KNELSON CONCENTRATOR AIDS IN PROCESSING SHIFT FROM SILVER TO GOLD PRODUCTION

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Abstract

The Kinross DeLamar Mine has been operated for more than 17 years producing precious metals dore' from ores, principally silver bearing with associated gold co-products. In late 1995 a new orebody was commissioned, the Stone Cabin orebody, and the site began a phased shift from silver dominance to gold dominance in terms of precious metals revenue. The Knelson Concentrator was selected to remove gold from a portion of the cyclone underflow stream in the grinding circuit. This paper describes the development of the flow sheet, specific mineralogical impacts on Knelson product and downstream materials, and impacts on mine/mill grade reconciliation.

General Site Background

The DeLamar mine site has been active in recent years, starting as a silver and gold operation in 1977-78 under ownership and operating control of Earth Resources Co. Silver prices and silver head grades have varied over the years demanding aggressive actions by the operating staff. Mining zones have been studied and engineered-maintaining mill feed supply for the entire 17 year operating life. Mill processing rates have seen a constant climb over the same period, reaching new production records in 1996. The site is midway through a process of changing emphasis from silver to gold production. Older DeLamar mining zone production rates continue to decline in 1996 and 1997 as production climbs from the recently developed Florida Mountain resource pits, Stone Cabin and Tip Top.

As early as 1987-88 exploration and metallurgical testing identified high grade gold zones where additional work involving amalgamation and gravity studies were pursued. The final permitting for active mining in the Florida Mountain area allowed road building and increased availability of materials for metallurgical testing. By June 1995 (approximately 4 months ahead of full mining/milling) a preliminary plan was developed for pilot testing of gravity recovery equipment and processing schemes. During the first three months of operation in the Florida Mountain pits there were difficulties in closure of mine/mill head grades. The Knelson Concentrator provided a means to accumulate gold that was not reporting to the cyclone overflow (COF), so that a more representative head grade could be calculated on the basis of COF and gravity collected precious metals.

Technical evaluation of two brands of centrifugal concentrators was undertaken along with in-circuit testing of a small 17.78 cm. (7") diameter centrifugal unit within the DeLamar mill circuit. At the time of this testing only small amounts of Florida Mountain ore were available for milling but the effectiveness of the small unit was proven on DeLamar ores. Additionally, the first insights into materials handling issues were gained by attempts to control feed rate to the unit and the handling of reject material.

The basis for selection of the Knelson Concentrator was predicated on installed (successful) locations, reliability, availability of parts, and cost. Urethane materials and stainless steel components also contributed to extended operating life prior to any required overhauls. Digital PLC control of the Knelson was also favored by the operating and metallurgical team.

Grinding Circuit - Knelson Location

Literature search regarding installed centrifugal concentrators provided valuable information regarding industry practices in locating these devices. Additionally, technical papers were studied with regard to downstream concentrate handling, general operating principles as described by B. Knelson (1988), gold particle size distribution and effects on circulating loads in grinding circuits. These individual aspects will be discussed in later sections.

The DeLamar grinding circuit contains SAG/Ball grinding with primary grinding in a 5.5 m. dia. x 2.74 m. long (18 ft. dia. x 9'-0" long) Hardinge SAG mill, with a 2.9 m. dia. x 4.5 m. long (9'-6" dia. x 15'-0" long) Hardinge ball mill and a supplemental 3.8 m. x 4.5 m. long (12'-6" dia. x 15'-0" long) Allis Chalmers ball mill providing secondary grinding. The primary grind is in closed circuit with a Derrick screen, the secondary grind closed by a D-20 Krebs six-cyclone cluster. A manual weir bar split divides the cyclone underflow feed to the two ball mills, allowing equalization of feed to the different size mills. Modification to the feed split area allowed construction of a three compartment box arrangement allowing a small stream of high specific gravity slurry to be stripped off the bottom of the middle compartment, and then sent to the Knelson area.

After a few unsuccessful attempts at locating the Knelson Concentrator with an Eriez drum magnet (with associated transfer sumps and pumps), we hit upon a different arrangement that alleviated any need for sumps and pumps. The entire Knelson 76 cm (30") Concentrator was recessed into the upper mill decking, allowing gravity feed from a 7.62 cm. (3") diameter rubber pinch valve under the 3-compartment splitter box. This line feeds the screen box ahead of the Knelson unit. The screen, a 58 cm. x 178 cm. (23 inch x 70 inch) urethane decked unit with 2x25mm openings (transverse slot) was purchased with the Knelson concentrator. The Knelson reject or tailings discharge (Knelson unit discharge plus screen oversize) then flows by gravity, joining secondary ball mill discharge to the common sump for the two ball mills. The Knelson tails rejoin the grinding circuit at that point. Knelson concentrates are discharged automatically on a variable frequency (currently set at a cycle time of 2 hours) and also flow by gravity in a reinforced, translucent hose to the feed box of the Eriez drum magnet, for grinding media and tramp iron removal. This equipment arrangement relies heavily on the feed screen of the Knelson removing the ball chips from the feed stream. We accept there may be inefficiencies in the Knelson bowl due to the presence of up to 30% by weight ground steel waste but have selected the 2-hour cycle to minimize the impact. Magnetic reject from the Eriez is discharged by sliding down a nearly vertical chute into a modified small dumpster. Analysis of this material indicates a potential entrapment of sands and heavy minerals resulting in a loss of up to 10.29 g/mt (0.30 oz/t) Au in this waste stream. Cleaned (only non-magnetic materials remain) Knelson concentrates end the journey with a short vertical drop into a secured 0.75 cu.m. (1 cu. yd.) dumpster. The dumpster is picked up by the refiner as a daily sample in the morning (or up to 3-days accumulation of individual daily bins on a Monday) and transfers the bin to the refinery for additional processing. The refiner transfers by hand shoveling, the entire daily bin contents which weigh 329 kg.(726 lbs.) on average (range from 115 kg. To 454 kg. (250 to1,000 lbs)) into storage drums to free the bin in case the material is not processed that same day (See Table -1- for Knelson Output data).

Currently, the material is then hand shoveled into the feed box of a 1.22 m. x 2.44 m. (4 ft. x 8 ft.) Wilfley shaking table with a rubberized top cover with 0.16 cm. (1/16") riffles spaced 2.06 cm. (13/16") apart. This was an existing piece of equipment previously used for tabling of crushed slag in the refinery. We hope in the near future to create a more automated (and regulated) feed system including a Midwestern screen 122 cm. (48") dia. and 20 mesh openings for oversize removal and an agitated tank/feed system. It is felt this will improve efficiency of this first stage upgrading effort. All streams from the feed material to the three streams from the tabling effort are hand sampled and assayed. All products are dewatered and weighed wet. While widely variable, these weights and assays are presented in this paper to provide the fundamental information used in evaluating the Knelson performance and impact on head grade at our site (See Table -2- for Knelson versus Table Product Comparison).

Tailings materials from the table effort assay on average 377 g/mt Au and 1063 g/mt Ag (11 oz/t Au, 31 oz/t Ag) and are recycled several times weekly to the main feed point for the grinding circuit, moved by small front end loader (See Table -3- for Table Tails data). Concentrates are accumulated and added to the Merrill-Crowe precipitates weekly and melted within the normal metal flow (Table -4- Table Concentrate data). The concentrate stream averages 345,226 g/mt Au and 288,757 g/mt Ag (10,069 oz/t Au and 8,422 oz/t Ag) and contains approximately 686 grams (20 ounces) of gold daily, ranging up to 2,777 grams (81 ounces) per day. Efforts at including the table middling from the rougher tabling into the melts proved wholly unsatisfactory due to the high levels of contained pyrite and other sulfides. The middling materials are now accumulated into a weekly composite and subjected to two additional stages of scavenger tabling on the same Wifley table (Table -5- Table Middlings data). In 1997 the proposed purchase of a Gemini table may provide a better upgrade mechanism for the mids and the various concentrates. Second and third retabling concentrates join the mainstream rougher table concentrates and M-C precipitates and are melted in the weekly call period. The daily Knelson output, using the data from table performance is reconciled into the daily contained ounces for gold and silver, arriving at a new head grade for both (See Tables -6-, -7- for Gravity gold recovered and head grade adjustments). Both tailings and middling from the scavenger tabling efforts are returned to the grinding circuit SAG mill feed stream, handled via forklift. We have purchased a small diesel fueled crucible furnace and are intent on melting the concentrates on a daily basis eliminating sampling errors in these high grade streams, and providing a more timely daily result for Knelson output.

Currently, the Knelson and tabling stream samples are handled with a great deal of caution in controlled sample containers and pulverizing equipment in the metallurgical laboratory. Potential for contamination of standard mine/mill samples remains. It is hoped we will install equipment during 1997 to provide all preparation needs within the refinery.

The silver assay results of this repeat or 'rougher-scavenger' tabling indicate the different mineralogical makeup of the silver versus gold, and are one of the issues covered later in this paper.

Performance Data

From the onset of mining Florida Mountain ores, adjustments to the cyclone overflow sampling system, including frequency of cut, total volume of sample, laboratory handling, and addition of a secondary sample cutter, did not adequately close the gap between mine projected head and mill sampled head. The Knelson Concentrator was added to the circuit to strip off coarse gold from the accumulation in the grind circuit and provide feedback metal content to close the mine/mill gap. Ore blending practices from two or more mine pits and several ore types require decisions on a nearly daily basis to maintain optimum blend and production budget success. For this reason we sought to secure a daily adjustment to the head grade based on precious metals recovered in the Knelson scheme. Scavenger ounces from 2nd and 3rd retabling efforts impact the month-end grade reconciliation (See Table -8-).

It is impossible to move procedures from standard sampling schemes in grinding circuits into an entire gravity circuit and commence grab sampling these extremely high grade streams with more confidence, but the information is desperately sought by management for the planning decisions mentioned above. Given the 40-60% variation in individual table product samples, the sum of all the streams and the individual samples are tracked and presented here for general interest. Better data and improved planning are anticipated when we switch to daily dore' button production for the Knelson concentrate-rougher tabling concentrates.

While not presented in this paper, improved effectiveness of Knelson and table efforts resulted when the equipment layout was modified and steady-state operation achieved.

The scavenger re-tabling of miscellaneous byproducts was undertaken to ensure minimum quantities of Knelson recoverable gold were returned to the grinding circuit. An interesting sidelight of this effort was the upgrading of silver content into the middling, scavenger #1 and scavenger #2 retable middling. Based on mineralogic studies undertaken, this is seen as a continuous upgrading of the naumannite mineral phase, the principal source of silver in either the DeLamar or Florida Mountain ores (See Table -9-).

Behavior of Gold, Silver Minerals in Circuit

Published technical data from installed Knelson sites and technical studies regarding the behavior of gold in grinding circuits are readily available in the industry. In addition to installation successes and failures (some of which were repeated in our effort), anticipated performance parameters were checked during our initial year of operation.

The ability to collect and recover fine gold using the Knelson is documented and indeed the choice of location within the grinding circuit as selected is based on published data describing benefits of aiming recovery and hardware at the finer sizes. This allows pickup of materials trapped in the grinding circuit that have been subjected to many passes through the grind as described by a host of other authors; Poulter, et al, Hendricks, et al, Darnton, et al, Darnton, et al, Laplante, et al (1994, 1994, 1995, 1992, 1990, respectively) and subsequent deformation and shearing as described in the Hemlo circuit by Laplante, Banisis, and Cauchon (1991). Mineralogical studies undertaken in the evaluation of Knelson recovered metal include visual particle size analysis of the table concentrates. Some 1500+ particles were visually inspected and sized (in apparent two dimensions) and statistically summarized. The 'projected area diameter' of the exposed surface area yields a suitable estimate of particle size per literature published regarding sizing of particles via microscopic examination by Stockham, Allen, Kaye, (1979, 1981, 1981 respectively), which for this specific sample was just above 37 microns. There is ample evidence of coarse particle recovery as well as frequent recovery in the size range of 10-20 microns. This is within predicted behavior for gold as described in a detailed analsis of gold fragements by Laplante, et al, (1990) for gold held up in the grinding circuit through several passes.

Mineralogical studies of middling from rougher tabling indicate an overall concentration of medium specific gravity minerals, and the significant concentration of our principal silver mineral, naumannite (chemical formula Ag_2Se, specific gravity 6.5-7.0). Gold losses to middling in the rougher or first tabling phase include carry-over due to inefficiencies in table performance as well as small inclusions of gold in naumannite or locked in silica grains. These gold losses impact the assay of the waste streams from tabling (middling or table tails). Naumannite carryover into table concentrates as well as gold with naumannite inclusions or pyrite inclusions limit the upgrade effect on table concentrates without additional grinding (regrinding).

Analysis of gold grains show the combination of gold and silver as 'electrum' in proportions varying from 61% to 67% Au. This also matches the critically slow leaching nature of precious metals at DeLamar and the need to pull this material out of the process streams where retention time will not exceed 48-72 hours. Analysis of distinct naumannite grains finds most near the 'pure' naumannite composition with some sulphur substituting for selenium.

Given the range of specific gravities of pure minerals and associations in the gravity concentrate it is not surprising to see a traceable upgrade in silver content in middling from repeat tabling efforts.

Au, pure, theor	19.3
Ag, pure, theor	10.5
electrum, (a)60:40	15.6
electrum, (b)40:60	14.0
naumannite	6.5-7.0
argentite	7.3
pyrite	6-6.5
steel, general	7.3-7.9

In orebodies with a more complex suite of ore minerals, the impacts of multiple pass upgrading would be more subtle and difficult to isolate. In our somewhat bi-variate precious metals occurrence the continued retabling removes more of the physical carryover and borderline separation factors and allows us to isolate the gold from silica except for dual mineral particles. It is these particles that limit the complete isolation or optimum upgrade of any of the streams. As our tabling efficiencies increase we will be able to reduce most gold recycling back to the grind circuit in tails/mids but we will be limited in reducing sulfides moving in the concentrate stream. No plans are currently underway to provide any regrinding efforts to the middling stream. A final visual indication of the mineralogical/specific gravity differentiation can be seen at the concentrate end of the shaking table where several distinct color 'bands' can be seen. These represent pyrite, reject remnant steel, naumannite, and electrum or gold, in order of increasing specific gravity.

While not readily visible in the data as presented here, Knelson concentrator output shows relevant shift in gold/silver content associated with each change in ore blend form the open pit mine(s). These impacts are typically minor but illustrate shifts from 50% gold/50% silver ore to 70% silver/30% gold ore. Knelson output, rougher table and scavenger table performance moves with these changes in raw mill feed.

Issues Remaining to Be Resolved

Our choice of location for the primary collection device (Knelson Concentrator) appears sound from a gold particle recovery basis and materials handling basis. Circulating loads for slurry and gold compare to those of several other mines who have undertaken similar studies such as Poulter, et al, Hendricks et al, Darnton, et al (1994, 1994, and 1995 respectively)(See Table -10-). That our own circulating loads have not yet returned to 'pre-gold ore' levels indicate that a second unit may be warranted. After a year of operation, if there were significant levels of buildup in the grind circuit the stripping action should have lowered the levels by this time. Initial estimates of trapped material will be rechecked soon and potentially removed or flushed when rubber mill linings finally require replacement. At this point it appears safe to assume a second 30" Knelson would meet with very similar success and lighten or drop the gold circulating load.

The remaining problem will be to install another unit, prove the ongoing reduction in enriched grinding circulating load, and find a location to install the second unit while retaining successful materials handling placement. The Eriez magnetic is sized suitably but we may have to get even more serious about Knelson location to get similar success. Refinery handling will be capable of more material, more efficiently if we complete the refinery modifications. It is highly likely we may switch feed piping to the Knelson circuit to a 'one cyclone per Knelson' basis and simply estimate the throughput based on the 2/6 of total circulating load (weight). After the second installed unit is running smoothly, we may potentially drop the in-depth weight/assay/ounces tracking for all the streams.

Conclusions

In conclusion, the following points summarize our decision to add the gravity circuit including a Knelson Concentrator at Kinross DeLamar.

- essential
- cost effective
- resolves disputes
- more secure than other methods
- demonstrable need/success
- installation consideration crucial

The unit performs an essential function, providing recovered gold/silver that was eluding standard sampling devices and practices. The unit has easily paid for itself and remains a high operating time, low maintenance performer in a difficult location within a grinding circuit. Data and grade reconciliation has reduced grade disputes and month-end closure variances. Compared to tabling, jigging, and other relatively 'open' gravity techniques the unit itself is secure and the concentrate handling is as secure as you are able to incorporate into site-specific cost/security evaluations. Based on successes to date and continued high circulating loads (Au) another unit may be warranted.

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Table -1-

Kinross DeLamar : Gravity Circuit

Table of Knelson Concentrate Data

Kneslon Concentrator Output

	'n'	x-bar	sd	min	max
Weight, lbs.	138	726.3	272	254	2,129
Assay, Au oz/t (F)	137	116.0	62	13	345
Assay, Ag oz/t (F)	137	171.0	82	15	568
Contained Metals					
Au, Oz., troy	137	41.5	27	6	140
Ag, Oz., troy	137	62.8	41	12	252

Table -2-

Kinross DeLamar : Gravity Circuit

Table of Knelson Concentrate Data

Knelson Concentrator Output
-vs-
Sum of Table Products

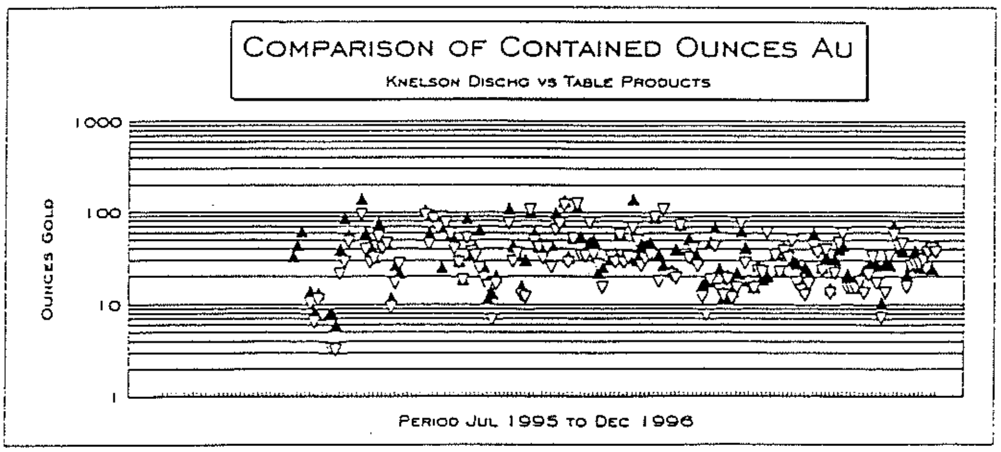

Table -3-

Kinross DeLamar : Gravity Circuit

Table of Wilfley Table Products

Table Tails

		Au	Ag
weight, lbs.	*x-bar*	625	
	'n'	138	
	sd	238	
	min	218	
	max	1,853	
assay, Au	*x-bar*	11	31
	'n'	137	137
	sd	10	22
	min	0	2
	max	85	111
Oz. Au contained	*x-bar*	3	10
	'n'	137	137
	sd	4	9
	min	0.1	0.9
	max	30	60

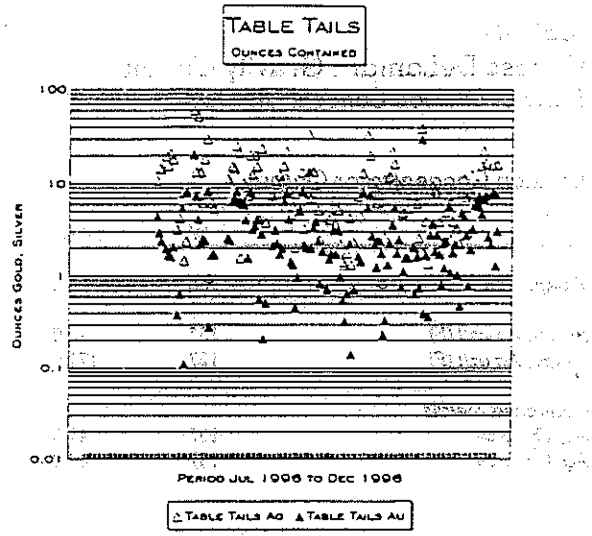

Table -4-

Kinross DeLamar : Gravity Circuit

Table of Wilfley Table Products

Table Concentrate

		Au	Ag
weight, lbs.	*x-bar*	5	
	'n'	138	
	sd	5	
	min	0	
	max	54	
assay, Au	*x-bar*	10,069	8,422
	'n'	137	137
	sd	4,079	2,721
	min	246	842
	max	28,849	21,000
Oz. Au contained	*x-bar*	20	17
	'n'	137	137
	sd	15	12
	min	0.1	3.5
	max	81	68

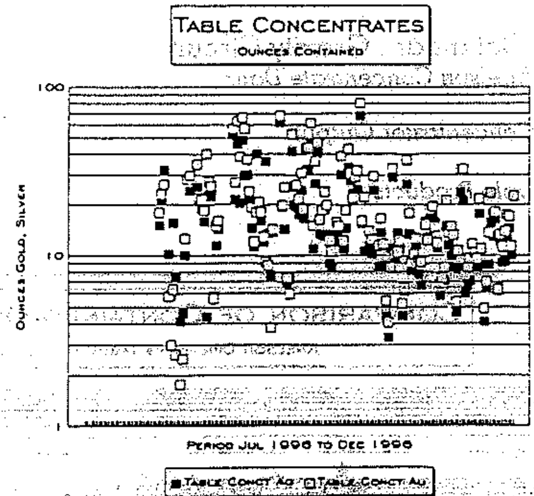

Table -5-

Kinross DeLamar : Gravity Circuit

Table of Wilfley Table Products

Table Middlings

		Au	Ag
weight, lbs.	*x-bar*	28	
	'n'	138	
	sd	13	
	min	7	
	max	65	
assay, Au	*x-bar*	966	1,640
	'n'	137	137
	sd	980	1,243
	min	74	367
	max	7,162	11,554
Oz. Au contained	*x-bar*	36	48
	'n'	134	134
	sd	25	30
	min	3	10
	max	125	

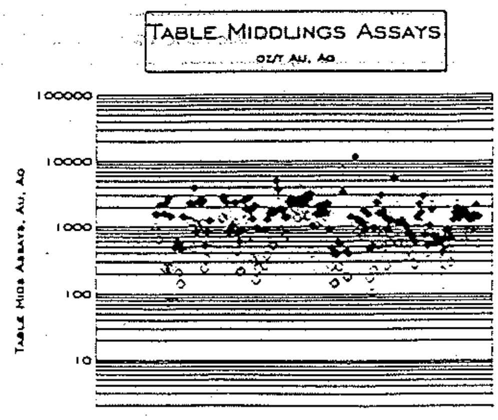

Table -6-

Kinross DeLamar : Gravity Circuit

Table of Knelson Adjustments to Head Grade

	Au Head COF	Au Head Adj/Grav
Jan-96	0.026	0.031
Feb-96	0.028	0.030
Mar-96	0.025	0.030
Apr-96	0.036	0.038
May-96	0.032	0.036
Jun-96	0.033	0.039
Jul-96	0.034	0.037
Aug-96	0.031	0.037
Sep-96	0.030	0.042
Oct-96	0.031	0.042
Nov-96	0.035	0.042
Dec-96	0.028	0.036

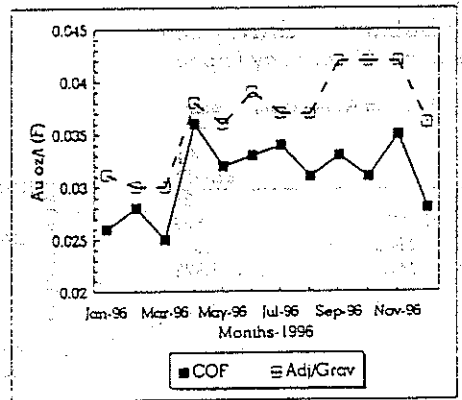

Table -7-

Kinross DeLamar : Gravity Circuit

Table of Gold Production from Knelson Source

	Au Oz. Pri.	Au Oz. K.C.	Au Oz. %K.C.
Jan-96	1,935	407	17%
Feb-96	2,486	204	8%
Mar-96	2,590	282	10%
Apr-96	3,082	244	7%
May-96	3,849	283	7%
Jun-96	3,648	451	11%
Jul-96	3,488	338	9%
Aug-96	3,513	538	13%
Sep-96	3,850	793	17%
Oct-96	3,545	967	21%
Nov-96	3,665	425	10%
Dec-96	2,733	567	17%

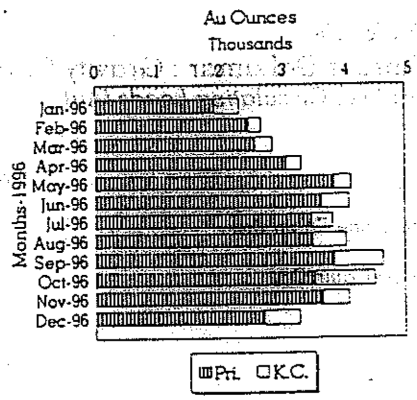

Table -8-

Kinross DeLamar : Gravity Circuit

Table of Scavenger Tabling Performance

Ounces Removed from Tailings Recycle Stream

	Prev Recy Mids Cont'd	Oz.'s to Conct.
KCMRR-0312	3.8	14.8
KCMRR-0412	124.6	24.4
KCMRR-0512	104.0	28.1
KCMRR-0101	101.0	11.0
Averages	83.3	19.6

Table -9-

Kinross DeLamar : Gravity Circuit

Table of Silver Mineralogy Impacts

Upgrading Effect in All Middling Streams

	Ag oz/t (F)
KC Output	27
Rougher Table Mids	859
Scavenger -1- Mids	1,050
Scavenger -2- Mids	1,972

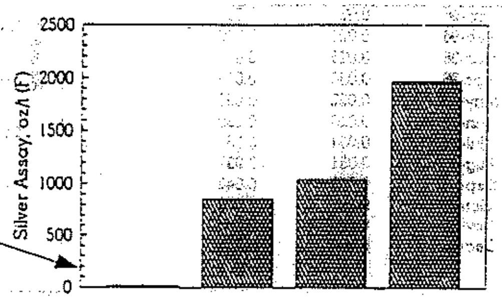

Table -10-

Kinross DeLamar : Gravity Circuit

Table of Circulating Loads (Au)

	Au oz/t (F) Cyclone U'Flo	Au % Circ. Load
Pre-Stone Cabin Ore	0.028	392 %
Stone Cabin Ore	0.214	1,872 %
	0.440	4,812 %
	1.228	7,959 %
	0.237	2,302 %
	0.139	1,620 %
	0.094	784 %
	0.280	2,800 %
	0.217	2,170 %

based upon pre-Stone Cabin cyclone u'flo gold assays