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Gold-PM Keynote

SELECTING THE BEST PROCESS FOR THE TREATMENT OF A REFRACTORY GOLD ORE - BARRICK'S EXPERIENCE

By

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ABSTRACT

More ore bodies have been found where the gold is not amenable to simple cyanidation alone. In the simplest of terms, these are refractory ores. The best choice of a processing route to treat a refractory ore will in most cases be site specific, due mainly to the metallurgical and mineralogical characteristics of the ore. The successful application of these processing techniques can result in mining operations that would otherwise have been impossible. However for an increasing number of low grade refractory ores, the estimated capital and operating costs mean that very careful project evaluation will be necessary, particularly at current gold prices. This paper will review some of the existing technologies and operations that are being used for the treatment of refractory gold ores, with particular emphasis on the technologies developed and practiced in Barrick's operations. Pressure oxidation, roasting and thiosulfate technologies will be reviewed.

Barrick Operations

- Focus on high potential assets in core regions
- Leverage competitive advantages
- Strong base of existing high quality mines
- Ongoing asset optimization
- Gold production of 6.12 Moz @ $831/oz all-in sustaining costs in 2015

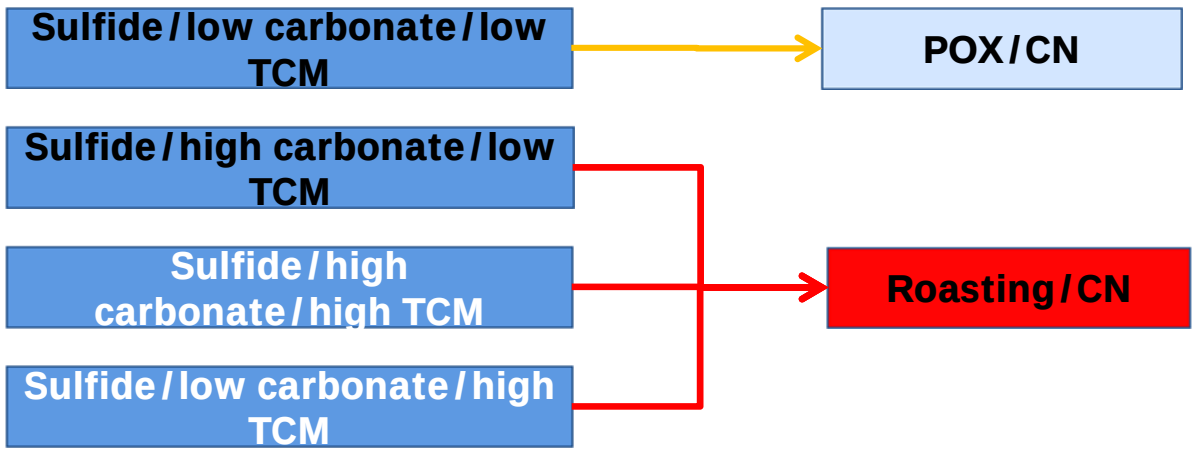
Barrick Operation - Cornerstone Mines

Goldstrike – Carlin Trend, Nevada

Goldstrike

- The Goldstrike property is located in Elko and Eureka counties in north-central Nevada, USA on the Carlin geological trend.
- The property was discovered in 1960's and purchased by Barrick in 1987.
- Autoclave facilities were built in 1989 to process sulfide refractory ores.
- Roasting facilities were built in 1999 to process high TCM double refractory ores.

Goldstrike

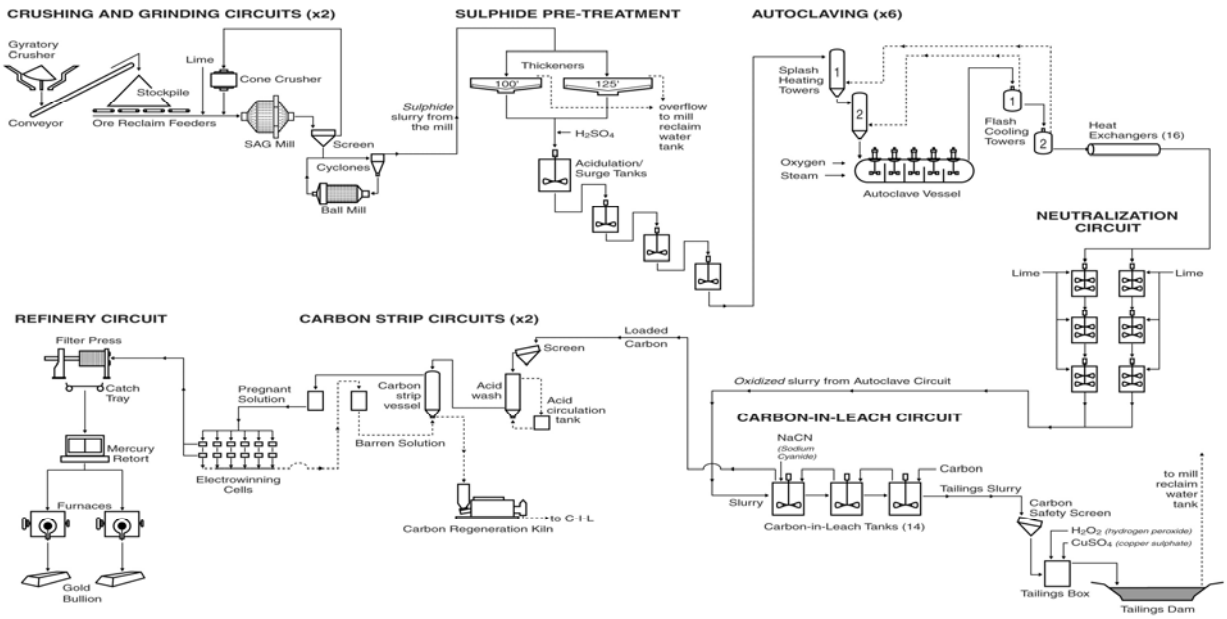


Autoclave Circuit – Goldstrike

Autoclave Circuit Design Criteria

- Throughput:
  - Mill 1: 6,500 TPD (80% passing 200 mesh)
  - Mill 2: 12,500 TPD (60% passing 200 mesh)
- 6 autoclaves :
  - 1 small autoclave: 92.6 STPH, 435 ^{o}F
  - 5 large autoclaves: 129.6 STPH, 437 ^{o}F,
- CIL: 19 hrs RT

Autoclave Circuit Flowsheet

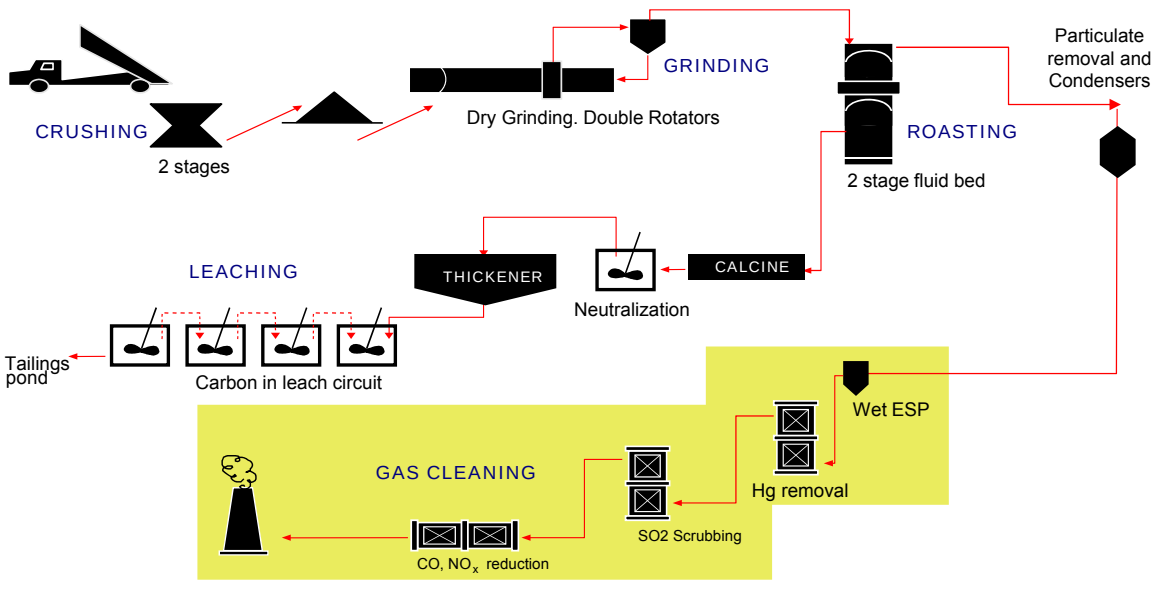


Roaster Circuit - Goldstrike

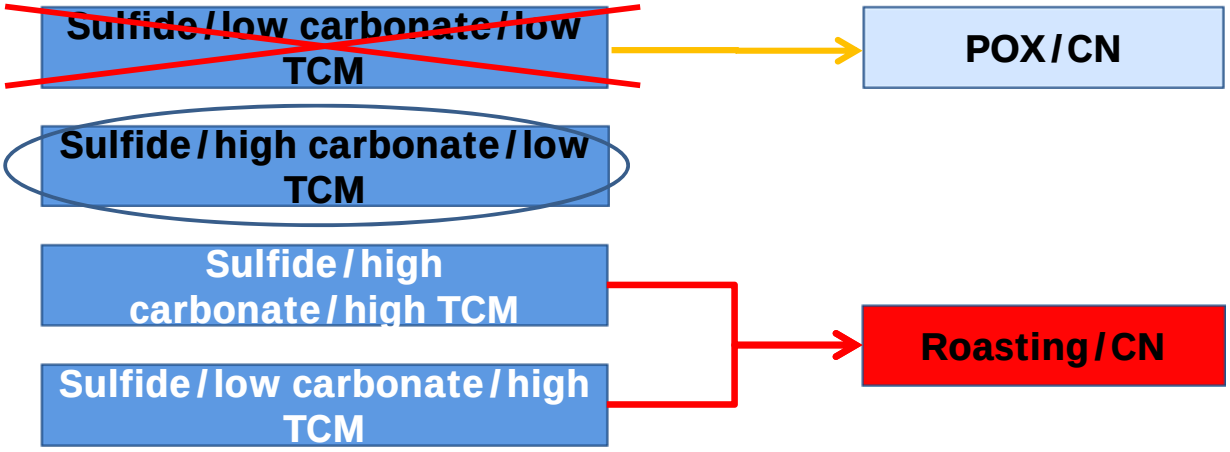
Goldstrike Roaster Circuit Design Criteria

- Throughput: 12,000 TPD
- Sulfide sulfur: 1.9%
- Total carbon matter: 1.4%
- Carbonate: 4%
- Mill Product, P_{80}: 74 µm
- First stage bed temperature: 1025 ^{o}F
- Second stage bed temperature: 1050 ^{o}F
- Retention time: 44min
- Gold recovery: 90%

Roaster Circuit Flowsheet



Goldstrike – Process Conversion



1st Conversion of the Circuit

- Evolving and changing ore body composition
- Running out of traditional acid ore
- High grade, high carbonate ore available (CO_3>4%)
- Maintain total ounce production
- Possible to process alkaline ore in existing autoclaves
- Challenge was to use existing facilities to process both acid and alkaline ores

Process Options Considered

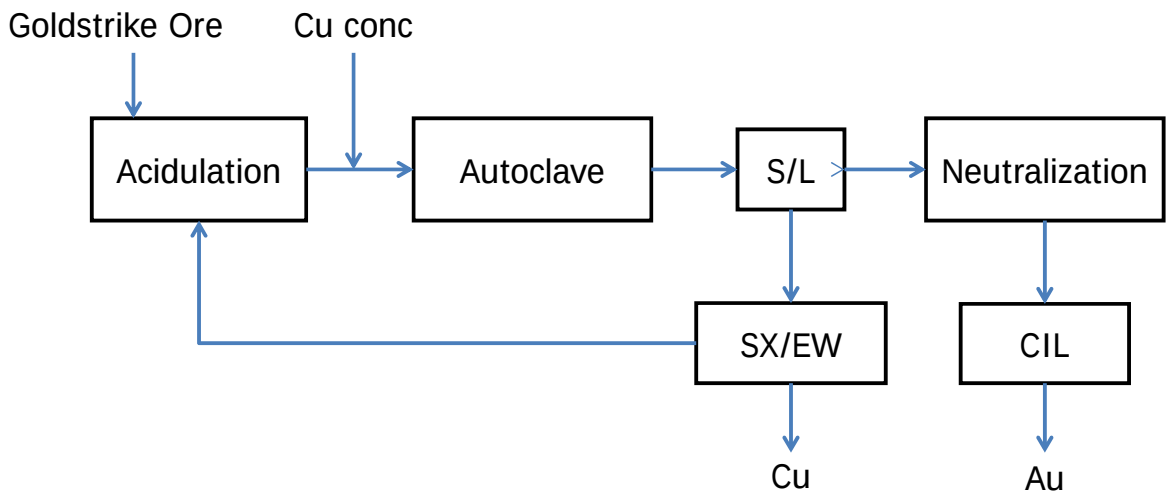
- Copper concentrate POX/SXEW/CIL
- Flotation
  - Flotation/APOX/CIL
  - Flotation/AlkPOX/CIL
- AlkPOX/ATS/RIL
- Alkaline POX (whole ore)/ CIL

Copper Conc. Process

Copper Conc. Concept

- Add chalcopyrite conc. to POX to supply enough sulfide to form acid which could be used to neutralize carbonate in the gold ore.
  - Recover copper by conventional Cu SX/EW
  - Reduce acid requirement ahead of APOX
  - Improved Au recovery: APOX > AlkPOX

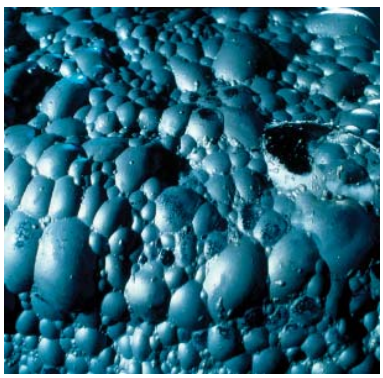
Copper Conc./SX-EW/CIL



Results from Copper Conc. Process

- Batch tests indicate good Copper and Gold recovery
- CAPEX estimate indicates a significant investment required
- Possible sources of concentrate are known but are not owner (Barrick) operated
- Long leads on equipment and design, not easily implemented within current time frame
- Need to compete with conventional smelting markets
  - Difficult to predict cycles
  - May offer economical advantage for dirty conc's

Flotation



Flotation Concepts

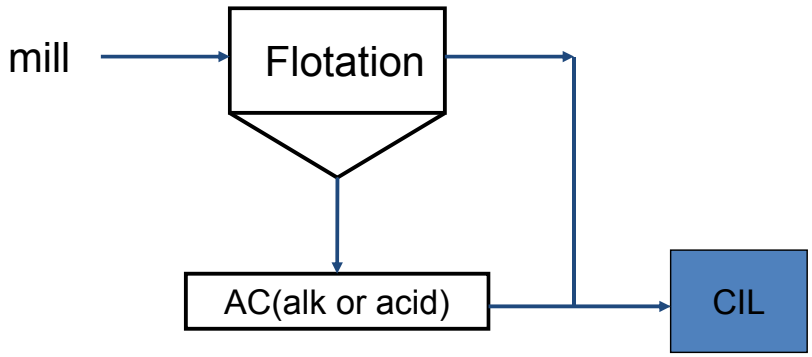
The Classic Flotation

- Selectively float mineralization (pyrite) into a high recovery concentrate that would be amenable to APOX and subsequent CIL gold recovery

The Reverse Flotation

- Selectively float gangue material (carbonate and or TCM) effectively forming as tailing a suitable product for either APOX or AlkPOX followed by CIL

Flotation/POX/CIL



Test Work Results - Flotation

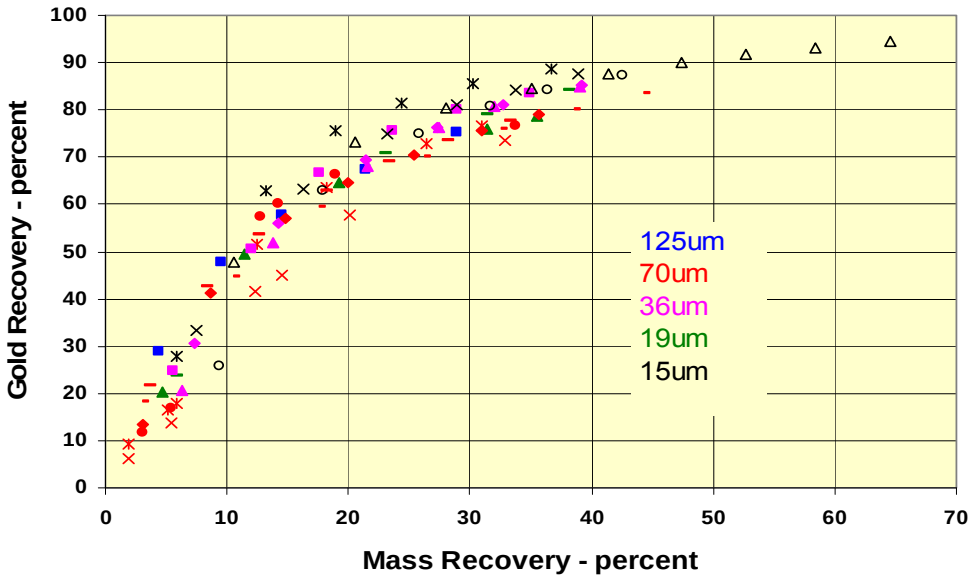
The Classic Flotation

- Selectivity was poor for most ore types
- Liberation dependent – fine grind required for increased recovery

The Reverse Flotation

- Selectivity again poor for either component (TCM or CO_3)
- Various reagent schemes tried with the search continuing

Effect of primary grind size on Au recovery



Results from Flotation Option

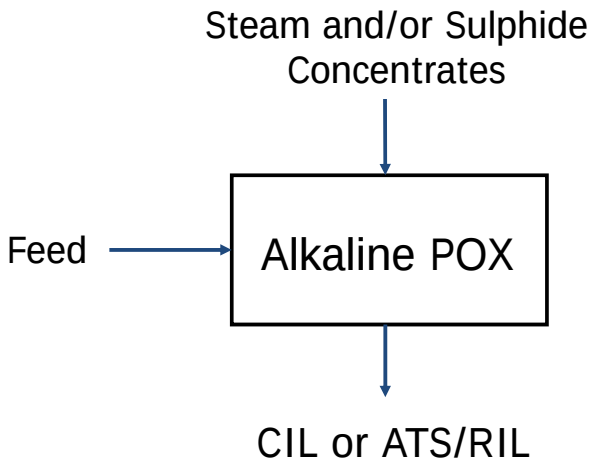
- Mineral liberation is the key for effective flotation of pyrite
  - Au recovery into con of ~85% at 35-40% mass pull with a primary grind of 75 micron
  - Poor selectivity of TCM against pyrite varied with ore type
  - Little selectivity was observed for carbonate flotation
- Poor selectivity in TCM and carbonate flotation was attributed to poor mineral liberation. Need ~15 micron for good liberation.

Alkaline POX

Alkaline POX Concepts

- AlkPOX/CIL
  - Injection of steam and oxygen at a rate great enough to maintain oxidation of pyrite followed by standard CIL extraction and recovery
- AlkPOX/ATS/RIL
  - Same AlkPOX conditions as before followed by ammonium thiosulfate lixiviant leaching, resin absorption and recovery

Alkaline POX/CIL or ATS/RIL



Alkaline POX Results

- AlkPOX/CIL
  - Bench top tests, pilot plant runs and two plant trials have been completed
  - Results have confirmed reagent consumption and gold recovery models
- AlkPOX/ATS/RIL
  - Numerous bench top and pilot plant tests have been completed
  - High reagent consumption, more complicated and environmental issue

Summary of Results

- Gold Recovery
  - Cu > AlkPOX > Float
- CAPEX
  - Cu > Float > AlkPOX
- OpEX
  - Cu > AlkPOX > Float
- Ease of Implementation
  - AlkPOX > Float > Cu

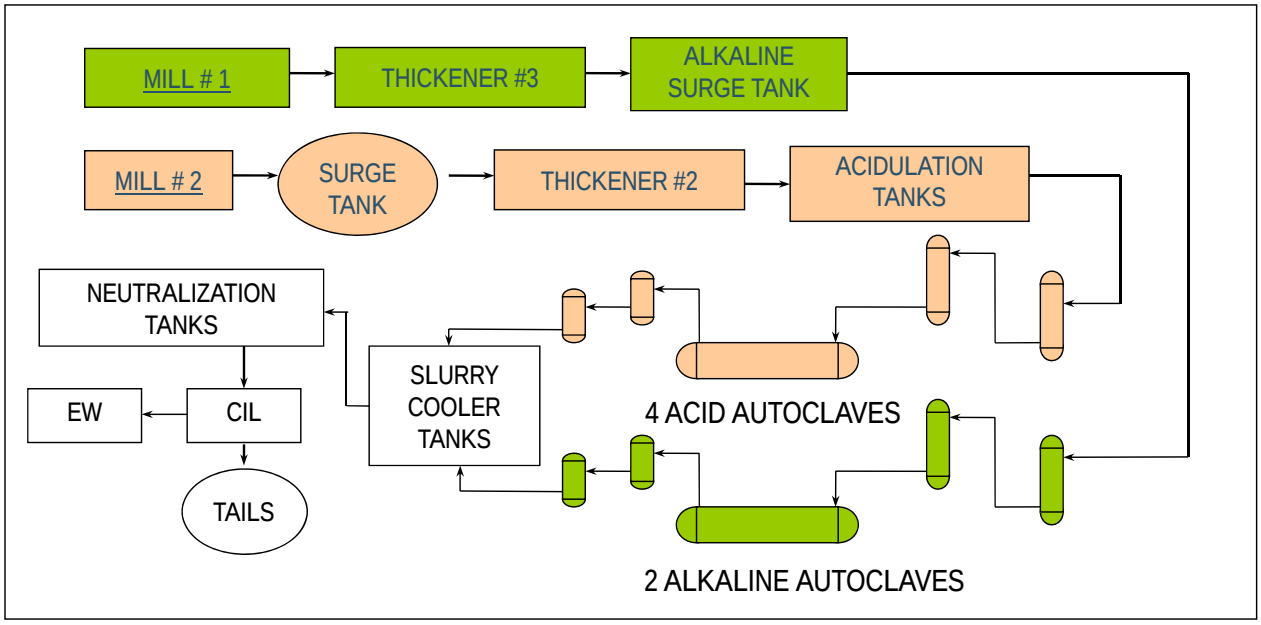
Alkaline Autoclave

- Oxidizing high CO_3 ore without the addition of sulfuric acid
- All sulfuric acid generated in the autoclave reacts with CO_3, buffering the autoclave discharge pH
- Higher temperatures and pressures required (437^{o}F, 480 PSIG)
- Loss of temperature in autoclave results in loss reaction
- Alkaline autoclaving is less effective than acid autoclaving
- Sulfide oxidation 60% TO 70%
- Gold recovery ranges in 78% TO 83%

Alkaline Autoclave - Challenges

- Convert one circuit into two separate and independent circuits with minimum cost
- Two mills, two thickeners, one acidulation/surge tank circuit, six autoclaves
- Remain flexible

Autoclave acid/alkaline POX Flowsheet

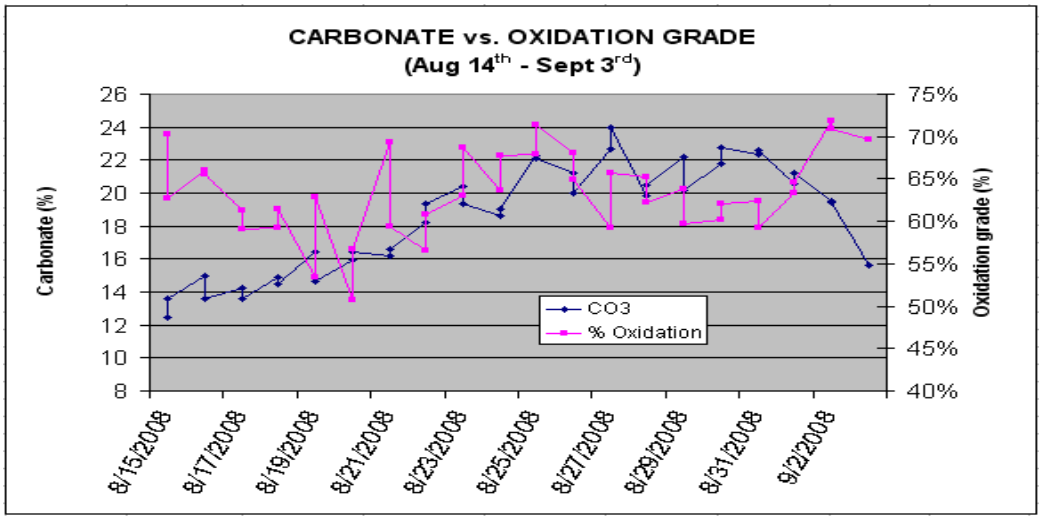


Alkaline Autoclave- 21 days Plant Trial

- 178,504 tons processed
- Sulfide: 1.32%
- Carbonate: 17.94%

Autoclave	Ore (tons)	S2- % discharge	O2 ton/ S2- ton	Steam (Klbs/ton)	Oxidation percent	Avg. Pressure (psig)
1	45,616	0.45	4.17	0.45	65.84%	430.0
2	48,109	0.51	3.85	0.51	62.04%	429.6
3	51,038	0.49	3.94	0.48	63.27%	429.6
4	33,742	0.46	3.99	0.43	64.08%	428.7

Alkaline POX - Oxidation Behavior

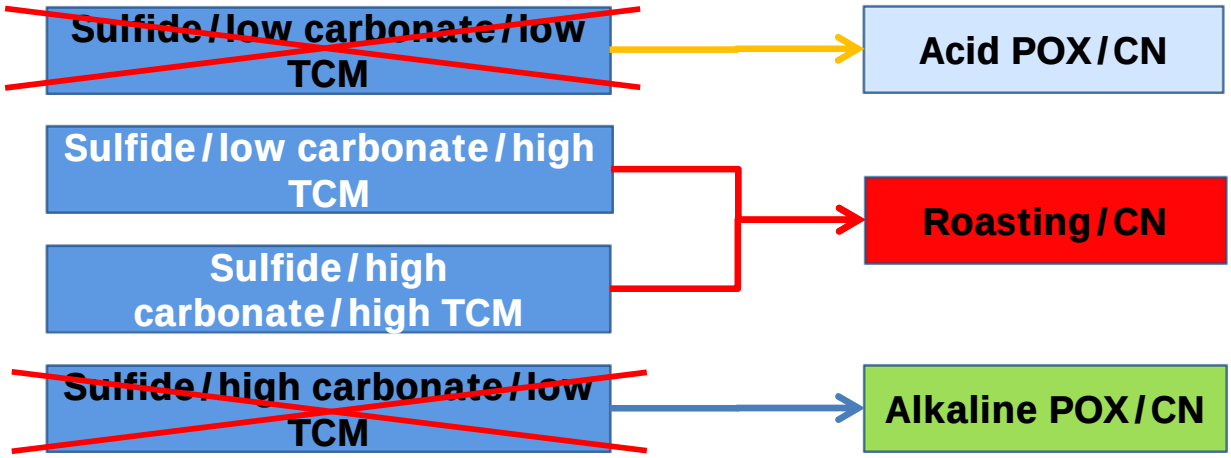


- Extent of oxidation is independent of the carbonate contents in the ore

Alkaline POX - Highlights

- Able to increase ounce production by utilizing high grade alkaline ores
- Oxidation of sulfides directly proportional to oxygen addition, but limited by pressure design of vessels
- Four tones of oxygen required for each ton of sulfide in the feed
- Carbonate content doesn't affect the oxidation
- Savings in acid and lime usage, but increase in propane usage

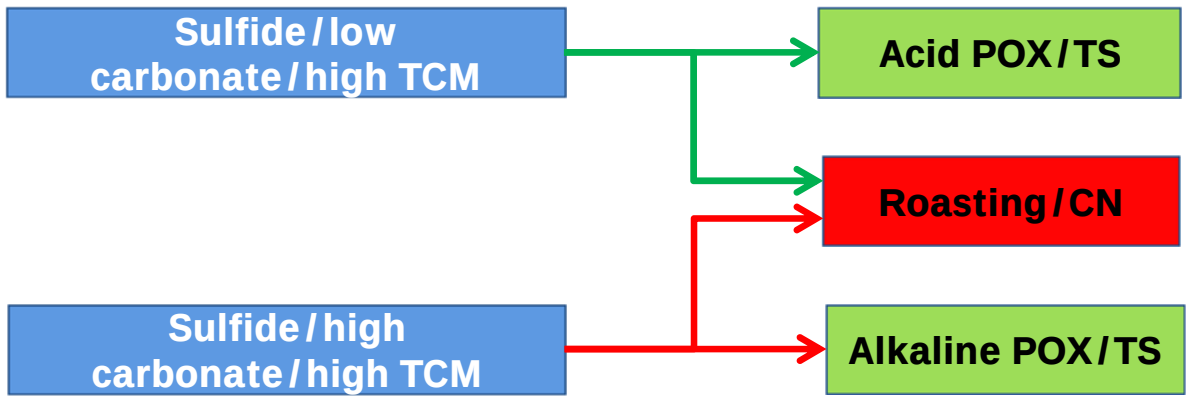
Goldstrike – Process Conversion



2nd Conversion of the Circuit

- Ores amenable to Acid Pressure Oxidation were exhausted by the end of 2008
- Alkaline POX technology has been adopted to extend the life of autoclaves for a few more years
  - Roaster operates until 2025
- The remaining orebody typically consists of:
  - Higher CO_3 content than historically processed, coupled with
  - High preg robbing levels/TCM's

Goldstrike – Process Conversion



TCM Leach Testing History

- Research Efforts Ongoing Past ~ 15 Years
  - Bench-scale thiosulfate testing since 2005
  - Bench scale testing of CaTS in 2009
  - Continuous pilot testing of CaTS in 2009
- Testing was used to identify key process variables and test the process variables on various ore types.

ATS RIL Test on Various Ore Samples

User Sample ID	Test No.	Sample head assays								Results	
		Au	S tot	S^{2-}	S_{SO4}	S^{o}	C tot	TCM	CO3	POX sulfide oxidation	4 hr-ATS Au recovery
		(g/t)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
NORTH MILL FEED Mar 24, 2009 BGMI	POX/ATS - 22	5.48	2.26	1.96	0.30	≤0.02	3.71	0.62	15.5	54.1	84.3
SOUTH MILL FEED Mar 24, 2009 BGMI	POX/ATS - 24	6.75	3.05	2.73	0.32	≤0.02	3.65	0.79	14.3	49.8	81.7
BR24-A, Mar 24, 2009 BGMI	POX/ATS - 26	6.72	1.18	1.11	0.07	≤0.02	5.92	1.54	21.9	70.3	82.2
BR24-B, Mar 24, 2009 BGMI	POX/ATS - 28	6.85	1.20	1.12	0.08	≤0.02	5.67	1.48	21.0	67.0	81.3
MP3, Mar 24, 2009 BGMI	POX/ATS - 30	8.47	2.38	2.13	0.25	≤0.02	2.58	0.77	9.1	53.1	77.4
BR20-A, Mar 24, 2009 BGMI	POX/ATS - 32	3.43	1.47	1.31	0.16	≤0.02	4.47	1.79	13.4	60.3	74.6
BR20-B, Mar 24, 2009 BGMI	POX/ATS - 34	4.63	1.54	1.39	0.15	≤0.02	4.50	1.78	13.6	61.2	81.0
BR25-A, Mar 24, 2009 BGMI	POX/ATS - 36	8.27	2.56	2.35	0.21	≤0.02	2.23	0.71	7.6	80.0	83.4
BR25-B, Mar 24, 2009 BGMI	POX/ATS - 38	9.15	2.71	2.51	0.20	≤0.02	2.46	0.67	9.0	80.9	83.5
MP4-A, Mar 24, 2009 BGMI	POX/ATS - 40	15.13	1.62	1.46	0.16	≤0.02	3.97	1.23	13.7	56.8	73.8
MP4-B, Mar 24, 2009 BGMI	POX/ATS - 42	18.42	1.78	1.61	0.17	≤0.02	4.02	1.24	13.9	64.0	72.3

Alkaline POX conditions: P80 particle size = 75 µm, 225°C, O_2 pressure=100 psi, retention time=1 hour, trona addition to POX feed=10 kg/t ore

CaTS RIL Pilot Campaign – Summary

- CaTS RIL achieved higher gold extraction for Acid POX treated ores than for Alkaline POX treated ores due to improved exposure of gold, similar to CIL for non-preg-robbing ores
- The trade-offs between Acid POX and Alkaline POX for CaTS RIL are expected to be similar to the trade-offs in CIL for non-preg-robbing ores

TCM LEACH ~ Project History

- Demo plant testing of CaTS for 16 months
  - Full simulation of leach/adsorption/elution/EW process, including full recycle of all streams
  - The demo plant processed oxidized slurry from the Goldstrike autoclave facility

Demo Plant-Objectives

- Demonstrate RIL Technology & ancillary equipment
- Determine achievable gold recovery and resin loading with different ore types
- Determine reagent consumption
- Determine effect of Au, Hg and As on process performance
- Demonstrate R/O, regeneration, and effect of recycling
- Collect pertinent data for permitting
- Train employees and develop operational expertise

Demo Operation - Limitation

1) Various operating conditions, reagents, and reagent strengths were tested as part of the Demo Plant operation
2) Feed availability issue: Shortly before the Demo Plant started up it was learned that the Goldstrike Autoclaves could emit mercury when running in the Alkaline autoclave mode. As a result a tank full of Alkaline autoclave discharge slurry was saved and ran through the Demo plant in July 2010, August 1 through 6, 2010, and again on September 29 through October 6, 2010. All other Demo Plant feed was Acid autoclaved ore as the plant autoclaves were not able to run in the Alkaline autoclave mode until after the Autoclave Mercury Controls Project was permitted, built, and operational.

Demo Operation – Feed Processed

Dates	Ore Processed	Ore Characteristics
8/1 – 8/6	Alkaline	Alkaline
8/6 – 8/17	BR31	Med Preg-robbing
8/17 – 8/20	BR10, BRSO AP	Med Preg-robbing
8/21 – 8/24	Storm	High grade
8/25 – 8/29	BR6, BRSO AP	Med Preg-robbing
8/29 – 9/23	BR31	Med Preg-robbing
9/23 – 9/26	Storm	High grade
9/26 – 9/27	BR3	High Preg-robbing
9/28 – 9/29	BR31	Med Preg-robbing
9/29 – 10/6	Alkaline	Alkaline
10/6 -	PR2	High Preg-robbing

Demo Plant: Gold Recovery Summary

- No significant gold in tails solution even with higher head grades
- Best recoveries at low grade (2.5 -3 ppm) with BR31;
  - Consistent and constant recoveries at 80 to 82%
- Typical Goldstrike BRSO/BR33 blend was good
  - Gold recovery 78.9% (actual) vs 79.3% (pred)
- Lowest recoveries at low grade with ALK (70% in July and August at 3.2 ppm) and 60% in October at 2.9 ppm feed with recycle streams and different leaching conditions
- PR2 showing low recovery (60 to 70% with average of 65%) in October (to the 17th) due to storage issue and leach conditions

Demo Plant: Gold Recovery Summary

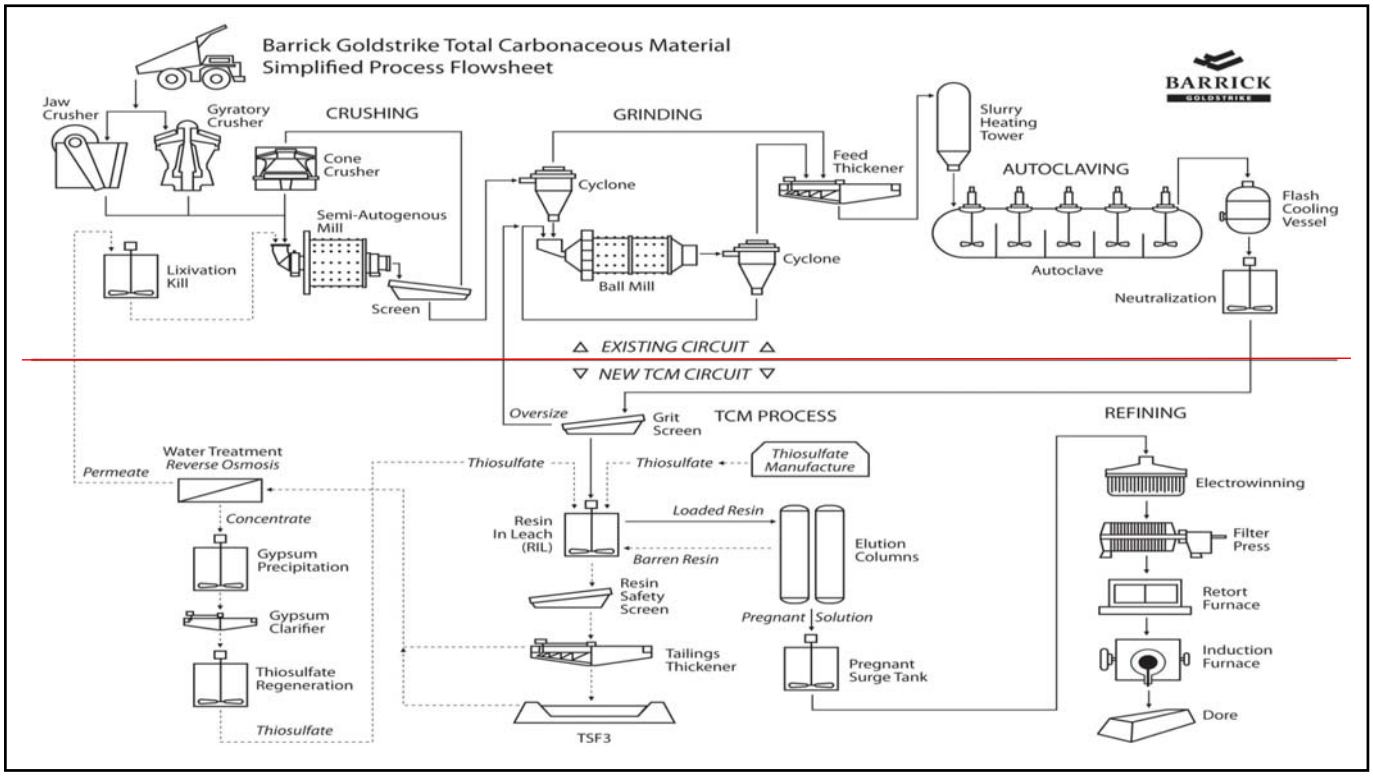
- STORM high grade ore has a good initial response (over 90% recovery), which is decreased when gold inventory in the circuit becomes high: less pronounced at high resin flow rate
- Proposed operational strategy to blend high grade in full scale plant
- Note: The Demo Plant ran many different types of ores and grades in the 16 months of operation. The Demo Plant results were limited to one type of Alkaline autoclave oxidized ore. The Demo Plant also did not run a lot of extremely high TCM or extremely strong preg robbing ores as doing so meant running the ores through the entire Autoclave facility which would experience extremely poor gold recovery as it was utilizing cyanide and activated carbon.

Demo Plant Product

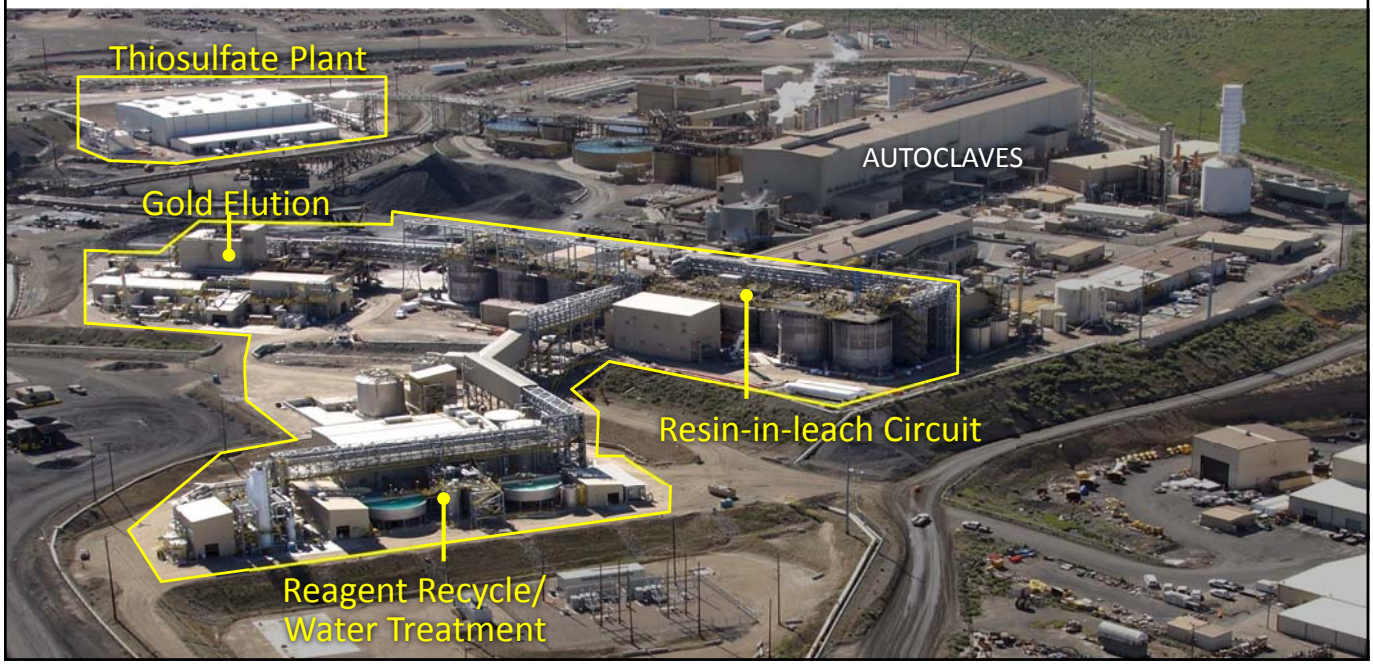
The Demo Plant was utilized to test all of the TCM Leach Processing circuits up to and including the pouring of one small bar of gold.

TCM Leach – Design Criteria

- Ore throughput 600 st/h
- Target feed P80 200 mesh (75 µm)
- Mill 1 Alkaline (270 TPOH)
- Mill 2 Acid (330 TPOH)
- Interstage screen: 500 µm
- Safety screen: 300 µm
- RIL condition: 50 ^{o}C, 0.1 M CaTS, with Cu and air
- Elution: Trithionate with sulfite



TCM Circuit – Thiosulfate Leaching



Innovation: Goldstrike TCM Process

Commissioning and Start up

Brownfield/Greenfield Project

- Operate A Train in CIL mode during construction of B Train
- Shut down process operations January, 2014
- Start up B Train in CIL mode (new tanks) May 1, 2014
- Shut down BCIL operation October 8, 2014
- Start new RIL operation on B Train November 10, 2014

Commissioning and Start up

- TCM BRIL first gold poured November 28, 2014
  - Startup of roughly half of the TCM facility
  - In December identified water treatment bottleneck with UF membranes fouling. Only able to maintain 25% of design feed flow rate.
- TCM ARIL commissioned January 22, 2015
- TCM ARIL first gold poured January 31, 2015

Commissioning and Start up

Ausenco Utilized for Commissioning

- Commissioning system well developed/understood
- Strong commissioning leadership & system knowledge

Barrick TCM Team

- Worked with Ausenco through water testing phase
- Assumed responsibility with ore processing phase

Goldstrike Operational Team

- Participated in energization and water testing phases
- Required for ore processing phase

Water Treatment plant was a turn key facility and was commissioned by Auburn

Commissioning and Start up

Operational Highlights in 12 Months

- Processed: ~ 3M tonnes feed
- Produced: over 220,000 oz

Current Status - Challenges

The TCM Leach process is a new process with complex chemistry and with unit operations that are extremely dependent on the product quality and quantity from the preceding unit operations.

A few of the challenges seen are:

Grinding

- Hard ores are challenging fine grind and throughput
  - Fine grind is important for recovery
  - Grits from grinding contributes to challenges in RIL screening, tank over flows, and RIL screen cleaning

Current Status - Challenges

RIL

- Lowering resin loadings (gold and polys) to design target will improve gold in solution losses and recovery.
  - Need to move more resin (elution challenges)
- RIL tanks over flowing
  - Clean inter-tank screens thoroughly and regularly
  - Tank over flows upset resin profile and lowers recovery
    - Grits from grinding contributes to RIL challenge
    - If testing of larger resin proves out it could be a big help
  - By-passing of a few RIL tanks to prevent overflowing could have more impact on recovery at higher throughput rates.

Current Status – Challenges

Water Treatment

- Permanent solution to MF/UF fouling is needed
  - MF trailers need to be ready for cold weather conditions
- Water Treatment automation has gaps and is being assessed

Elution

- More elutions per day are needed to move more resin through RIL and bring down gold in solution losses.
  - Engineering design warranty was for 8 elutions per day as maximum (for high grade ores).
  - More automation may be needed

Conclusions

- Goldstrike has been a flagship operation for Barrick.
- The processes have been evolved to meet the feed constraints and the process has been selected based on the economics.
- Various option options allow to treat various feeds from the area.

Innovation: Goldstrike TCM Process