkably well, with an average survival rate of 90%. Some specimens of the colle, the fastest growing of the three tree species, have reached a height of over two metres in less than three years (Photo 3). This year, trials have also been initiated with pine trees. About 1,000 seedlings of *Pinus radiata* were planted around the mine site during the 2001-2 revegetation campaign. Non-native pine are commonly planted in the Peruvian Andes though rarely above the 3,800 metre elevation; potential for long term survival at 4,200 metres is uncertain.

Extensive slope stabilization work and revegetation has also been carried out along the access road that connects the mine site with National Highway 14 at the Conococha crossroads. Approximately 200 ha of land have been revegetated.
Photo 1: Ground preparation and seeding are done by hand at Antamina, utilizing local labor. A significant challenge has been gaining acceptance of the need for safety equipment such as harnesses when working on steep slopes.

Photo 2: Successful revegetation on angle-of-repose fill slopes below the tailings dam haul road. Localized slope failures usually occur during the rainy season in areas with more than 50 cm of applied topsoil. They are stabilized by constructing rock walls for drainage control and reseeding at the beginning of the following rainy season.
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Photo 3: These specimens of the native tree "colle", planted as seedlings in late 1999, reached a height of over two metres in approximately 30 months, at an altitude of 4,200 metres.

mainly cut and fill slopes and reclaimed borrow pits. Techniques and seed mixes have been similar to those utilized at the mine although more expensive measures have been employed in some areas, where over-steepened fill slopes have proven difficult to stabilize. Although road construction activities largely ceased in early 2001, revegetation work continues in some critical areas including Laguna Canrash and the Chiquian bypass (Photo 4).

Livestock, principally cows and sheep, roam extensively throughout the Peruvian Andes and have proven to be a major challenge to Antamina’s revegetation program. Uncontrolled grazing has caused severe damage to revegetated areas along the access road and has resulted in significant damage to reclaimed areas even at the mine site. Without education on good grazing practices, Andean farmers tend to direct their flocks to any green area, whether or not the vegetation is ready to support grazing; and the commercial species best suited for establishing a good ground cover are highly palatable. Antamina has experimented with control measures including education on good grazing practices, financial incentives to farmers to keep their flocks off recently revegetated areas, around-the-clock vigilance and, in one case, legal action. None of these measures have been entirely successful; for instance, CMA curtailed around-the-clock vigilance after an unarmed guard was threatened by a local shephard with a shotgun.
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Photo 4: Antamina access road, km 18+700 along the Chiquian bypass. Rock, walls have been constructed mid jute matting has been placed by hand to aid in stabilizing and revegetating an over-steepened fill slope.

Topsoil Management and Reclamation Planning

At the current milling rate of approximately 70,000 tonnes per day and over the course of a mine operating life of at least 23 years, some two billion tonnes of rock will be excavated from the pit. Of this total, roughly 600 million tonnes will be ore and 1.4 billion tonnes will be mined rock, which will be stored in three major dumps around the project site: the South Dump in Qda Antamina below the pit, the East Waste Dump in Qda Huincush above the concentrator and the Tucush Dump in Qda. Tucush, a tributary valley to Qda Ayash, northeast of the pit. Project development will entail the disturbance of 1,678 ha of land at Yanacancha. Of this total, 767 ha, mostly clump platforms and 2H:1 V dump slopes, will be revegetated as part of mine closure (most of the remaining disturbance area—the open pit and tailings impoundment—will be flooded at closure).

There being presently no Peruvian regulatory requirements for reclamation at mine closure, the project's commitments in this area have been established on the basis of the environmental policies of the project sponsors and through negotiations with the Independent Engineer, which represents the consortium of lenders that have provided financing for project development. The long-term objectives of CM A's Reclamation Plan are as follows:

- Leave land and watercourses in a stable condition, safe for public access following mine closure.
- Reclaim disturbed land surfaces to a use compatible with pre-mine land use.
Where feasible, revegetate the land to a self-sustaining state using appropriate plant species.

- Provide effective erosion control through a combination of revegetation and drainage features.
- Reclaim watercourses to a self-sustaining condition that satisfies long-term water quality objectives.
- Eliminate significant adverse effects on air quality.
- Comply with Peruvian regulatory requirements.
- Comply with applicable World Bank guidelines (i.e., those appended to the project loan agreements).

To meet these objectives, the Reclamation Plan commits Antamina to achieving final dump slopes of 2H:1V and applying 50 cm of topsoil to the slopes and 40 cm to dump platforms, prior to revegetation. In addition, during the first few years of operation CMA is to conduct a series of formal revegetation trials on platforms and 2H:1V slopes.

Based on the present mine plan and reclamation commitments, the long-term topsoil requirement will be approximately 3.4 million cubic metres, of which 90% will be to revegetate the mined rock dumps in their ultimate configuration. To meet this requirement, CMA has conducted a comprehensive assessment of topsoil resources available for recovery, and has developed a five year Topsoil Management Plan based on the current five year mine plan.

The average soil depth for salvage (combined A and B horizons) is approximately 75 cm. For the purpose of topsoil resource estimation, the Topsoil Management Plan assumes 100% recovery; to date, this has not always been achieved. One of the difficulties is that the A horizon is clearly distinguishable but the B horizon is not; hence dozer operators often recover only the A horizon. Recovery is also affected by local topography, which in places is deeply incised, and by the presence of boulders on the ground surface, which impede dozer operation. The CMA Environment and Mine Operations departments have worked together to provide training to dozer operators to maximize topsoil recovery. Photo 5, shows areas that were stripped during 2000 and 2001 in the ultimate footprint of the East Waste Dump (EWD).

Due to the difficult topography of the mine site, one challenge is to identify suitable locations for topsoil stockpiles. Many laydown areas were developed in the vicinity of the concentrator and camp during construction, but some of these are below the ultimate level of the tailings impoundment, and competition for laydown space has developed. At present, sufficient space is available to store the approximately one million cubic metres of topsoil that will be recovered during the years 2001 to 2005; beyond that time, additional space will need to be identified.
The Topsoil Management Plan describes contingency measures in the event of an inability to meet the staled topsoil requirements. Possible contingency measures include (1) partial stripping and recovery of topsoil in areas that are not planned for disturbance; (2) recovery of clay and till materials which, while lacking in organic material, are available in large quantities and may provide a suitable substrate for revegetation; and (3) reducing the thickness of applied topsoil, in accordance with preliminary results of revegetation trials and experience at other Peruvian projects, which suggest that successful revegetation is possible on as little as 15 cm of topsoil.

Topsoil recovery and storage will continue to be a significant challenge for the project during the coming years.

Revegetation Trials

CMA has initiated a series of revegetation trials designed to demonstrate the project's ability to meet its reclamation commitments under the project loan agreements. The trials include several different treatments of seeded commercial species and transplanted native species onto varying topsoil thicknesses. One set of test plots was established in late 2000 on top of a muck pile at the east portal of the coarse ore conveyor tunnel (Photo 6). A second set of plots was established in late 2001 on a portion of the East Waste Dump (EWD) that was resloped to 2H: 1V for the purposes of the trial (Photo 7). The platform and slope test plots will be monitored for three years; success will be judged on
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Photo 6: Platform test plots one year after seeding. These plots were established on 25 cm of topsoil. Note coarse ore conveyor and stacker in background.

Photo 7: 2H:1V slope test plots shortly after seeding, December 2001. Applied topsoil thickness varies from 50 cm to 75 cm. Slope length is approximately 140 m. Four different treatments were applied, including seeding with commercial species and planting with the native grass “ichu”, which can be seen growing in undisturbed areas in the foreground of the photo.
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the basis of biomass development and observed erosion. Results to date indicate excellent vegetative cover development and minimal soil erosion, even on the slope plots.

Puerto Punto Lobitos

CMA's coastal forestation project warrants attention in this paper, although it is not really part of CMA's reclamation program, nor at high altitude. The concentrate slurry pipeline terminates at Puerto Punto Lobitos, on the Pacific coast near the town of Huarmey. There, the project has constructed concentrate dewatering and storage facilities, and a marine terminal capable of handling ships up to 50,000 dwt. The Huarmey area is part of the South American coastal desert that extends from Copiapó in north-central Chile to the extreme northern Peruvian coast, near the Ecuadorian frontier. The coastal climate is essentially rainless and human development is controlled by the availability of fresh water, which is limited to what flows to the coast in rivers formed from precipitation and runoff in the Andes.

The analysis of project alternatives conducted during design studies included consideration of options for disposal of the slurry transport and interbatch water carried in the concentrate pipeline from Yanacancha to the port. Rather than ocean disposal—which would have been difficult to permit and would have wasted a potentially valuable resource in this arid coastal desert—the project elected to treat the water for removal of cyanide and metals, and "dispose" of it by evapotranspiration. An irrigation system covering 170 hectares was constructed in the desert between the port and the Pan-American highway, a few kilometres south of Huarmey. Numerous tree species and interrow crops such as alfalfa are now growing (Photo 8), a process which effectively disposes of an average flow of approximately 65 L/s of water from the pipeline. Within a few years, travelers on the Pan-American Highway will be treated to the unlikely scene of a Peruvian coastal forest.

Conclusion

The Antamina project is one of the first major mining projects in Peru to be designed for closure. The need to recover and conserve topsoil for eventual use in reclamation was recognized during project feasibility studies and has been incorporated into project construction and operation planning. Both informal and formal trials are being employed to gain the experience that will be necessary in the long run to comply with the project's commitments for rehabilitation at closure. The project sponsors are confident that if and when the Peruvian government promulgates regulatory requirements for reclamation, Antamina will be well-placed to meet them.
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Photo 8: A view of the Puerto Punto Lobitos forestry project, January 2002.