Agnico Eagle - Goldex Mill

SAMUEL MORIN, Junior metallurgist
DAVID YERGEAU, Geologist

Introduction

Agnico Eagle Mines Limited has had an interest in the Goldex property since 1993, but exploration works started in the mid 1920s by different property owners until Goldex Mines Limited fully acquired the project in 1971. Multiple development and milling campaigns followed and Agnico Eagle amalgamated with Goldex Mines in 1996 to pursue exploration until commercial production first began in 2008.

The initial orebody (GEZ) produced 9 000 000 tonnes at 2 g/t Au and was milled from 2008 to 2011. Satellite zones (M and E) were subsequently milled from 2013 until present. Two additional zones (Deep and South) were added to the life of mine in 2017. Starting 2018, the mill receives ore from the M, E, Deep and South zones.

History

The Goldex Mill is located within the limits of the municipality of Val-d'Or, northwestern Quebec, Canada. The GEZ achieved commercial production in August 2008; however, mining operations on the GEZ have been suspended since October 2011. In late 2013, mining and production began from the M and E Zones of the Goldex mine. Agnico Eagle does not expect to produce more gold from the GEZ until geotechnical concerns with the rock above the mining horizon are resolved, which may never occur.

A backfill paste plant was built in 2013 to accommodate the new mining method (long hole open stope and fill). The mill capacity was increased from 8000 t/d to 8800 t/d in 2018 with the addition of a scalping screen to the crushing circuit and the modification of the ball mill discharge pump during 2019 to increase circulating load.

Orebody

Most of the Goldex ore zones, with the exception of the newly exploited South Zones, are hosted within a post-volcanic (i.e., 2687 Ma) WNW-trending and steeply S-dipping quartz diorite sill hosted in mafic to ultramafic Archean metavolcanic rocks. The geology and main foliation are oriented N280/75-85°, and the rock layers are overturned (i.e., south polarity) at the property scale. Gold is associated with quartz–tourmaline ± pyrite veins and vein stockwerks and is present either under its native form (70%) or included in pyrite and tourmaline grains (30%). More than 60% of the gold is recovered by gravity concentration; this is unique for a low-grade (i.e., 1.5 to 2 g/t Au) underground exploitation.

Figure 1. Goldex mine site

South Zones are comprised of quartz-sulfide veins, sulfide stringers (mostly pyrrhotite ±chalcopyrite-pyrite-sphalerite) and disseminated sulfides hosted in strongly silicified (i.e., silica flooding) and biotite-rich alteration zones. They are composed of several thin (<2 meters) high-grade zones that are stacked in the volcanic rocks south of the Goldex ore zones quartz diorite. The main ore zones are steeply dipping to the north and have a mean ENE-WSW orientation.

Metallurgy

Initial mill testing in 2005 led to the actual design of the Goldex mill flowsheet, comprised of a gravity circuit in a closed loop with a ball mill and a bulk

pyrite flotation circuit followed by leaching. Considering that Agnico Eagle already had leaching tanks and the required water treatment plant on another nearby site (LaRonde), the decision was made to not use cyanide on site in any process. This has led to an entirely physical concentration design for the gravity circuit and the use of leaching tanks located at LaRonde, approximately 70 km away, to process pyrite concentrate. Figure 2 presents the Goldex flowsheet.

Milling Practice

Crushing

The crushing circuit at Goldex consists of one primary jaw crusher located underground and one secondary cone crusher with a three-deck scalping screen. Nominal circuit capacity is 600 t/h and final crushing product, presented in Table 1, is 100% passing 50.8 mm with a P80 of approximately 32 mm.

Table 1. Crusher product screen analysis

Size (mm)	Percent
+50.8	0
38.1	15
25.4	15
12.5	20
-12.5	50

Grinding

Ore is conveyed from the crushing circuit to a 7000 live tonne (25 000 total) capacity stockpile protected by a dome to reduce dust and noise. Primary grinding is achieved by a 7.3 m x 3.7 m SAG mill with a steel charge of 18%, maintained by adding 127 mm balls. Lining consists of steel lifters and inserted steel rubber plates. Secondary grinding is done by a 5.0 m x 8.2 m steel and rubber lined ball mill in closed circuit with gravity concentrators. The circulating load averages 200% and the final grinding product P80 is 125 µm.

The grinding product is critical for downstream process. Flotation can absorb variation whereas grinding over 130 µm translates to considerable losses during concentrate leaching due to ineffective liberation. Table 2 presents the grinding circuit data.

Gravity Circuit

The ball mill discharge feeds three screens returning coarse (+ 2.5 mm) material to the mill feed. Fine material is concentrated through three 48-inch Knelson batch concentrators recovering high density material. Every 30 minutes, concentrates discharge in three silos feeding three Gemini GT1000 shaking tables. A fourth table is in place to clean middlings from the three main tables. The final gravity concentrate assays at 50% Au and is poured on site. Global circuit recovery varies between 68 and 70%.

Table 2. Grinding circuit data (2018)

Semi autogenous Mill	
Average slurry density	80% solids
Ball size	133 mm
Ball consumption	0.48 kg/t
SAG mill work index	16.86 kWh/t
SAG mill speed	Variable (9 to 13 rpm) 58 to 83% of critical speed
SAG mill lining	Steel and rubber
SAG mill motor	4500 HP
Product	1000 µm
Ball Mill	
Average slurry density	77% solids
Ball size	50.8 mm
Ball consumption	0.32 kg/t
Ball mill work index	16.63 kWh/t
Ball mill speed	15.9 rpm 73% of critical speed
Ball mill lining	Steel and rubber
Ball mill motor	4500 hp

Flotation

The cyclone overflow target solids fraction is 40%. This slurry is conditioned in a 40 m³ tank during 2.5 minutes where the secondary collector (Dithiophosphate), frother (Methyl Isobutyl Carbinol) and either lime or carbon dioxide is added to control pH. Primary collector (Potassium Amyl Xanthate) is added earlier during grinding to maximize retention. Table 3 presents reagent dosages for the flotation circuit.

Table 3. Flotation reagents dosages (2018)

Reagent	**g/t**
Primary collector (KAX)	20
Secondary collector (Danafloat 233)	45
Frother (MIBC)	16
Hydrated lime	50
CO_2 gas	16

The pulp is then gravity-fed at 0.5 g/t Au to a bank of three 38 m³ mechanical cells followed by another identical bank to form the rougher and scavenger stages respectively. A cleaning column collects concentrates from both stages and recirculates the tailings to the circuit head. The final concentrate consists of the first rougher cell and the column products for a total mass pull of 2.5% at 18 g/t Au. The final tailings from the last scavenger cell average 0.1 g/t Au and are thickened to 58% and pumped either to the tailing ponds or to the backfill paste plant.

Return to TOC

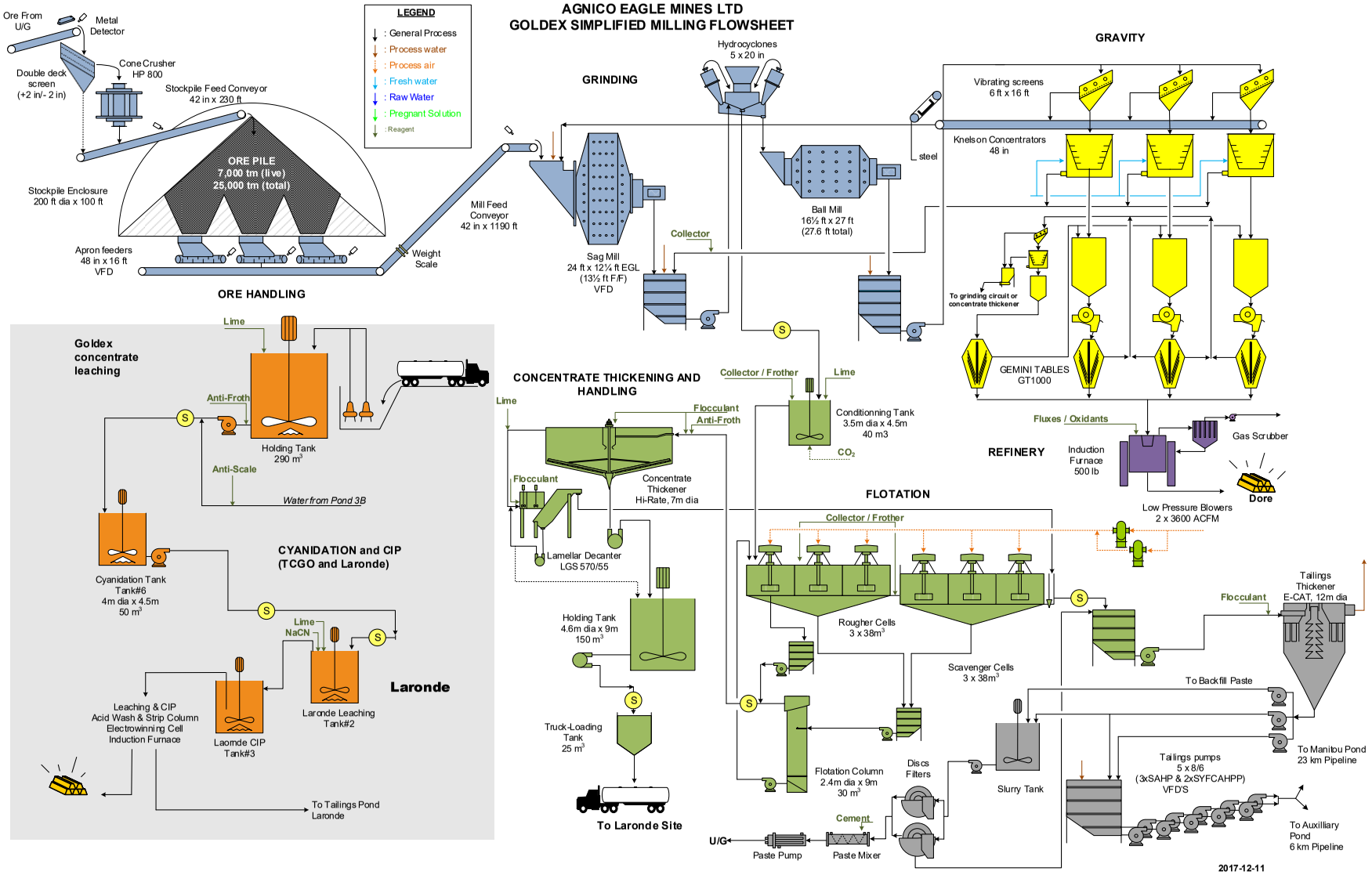

Figure 2: Goldex Mill flowsheet

Return to TOC

The final concentrate is also thickened to 58% and trucked at LaRonde (Agnico Eagle site) to be leached. The flotation circuit recovery varies between 75% and 80%.

The pH is maintained between 9.0 and 9.5 throughout the flotation circuit to maximize pyrite recovery. Potential dilution with backfill paste increases slurry pH. Gaseous CO_2 is used to lower the pH owing to its low health and safety issues compared with sulfuric acid. Reducing KAX addition to a minimum is one of the main goals at Goldex due to its tendency to passivate ore surfaces, which hinders leaching, and has led to its partial replacement using Danafloat 233.

Cyanidation

Leaching occurs off-site at LaRonde where the flotation concentrate is processed through custom milling. Recovery is estimated using monthly laboratory leaching tests conducted on representative samples.

As previously mentioned, grinding product size (gold liberation) and KAX dosage are monitored to maximize leaching performances. Historically, recoveries averaged 93% to 94% but could drop significantly in the low 80% during winter months with high tonnage periods. Cold temperatures slow down KAX degradation leaving the ore surface coated for longer. Higher tonnage yields slightly coarser material to the cyclone overflow. Using Danafloat 233 instead of KAX greatly stabilized recovery near its higher limits during winter months.

Backfill paste

Tailings are thickened to 58% and pumped to a stock tank feeding two sets of fourteen (14) disc filters of 3.8 m diameter. Cakes are filtered to 20-25% humidity and dropped on a conveying system to be transferred in a mixer. Binder is mixed with water in a separate tank from which the overflow feeds the mixer instead of being pumped. This reduces the risk of clogging pipes when working with cement. Nameplate capacity was originally 7000 t/d and increased to 8000 t/d in 2015 with the addition of a second paste pump.

Binder is added at an average 3.5% ratio (solids/solids) and is either composed of 80% slag and 20% cement, 90% slag and 10% cement, or 100% cement in terms, depending on the mining schedule. The higher the cement content is, the faster maximal unconfined compressive strength (UCS) will be reached at the expense of being lower than using slag.

Paste quality is monitored by sampling final paste product and encasing it in multiple cylindrical containers being stored during up to 28 days to represent in situ curing time. The UCS on these samples is then measured by rupture tests at different curing times according to the mining schedule.

Tailings Management

Manitou - Goldex project

Tailings generated at Goldex are essentially sulphides free and exempt of cyanide given the nature of the process. This has led to a partnership program with the provincial government to restore a 30-year-old orphan deposition site (Manitou) that has generated acid mine drainage affecting an area of nearly 2 km^2. Rehabilitation work began in 2006 and was planned to last approximately 12 years but is still ongoing due to the 2-year hiatus and change in tailings management with the backfill paste plant. To revert acid generation, Goldex tailings are simply stacked over Manitou's material to stop oxygen from reacting with the sulphides in place by increasing the water table level. The pH is thus restored to a neutral value and revegetation is possible. As of 2018, 14 million tonnes out of 16 million had been deposited. Figures 3 and 4 show progress from 2004 to 2017. Goldex tailings have to be pumped in a 23 km pipeline to reach the deposition site. To facilitate maintenance, five 8/6 pumps (upgraded to 6 in 2011) are installed on site to provide the required total dynamic head.

Figure 3. Manitou site in 2004

Figure 4. Manitou site in 2017

Return to TOC

Auxiliary pond

The now auxiliary pond was selected as the main deposition site prior to the Manitou partnership (2006). The Goldex tailings being benign and alkaline, the only constraints for selecting a site were physical. The pond is currently located 4 km south of the mine site, away from any drinking water wells, eskers, recreational and residential area and forestry operations. The site is used sporadically when the Manitou pipeline is unavailable due to maintenance. As of 2018, 2 million tonnes have been deposited.

Personnel

There are currently over 400 employees on site at Goldex, including human resources, health and safety, engineering, geology, construction, maintenance, operations, metallurgy and environment. Table 4 summarizes the operations personnel solely at the mill as of 2019.

Table 4. Summary of operations personnel (2019)

	Number
Mill superintendent	1
Operational supervisor	1
Mechanical supervisor	1
Senior metallurgist	2
Metallurgist	1
General planner	1
Team captain (flotation operator)	4
Grinding operator	4
Backfill paste plant operator	4
Crushing operator	4
Surface labourer	1
Electrical labourers	3
Maintenance and repair labourers	10
Health and safety instructor	1
Total	38

Operating Costs

Mill operating costs contribute to approximately 30% of total site cost. Table 5 summarizes the mill operating costs as of 2018, for a total cost per tonne of $9.22.

Table 5. 2018 Summary of operating costs ($ per tonne)

	Production	Services	Maintenance
Labour	0.95	0.38	0.54
Contractors	0.37	0.34	0.59
Material	0.10	0.08	1.43
Consumables	1.74	0.11	-
Energy	2.53	0.10	-
Transportation	0.52	-	-
Total	5.63	1.03	2.56

Summary

The Goldex mill currently (2019) processes 8000 to 8500 tpd at 1.5 to 1.8 g/t Au for a total recovery varying between 92% and 94%. Low-grade production is achievable due to a high free gold content (70%), which reduces production costs. Maximizing flotation recovery while minimizing KAX consumption to optimize leaching recovery is an ongoing project at Goldex. There is no cyanide on site and therefore the pyrite concentrate is sent to a remote mill for leaching. Tailings are pump to the Manitou orphan site (provincial government partnership), auxiliary pond or backfill paste plant.

References

GENEST, R., LAGUEUX, J.F., ROBICHAUD, F. BOILY, S. (2012) *Technical Report on Production of the M and E Zones at Goldex mine*. Agnico Eagle Mines Limited.