A Review of Placer Gold Concentrate Recovery & Upgrade Options

Yukon Geological Survey
Miscellaneous Report - 5
(YGS MR-5)

Preamble: In 2010-11, Yukon Geological Survey awarded a contract to NEW ERA Engineering Corporation of Whitehorse to undertake a study of recent developments in gravity gold recovery techniques. In partial fulfillment of the contract, Randy Clarkson attended the Gravity Gold 2010 Optimizing Recovery Conference in Ballarat, Australia, and presented the following report and recommendations at the Yukon Placer Workshop in November 2010.

A Review of Placer Gold Concentrate Recovery & Upgrade Options Yukon Placer Forum

By: Randy Clarkson, P.Eng. - November, 2010

NEW ERA Engineering Corporation

About the Author

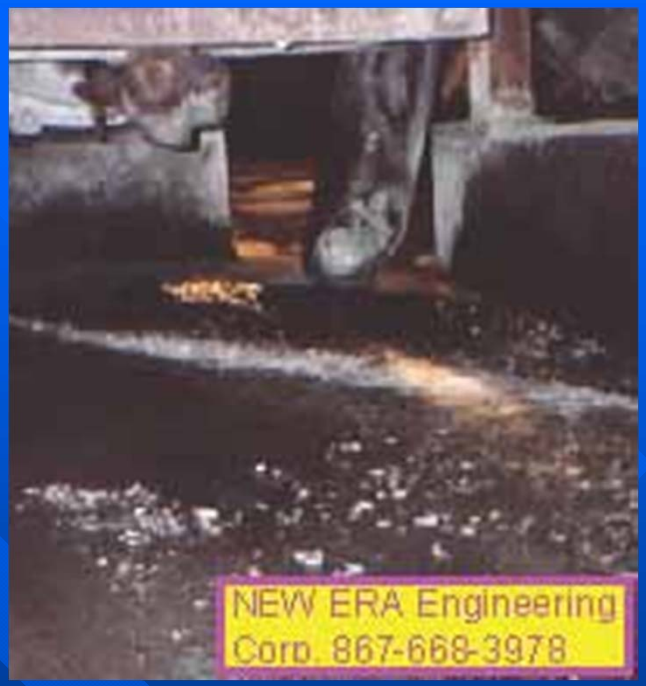
- **Professional mining engineer working out of Whitehorse since 1980 on placer, lode mining and small hydro projects**
- **Developed innovative technique using Radiotracers to assess the real efficiency of various gold recovery and sampling systems**
- **World Authority regarding Placer Gold Mining and Gravity Gold Recovery**
- **Author of several publications on placer exploration, sampling, gold recovery and alluvial mining technology**

Gravity Recovery in Lode Gold Operations

- **Gravity pre-concentration in lode gold ores was common prior to 1960's**
- **Used mineral jigs, pinched sluices, riffled drums and tables**
- **Generally located at grinding mill discharge**
- **Fell out of favor with improvements in froth flotation and cyanide leaching**
- **Considered to be out-of-date technology**
- **Concerns over security of concentrates**

Rebirth of Gravity in Lode Gold 1980's

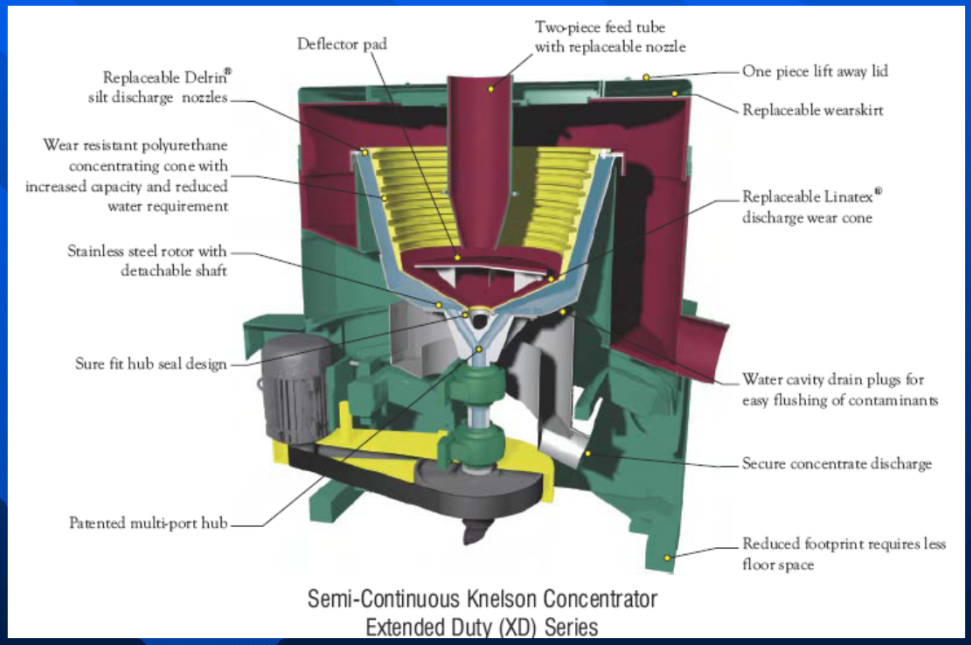
- **High losses of coarse gold in traps in milling circuits – security concerns**
- **Limited residence time in CN- leach circuits to dissolve coarse particles**



- **Losses of coarse gold in flotation circuits**
- **Faster pay back on gold dore bar**
- **Less expensive than most other methods**

Rebirth of Gravity in Lode Gold 1980's

Facilitated by the invention and promotion of the Knelson and Falcon centrifugal batch concentrators



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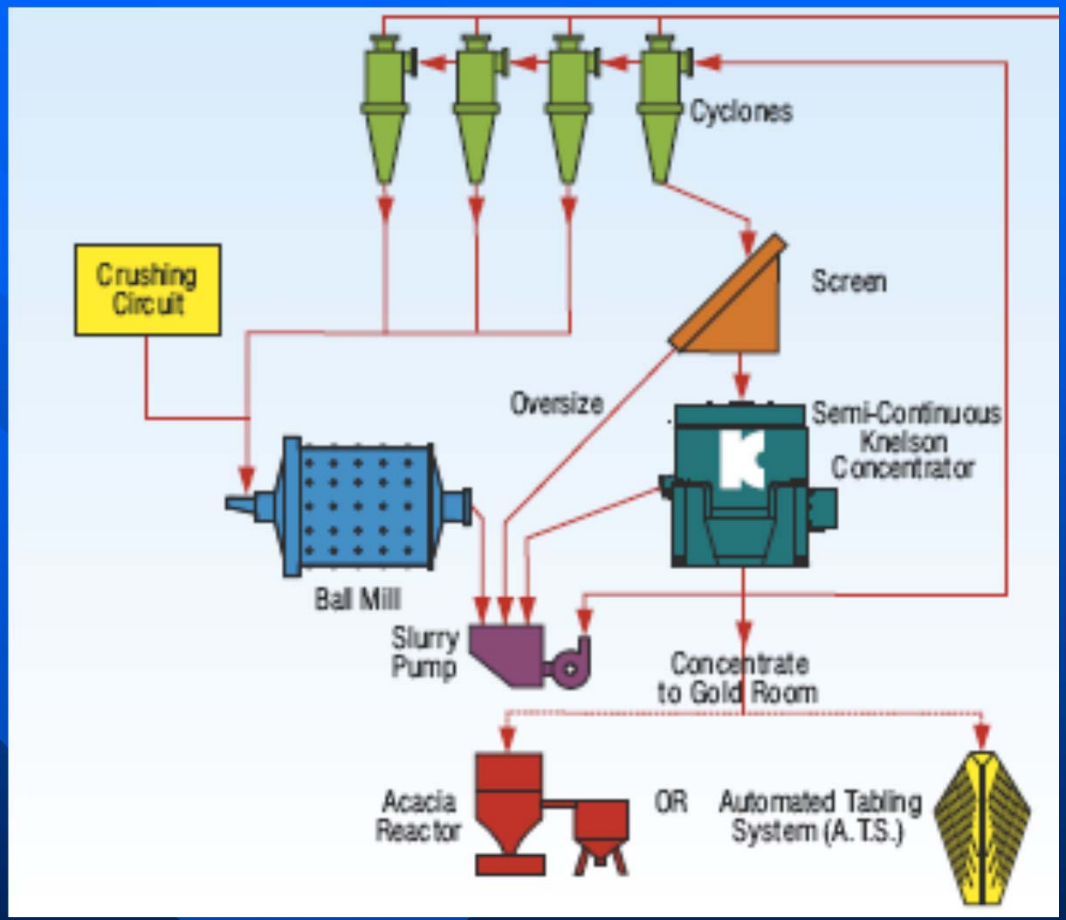
Typical 1980 Installation

- Knelson or Falcon centrifugal concentrators installed in one of the many cyclone underflow streams
- Issues with addition of clean water to water jacket – upset water balance
- Reduced but continuing issues with gold lock up
- As only part of cyclone U/F is treated at one time



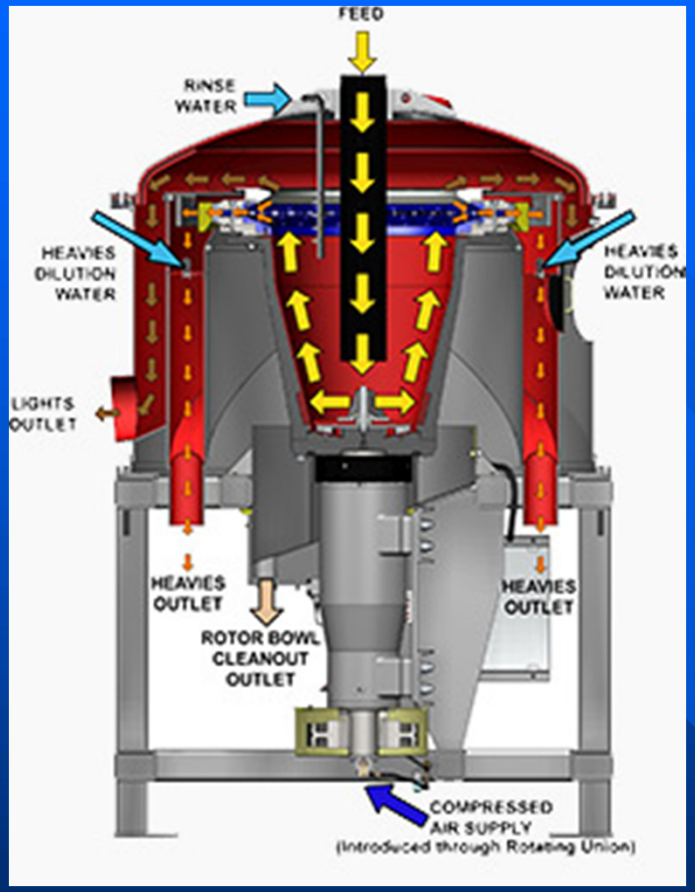
Typical 1980 Installation

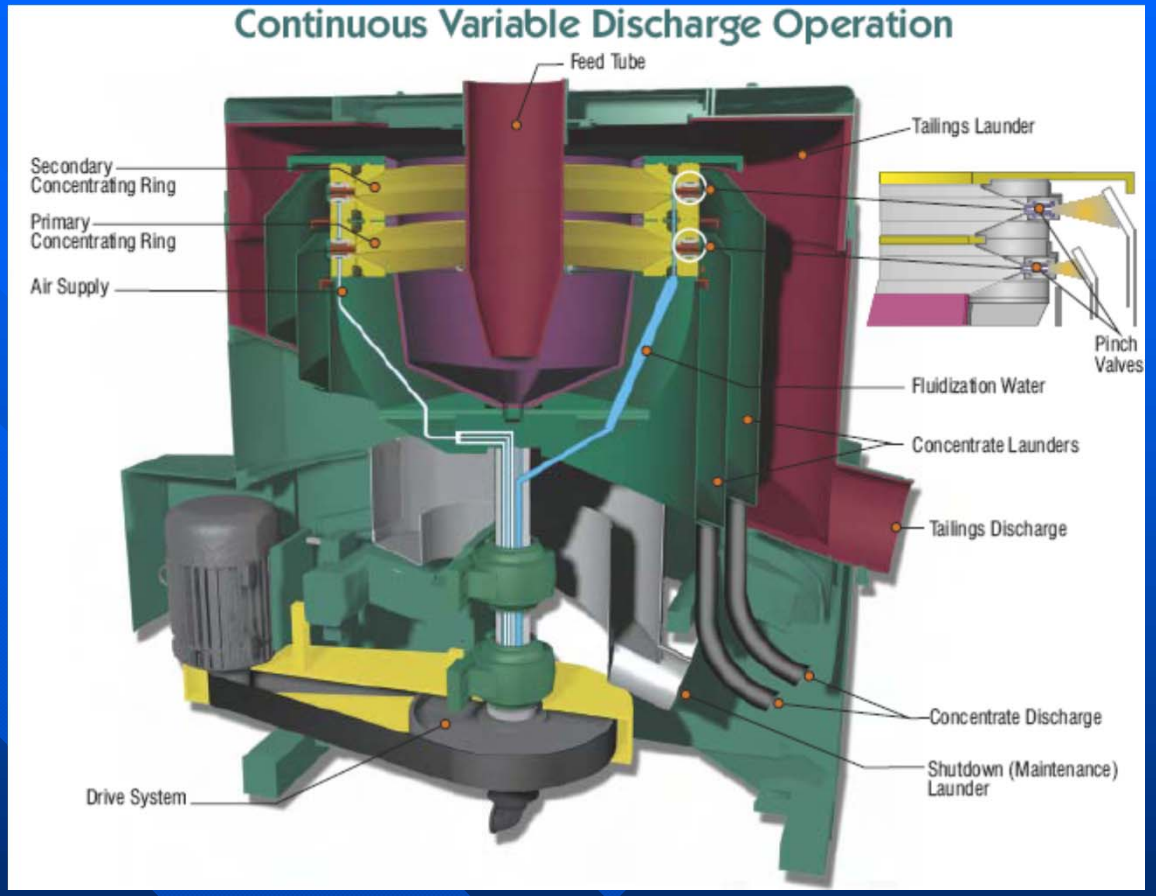
- Need to upgrade these concentrates
- Generally with shaking tables
- Then smelting to dore bar
- Table tailings to CN or flotation
- Generally only 20-30% of gross (free) gold recovered by gravity

Gravity Recoverable Gold

- **Test process developed by late Professor Andre Laplante at McGill University**
- **Samples were concentrated on lab scale Knelson concentrator and resulting concentrates were fire assayed**
- **Allowed the determination of gross gravity recoverable gold**
- **Often some of this gold was locked in sulphides**
- **Could not be upgradeable sufficiently with gravity methods**

Continuous Discharge Concentrators





- **Knelson and Falcon adapt/develop continuous discharge centrifugal concentrators**

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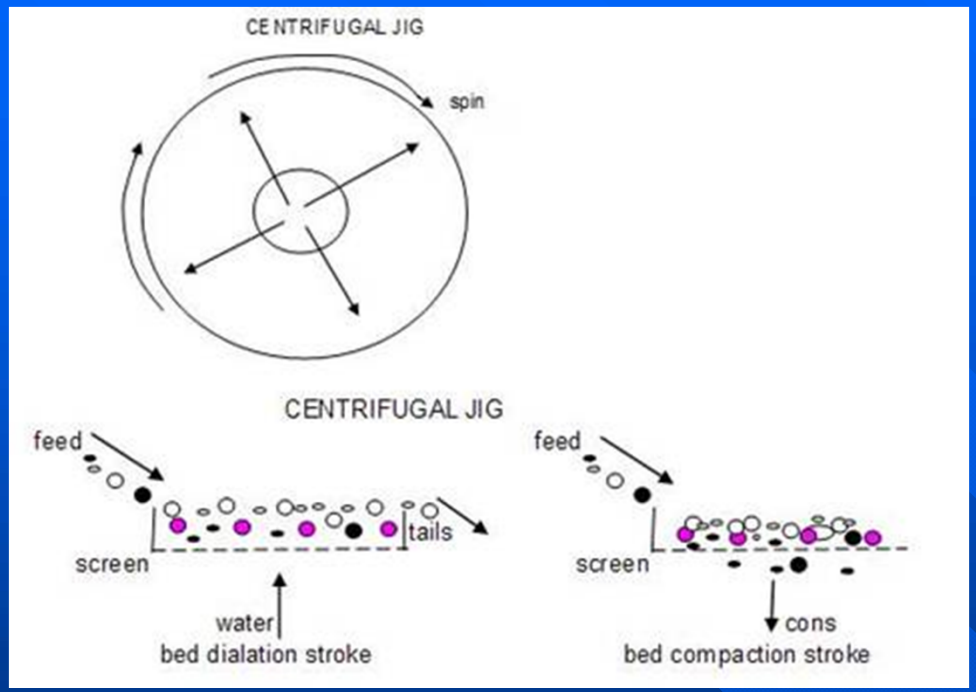
Other Continuous Discharge



- **Kelsey centrifugal jig**
- **Pulsing action, water injection and ragging**
- **2 models 10 & 60 tph**

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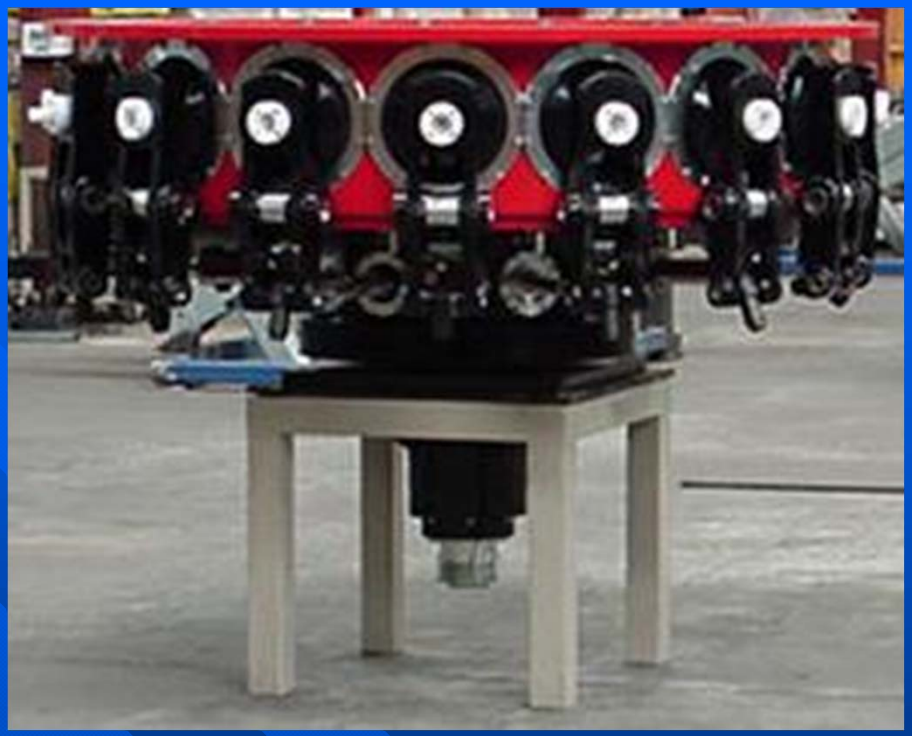
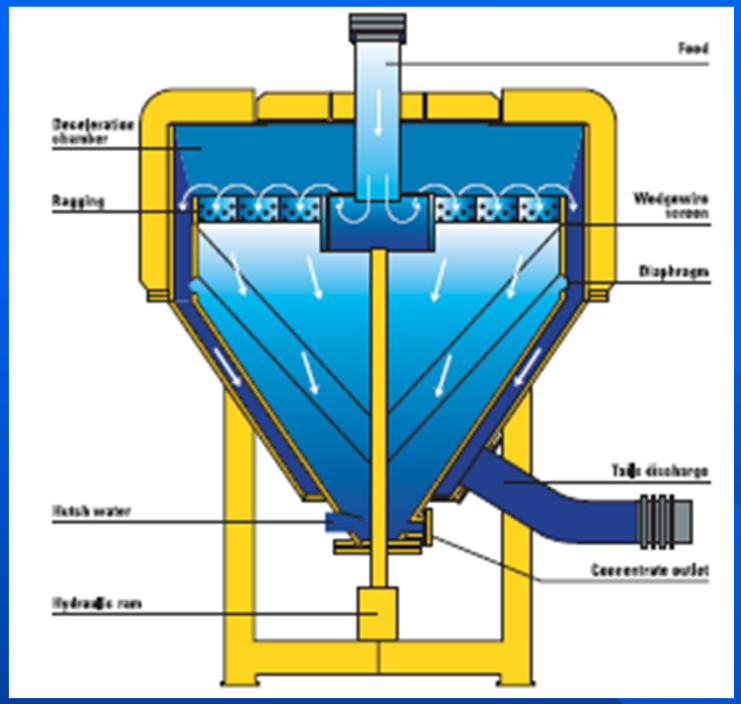
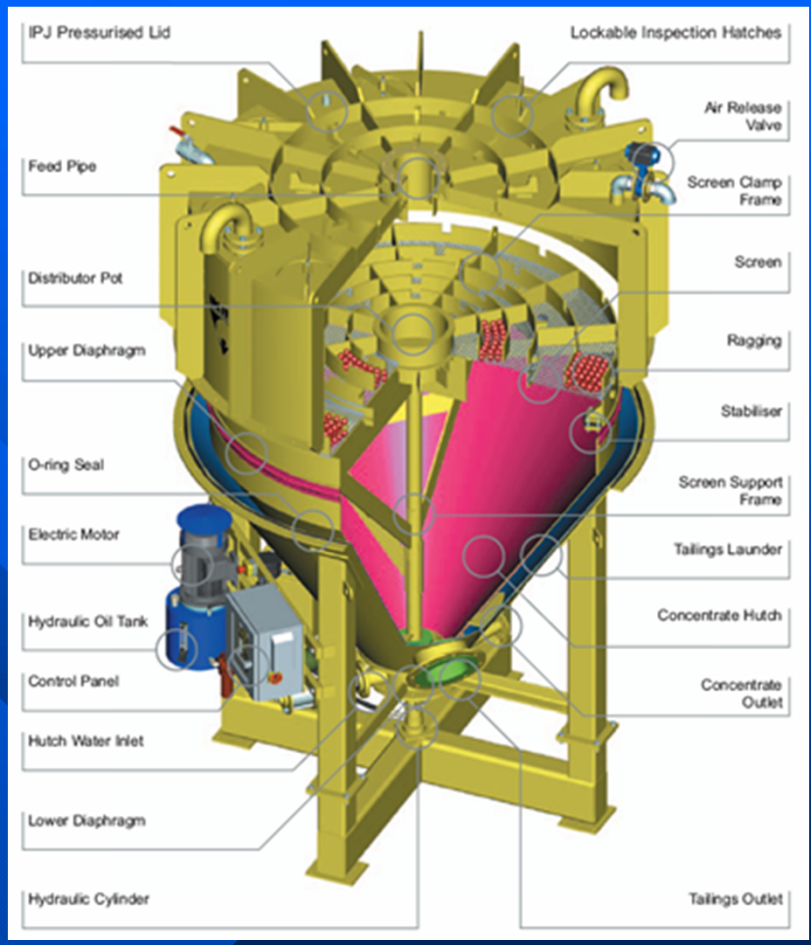
Kelsey Centrifugal Jig



- **Expensive to buy and complex to operate**
- **All feed must be finer than internal screen**
- **All tailings screened to recover ragging as oversize**
- **Regular lubrication and tuning of internal parts**

Gekko InLine Pressure Jig





Sealed unit operates under pressure
Requires pressure locks on feed and on discharge of concentrate and tailings

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Gekko InLine Pressure Jig

- **10:1 concentration ratio 90%**
- **Similar recoveries as conventional jigs**
- **Much more expensive than conventional jigs**

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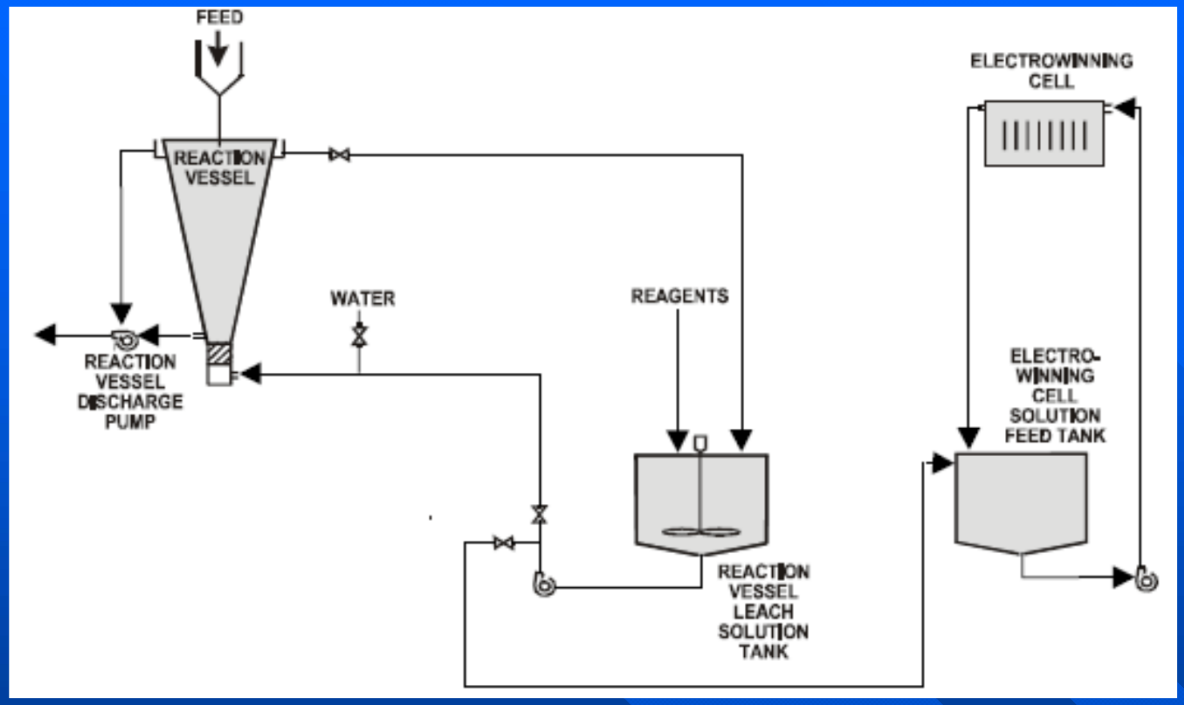
Continuous Gravity Concentrators

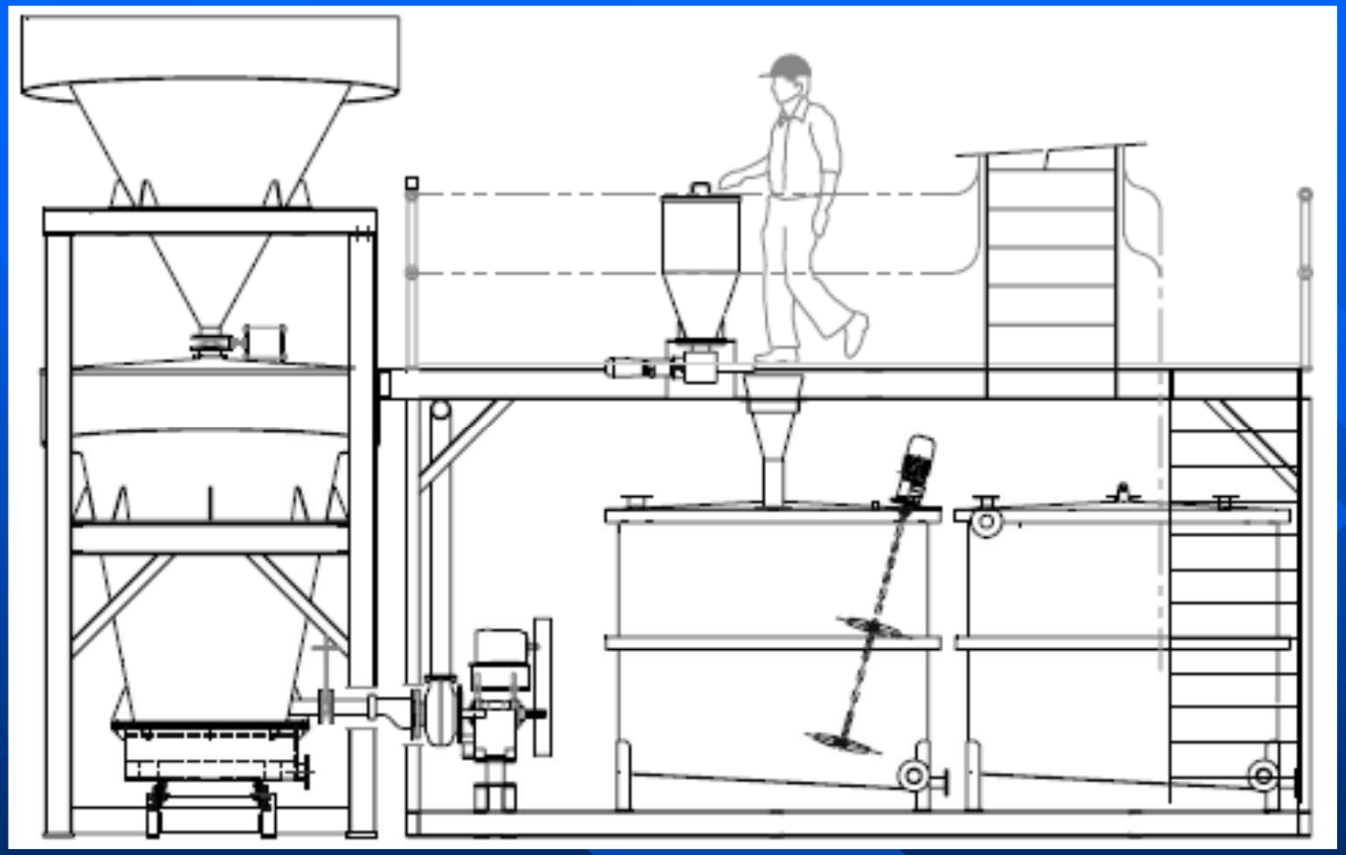
- **Originally designed for other applications than gold**
- **All have low concentration ratios 10:1**
- **Created large volumes of concentrates with locked gold in sulphide minerals**
- **Development of intensive leach reactors to treat the locked gold concentrates**
- **Move away from gravity upgrading**

Intensive Leach Reactors



- **Fast Leach Kinetics due to continuous contact with high concentrations of CN and oxidant**
- **Used for free and sulphide locked gold**
- **Coupled with electro-winning or carbon absorption to remove gold from pregnant solution**

Consep ACACIA Intensive Leach Reactors



Consep (Knelson) ACACIA - Fluid Bed Version

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Gekko InLine Reactor

- **Rotary Reactor Drum Lined with Baffles**

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Modular (Underground) Plants

- **Crushing, grinding, cyclone sizing, continuous discharge gravity recovery devices, intensive leach reactors, and electro-winning cells on portable skids**

Gekko Python

Placer Gravity Recovery & Upgrading

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Placer Gold Recovery & Upgrading

- **Separate into Stages :**
- **Primary recovery - sluices or jigs**
- **Secondary upgrading – long toms, jigs, spiral drums & centrifugal concentrators**
- **Final cleaning – shaking tables, gold wheels, panning & other methods**
- **Smelting**

Sluiceboxes

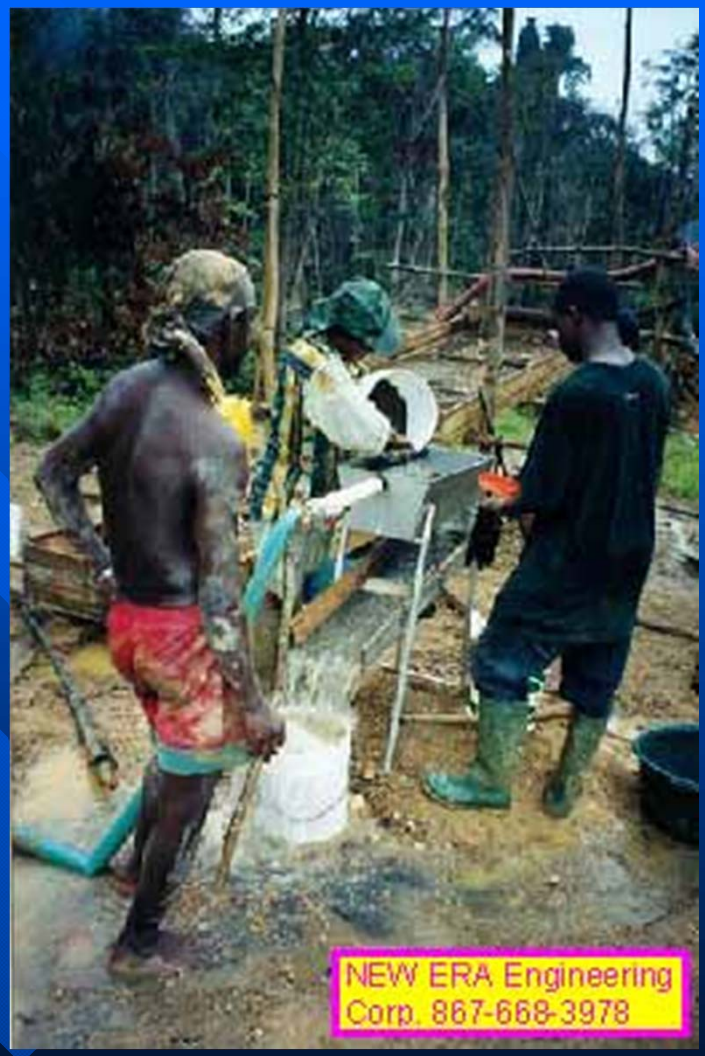
Screening improves recovery

Common Shapes of Jigs

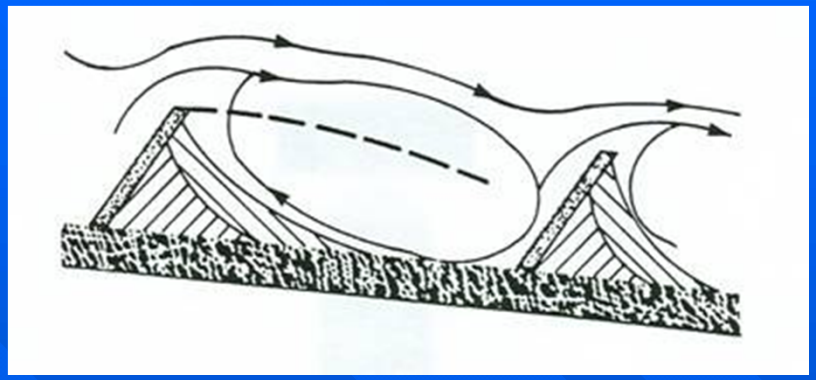
- **Rectangular – 1/3 yd3 per square feet of jigging area**
- **Circular – simpler central feeder – diminishing radial velocity acts like a scavenger – higher capacity ~0.5 yd3 per square foot of jigging area**
- **high density slurry**
- **Jigs require at least three stages of concentration**

Methods for Secondary Upgrade

- **Long Tom (sluices)**
- **Hydraulic Jigs**
- **Mechanical Jigs**
- **Reverse Spirals**
- **Centrifugal Concentration**

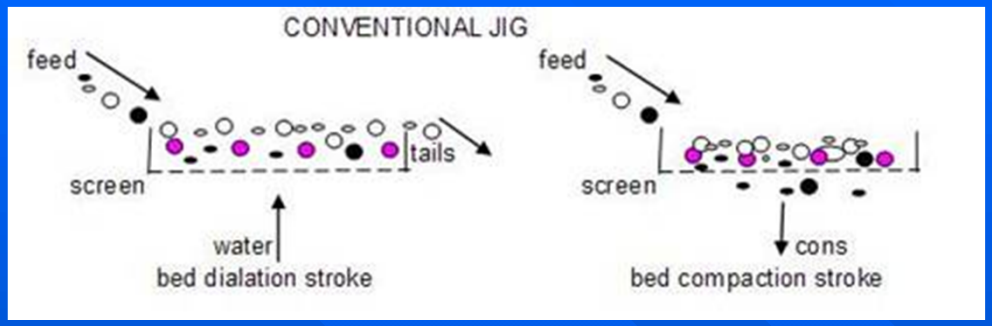


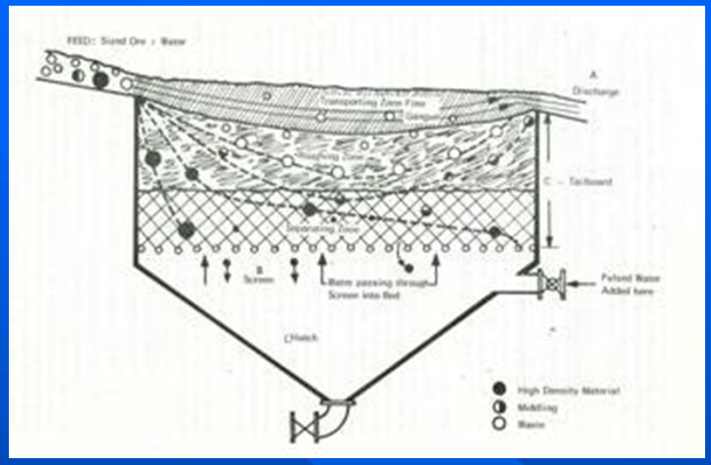
Secondary Concentration with Sluices



- **Feed Hopper with screen to control feed rate;**
- **Long narrow sluicebox fitted with expanded metal riffles/ Nomad matting;**
- **2/12 or 10 degree slope**
- **Use clear water where available;**
- **Wash down sluice when gold migrate or mats harden**
- **Watch for coarse gold loss**

Concentration with Mechanical Jigs



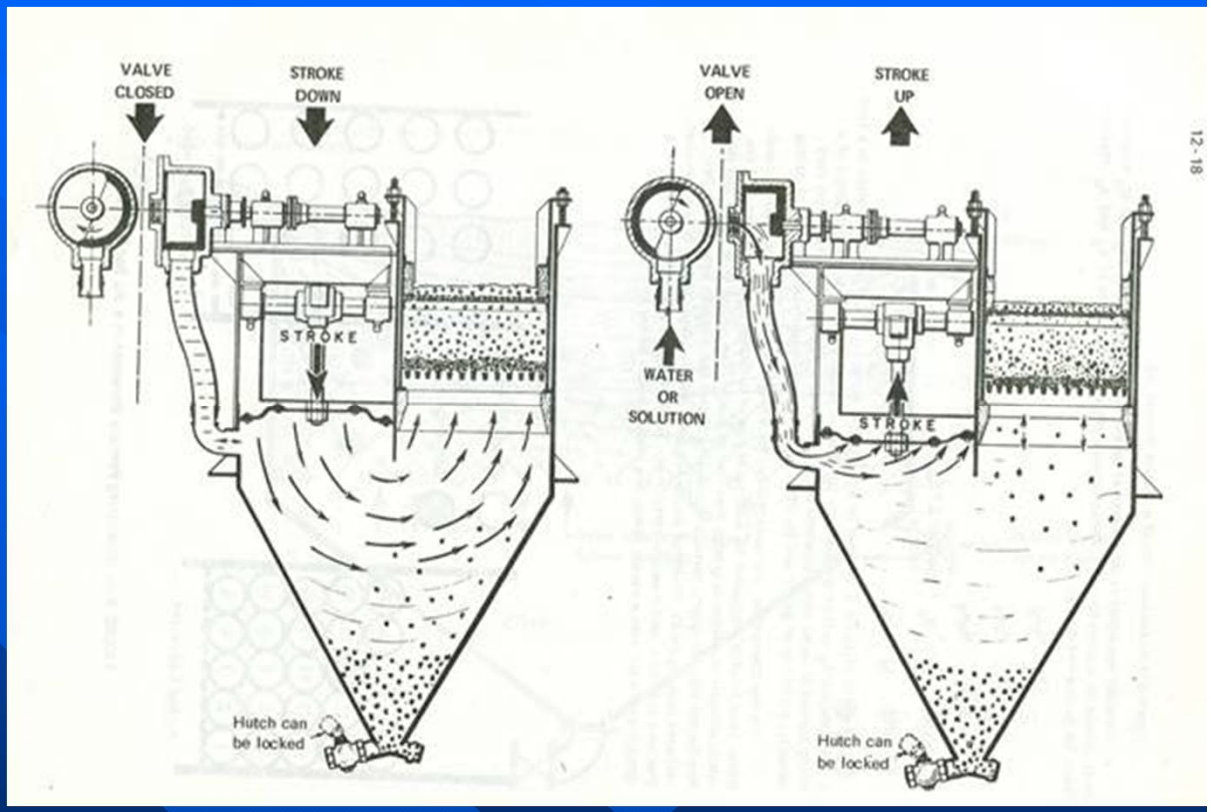


Alternating compaction and dilation of bed (ragging)

Cause by diaphram or mechanical movement of screen

Requires constant -6 mm (prefer -1 mm) feed gravels & high density slurries

Secondary Concentration with Hydraulic Jigs



- **Water pressure activated jigging action**
- **Requires a constant pressure volume of water**

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Secondary Concentration with Hydraulic Jigs

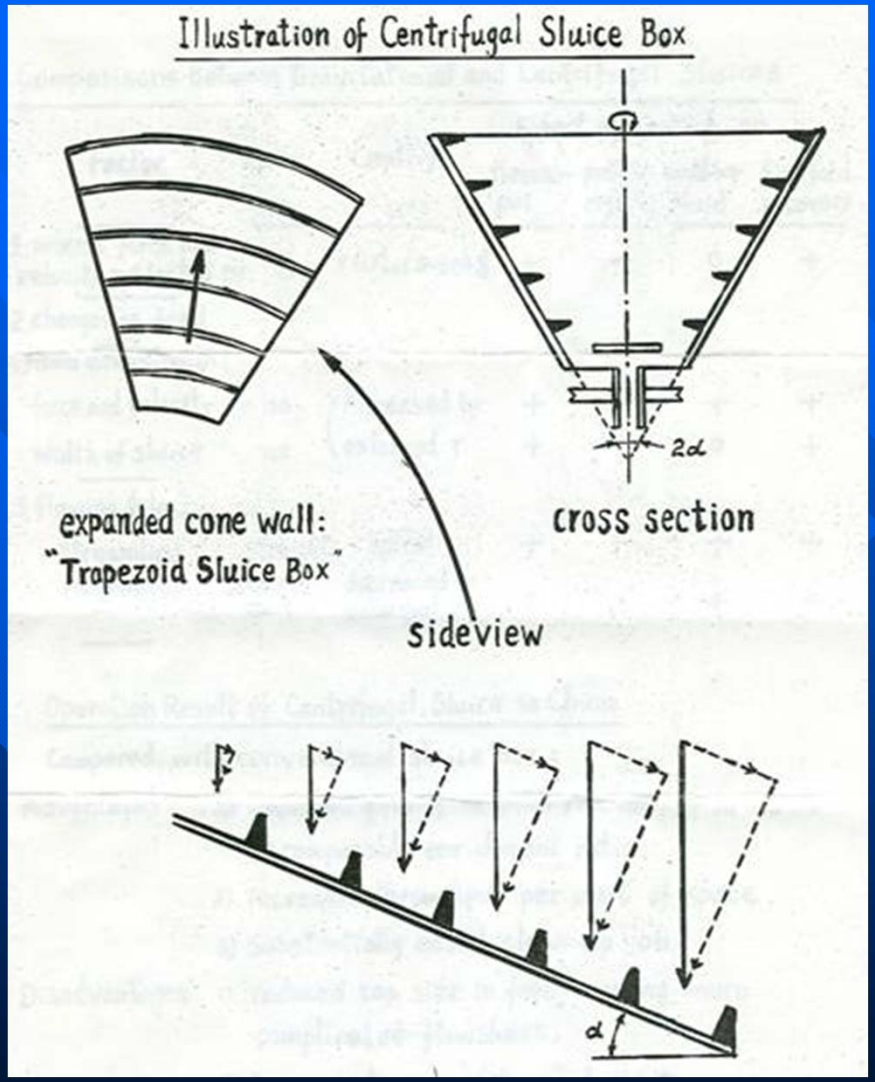
Clean ragging periodically to recover coarse gold;
Not great at fine (-150 micron) gold recovery;
Locate sluice downstream to catch fine gold

Reverse Spiral Drums

- **Inclined long cylinder with smaller diameter trommel screen inside a barrel with reverse spirals**
- **Concentrate is carried up behind spirals - tailings flow over the lower end**

Centrifugal Secondary Concentration

- **Vertical and Horizontal axis**
- **Riffled and Shaped**
- **With and without water jacket**
- **Use rotation for centrifugal force to concentrate heavy minerals in riffles / or annulus of cone (Falcon)**



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Centrifugals w/o Water Jacket

- **Horizontal and Vertical Axis**

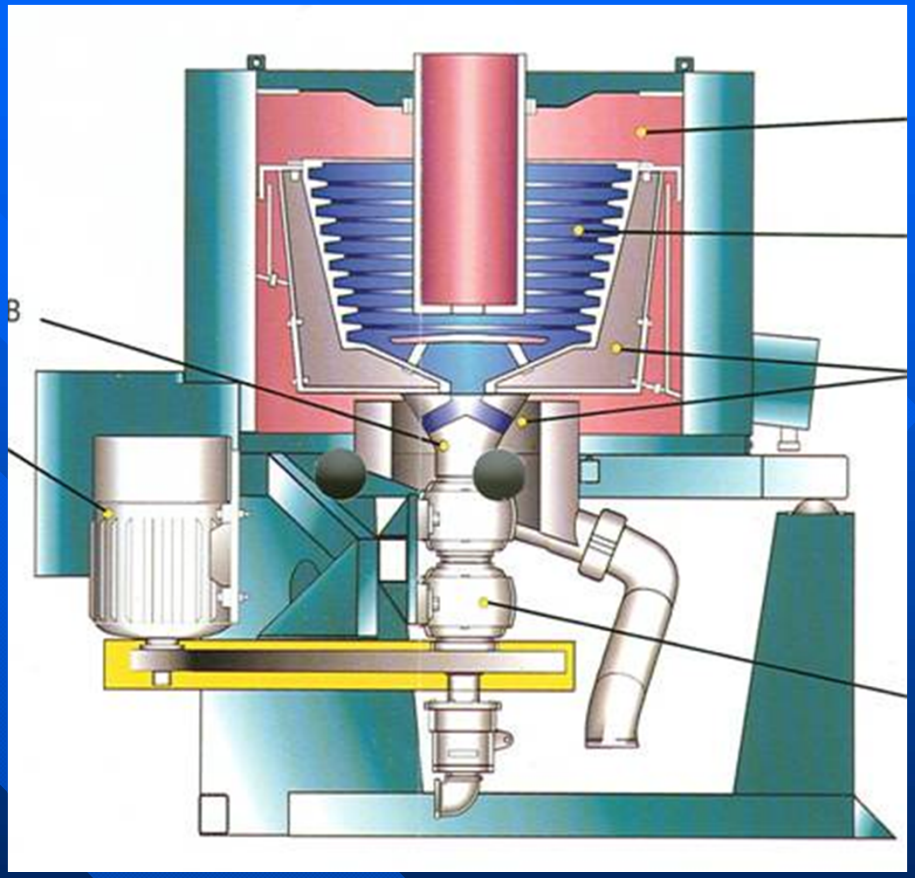
Centrifugals w/o Water Jacket

Guyanese Version

- **Riffled without water jacket**
- **Riffles pack easily**

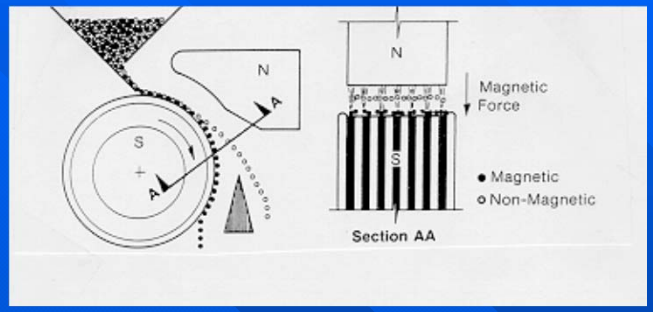
Centrifugals with Water Jacket

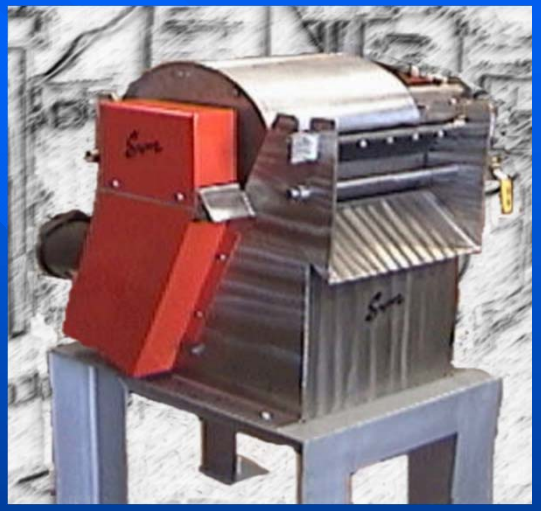
- Vertical
- High radial “g” forces
- Use high pressure water to loosen riffles
- Helps avoid riffle packing
- Need to balance rotation and back pressure
- Easy to loose concentrate on shut down



Final Cleaning Methods

- Can be the Most Labor Intensive, Time Consuming and Potentially Frustrating Job at Placer Mine
- Magnetic
- Electromagnetic
- Gold Wheels
- Shaking Table
- Wave Table
- Mozeley Concentrators
- Spirals
- Froth Flotation
- Mercury Amalgamation
- CN leach methods





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Enhancements to Final Cleaning

- **Pre-screening- vibrating and rotating trommel screens**
- **Conditioning to remove particle coatings – lime or other reagents**
- **Regrinding to polish surfaces or grind softer / less malleable minerals to a finer size**

HI Magnetic Wet Drum Separator

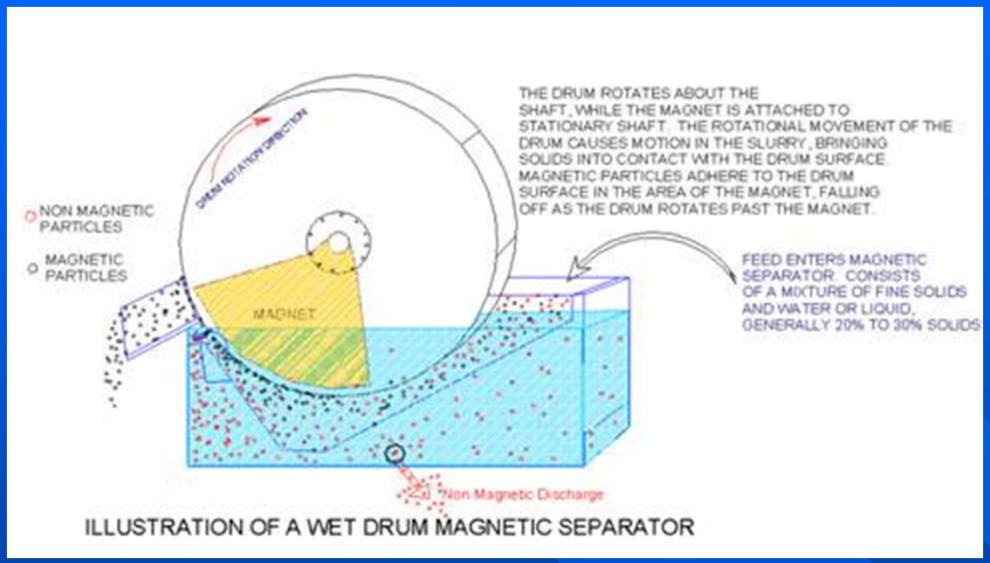
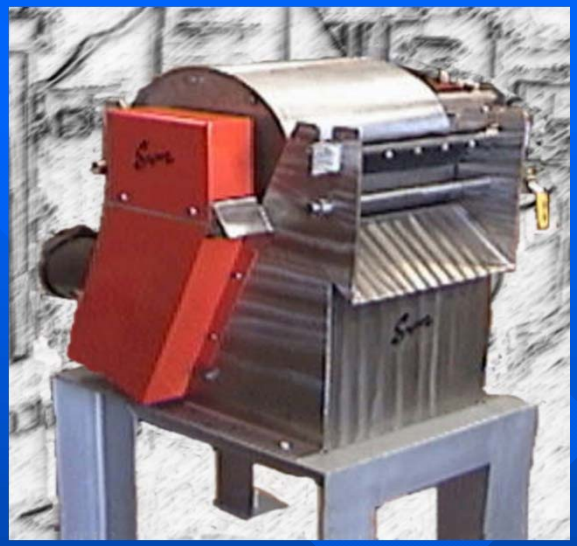
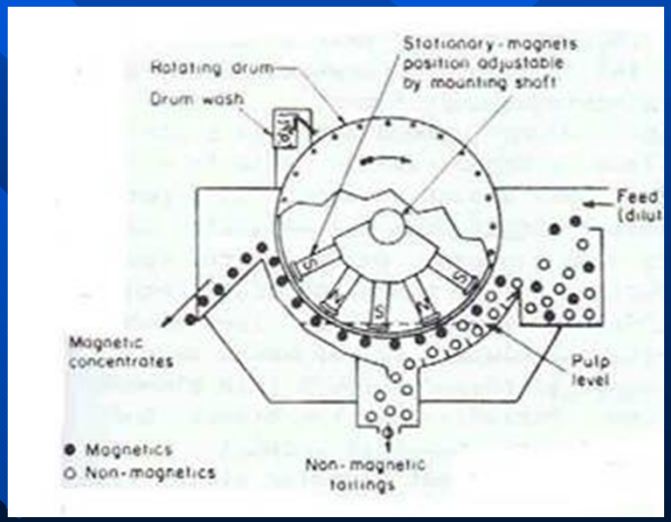


ILLUSTRATION OF A WET DRUM MAGNETIC SEPARATOR



Magnetics in slurry attach to rotating drum and are discharged over the edge (HIWMS)



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Magnetic Belt Separation

- Vibrating pan underneath spreads out the concentrate
- Permanent magnet above pulls magnetics to belt
- Belt conveys magnetics to separate discharge port

Electromagnetic Separation

- Applies a surface electric charge to mineral particles before entering an electrostatic field
- Particles will be repelled from one of the electrodes and attracted to the other depending on the charge on the particle
- Can direct the particles to fall into separate chutes

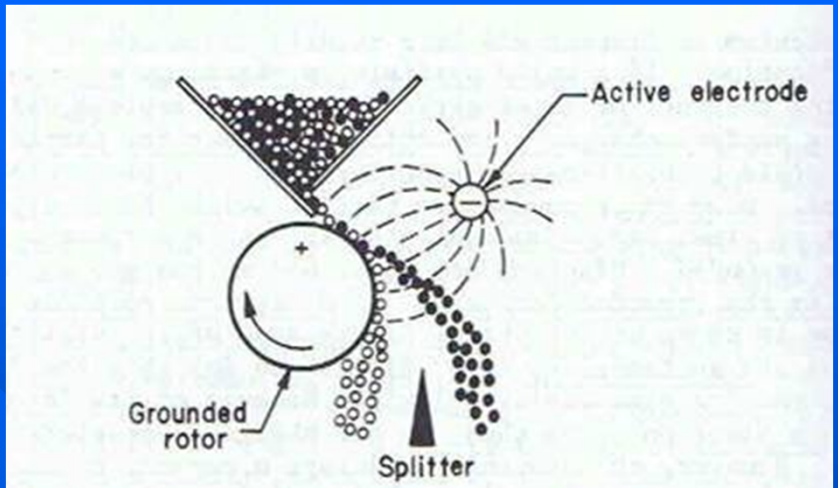


Fig. 2. Separation by conductive induction.

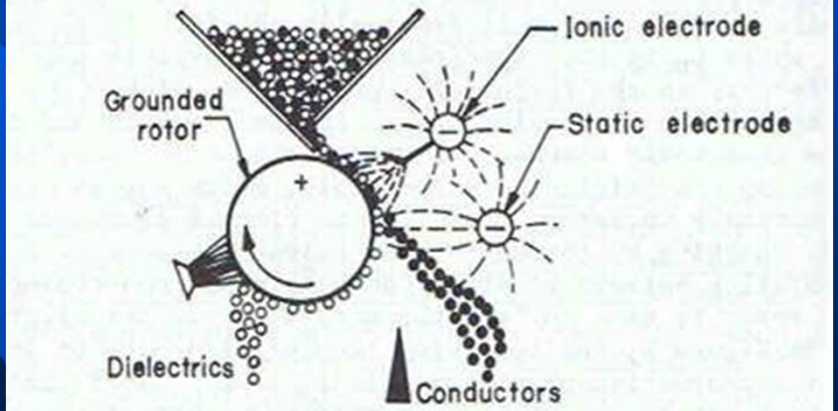
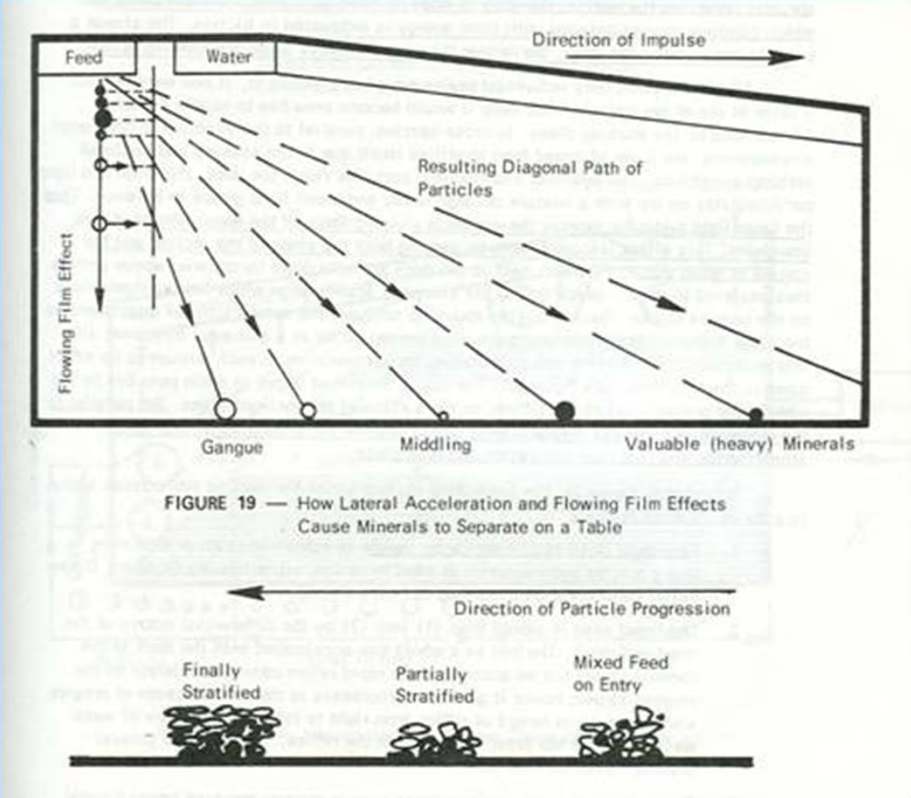


Fig. 3. Separation by ion bombardment.

Gold Wheel

- Relatively cheap
- Low capacity for cleaning concentrates
- Available in large diameters
- Some models are portable with 12 volt motors
- Easy to fabricate

Shaking Tables (Flowing Film)



Conventional Deister Type Table

Operates with flowing film and elliptical throw

Waste flows with water, gold to end of table

Need fine screening – 2 mm screened feed

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Shaking Tables

Homemade conventional and Gemini tables – higher grade – lower recovery
Models with rotating magnet

Wave Table

Micron Mill Wave Table

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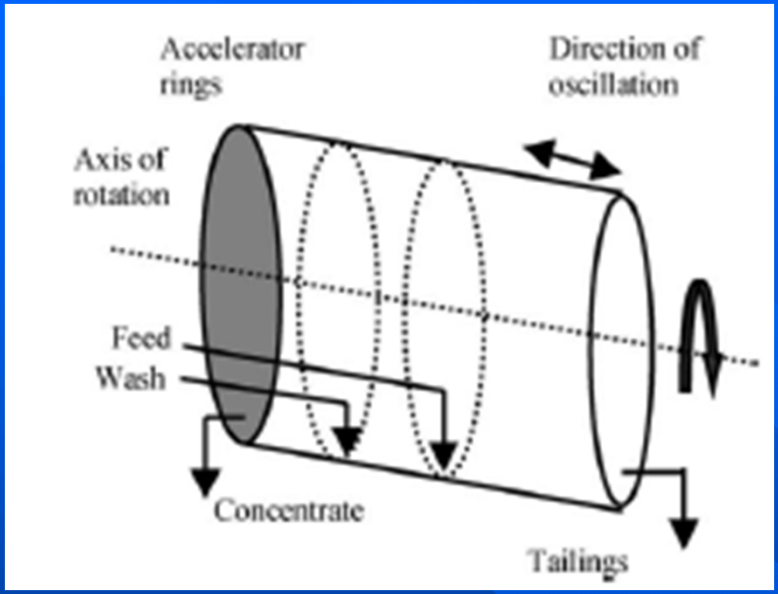
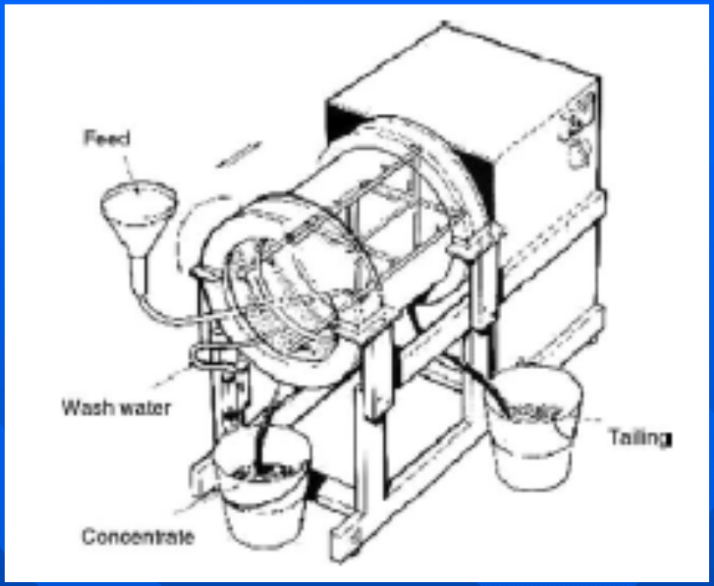
Mozeley Gravity Separator





Centrifugal and shaking forces cause heavy particles to move up the drum and light particles to move down slope and discharge as tailings

Discharge of heavy particles is assisted by internal scrapers which rotate slightly faster than the drum

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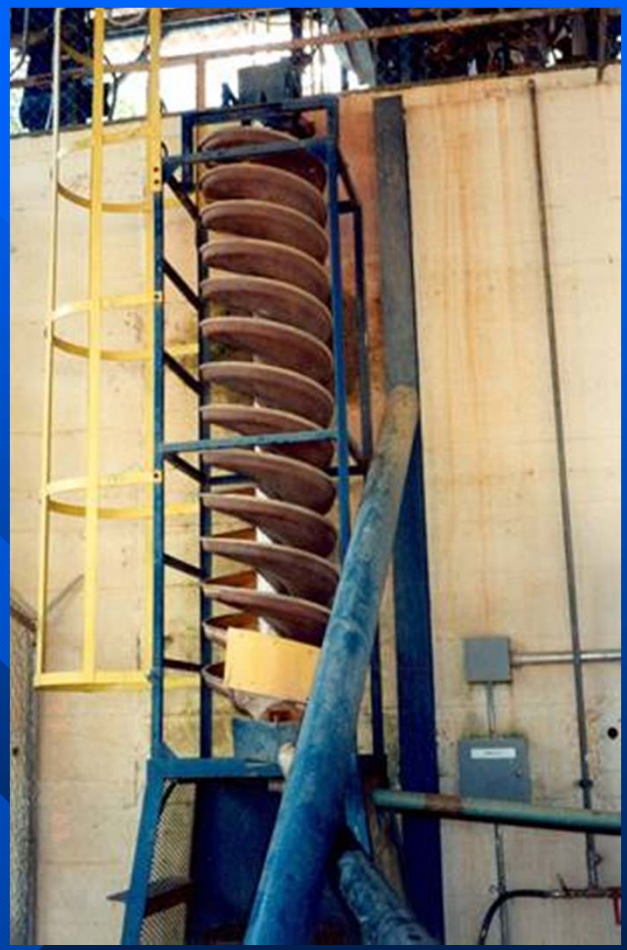
Spiral Concentrators

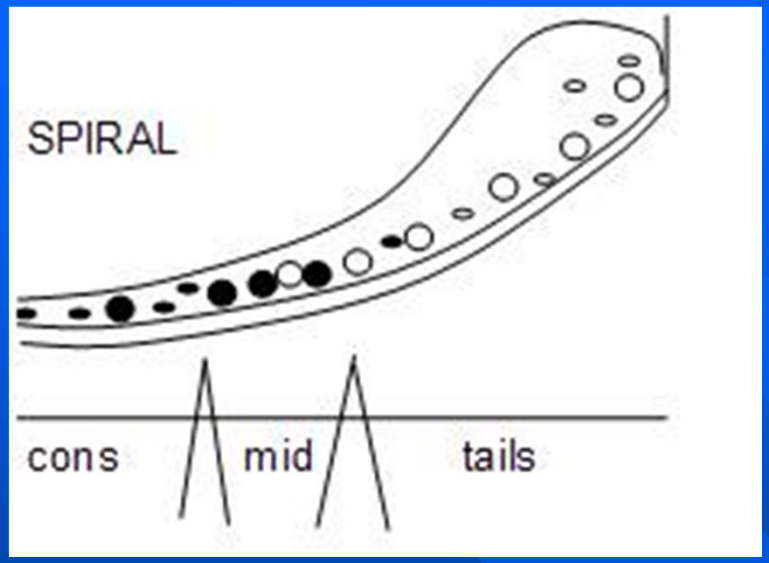
Reichert and Humphrey spirals have a capacity of about 2 tph (40% density slurry by weight)

Humphrey requires wash water at several points and has several concentrate withdrawal ports

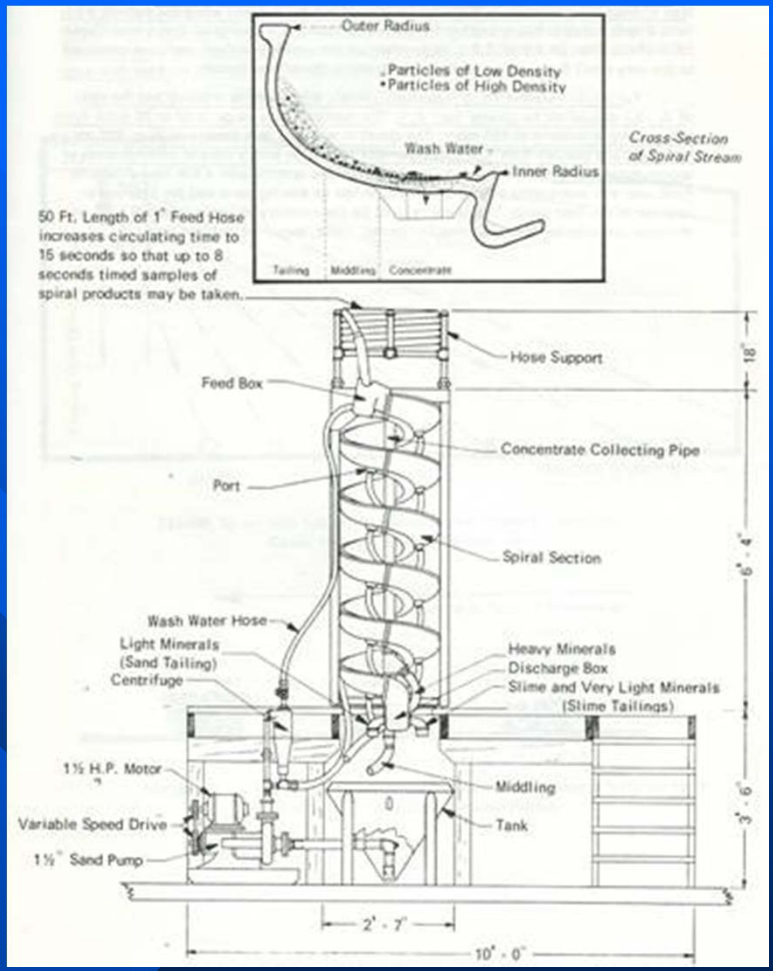
Reichert spirals – no wash water – concentrate withdrawal at bottom only



Spiral Concentrators



As the slurry flows down the spiral it is subject to centrifugal forces which place water near the outside of the rim and heavy concentrate along the inner part of the spiral



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Riechert Cones

- Form of pinched sluice used in beach sand industry
- Capy of 50-75 tph for double cone
- Requires screening to minus 2 mm (wedge wire screen) and hydrocycloning to dewater the screen undersize
- Constant feed and density
- Affected by tramp oversize

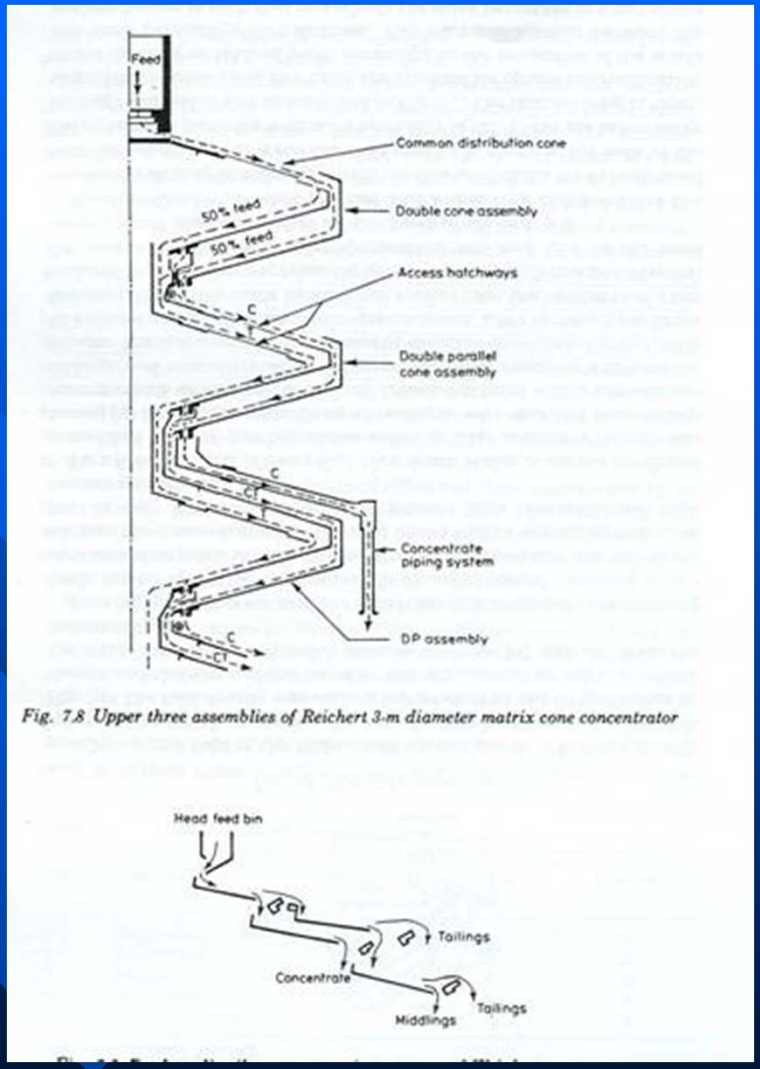
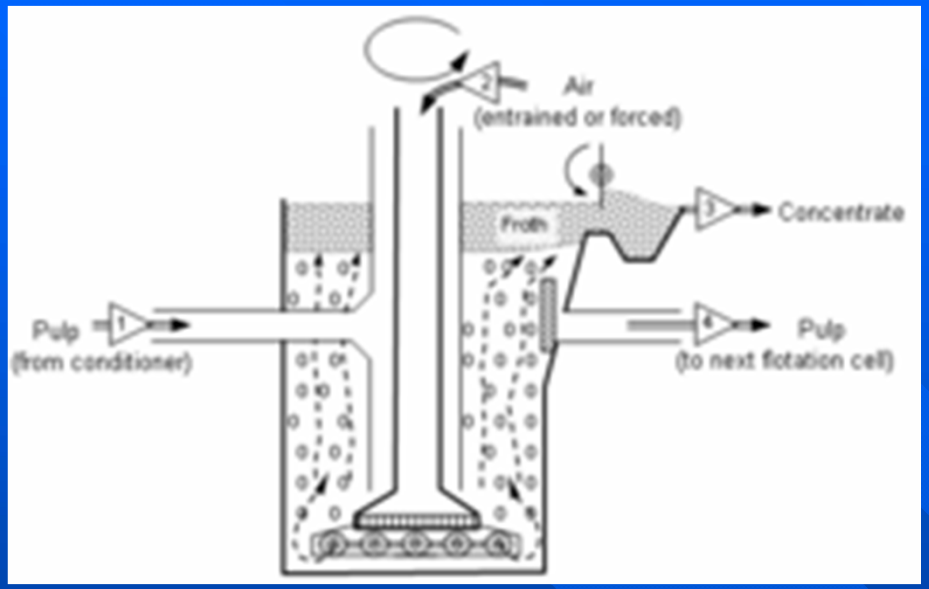


Fig. 7.8 Upper three assemblies of Reichert 3-m diameter matrix cone concentrator

Froth Flotation



- Limited to fine (-0.3 mm) and/or flat particles
- High density slurry (25 to 40% by weight)
- Surfaces of economic minerals are rendered hydrophobic (water hating) with the use of chemical surfactants – need to clean surfaces
- Frothers are used to create a stable froth
- Agitation and air bubbles introduced – attach to hydrophobic particles
- Rise to surface and are skimmed off as a concentrate
- Need to depress other hydrophobic minerals
- Higher cost – potentially toxic effluents

Froth Flotation

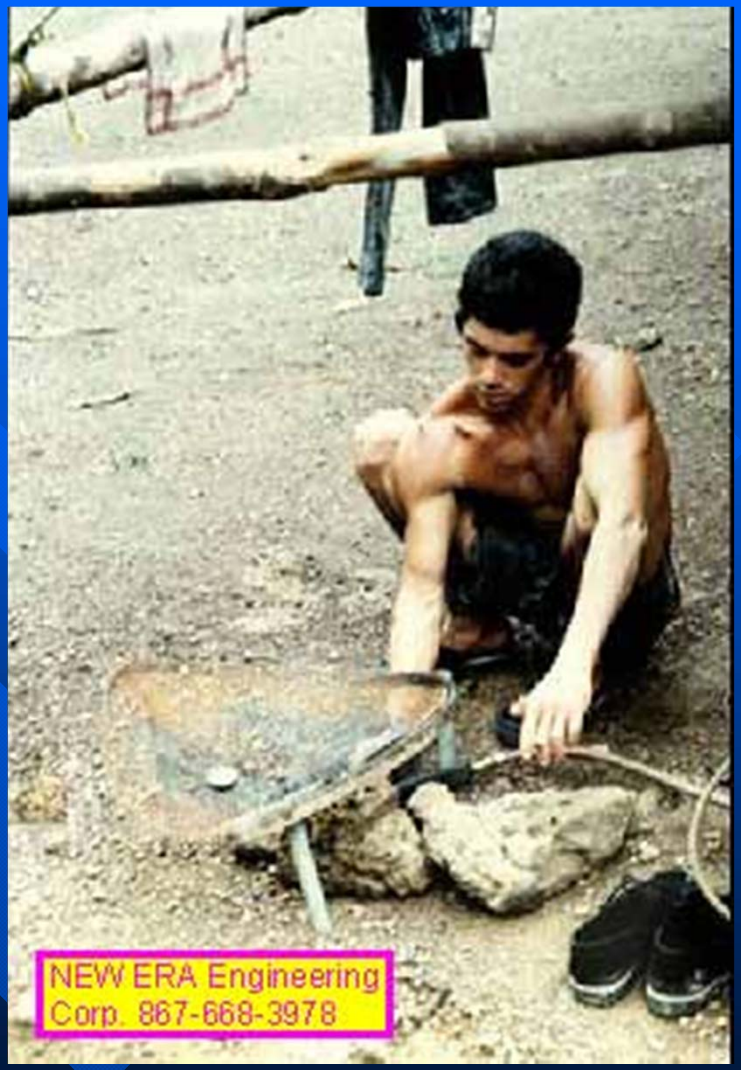
- **Walsh reported low 24-43% recoveries on Alaskan alluvial concentrates due to size and surface characteristics**
- **South African research>95% recovery of gold smaller than 0.25 mm and 70% at smaller than 0.003 mm**
- **Berry – Saskatchewan River – recoveries similar to gravity 97% - no magnetic minerals in concentrate – need to recycle process water**

Mercury Amalgamation

1) **Uniquely Effective at cleaning fine gold concentrates provided the gold particle surface is clean;**
2) **Mercury is cheap relative to price of gold;**
3) **Inexpensive simple equipment;**
4) **Very Portable**

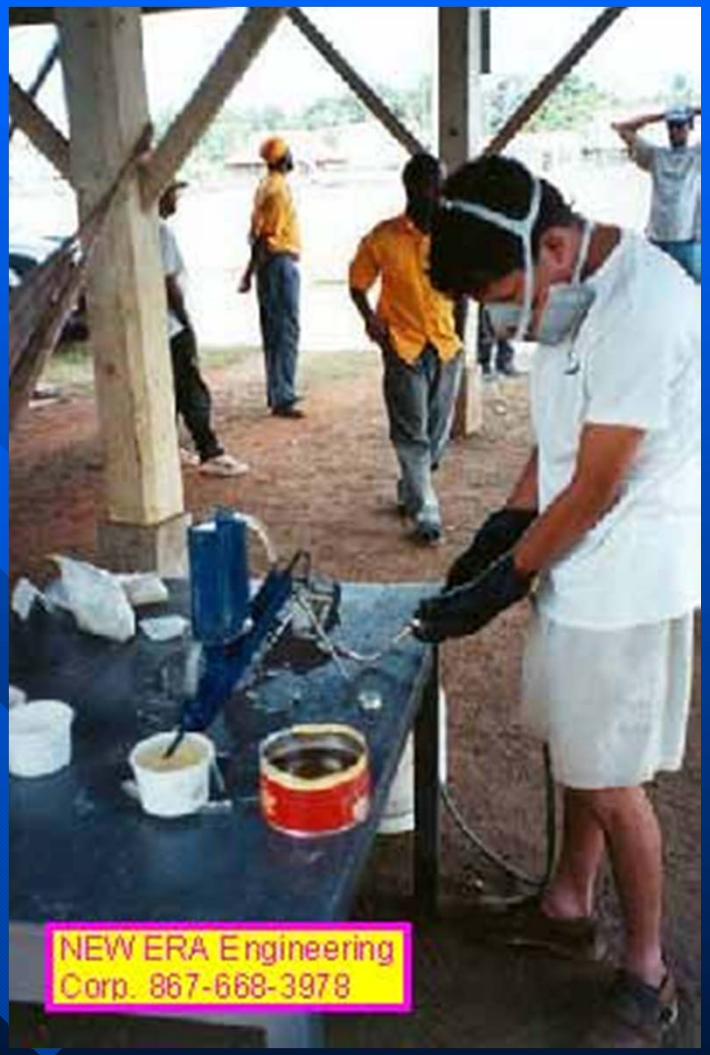
Poor Practices

- **Improper handling/ equipment**
- **Use in open circuit**
- **Open burning of amalgam pastes**
- **Chronic health effects to workers, village and camp residents;**
- **Losses to tailings/ waters**
- **Mercury accumulation in humans and environment**

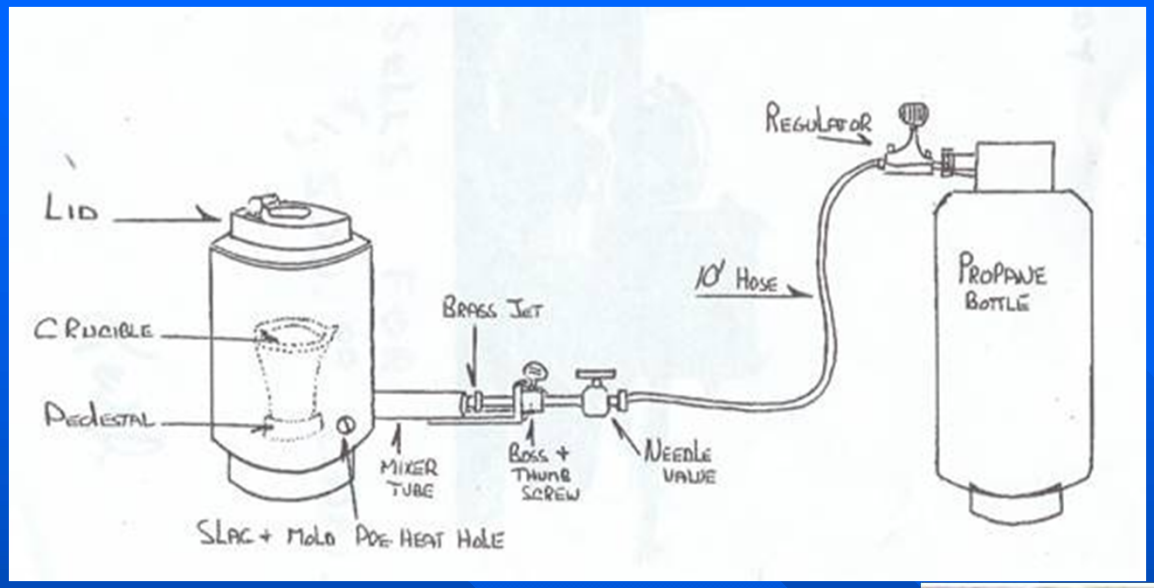


How to Improve Mercury Usage

- Personal protection – gloves, respirators;
- Locate away from camp / village facilities;
- Use in closed circuit as final concentrate cleaning only;
- Recycle process water;
- Recover mercury from concentrate tailings; and
- Proper disposal of final concentrate tailings.



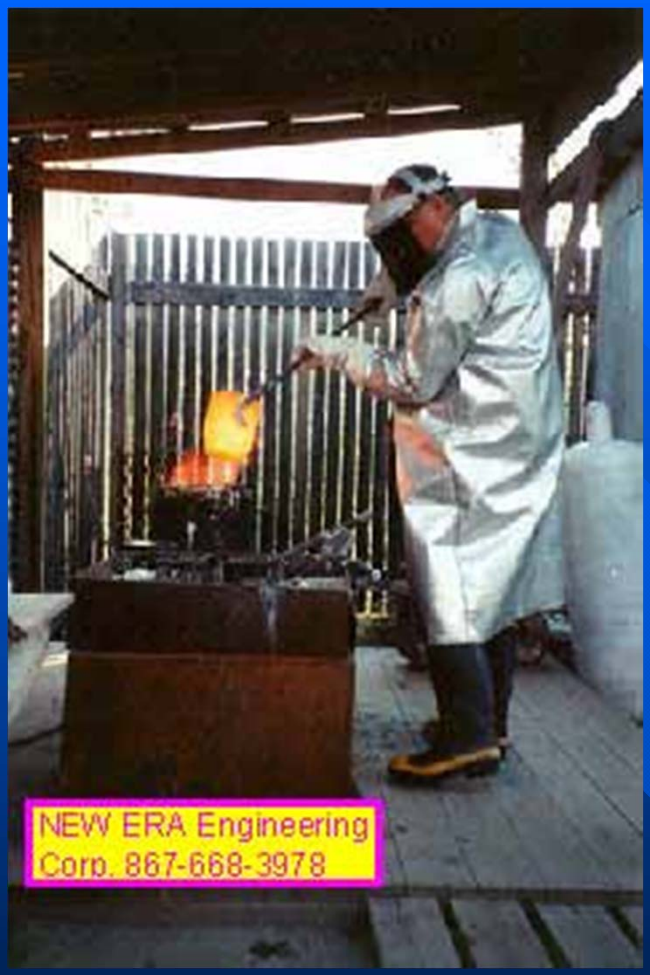
Smelting Dore

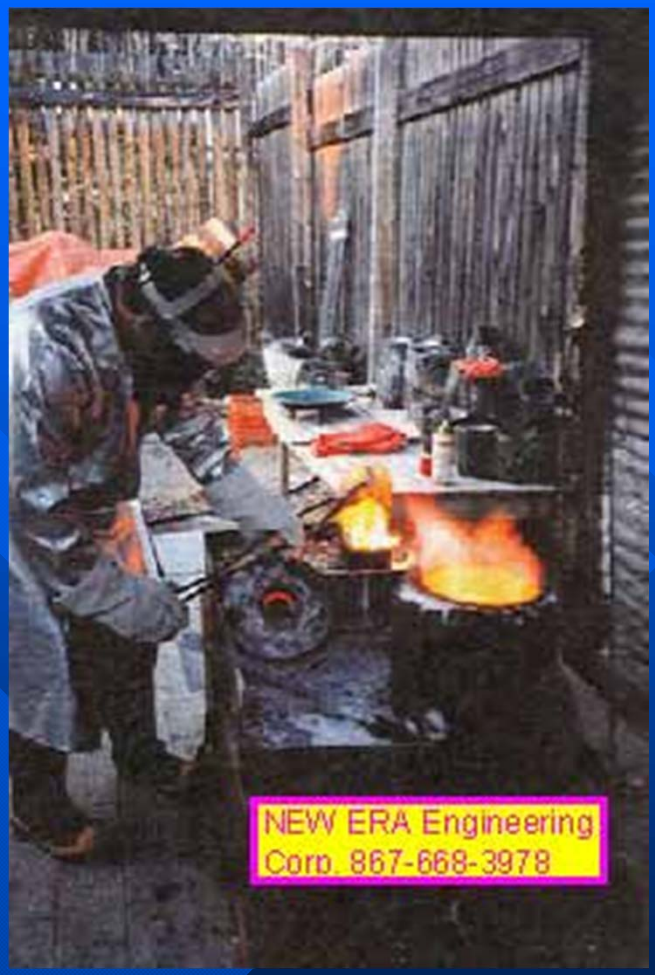


Mix dirty concentrates with flux
Melt to slag
Cool and separate slag

Safer to ship dore bar than particles of gold

Smelting





- **Concentrate and Flux (Soda Ash & Borax) are melted in furnace**

Smelting

- **Clean Placer Gold – Flux = 50% Borax, 50% soda ash**
- **Dirty Placer Gold = 100 % Soda Ash**
- **Use caution when using high soda ash fluxes, as gas escapes the level will rise in the crucible**
- **Mix 50% concentrate and 50% flux**
- **Always warm the mold before use**
- **Move back and forth when pouring**
- **Regrind and pan flux as it has some gold**

Future Research on Upgrading

- **Placer Industry is on its own – New Hard rock mines are using CN reactors to upgrade**

- **Literature Search for other concentrate upgrade methods – (Russia and China)**
- **Select equipment and methods to evaluate**
- **Conduct laboratory testing to optimize equipment and methods for upgrading concentrates**

- **Requires access to highly specialized high-cost process equipment and laboratory**
- **Requires experience and familiarity with the placer industry**

Suggestion

- **Use the facilities and equipment at the University of B.C.**
- **Sponsor a post graduate student to conduct the experimental design and test work**
- **Laboratory Supervision by professors**
- **Assistance and field supervision from KPMA?**

UBC Mining Faculty

Dr. Bernhard Klein: Head of the UBC Department of Mining Engineering, Faculty Supervisor, Center for Coal and Mineral Processing (CMP) Laboratory Facility
Director, Center for Industrial Minerals Innovation (CIMI)
Research Interests: Ultrafine grinding; High pressure grinding rolls; Hydraulic transport of non-Newtonian mineral slurries; Industrial minerals; Mine-mill integration; Continuous centrifugal gravity concentration; Improved technologies for artisanal and small scale gold miners; and Metal leaching from waste rock

Dr. Marcello Veigo Associate Professor
Research Interests: Biogeochemical cycle of heavy metals in the environment; Bioaccumulation and adverse health effects of metals in the environment, specially mercury
Artisanal and small-scale gold mining; Mercury pollution from gold mining and hydroelectric reservoirs
Acid Rock Drainage; Process mineralogy applied to mining and mineral processing; Sustainable development in mining
Mining communities and social issues related to mining; Mine closure and reclamation planning;

NEW ERA Engineering Corporation

Recommendations for Further Research*

*The recommendations presented below are excerpted from the Final project report submitted to YGS from NEW ERA Engineering Corporation.

Most of the lode gold mines are phasing out conventional gravity concentrate upgrading methods such as jigs, mineral tables and batch operated centrifugal concentrators. Therefore at the Ballarat conference there was no discussion of innovations in these conventional technologies which are generally applied to upgrade placer gold concentrates.

This signals a fundamental change in the methodology of gravity concentration in lode gold mines. The mines are less likely to attempt to recover the coarser free gold particles in a high grade batch concentrate and are switching to recovering larger volumes of low grade concentrates of auriferous sulphides. These larger volumes of auriferous sulphides are upgraded with intensive leach reactors. These are reactor vessels with very high concentrations of cyanide (3,000 to 50,000 ppm) and oxygen (>15 ppm).

Intensive leach reactors are less likely to find an application in most of our Yukon placer mines due to their high cost, complexity and toxicity. It is also unlikely that we will see many innovations in the upgrading of gravity concentrates from placer mines at similar lode gold technical forums as the market for these innovations will be further restricted to placer mine applications. Innovations in gravity recovery of gold and for the upgrading of gravity concentrates will have to be developed specifically for placer mining applications.

I am recommending that the Klondike Placer Miners' Association spearhead further research into upgrading of gravity gold concentrates by developing a joint post graduate industry research program. This would possibly involved post graduate students and their advisors from the Mining Engineering Departments of the University of British Columbia in Vancouver, and the University of Alaska in Fairbanks.

A laboratory and field program would be designed to allow the testing of various gravity concentrates in the field during the operating season and in the university laboratories during the academic season. Technologies tested should include gravity, magnetic, electromagnetic, flotation as well as intensive cyanide. From this test work a guideline could be developed to assist placer miners in selecting and operating concentrate upgrading equipment.

Tara Christie and I have already been in discussions with the head of Mining Engineering at UBC and intend to meet with the U of Alaska shortly.