

A large industrial furnace is shown in operation, pouring molten metal into a mold. The furnace is a large, cylindrical structure with a circular opening at the top. A bright, glowing stream of molten metal is being poured from the opening into a rectangular mold. The mold is supported by a metal frame. The background shows other industrial equipment and a concrete floor. The overall scene is dimly lit, with the primary light source being the intense heat of the molten metal.

Processing Gold Ores

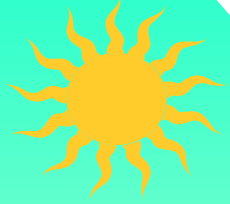


Agenda

- ➔ Evolution of the gold industry
- ➔ Gold ore types and characteristics
- ➔ Processing gold ores
 - ▣ processing stages
 - ▣ unit operations
- ➔ Process development for gold ores
- ➔ An expert system for gold process design
- ➔ A gold mine in Amazon
- ➔ Summary

Evolution of the gold industry





Evolution of gold industry

➔ Pre-cyanidation

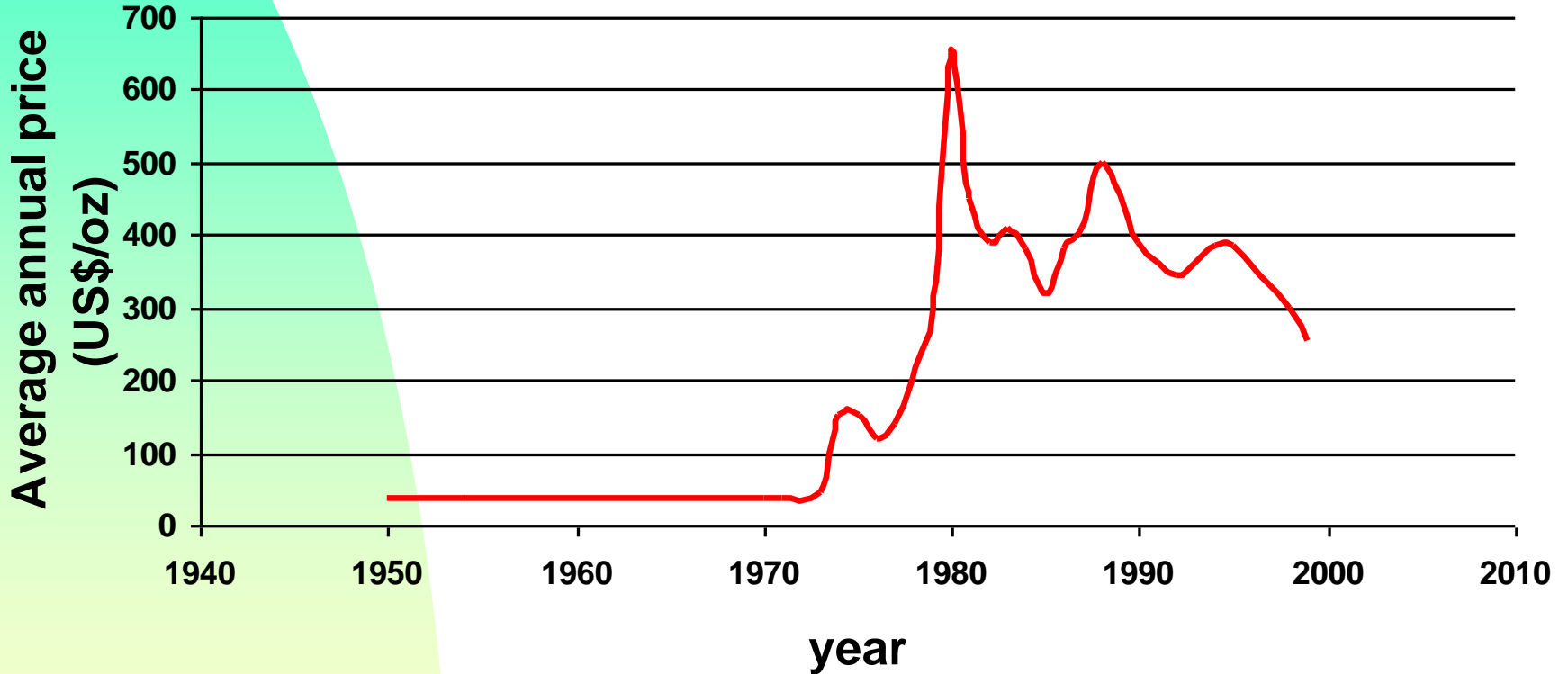
- ✓ Ancient Egypt (3050 a.c)
- ✓ Turkey - gold coins (700 a.c.)
 - Gold refining (560 a.c.)
- ✓ Roman Empire
- ✓ Gold rushes
 - 1500-1750 - Spanish and Portuguese Colonies
 - South America
 - 1800-1900 - California, New Zealand, Canada, Australia

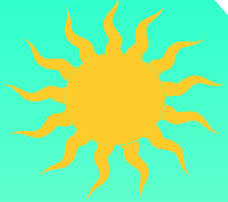


Evolution of gold industry

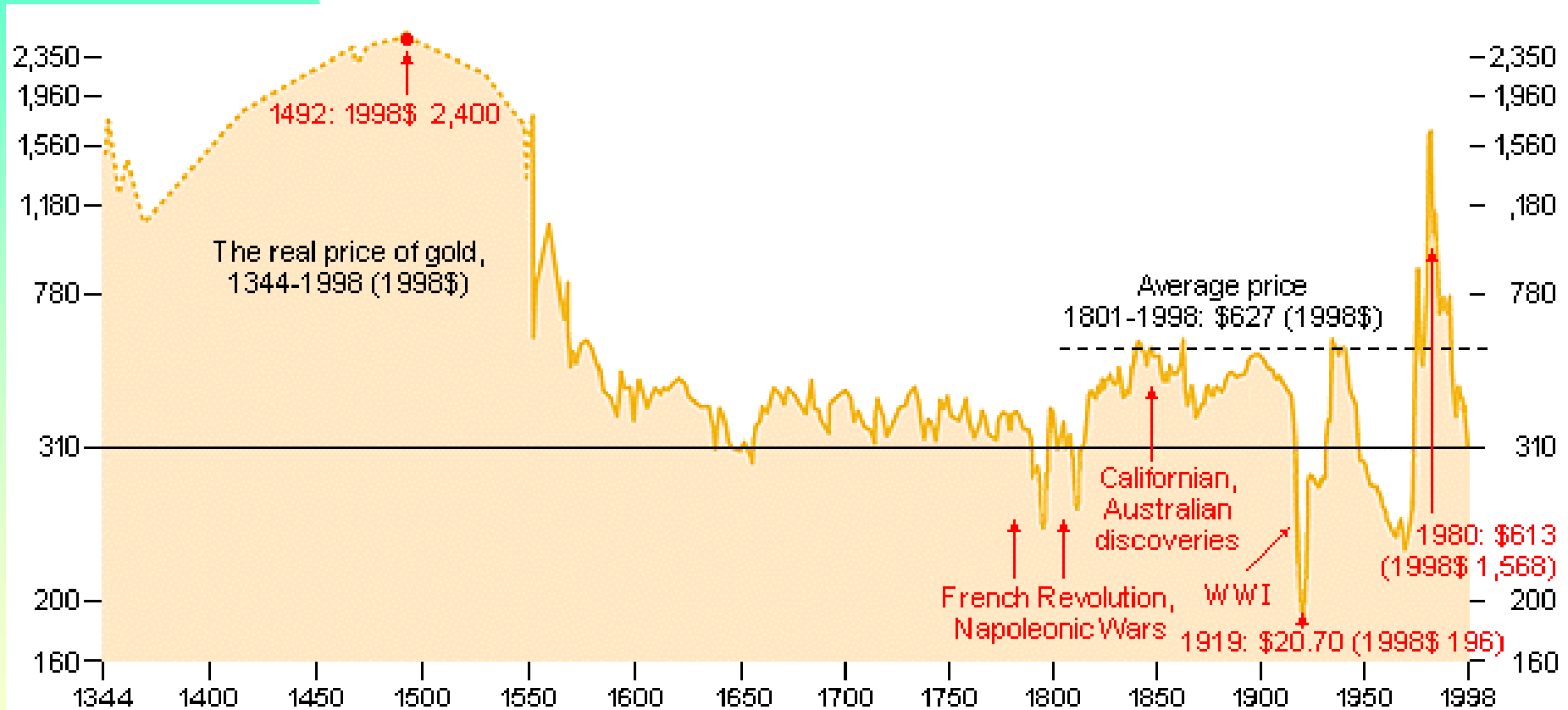
- ➔ “100 years of cyanidation”
 - 1889 - Crown Mine - New Zealand
 - Exploitation of Witswatersrand deposits
 - ✓ South Africa as main gold producer
 - Processing route evolution
 - ✓ application of basic mineral processing technology
 - Low incentive from low gold prices

Gold price over the last 50 years





Gold price since 1344

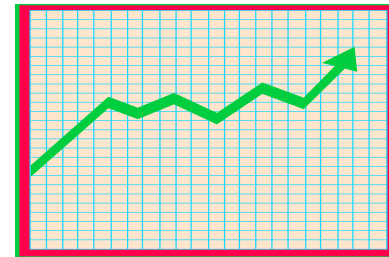




Evolution of the gold industry

➔ “Accelerated development years (1972-1990)

- Driving force: gold price
- Development of gold processing
 - ✓ CIP process
 - ✓ Heap Leaching
 - ✓ SAG Milling
 - ✓ Refractory ore treatment



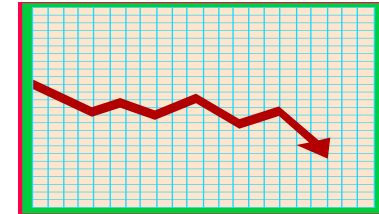
Evolution of the gold industry



➔ Evolution of gold industry

□ Gold industry in the 1990's

- ✓ declining gold prices
 - need for cost reduction
 - low cash cost properties

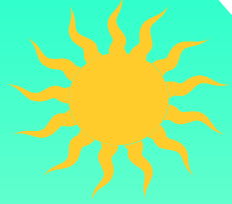


□ Trends for next decade

- ✓ new “rump-up” of gold prices
 - development of projects now “on hold”
- ✓ increasing control and automation



Gold ore types and characteristics



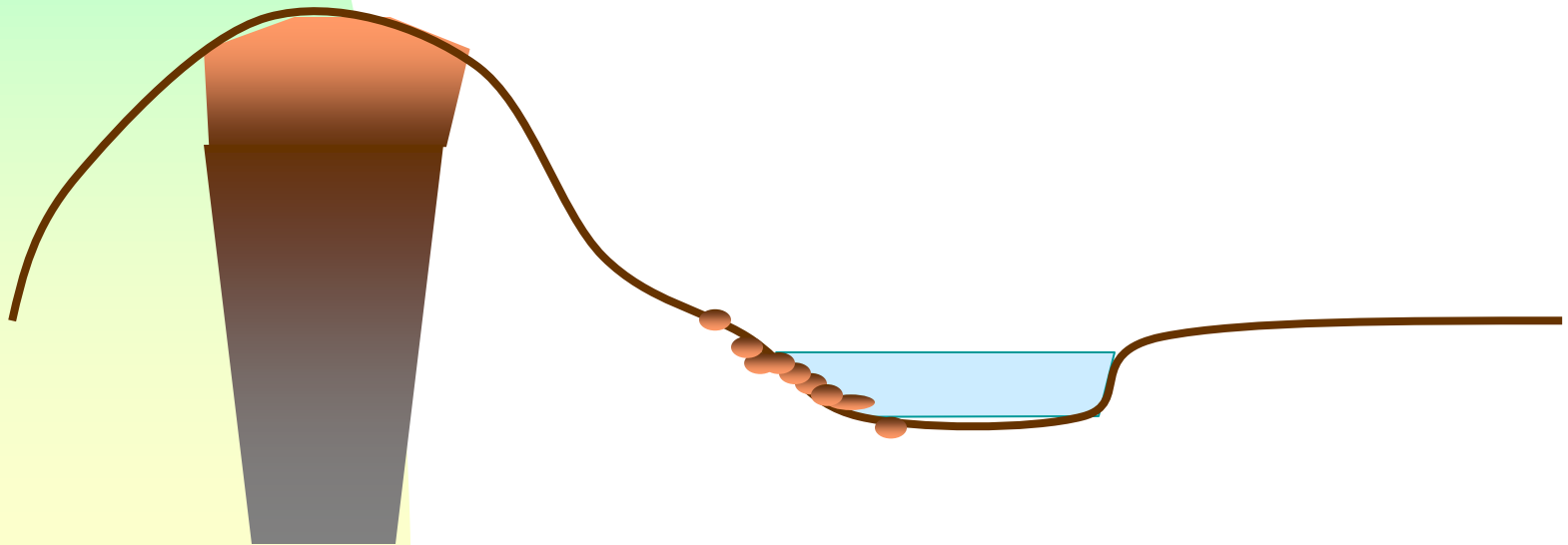
Gold ores

- ➔ Gold: Process and Mineralogy
 - Most noble metal, native occurrence
 - Also associated with silver, tellurium, bismuth and PGM's
 - typical ore grades: 0.5 to 20 g/t
 - Primary gold source: ores
 - Secondary gold sources
 - ✓ gravity concentrates
 - ✓ flotation concentrates
 - ✓ plant tailings
 - ✓ refinery tailings
 - ✓ recycled gold

* PGM means platinum group metals

Types of gold deposits

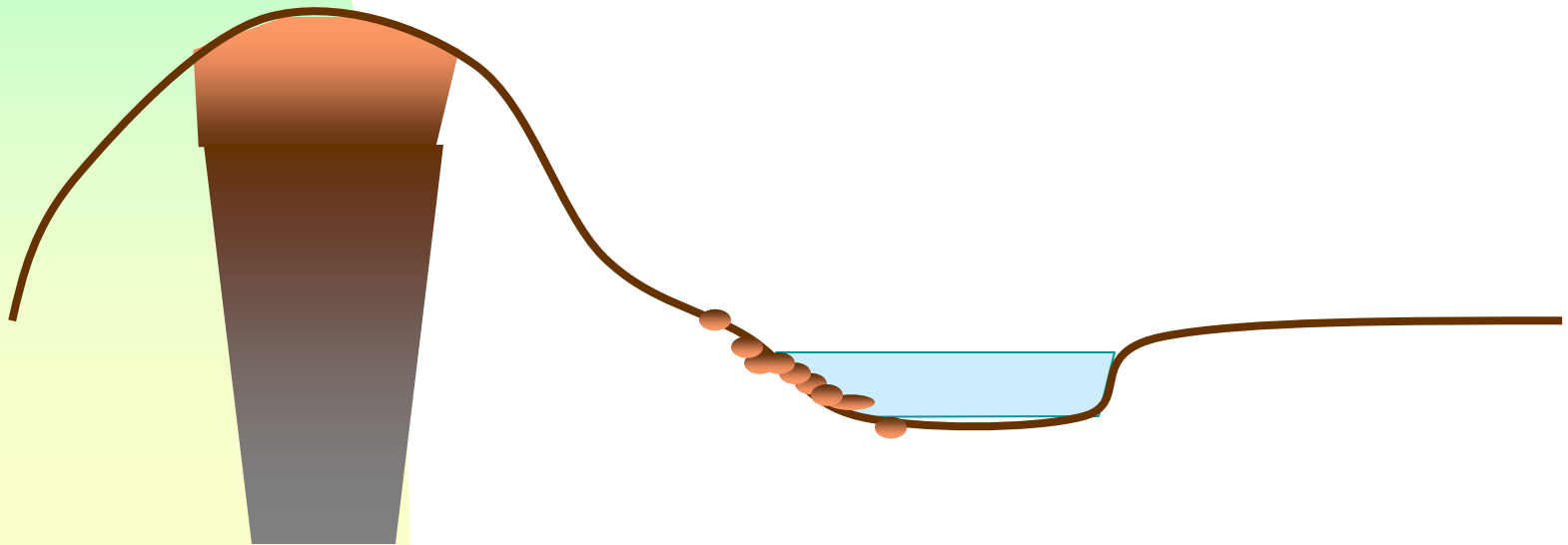
- ➔ Placer ores
- ➔ Oxidized ores
- ➔ Primary ores





Types of gold mining methods

- ⇒ Placer ores => Placer mining
- ⇒ Oxidized ores => Open pit
- ⇒ Primary ores => Underground mining

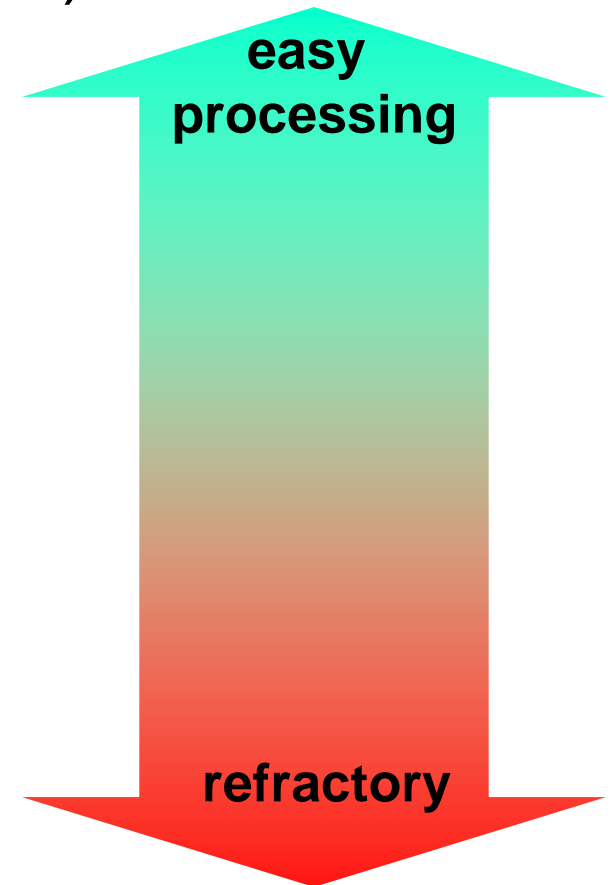




Gold Ore Types

→ Main ore types (after Marsden)

- ✓ placers
- ✓ oxidized
- ✓ free milling
- ✓ silver rich
- ✓ iron sulphide bearing
- ✓ arsenic sulphide bearing
- ✓ carbonaceous
- ✓ copper bearing
- ✓ antimony bearing
- ✓ gold telluride bearing





Gold ore characterization and testing

- ➔ Mineralogical characterization
- ➔ Technological tests
 - exploratory testwork
 - diagnostic leaching
 - optimization testwork
 - pilot plant



Gold Liberation

- ➔ “Free gold” definition and discussion
 - Classic definition: Gaudin
 - ✓ Physical liberation of the valuable mineral from gangue
 - ✓ **Limitation:** Hydrometallurgical and Pyrometallurgical processes: **access** of gas or solution to mineral is the issue
 - Definition adopted: **free gold = accessible gold**
 - ✓ direct correlation with processes
 - ✓ used by hydrometallurgists



Refractory gold

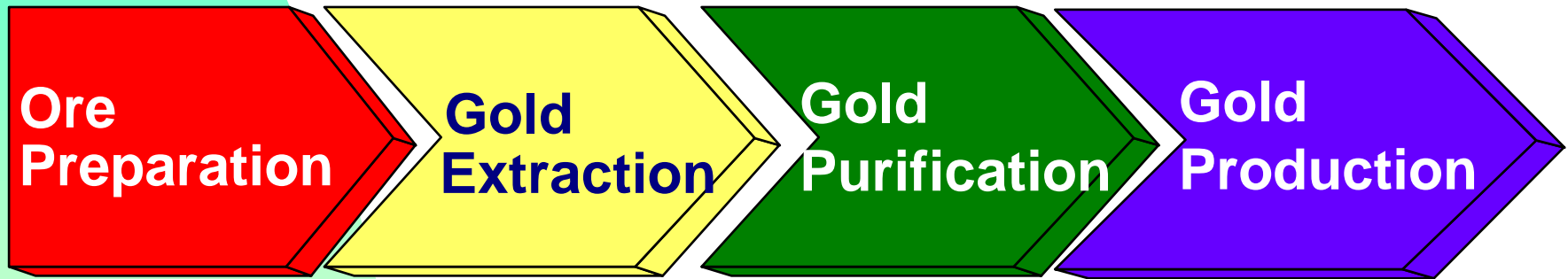
- ➔ Refractory gold: cannot be made accessible using only comminution
 - Ore needs chemical pretreatment prior to gold extraction
- ➔ Main causes of gold refractoriness
 - gold encapsulated in quartz/silicates
 - gold encapsulated in sulphides
 - ore containing active carbonaceous matter



Industrial gold ore processing



Gold ore processing



- **Gold liberation**
- **Particle size adjustment to next processes**
- **Physical concentration and oxidation pretreatment**
- **Extraction of gold from ore into solution and/or concentrate**
- **Purification of gold bearing solution**
- **Recovery of gold from solution or concentrate to produce a bullion bar**

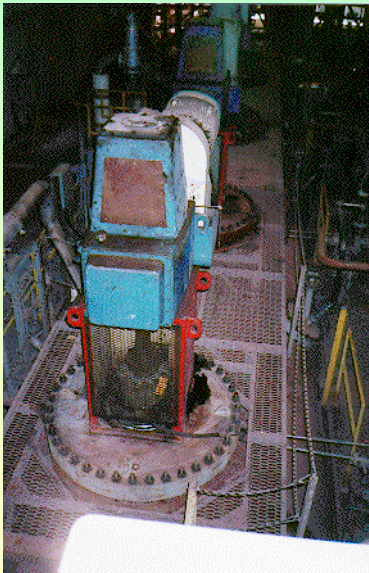
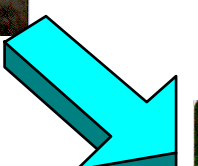
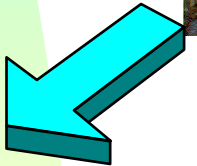
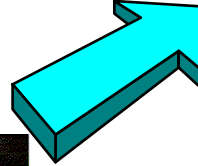
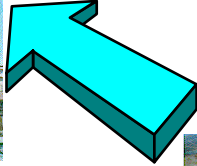
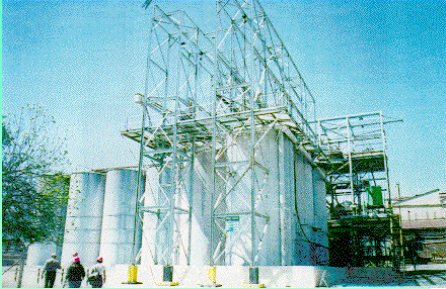
Unit operations for each step





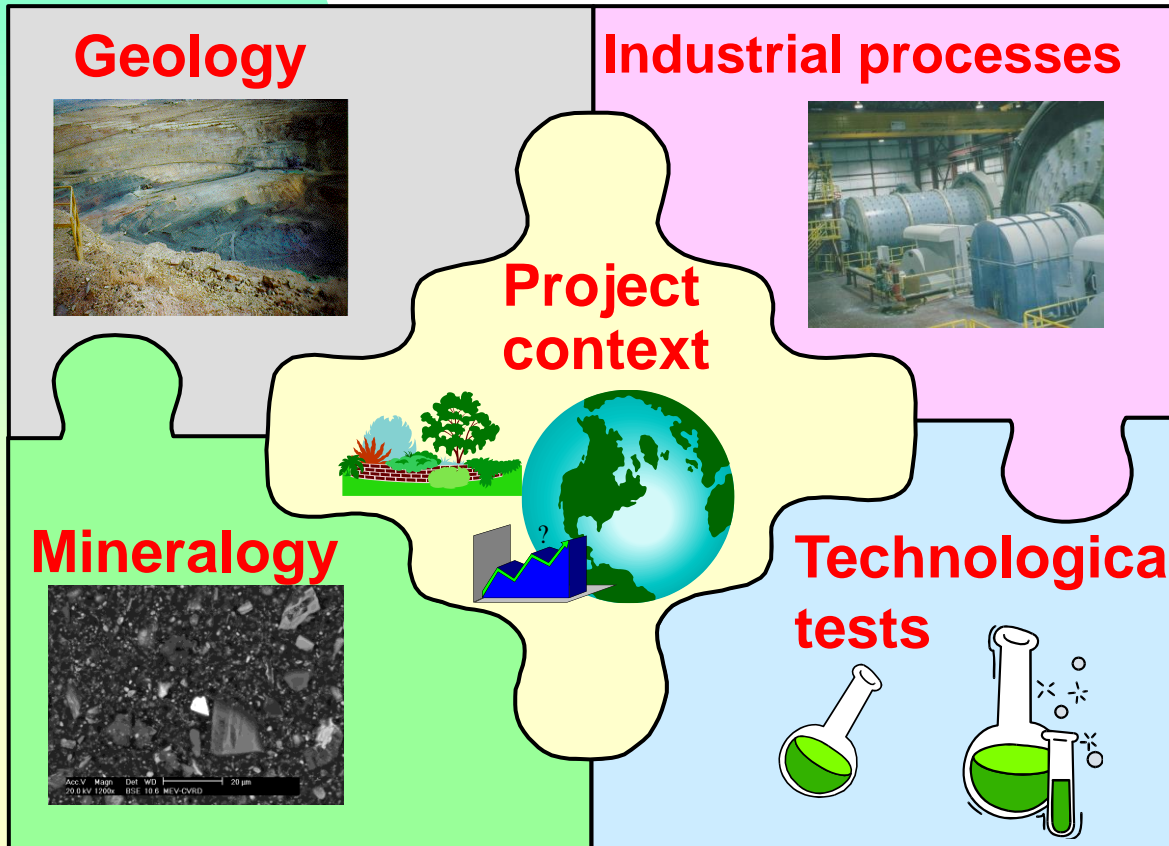
Process development for gold ores

Process development

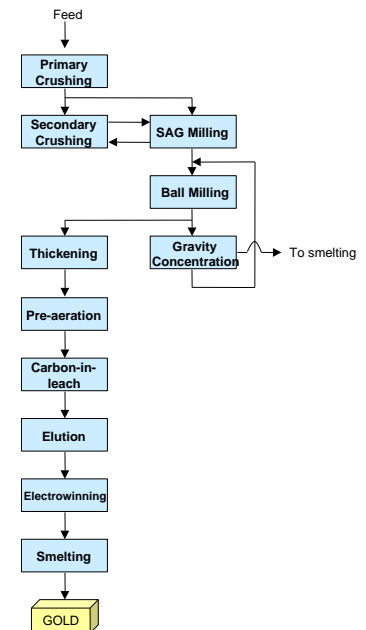


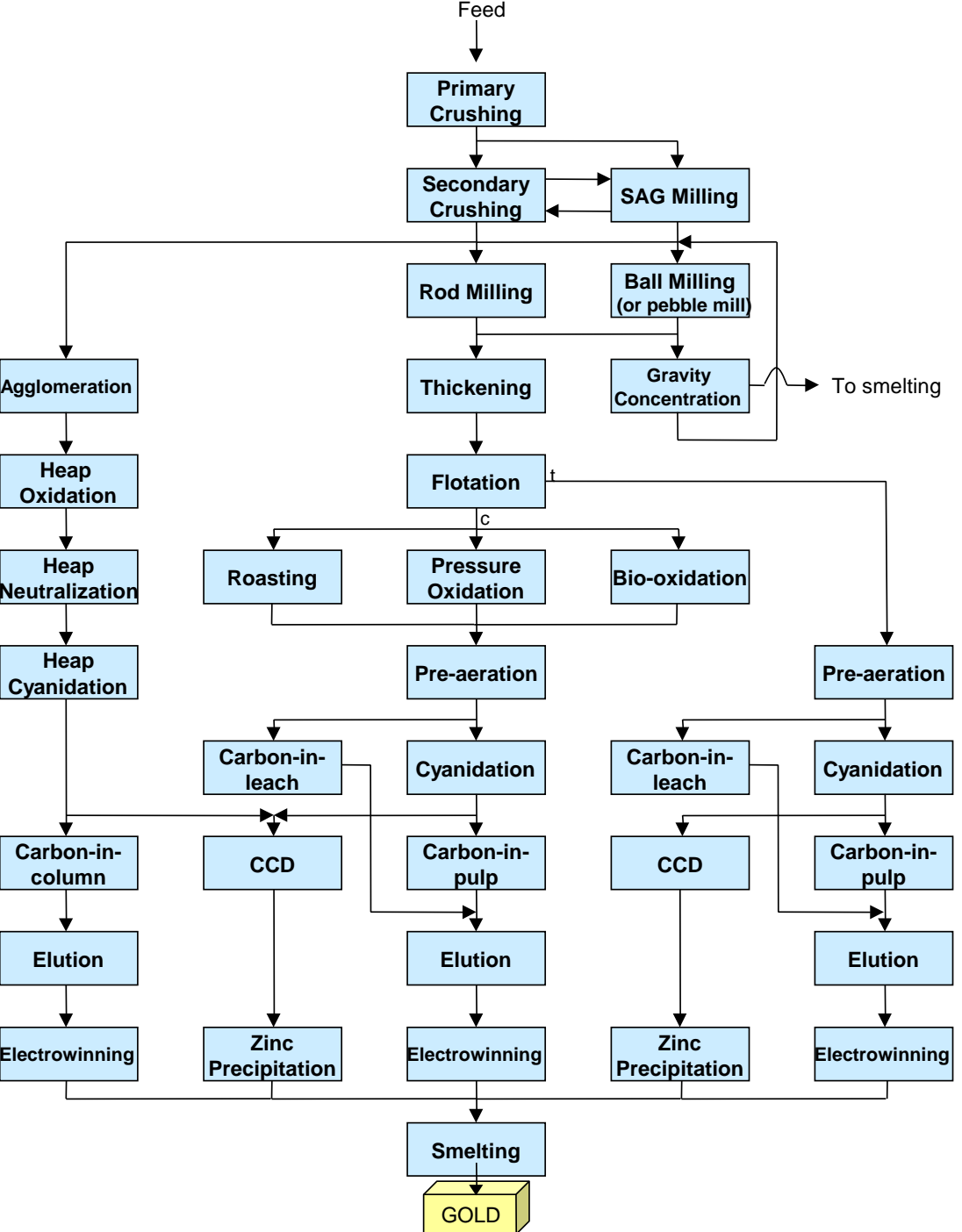


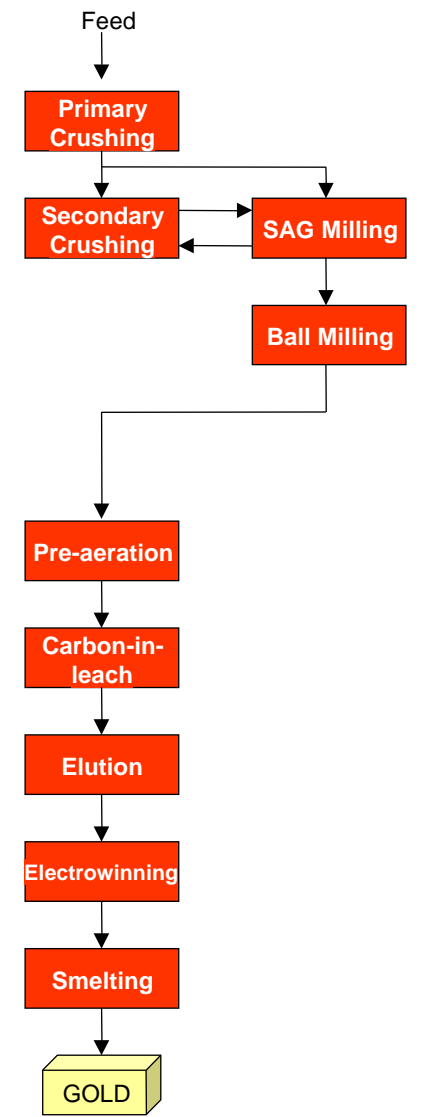
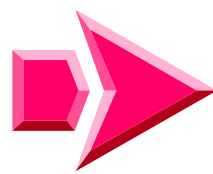
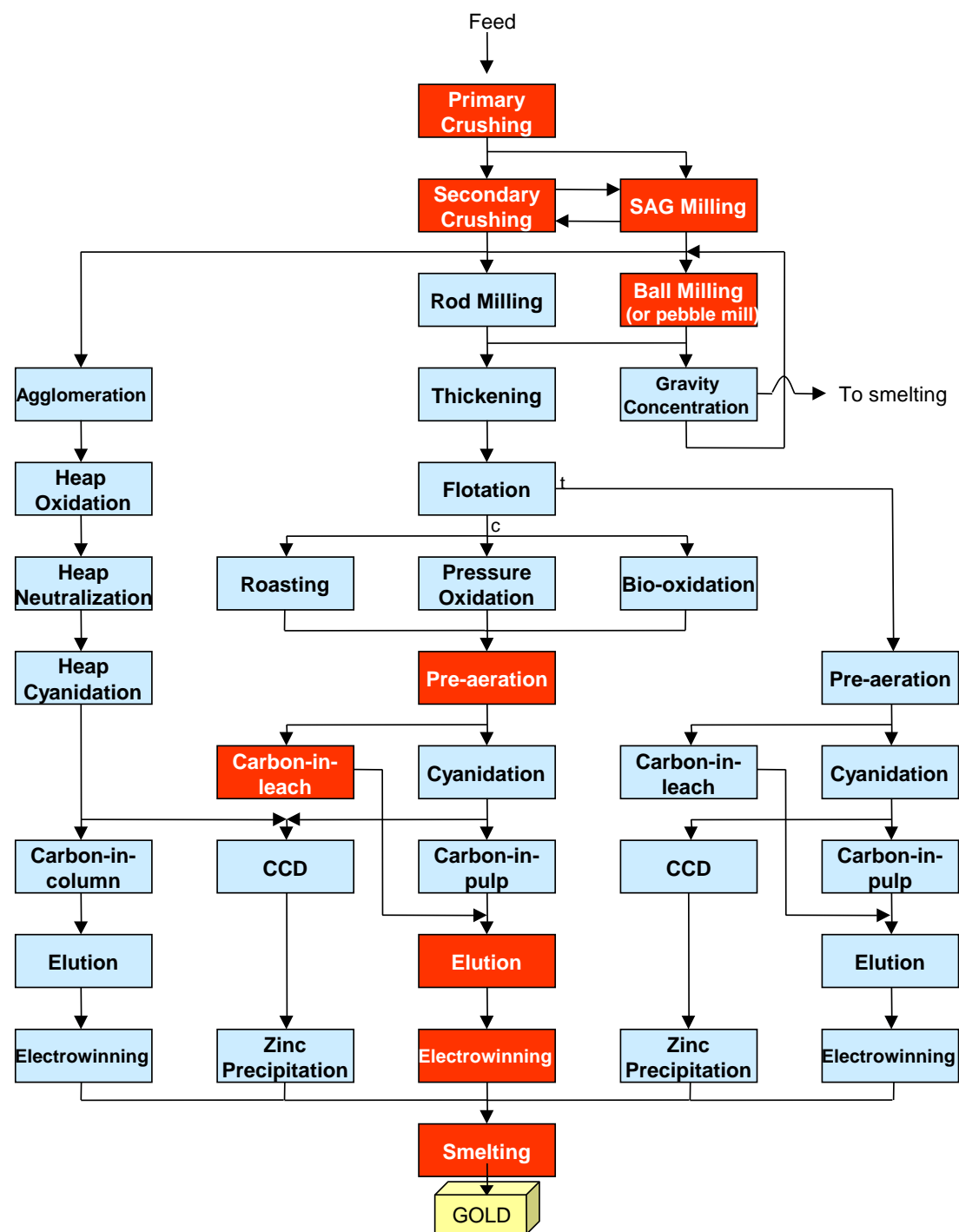
Process design



Process routes









Fazenda Brasileiro ore

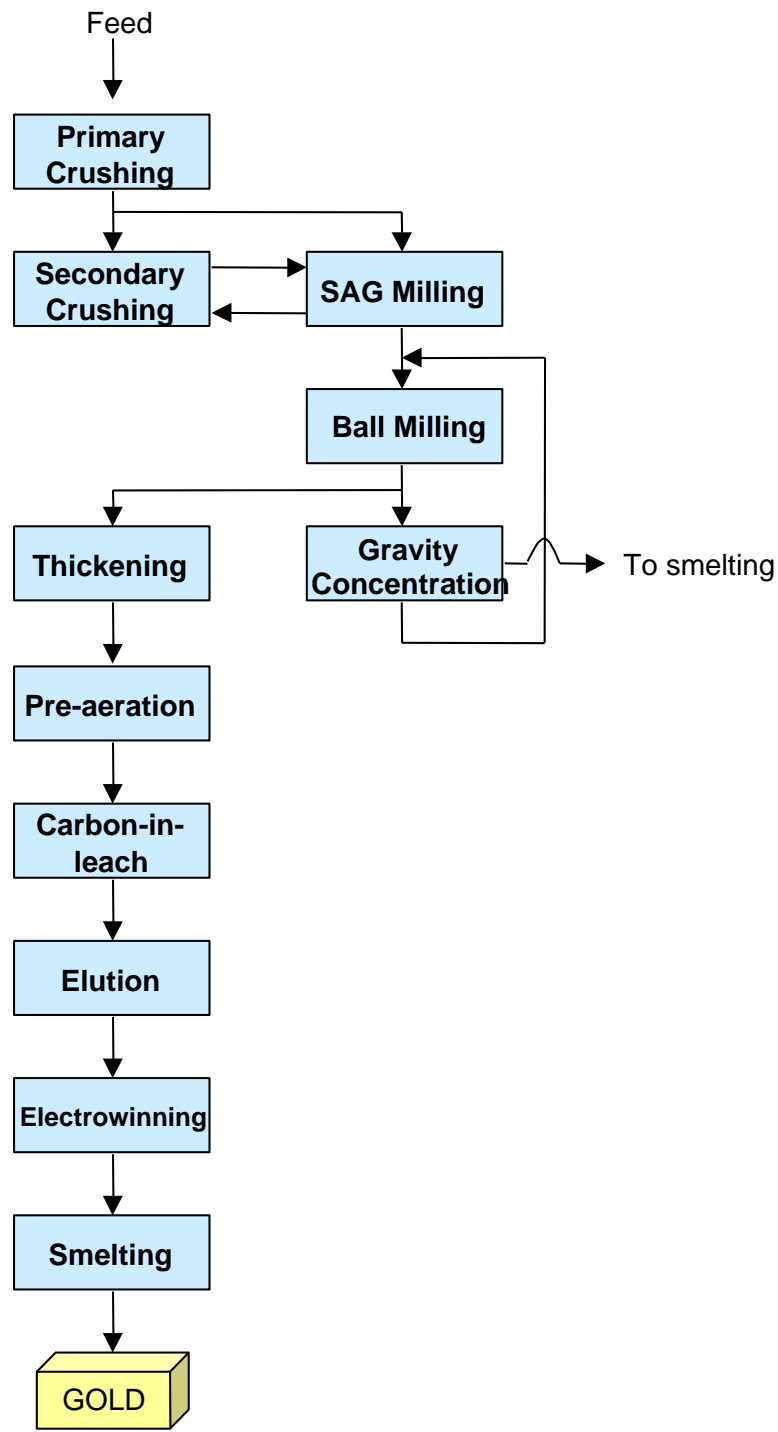
➔ Main ore characteristics

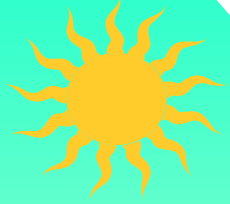
- deposit type: “greenstone belt”
- mineralogy: fine gold ($d_{95}=37$ microns), free or in borders/fractures, associations with sulphides and quartz
- laboratory tests: high recoveries for both direct cyanidation and flotation, good recovery in gravity concentration



Fazenda Brasileiro ore

➔ Conventional process route





Refractory sulphide ore

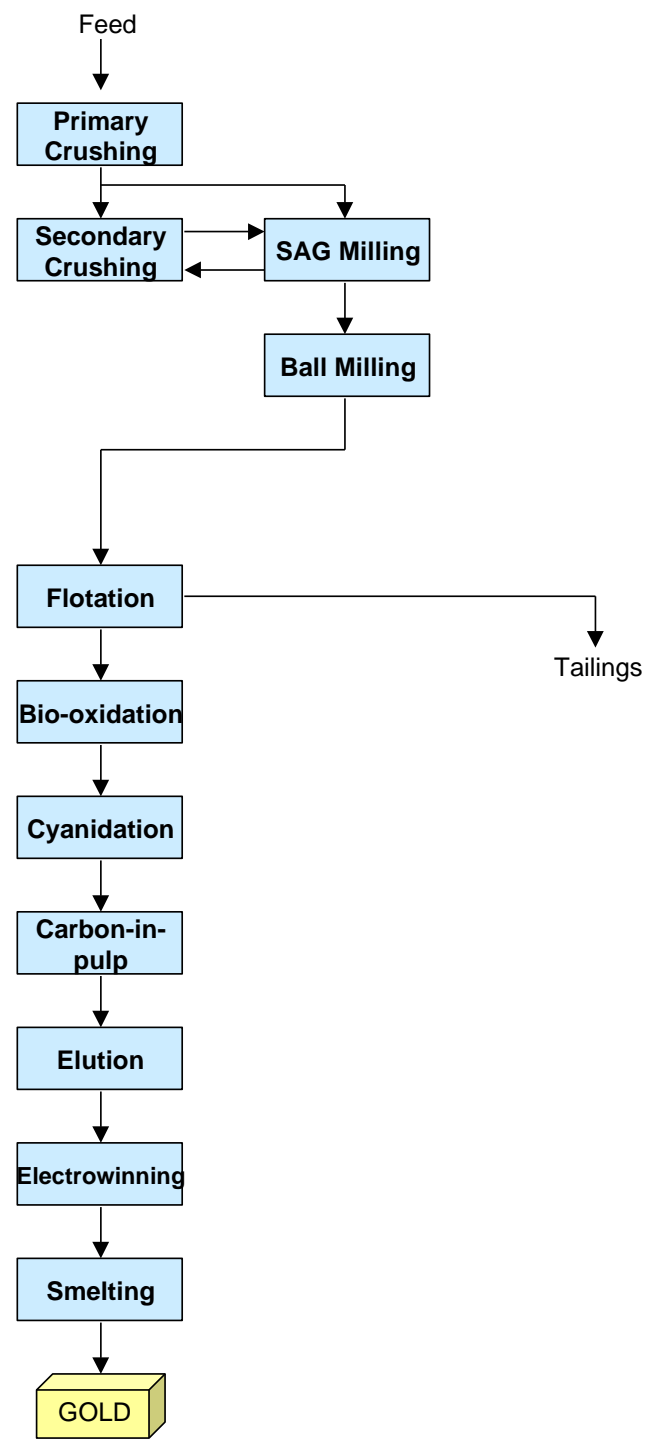
➔ Main ore characteristics

- ✓ deposit type: “greenstone belt”
- ✓ mineralogy: very fine gold($d_{95}=3$ microns), encapsulated and in borders/fractures, association with sulphides
- ✓ laboratory tests: low recoveries in direct cyanidation and gravity concentration tests, high recoveries in flotation tests, high recoveries by cyanidation after bio-oxidation or pressure oxidation



Refractory sulphide ore

➡ Processing route with pretreatment





Placer ore

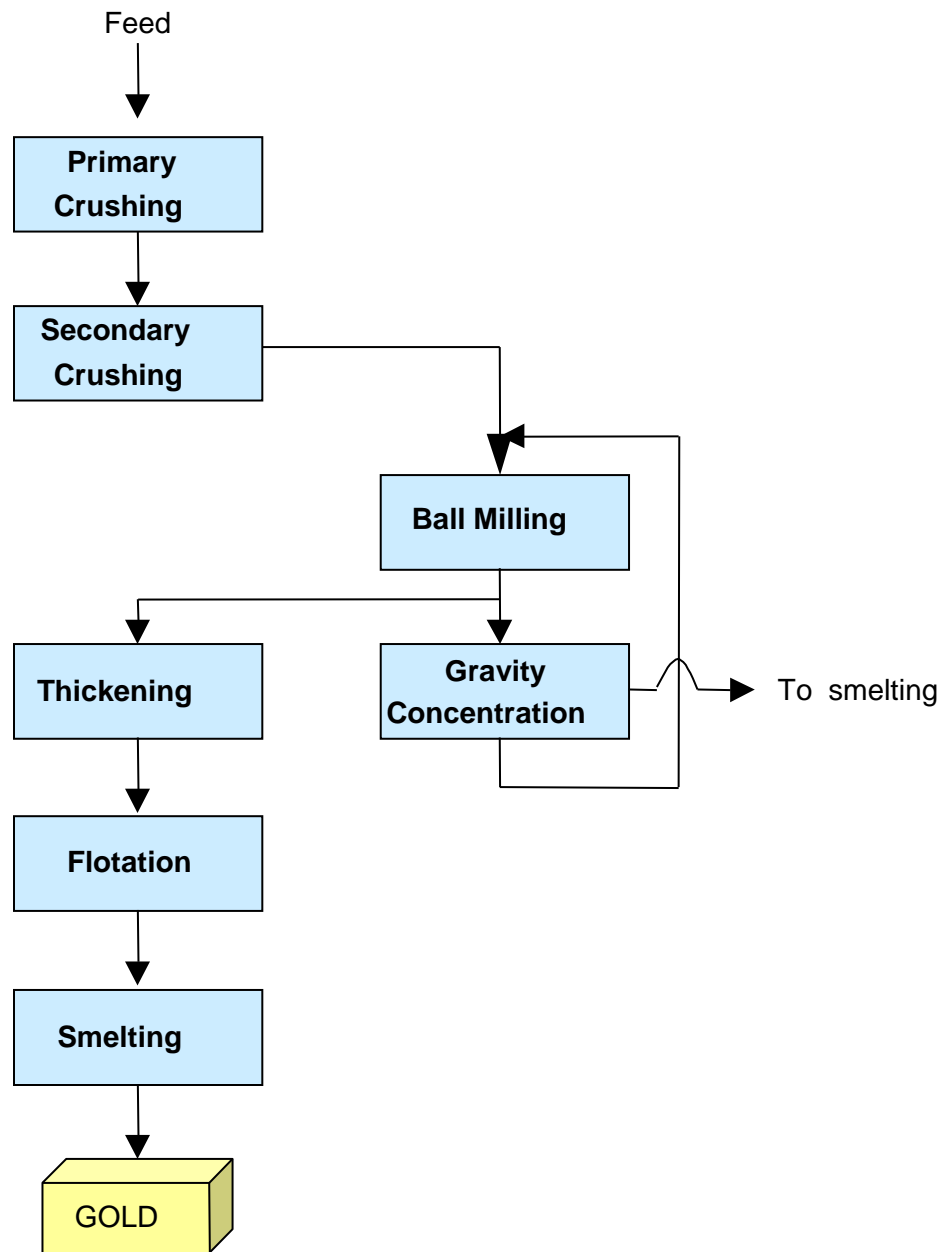
➔ Main ore characteristics

- ✓ deposit type: “placer”
- ✓ mineralogy: medium size gold($d_{95}=100$ microns), some physically liberated, some associated with sulphides



Placer ore

➔ Physical only processing route





Expert system for gold process design



Intelligold - expert system for process design

➔ Objective:

- Integration of gold process design knowledge into artificial intelligence software

➔ Principles

- Use of logical variables and fuzzy sets to represent information
- Organization of information into a “knowledge building” stepladder



Decision rules,
fuzzy sets

Process routes
indication

Flowsheet
alternatives

Hypertext with
literature review
and case studies

Cost and
revenues
calculation

Mining method
user input

Ranking of alternatives

Alternative NPV/IRR Risk factors

Project start

**Ore/deposit
information**

Continue investigation

- . Do research
- . Gather more data

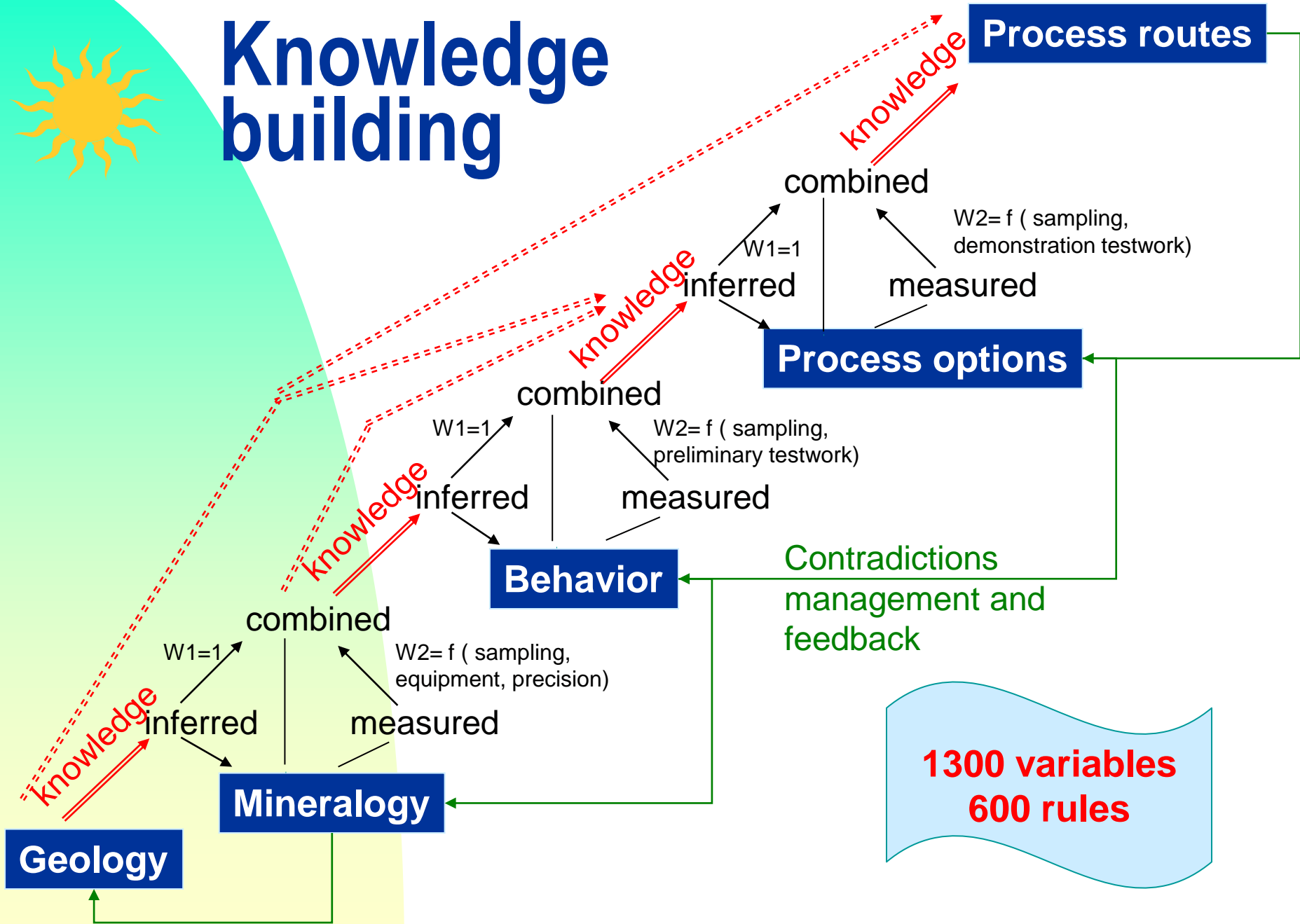
**DECISION
MAKING**

Abandon or
hold

Implement
project



Knowledge building





A gold mine in the Amazon

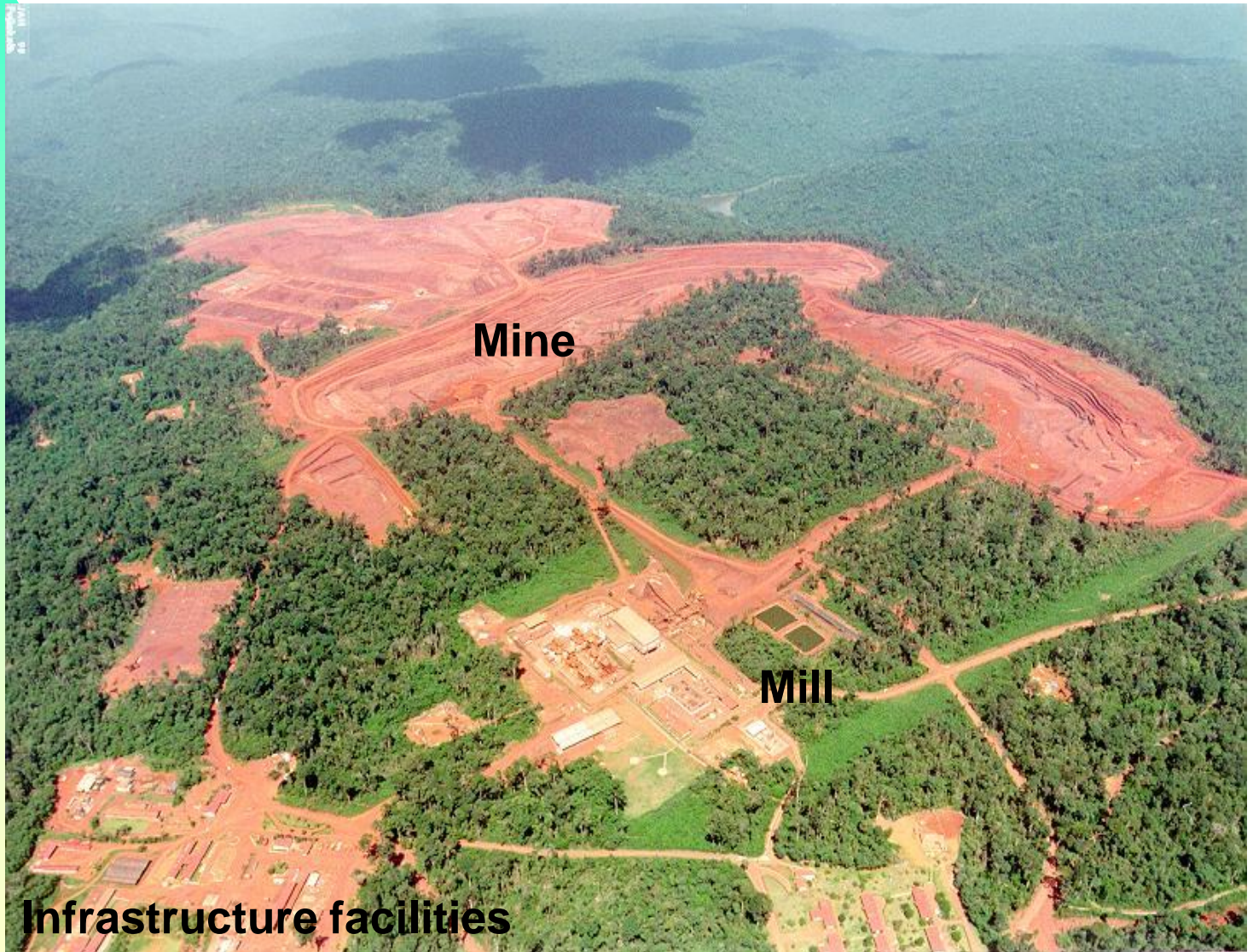


A gold mine in the Amazon

➔ Igarapé Bahia Mine

- Largest Brazilian gold mine
 - ✓ 10-12 tons of gold/year
- Very low cash cost
- Located in the Carajas Reserve
 - ✓ Forest reserve area owned by a mining company - CVRD
 - ✓ Only 0.4% of area occupied by mine activities
 - ✓ Preservation of area and native cultures

Aerial view of mine site





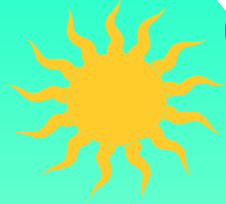
Mine





Processing installations





Grinding mills





Gold smelting furnace





Waste disposal





Summary

- ➔ Gold is an important resource to economy
- ➔ Gold ores are found in different types
- ➔ Processing is highly dependent on mineralogical characteristics
- ➔ Process design is a challenging activity
- ➔ Intelligent systems can be used to design and operate gold plants
 - ▣ **Advanced use of information technology in mineral industry is a key issue in the 21st century**