

16.0 METALLURGICAL TESTING AND MINERAL PROCESSING

16.1 *Metallurgical Testwork*

There is no specific physical upgrading or agitation acid leach testwork for the Mada project. There has been many metallurgical studies conducted for the Nkamouna project and a prefeasibility study was completed in March 2006. However, it is anticipated that the mineralization and metallurgical processes for both Nkamouna and Mada will be similar, based on mineralogical characterizations performed by Pittsburgh Mineral & Environmental Technology (PMET) on samples from Nkamouna, Mada, and Rapodjombo.

A bulk sample was taken from 25 Mada pits (53, 1-meter samples) that were metallurgically tested by Metcon (Tucson, Arizona) and compared to the Nkamouna metallurgical tests. The Mada and Rapodjombo metallurgical samples were found to be consistent with the Nkamouna column (heap leach) tests.

Geovic conducted metallurgical test work in-house in the early development phase for the nearby Nkamouna project. Subsequently, six commercial testing laboratories, two industrial services firm and one university were utilized as listed below:

- Geovic (sizing, analyses, magnetic separation; 1997-2001).
- Pittsburgh Mineral & Environmental Technology (mineralogical characterization November 2002).
- MBX-Systems (bio-leaching evaluation).
- Lakefield Research (physical separation testing; 2001, high pressure acid and atmospheric leaching).
- Oregon State University, Drs. Erwin Schutfort and Norman Rose (SO₂ leaching).
- Metcon Research Inc. (column leaching studies and physical separation tests; 2003).
- Oregon State Radiation Labs (physical separation; 2003).
- Mountain States Research and Development Inc. (MSRDI) (bench-scale testing including: attritioning, scrubbing, physical separation, settling tests, heavy media separation, pilot scrubbing tests, bulk sample preparation; and pilot-scale testing 2003 -2005).
- Hazen Research Inc. (literature search of processing techniques, bench-scale testing including: grindability, leaching, solution purification, solvent extraction, manganese recovery; 2004-2005) Hazen also completed a pre-feasibility capital and operating cost estimate of the Metals Recovery Plant, a complete copy of which is attached as Appendix C. The Hazen PFS is based on bench scale

tests conducted on representative composites of PUG concentrates and general knowledge in cobalt and nickel engineering, design, and processing.

- Pocock Industrial, Inc. (settling tests and filtering tests on tailings from the physical upgrade plant (PUG), 2004).
- Dorr Oliver Eimco (settling tests and filtering tests on tailings from the PUG and MRP tailings, 2005).

16.1.1 Physical Upgrading Tests

Early Investigations

Early in the history of the Nkamouna Project there were a number of metallurgical investigations that were scoping in nature and investigated several alternative-processing techniques. These studies were laboratory investigations coupled with technical and economic evaluations. This work laid the groundwork for the approach being utilized today.

The work completed by PMET identified asbolane as the source of the cobalt in the Nkamouna, Mada and Rapodjombo deposits. It also established cobalt and nickel levels in the asbolane (7 to 19.5 percent CoO, 2 to 15 percent NiO). The subsequent test work confirmed that cobalt existed in a discrete, upgradable form that was soluble in H₂SO₃ at atmospheric pressure.

Several investigators, including Geovic, Lakefield, and Oregon State, determined that a relatively simple physical process could produce an asbolane concentrate. The concept of dis-aggregation of the ore and the size separation of coarser, harder asbolane from the finer softer lateritic iron oxides was firmly established.

Dr. Erwin Schutfort and Dr. Norman Rose determined that utilizing sulfurous acid under atmospheric conditions resulted in rapid dissolution of cobalt but less extraction of nickel. These studies led to investigating the application of heap leaching the ore. Extensive column leaching studies were conducted at Metcon Research as well as preliminary agitated leaching studies. These tests indicated that the agitated leach produced higher metal extraction and lower reagent consumption due to shorter leaching time.

Scoping Studies

As a result of these preliminary studies, Geovic embarked upon a process development program focusing on developing the details of the physical upgrading and sulfurous acid leaching of the resulting concentrate. In the spring of 2003, Mountain States R&D International, Inc. (MSRDI) under the direction of Bateman Engineering Inc., undertook a program of scoping out several approaches to concentrating the asbolane. MSRDI investigated the approach suggested by Dr. Schutfort at Oregon State, based on scrubbing and size separation. They tested four different lithologic samples by scrubbing and screening at 1.0 mm. The result indicated the viability of the scrubbing approach.

The testing demonstrated that the coarse, hard asbolane present in the Cameroon deposits could be concentrated by simple physical separation techniques. Cobalt values were physically upgraded (PUG Factor) from 1.4 to 2.3 times the feed grade. The finer grained, softer limonite ore type responded most favorably.

Parametric Testing

Encouraged by these results, Geovic initiated a comprehensive upgrading program at MSRDI on samples from Nkamouna. The program included scrubbing/attritioning of a variety of lithologic samples with and without reagents. MSRDI evaluated size separations at mesh sizes from 8 to 100. The objective was to optimize economic performance not recovery. The results of this program verified the applicability of the PUG process - cobalt upgrading by a factor of 3 with +70 percent recovery. It further defined the operating conditions and highlighted the different response of the two ore types of breccia and ferralite.

16.1.2 Leaching and Metal Recovery Testing

Hazen Research, Inc. prepared a composite sample from the Nkamouna samples that were concentrated by MSRDI.

Hazen completed a comprehensive series of bench-scale tests investigating the dissolution of the asbolane concentrate, the purification of the resulting leach solution and the production of cobalt, nickel and manganese products. They investigated solvent extraction and sulfide precipitation for cobalt and nickel recovery as well as the production of a manganese carbonate product.

The laboratory work also determined the composition of the potential products as well as waste products. This information is being utilized in the marketing and environmental permitting for the project.

In addition to completing the laboratory investigations, Hazen completed a prefeasibility study of the Metals Recovery Plant (MRP). This study concentrated solely on the leaching and metals recovery operations. It included a conceptual design, preliminary equipment selection and capital and operating costs of several alternative scenarios. Hazen also completed an extensive literature search and prepared a comparison of the Nkamouna flowsheet with several other cobalt laterite operations. In addition, Hazen defined emission points and quantities for permitting.

16.1.3 Metallurgical Performance

The process flow sheet discussed earlier is one in which two major operations, physical upgrading and leaching and metals recovery (MRP) treat a blend of 10 percent breccia and 90 percent limonite. The products of these operations consist of cobalt and nickel oxides and manganese carbonate. The test work has confirmed the feasibility of these operations.

Physical Upgrading (PUG)

The best estimate of the performance of the commercial PUG is the work completed by MSRDI on the Mini-Bulk Sample Program. This work suggests that for limonite rich ore, attaining a PUG factor in excess of 3.0 for cobalt results in greater cobalt losses. Continued scrubbing apparently can cause increased cobalt losses, but achieves higher cobalt concentration ratios, grades, and economic performance.

<u>PUG Factor</u>	<u>% Cobalt Recovery</u>	<u>Remarks</u>
3.0	67.9	Lower Limonite/Ferralite Composite
3.02	72.2	Overall Composite
3.5	57.4	Lower Limonite/Ferralite
4.5	52.6	Lower Limonite/Ferralite Clay

Treatment of breccia ores generally results in PUG factors of 2.0 or less for cobalt with about 75 percent cobalt recovery. Therefore for a PUG factor of ~3.0 and a recovery of 66 percent cobalt appears to be possible for ore comprised of 90 percent ferralite and 10 percent breccia. Nickel recovery is estimated to be about 32 percent and manganese about 59 percent.

Leaching and Metal Recovery

Hazen projected metal recoveries and product purities for their prefeasibility report. The metal recoveries used for the MRP (recovery from concentrate) are:

Cobalt	92% leach - 2% process loss = 90%,
Nickel	52% leach - 2% process loss = 50%
Manganese	90% leach - 2% process loss = 88%

These estimates take into consideration leach recovery, scale-up from laboratory conditions, washing efficiency and other losses such as SX and pyrohydrolysis. The recovery figures are reasonable and credible estimates.

The overall recoveries for the combined processes are:

	<u>Co</u>	<u>Ni</u>	<u>Mn</u>
PUG Recovery	66	32	62
MRP Recovery	90	50	88
Overall Recovery	59	16	55

16.1.4 Testwork Summary and Conclusions

In PAH's opinion, the metallurgical test work completed for the Nkamouna project has been well executed by reputable, industry-recognized laboratories. The concept of producing an asbolane concentrate by scrubbing and sizing has been demonstrated, at the bench-scale, on a wide variety of samples of various

ore types. The unit operations that constitute the PUG process are simple, robust and capable of being scaled up without a great deal of uncertainty. However, the designed PUG process has not yet been specifically tested for the expected ore blend of 90 percent ferralite and 10 percent breccia that now constitutes the project basis.

16.2 *Process Description*

Two key attributes of the Nkamouna and Mada ores determine the process flow sheet. The first is the fact that the cobalt, a large amount of the nickel and the manganese are contained in the mineral Asbolane, a manganiferous oxide mineral. Asbolane is much coarser and harder than the other lateritic oxides and can be upgraded by scrubbing and size classification to produce an asbolane concentrate. The other key aspect of asbolane is the high manganese content (MnO_2) that determines the process for recovering metal values from the concentrate. A reducing leach, employing SO_2 , (H_2SO_3) dissolves the cobalt, nickel and manganese contained in Asbolane. Consequently, Nkamouna and Mada have the potential to produce cobalt, nickel and manganese chemicals. The process consists of two sections, the physical upgrading (PUG) and the metals recovery plant (MRP).

The process will be designed to treat a blend of two ore types; ferralite and breccia. The average chemical analysis of the ore types is 0.21 percent Co, 0.48 percent Ni and 1.15 percent Mn. The process assumes treatment of a nominal 7,000 tpd ore in the PUG, producing 1,500 tpd concentrate to feed the MRP. The following options will be evaluated for processing mineralized material from Mada.

- Truck the Mada mineralized material to the Nkamouna PUG and MSP plants.
- Install a PUG plant at Mada and truck concentrates to the Nkamouna plant.
- Install a new PUG and MRP in the north Mada area.

16.3 *Tailings Disposal*

Leach tailings will be neutralized with a 30 percent slurry of slaked lime ($\text{Ca}(\text{OH})_2$) in a CCD tails holding tank. The neutralized MRP tails are combined with the PUG tailings and pumped to the tailings storage facility for permanent disposal. Samples of neutralized tailings were subjected to the USEPA Toxic Characterization Leaching Protocol (TCLP) and were found to be non-hazardous.

As currently envisioned, there are four waste and low-grade streams from the process. Two from the PUG plant, and two from the MRP. The PUG plant feed is a nominal 7,000 tpd with 1,500 tpd of product to the MRP, 4,700 tpd of PUG tailings, and 800 tpd of middling concentrates. The PUG middling concentrates will be stored in a segregated area of the mine backfill. The PUG tailings will be disposed of in a tailings storage facility.

The two waste streams from the MRP are the manganese precipitate and the CCD leach tails. The manganese precipitate is stored in a segregated area of the mine backfill (~ 55 tpd) and the CCD leach tails (~ 1,385 tpd) are disposed with the PUG tails in a tailings storage facility.

Depending on the process decision from the options discussed in 16.2 above, after the Napene Creek tailings storage facility is filled to capacity, tailings from additional Mada resources could be piped to other alternate tailings disposal areas currently being considered within a 4 kilometer radius of the Nkamouna plant site.

16.4 *Process Water Balance*

An overall water balance was prepared from material balances around the PUG Facility, MRP, and Napene Creek TSF. Except for the tailings storage facility, all flows are constant throughout the year. Knight Piesold estimated water flows in and out of the TSF on a monthly basis, including excess water generated by consolidation of settled tailings, seasonal rainfall and evaporation. This computer model was revised to simplify the overall balance by combining monthly flow estimates into quarterly averages. More conservative estimates of impounded water, especially in the first three years of operation, were used in the overall balance.

The overall water balance shows that the need to divert surplus water around the tailings dam is a rare event. Alternatively, tailings supernatant water can be accumulated during these periods to reduce the demand for Edje River water makeup. The overall water balance is simplified as all water in the mine and infrastructure areas are currently planned to be diverted around such facilities and placed in natural drainages. In this manner, the Napene Creek TSF water balance will be independent of external variations.

Demand for Edje River water over the project life was estimated from the overall water balance. Impound volumes were also estimated on a quarterly basis by adding solids volumes to water impound volumes.