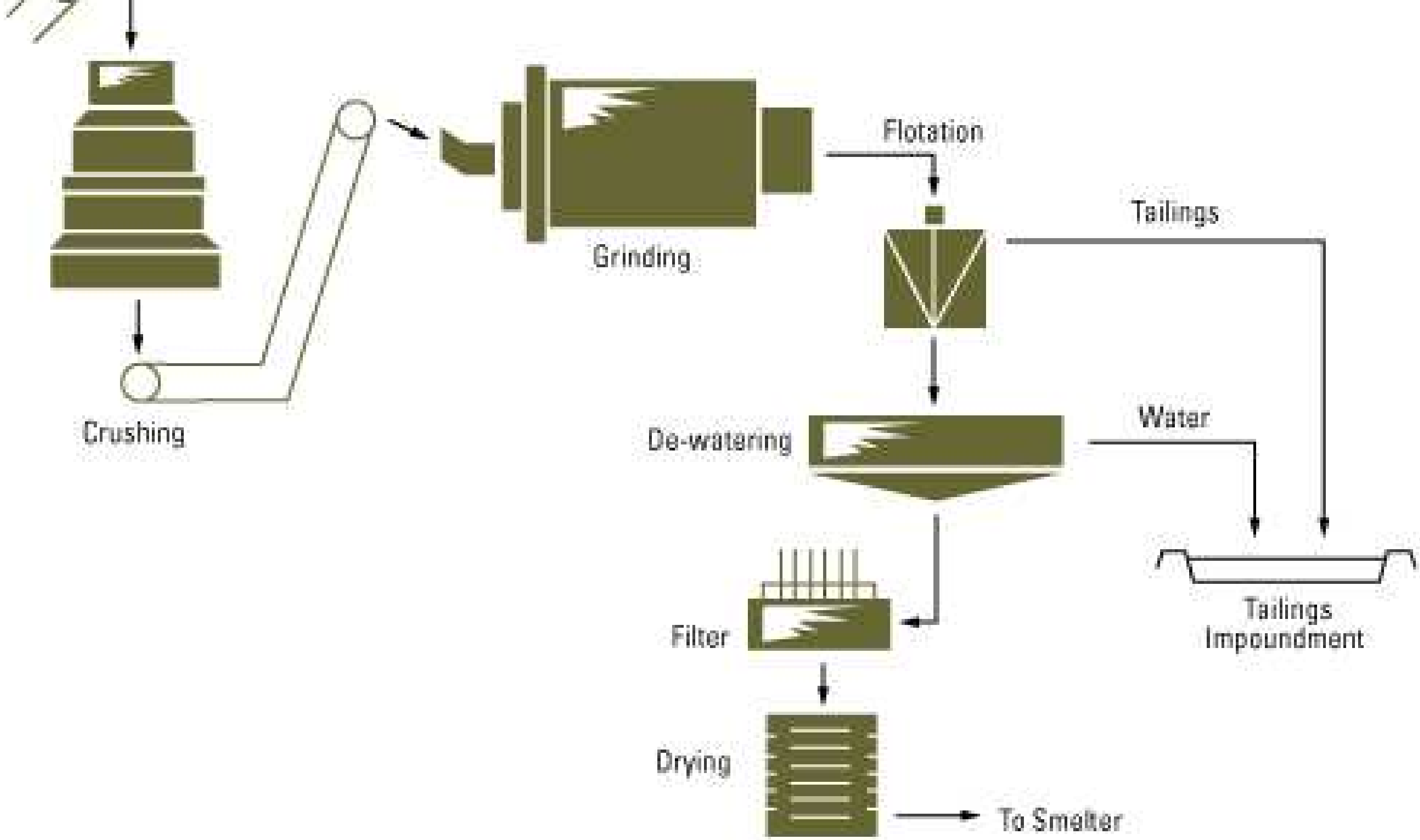
Mineral dressing
(= Ore beneficiation)

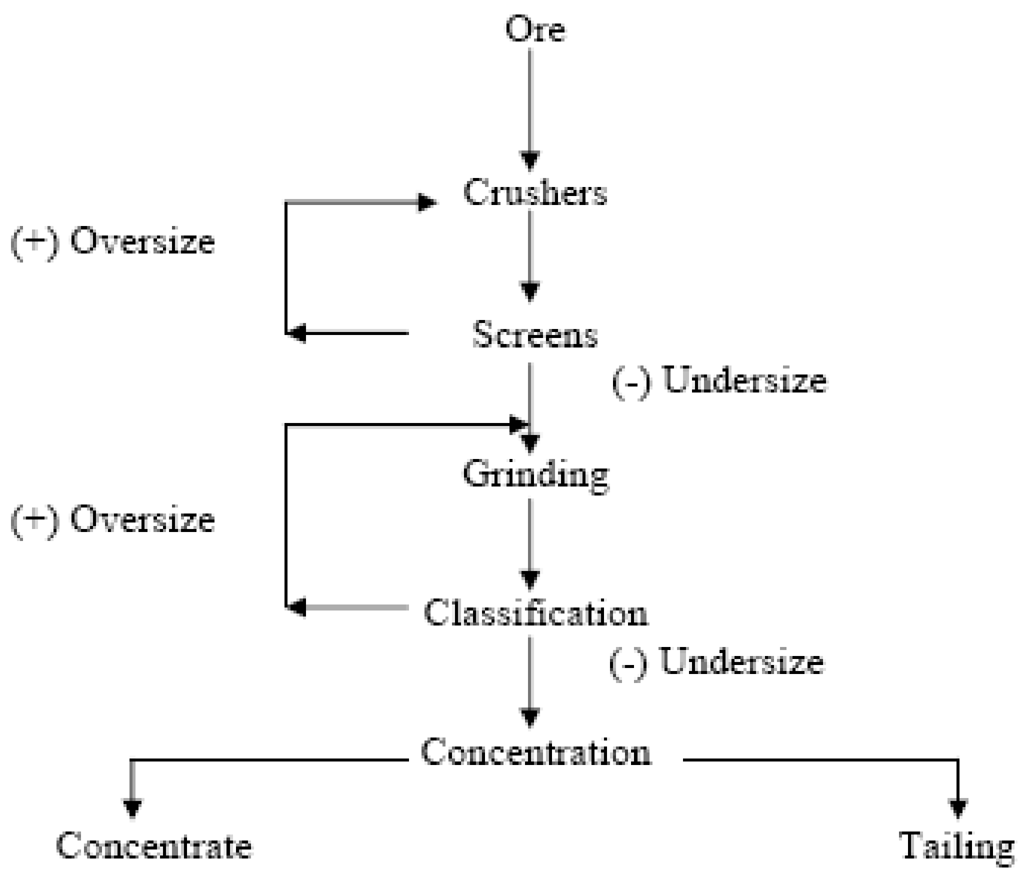
The first process most ores undergo after they leave the mine is mineral dressing (processing), also called ore preparation, milling, and ore dressing or ore beneficiation.

Ore dressing is a process of mechanically separating the grains of ore minerals from the gangue minerals, to produce a concentrate (enriched portion) containing most of the ore minerals and a tailing (discard) containing the bulk of the gangue minerals.

KIDD CREEK CONCENTRATOR



A simple flowsheet of a mineral processing plant

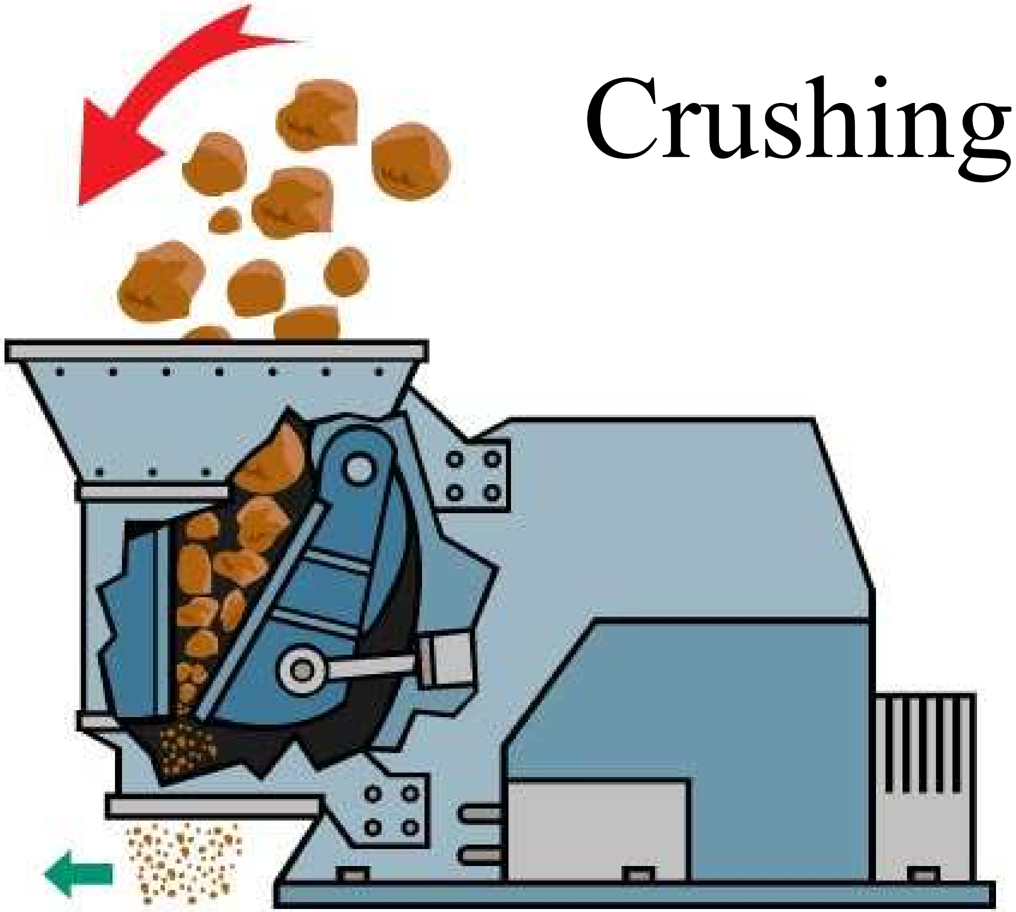


Mineral dressing

Since most ore minerals are usually finely disseminated and intimately associated with gangue minerals, the various minerals must be broken apart (freed) or “liberated” before they can be collected in separate products.

Therefore, the first part in any ore dressing process will involve the crushing and grinding (which is also known by a common name called “comminution”) of the ore to a point where each mineral grain is practically free.

Crushing



<u>Comminution</u>

- **<u>Crushing and grinding</u> are usually carried out in a sequence of operations by which the lump size is reduced step by step. There are *3 stages of crushing* and *2 stages of grinding*.**
  - **i. <u>Primary Crushing (coarse crushing):</u> In primary crushing, ore or run-of-mine ore (up to 1 m in size) is crushed down to about 10 cm and it is done in a jaw or gyratory crusher.**
  - **ii. <u>Secondary Crushing (intermediate crushing):</u> In this case, ore is crushed from 10 cm to less than 1 – 2 cm size; for this purpose jaw, cone or roll crushers are used. These secondary crushers consume more power than primary crushers.**
  - **iii. <u>Tertiary Crushing (fine crushing):</u> By tertiary crushers ore is crushed from 1 – 2 cm to less than 0.5 cm. Short head cone crushers, roll crushers, hammer mills can be used for this purpose.**

Comminution

- **The two stages of grinding are:**
  - **i. <u>Coarse Grinding:</u> Rod mills are generally used as coarse grinding machines. They are capable of taking feed as large as 50 mm and making a product as fine as 300 microns.**
  - **ii. <u>Fine Grinding:</u> Fine grinding, which is the final stage of comminution, is performed in ball mills using steel balls as the grinding medium. The ball mill, after feeding 0.5 mm material may give a product that is less than 100 microns. Grinding is usually done wet.**

The principle purposes of grinding are:

- **i. To obtain the correct *degree of liberation* in mineral processing.**
- **ii. To increase the *specific surface area* of the valuable minerals for hydrometallurgical treatment; i.e. leaching.**

The mills

Sizing Methods

- **There are two methods of industrial sizing.**
  - **i. Screening**
  - **ii. Classification**

- **Screening is generally carried out on relatively coarse material, as the efficiency decreases rapidly with fineness. Screening is generally limited to materials above about 250 microns in size, finer sizing normally being undertaken by classification.**

- **Classification: Classification is defined as a method of separating mixtures of mineral particles into two or more products according to their settling velocities in water, in air or in other fluids as given in below figure. Industrial classification may be carried out in different types of classifiers and these classifiers are; hydraulic classifiers, mechanical classifiers and cyclones. Basically they all work according to the principle that the particles are suspended in water which has a slight upward movement relative to the particles. Particles below a certain size and density are carried away with the water-flow, whereas the coarser and heavier particles will settle.**

Concentration

- **The second fundamental (main) operation in mineral processing, after the release, or liberation, of the valuable minerals from the gangue minerals, is the separation of these values from the gangue, i.e. concentration.**
- **Concentration is usually accomplished by utilizing some specific difference in physical (or chemical) properties of the metal and gangue compound in the ore.**
- ***In concentration the following terms are used:***
- **Head is the feed to a concentrating system.**
- **Concentrate is defined as the valuable mineral(s) separated from ore undergoing a specific treatment.**
- **Tailing is the fraction of ore rejected in a separating process. It is usually the valueless portion, i.e. discard or waste.**
- **Middlings are the particles of locked valuable mineral and gangue, i.e. liberation has not been attained. Further liberation can be achieved by further comminution.**
- **Recovery is the percentage of the total metal, contained in the ore that is recovered in the concentrate.**

Physical Concentration Methods

- **1. Separation dependent on optical and radioactive properties of minerals, i.e. hand pickling, optical sorting, radioactive sorting, etc.**
- **2. Separation dependent on specific gravity (density) difference of minerals, i.e. heavy-media separation, gravity concentration by use of tables, jigs, cones, etc.**
- **3. Separation utilizing the different surface properties (i.e. surface chemistry) of the minerals, i.e. froth flotation, etc.**
- **4. Separation dependent on magnetic properties of the minerals, i.e. low and high, dry and wet magnetic separation, etc.**
- **5. Separation dependent on electrical conductivity properties of the minerals, i.e. electrostatic separation, etc.**

Tyler screen scale starts with 1.05 inch (26.67 mm), for smaller particle sizes the dimensions are usually given in microns (1 micron = 10-3 mm). Thus, 200 mesh (#) is equal to 74 microns in the Tyler Screen Series

The Tyler Standard Series for Screen Analysis			
	Aperture Size		Tyler Mesh #
	Millimeters	Microns	
← $\sqrt{2}$ series	26.67	-	-
	18.85	-	-
	13.33	-	-
	9.423	-	-
	6.680	-	3
	4.699	-	4
	3.327	-	6
	2.362	-	8
	1.651	-	10
	1.168	-	14
	0.833	833	20
	0.589	589	28
	0.417	417	35
	0.295	295	48
	0.208	208	65
	0.147	147	100
	0.104	104	150
	0.074	74	200
	0.052	52	270
	0.037	37	400

Pretreatment Processes

- **i. Drying**
- **ii. Calcination**
- **iii. Roasting**
- **iv. Agglomeration**

Pretreatment Processes

- Drying

Drying usually means the removal of mechanically held water or moisture from concentrate, or other solid materials by evaporation, i.e. expensive operation, usually done in a drying furnace (fixed or fluidized bed, or kiln).

Moisture Determination

Take a grab sample weighing 100 to 1000 grams or more (It should include representative portions from the top, bottom and center of the car of ore or concentrate)

Sample
↓
Weigh the Sample
↓
Put into Drying Oven
↓
Dry @ 105°C
↓
Weigh again
↓
Determine the Loss in Weight
↓
Calculate % Moisture

% Moisture = {(wet weight - dry weight) / wet weight} * 100

Calcination

- **Calcination is the thermal treatment of an ore or a concentrate to effect its decomposition and the elimination of a volatile product, usually CO_2, water vapor, or other gases.**
- **Therefore, by contrast with drying, calcination involves the removal of H_2O, CO_2, etc., which are <u>chemically bound</u> as e.g. hydrates or carbonates.**

Temperature necessary for the decomposition pressure to reach 1 atm varies, e. g.

$FeCO_3$ and $Mg(OH)_2$; $T \geq 200°C$
$MnCO_3$, $MgCO_3$; $T \geq 400°C$
$CaCO_3$; $T \geq 900°C$
$BaCO_3$ and Na_2CO_3; $T \geq 1000°C$

Calcination

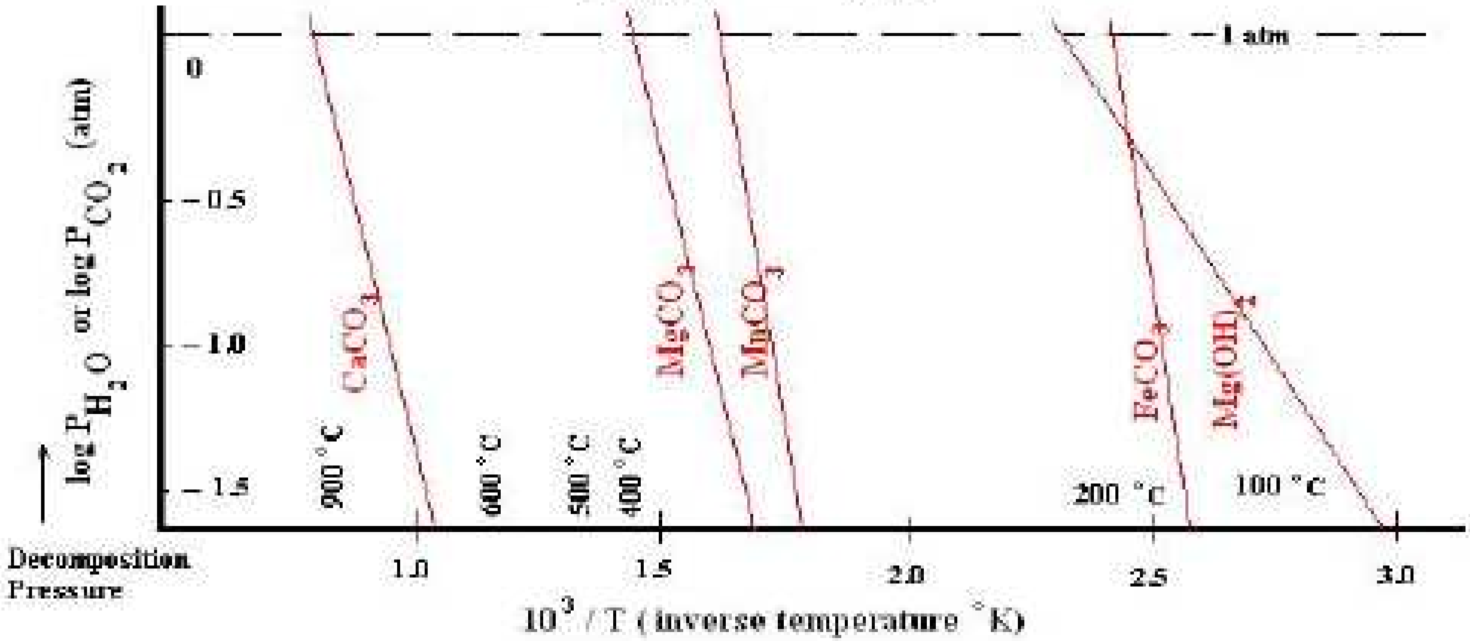
Lost ↑ Lost ↑

Material → Free water → Chemically bound H_2O,CO_2 → Completely dehydrated and calcined material

Drying ↑ Calcination ↑

→ Increasing Temperature

$T_{calcination} >> T_{drying}$



Roasting

- Roasting is the oxidation of metal sulfides to give metal oxides and sulfur dioxide.

Typical examples are:

$$\left.\begin{array}{l} 2ZnS + 3O_2 = 2ZnO + 2SO_2,\ \Delta H_{298\,^{o}K} = -220\ \text{Kcal/gm-mole} \\ 2FeS_2 + 11/2O_2 = \underbrace{Fe_2O_3}_{\text{Product (calcine)}} + 4SO_2,\ \Delta H_{298\,^{o}K} = -410\ \text{Kcal/gm-mole} \end{array}\right\}\ \text{Strongly Exothermic Reactions}$$

Temperature of Roasting

Troast > 500 - 600°C: in order for the reactions to occur with sufficient velocity.

Troast < 1000°C: roasting is usually carried out below the melting points of the sulfides and oxides involved and to avoid ferrite formation.

Dead roast or sweet roast: Roasting to completion with the elimination of most of the sulfur by overall reaction.

Partial roasting: Removal of some of the sulfur by roasting.

e.g. partial roasting of copper concentrates

$CuFeS_2 + 4O_2 = CuSO_4 + FeSO_4$

$2CuS + 7/2O_2 = CuO.CuSO_4 + SO_2$

Types of Roasting

1. Oxidizing roast
2. Volatilizing roast
3. Chloridizing roast
4. Sulfating roast
5. Magnetizing roast
6. Carburizing roast
7. Sinter or Blast roasting

Agglomeration

When the particle size of an ore or concentrate is too small for use in a later stage of treatment, i.e. in the blast furnace, it must be reformed into lumps of appropriate size and strength that is agglomerated.

Types of agglomeration

i. Sintering

ii. Pelletizing

iii. Briquetting

iv. Nodulizing

Extraction via Flotation:

- Froth flotation - a process where valuable minerals are separated from tailing by inducing them to gather on the surface of a froth layer.
  - This process is based on the ability of certain chemicals to modify the surface properties of the mineral(s).
  - Other chemicals are used to generate the froth and still others are used to adjust the pH.

- The process of froth flotation involves crushing and grinding the ore to a fine size
  - This separates the individual mineral particles from the waste rock and other mineral particles.
  - The grinding is normally done in water with the resultant slurry called the pulp.

- The pulp is processed in the flotation cells.
  - Here the pulp is agitated with a flotation mixture
  - Fine bubbles are introduced

- The ability of a mineral to float depends upon its surface properties.
  - Chemical modification of these properties enables the mineral particles to attach to an air bubble.
  - The air bubble and mineral particles rise through the pulp to the surface of the froth.

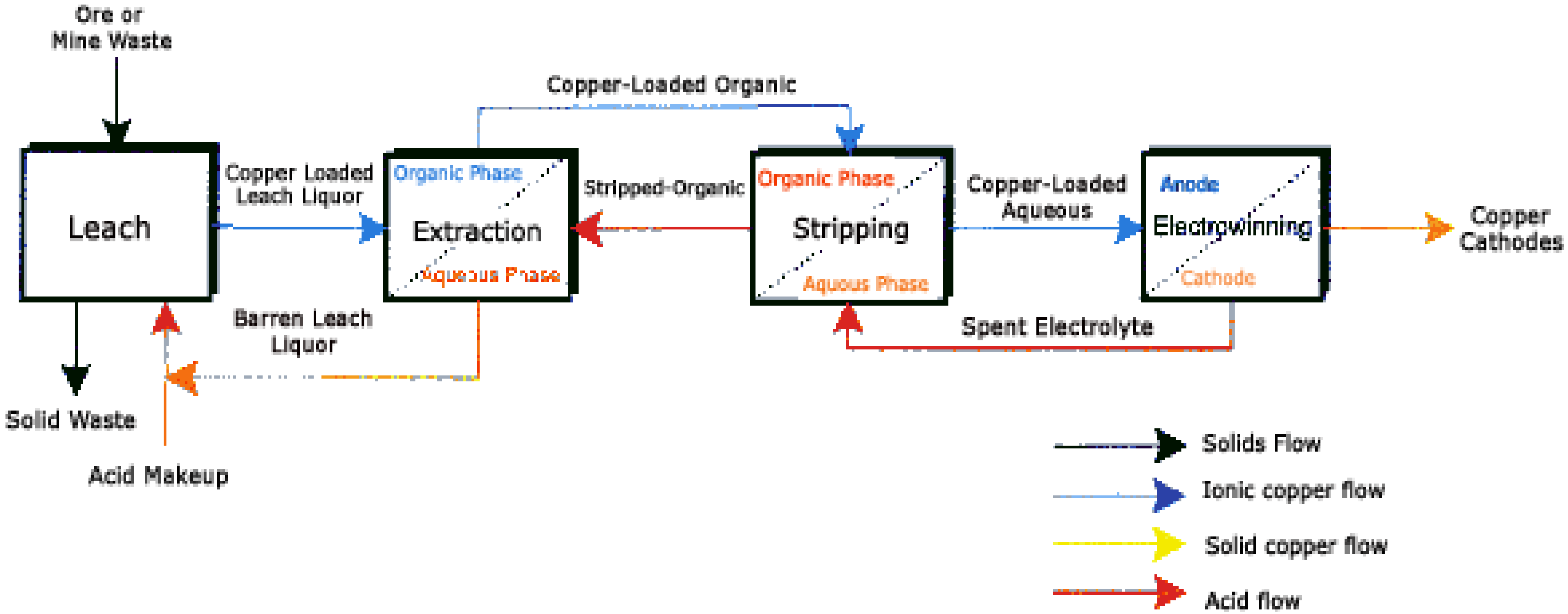
- Even though the air bubbles often break at this point, the mineral remains on the surface of the froth.

- The mineral is physically separated from the remaining pulp material and is removed for further processing.

Sulphide Minerals

- **Are sometimes roasted**
  - **Heated in air without melting to transform sulphides to oxides**
  - **Gives off H_2S and SO_2**
  - **Then oxides processed like Fe**
- **Process of roasting and smelting together creates a matte**
  - **Sulfides are melted into a matte and air is blown through. S is converted to sulfur dioxide and Fe to iron oxide, and Cu and Ni stay in melt**
- **Solvent extraction/electroplating**
  - **Used where rock contains Cu but in too little amounts to be recovered by classical methods**

Simplified Flow Chart
Leach - Solvent Extraction - Electrowinning Process



Heap Leaching

- In this process, typically done for Au, the ore is not ground, but rather, crushed and piled on the surface.
- Weak solutions of NaCN (0.05%) percolate through the material leaching out the desired metals.
- The solutions are collected and the metals are precipitated

Cyanide extraction for Gold

- Preparation
  - ground into fine powder –
  - mixed in solution of NaCN (sodium cyanide) & water
  - referred as SLURRY

- Extraction
  - Zinc powder is added to this gold-cyanide solution – which precipitates out the gold -
  - The mixture then goes thru a filter where the precipitate sticks to a heavy canvas filter which is later cleaned to remove the gold.
  - Extreme heat is applied which burns off the Zn

- ENVIRONMENT:
  - Gold mines make sure that cyanide doesn't escape, by using containment systems and recycling the water.
  - Entire operation must be kept on the alkaline side – HCN is volatile and poisonous

- ALTERNATIVE PROCESSES
  - Gold extraction by Mercury. Elemental Hg forms an amalgam with many metals, such silver and gold.
  - Mercury boiled off, precious metals remain.
  - Practised in Central America 1570-1900, and in Brazil until now.

Cyanide in the beneficiation of gold

- 0.05% NaCN solution is used to extract Au and Ag from ore
- Au dissolves by two processes occurring simultaneously on its surface.

Cathode

- At one end of the metal, the cathodic zone, oxygen takes up electrons and undergoes a reduction reaction.

  $O_2 + 2\ H_2O + 2\ e^- \Rightarrow H_2O_2 + 2\ OH^-$

Anode

- At the other end, the anodic zone, the metal gives up electrons and undergoes an oxidation reaction.

  $Au \Rightarrow Au^+ + e^-$

  $Au^+ + 2CN^- \Rightarrow Au(CN)_2^-$

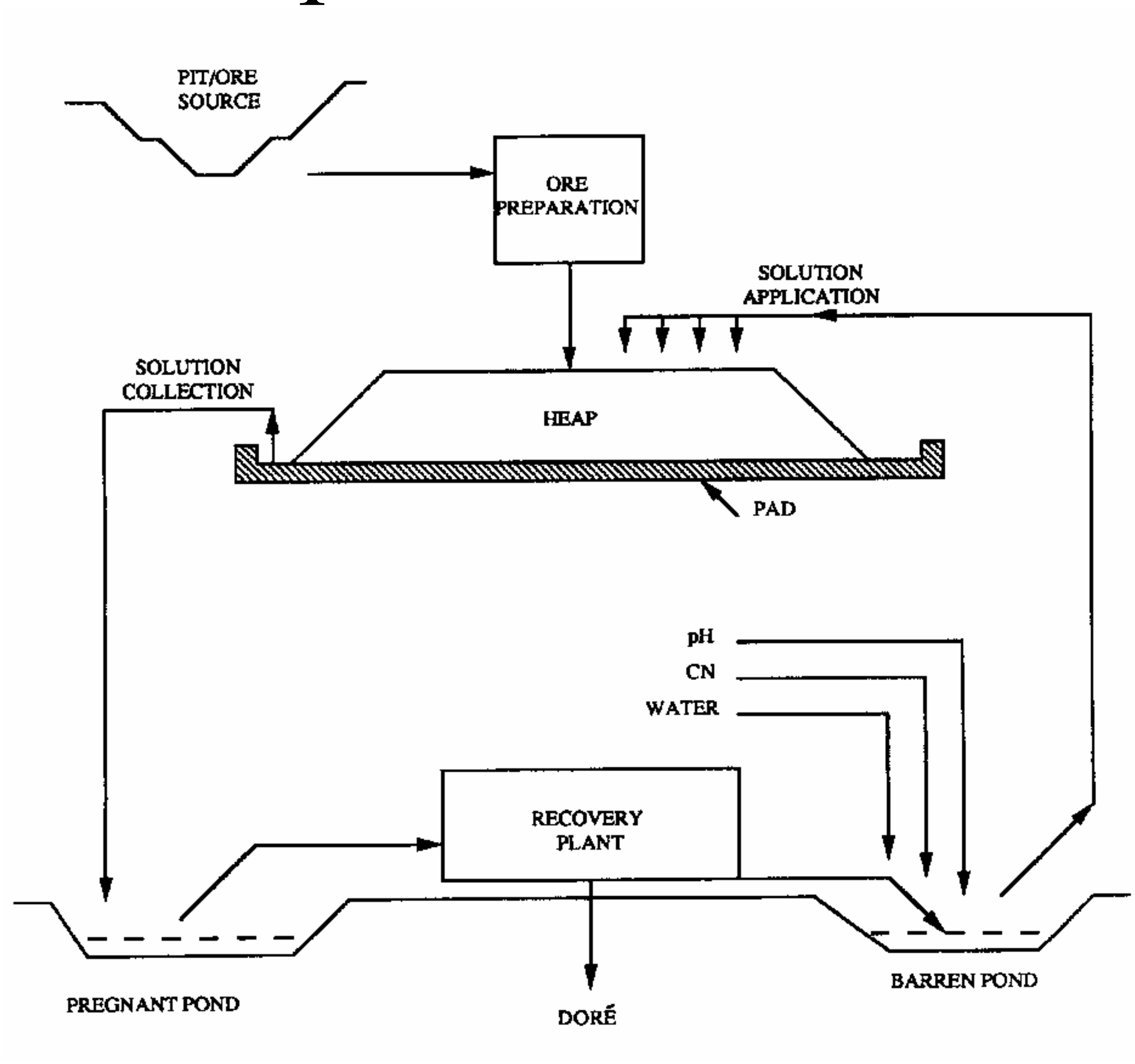
- And then form strong complexes by Elsener's/ Adamson's 1st reaction:

$4Au + 8NaCN + O_2 + 2H_2O = 4NaAu(CN)_2 + 4NaOH$

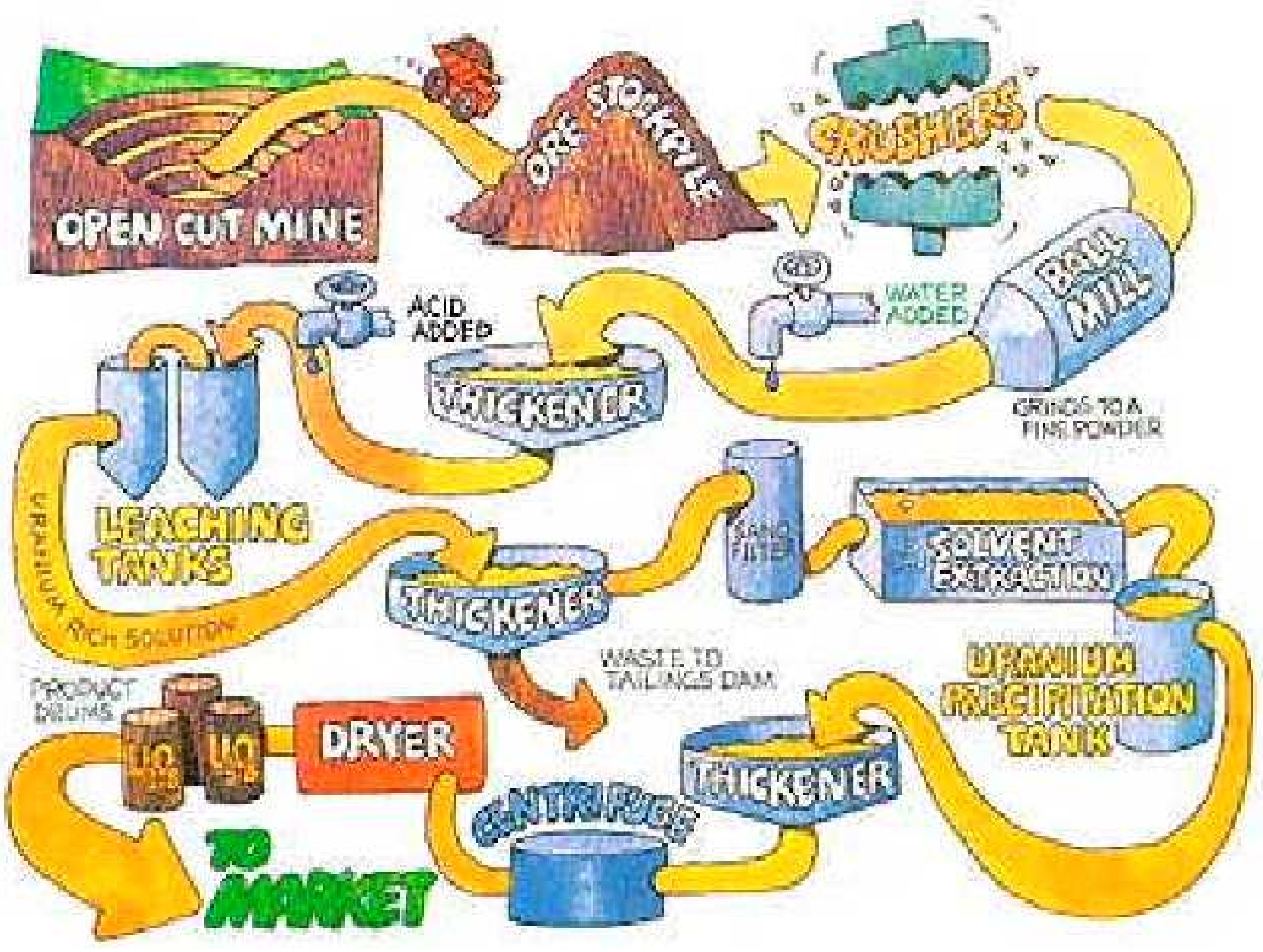
Or Adamson's 2nd reaction

$2Au + 4NaCN + 2H_2O = 2NaAu(CN)_2 + H_2O_2 + 2NaOH$

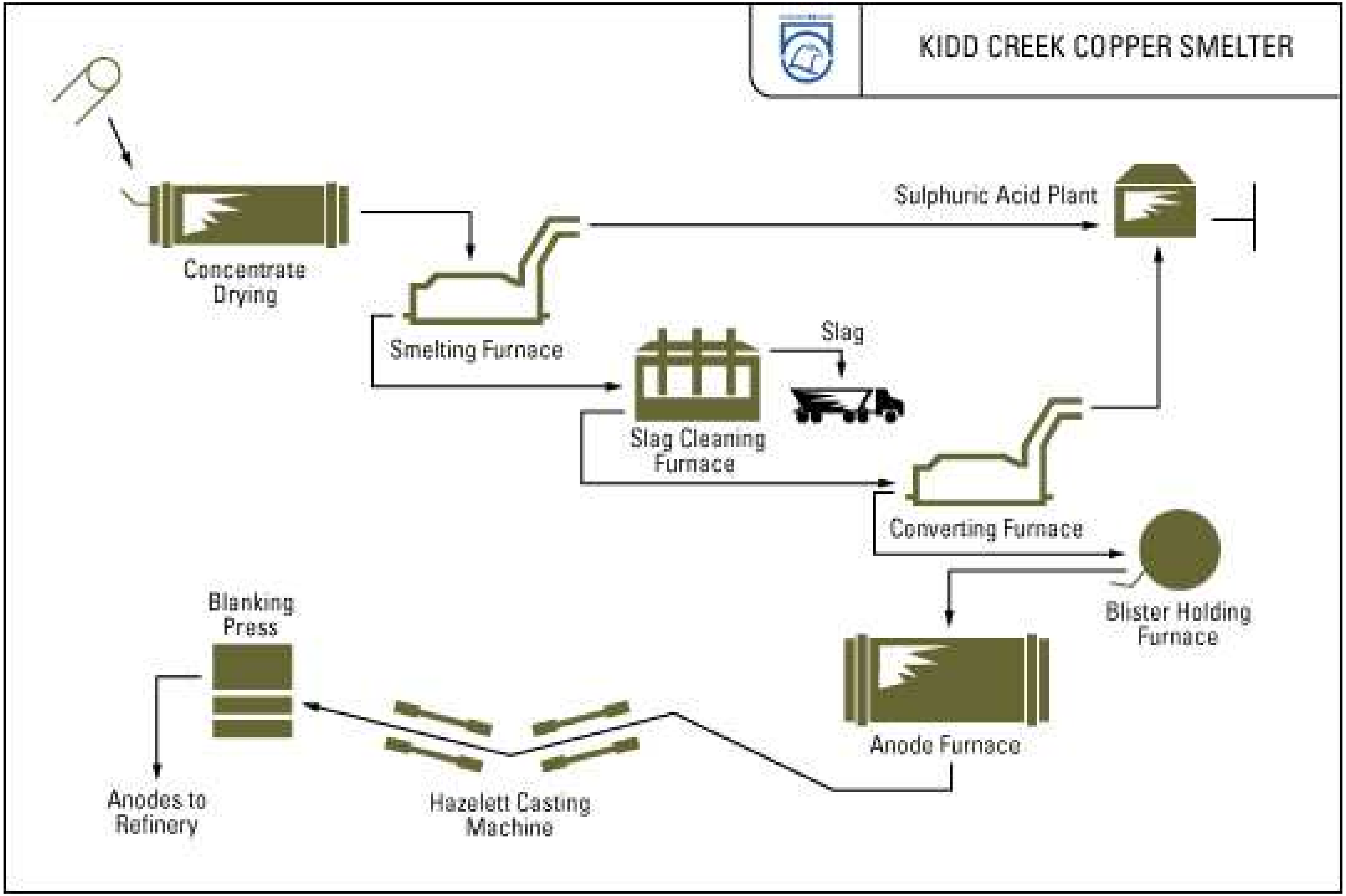
Heap Leach Process



Solvent extraction of U from its ores

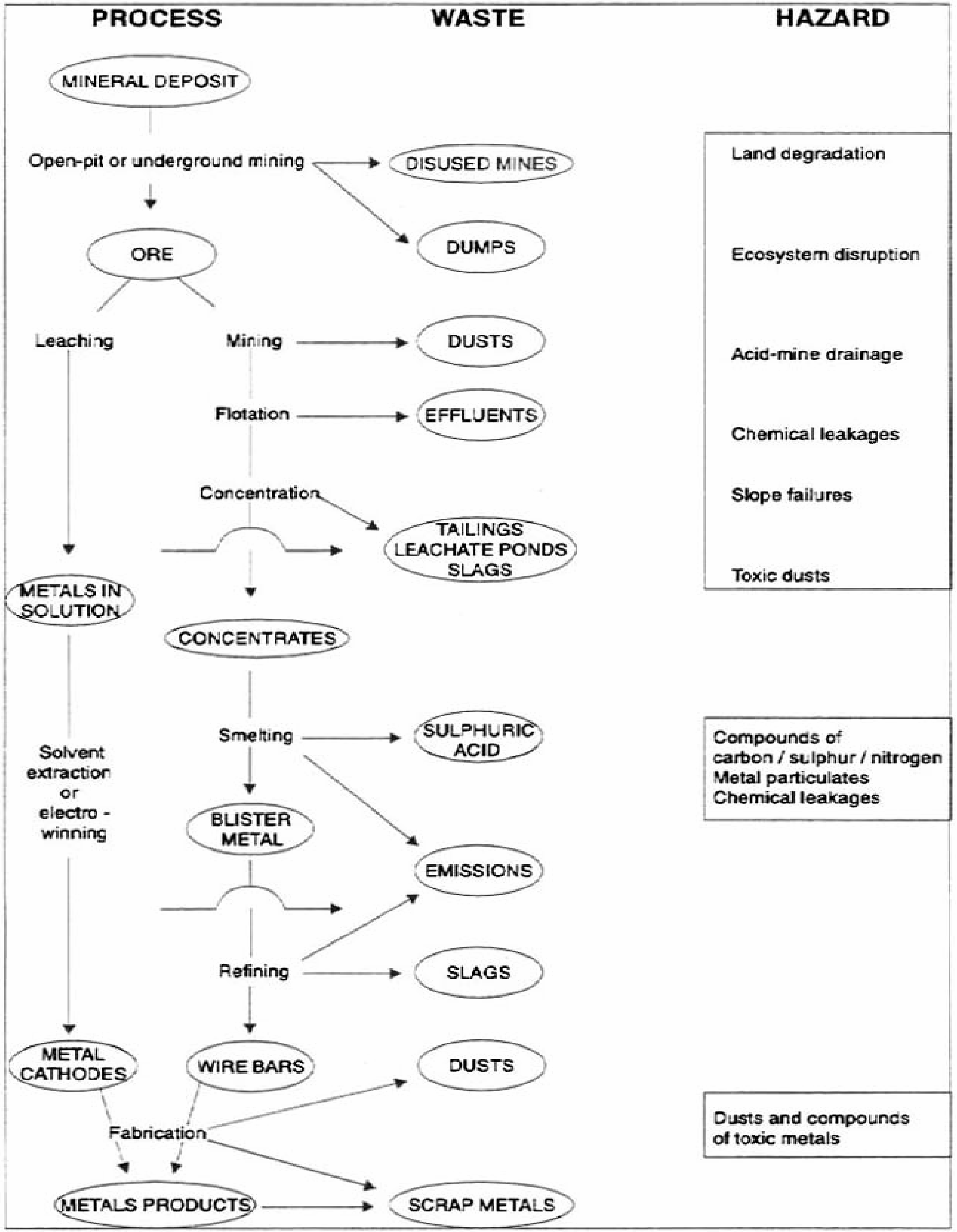


Smelting


KIDD CREEK COPPER SMELTER
Concentrate Drying
Smelting Furnace
Sulphuric Acid Plant
Slag
Slag Cleaning Furnace
Converting Furnace
Blister Holding Furnace
Anode Furnace
Hazelett Casting Machine
Blanking Press
Anodes to Refinery

Potential Environmental Problems

- A. Mining operation itself
  - Disposal of a large amount of rock and waste
  - Noise
  - Dust
- Beneficiation
- Smelting and refining


PROCESS
WASTE
HAZARD
MINERAL DEPOSIT
Open-pit or underground mining
DISUSED MINES
DUMPS
ORE
Land degradation
Ecosystem disruption
Leaching
Mining
DUSTS
Acid-mine drainage
Flotation
EFFLUENTS
Chemical leakages
Concentration
Slope failures
TAILINGS
LEACHATE PONDS
SLAGS
Toxic dusts
METALS IN SOLUTION
CONCENTRATES
Smelting
SULPHURIC ACID
Compounds of
carbon / sulphur / nitrogen
Metal particulates
Chemical leakages
Solvent extraction or electro - winning
BLISTER METAL
EMISSIONS
Refining
SLAGS
METAL CATHODES
WIRE BARS
DUSTS
Fabrication
Dusts and compounds
of toxic metals
METALS PRODUCTS
SCRAP METALS