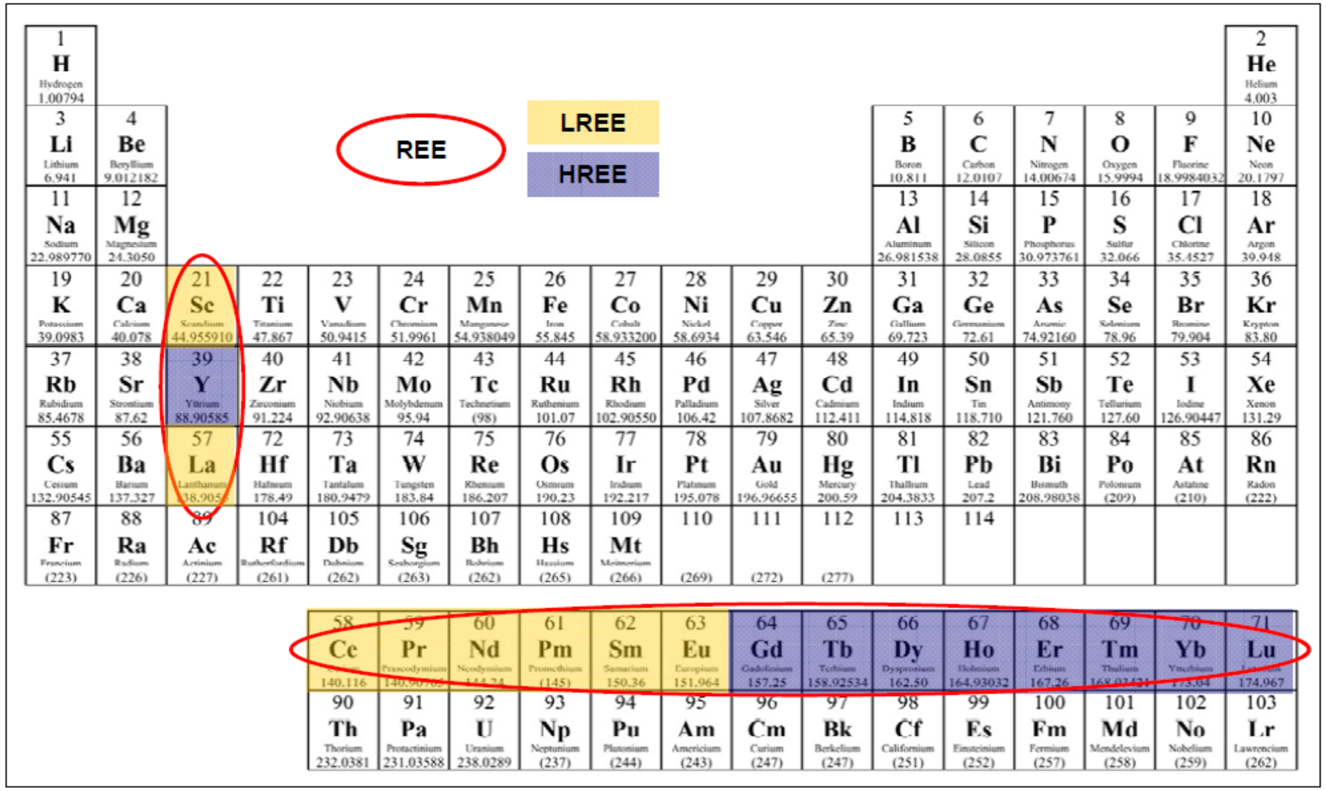
Rare Earth

Introduction to the Rare Earth Elements

- 15 lanthanides
- La through Lu
  - Pm is rare in nature – mostly human-made
- Plus scandium and yttrium are often included
- a.k.a. Rare Earth Minerals, Oxides, and/or Metals



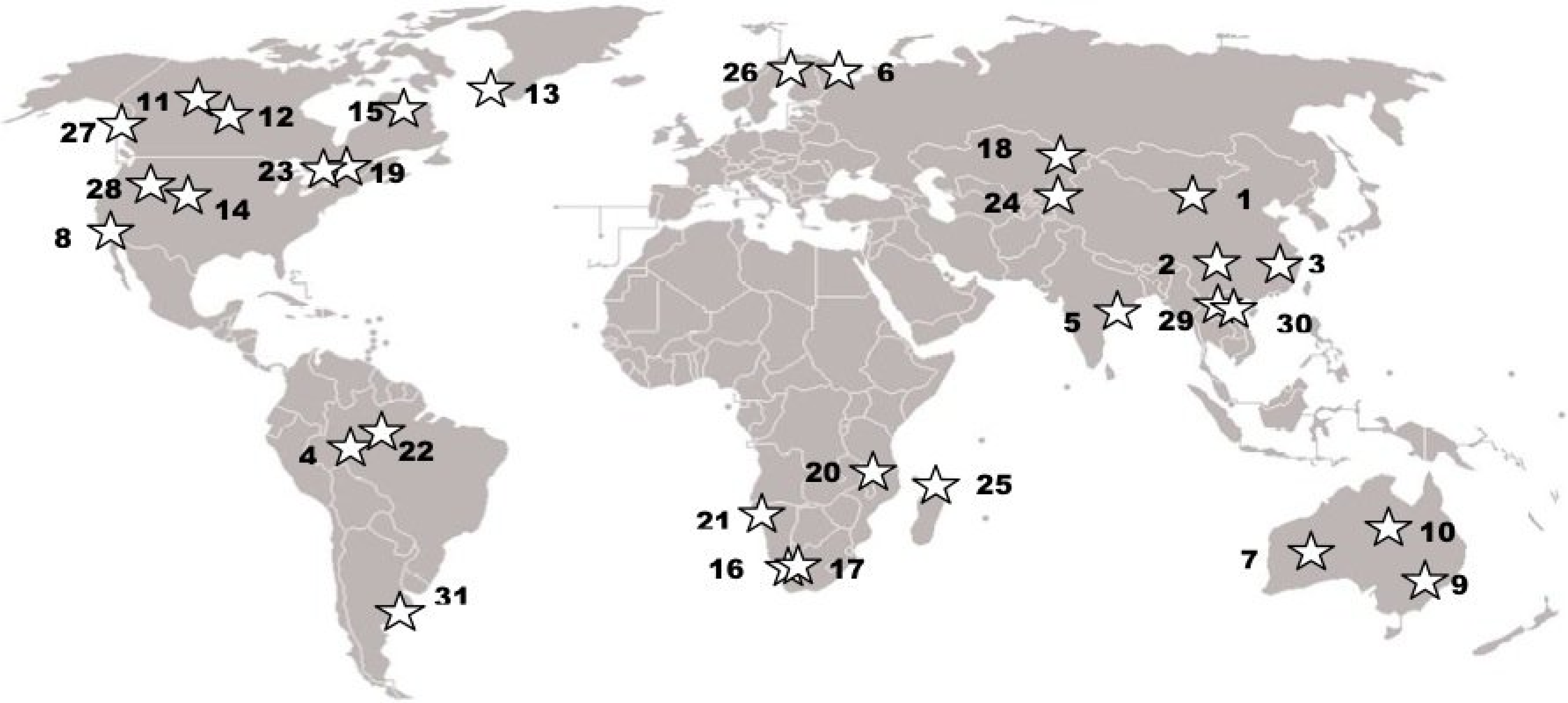
Periodic table of the elements showing the division between LREEs and HREEs (Schuler et al., 2011).

Scandium

Yttrium

RARE EARTH ELEMENTS

- **The rare earth metals include sixteen elements such as:**
- **yttrium (atomic number 39),**
- **lanthanum (57),**
- **Cerium (58),**
- **praseodymium (59),**
- **neodymium (60),**
- **promethium (61),**
- **samarium (62),**
- **europium (63),**
- **gadolinium (64),**
- **terbium (65),**
- **dysprosium (66),**
- **holmium (67),**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Technological applications of rare earths

- Rare earth metals and their compounds are in demand, and are often crucial for, a broad and rapidly expanding range of applications that rely upon their chemical, catalytic, electrical, magnetic, and optical properties.

- Rare earths are widely used for traditional sectors including metallurgy, petroleum, textiles, and agriculture.

- They are also becoming uniquely indispensable and critical in many high-tech industry such as hybrid cars, wind turbines, and compact fluorescent lights, flat screen televisions, mobile phones, disc drives, and defence technologies

Magnetics

Nd | Tb, Dy | Pr

Computer Hard Drives
Disk Drive Motors
Anti-Lock Brakes
Automotive Parts
Frictionless Bearings
Magnetic Refrigeration
Microwave Power Tubes
Power Generation
Microphones & Speakers
Communication Systems
MRI

Phosphors

Nd, Eu, Tb, Y | Er, Gd | Ce, Pr

Display phosphors - CRT, LPD, LCD
Fluorescent Lighting
Medical Imaging
Lasers
Fibre Optics

Metal Alloys

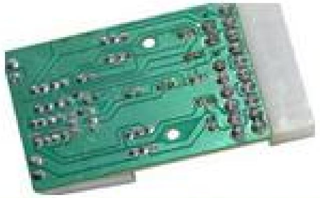
Nd, Y | La, Ce, Pr

NimH Batteries
Fuel Cells
Steel
Super Alloys
Aluminium / Magnesium

Catalysts

Nd | La, Ce, Pr

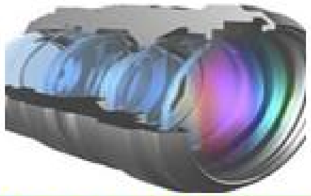
Petroleum Refining
Catalytic Converter
Fuel Additives
Chemical Processing
Air Pollution Controls



Ceramics

Nd, Y, Eu | Gd, Lu, Dy | La, Ce, Pr

Capacitors
Sensors
Colorants
Scintillators
Refractories



Glass & Polishing

Nd | Gd, Er, Ho | La, Ce, Pr

Polishing Compounds
Pigments & Coatings
UV Resistant Glass
Photo-Optical Glass
X-Ray Imaging

Defense

Nd, Eu, Tb, Dy, Y | Lu, Sm | Pr, La

Satellite Communications
Guidance Systems
Aircraft Structures
Fly-by-Wire
Smart Missiles

CREOs
HREOs
LREOs

Minerals

- **The two major minerals used as sources of rare earth metals are monazite (Ce-La-Nd-Pr phosphate) and bastnasite (Ce-La-Nd-Pr fluorcarbonate).**

- **Monazite is, or has been, mined in Australia, India, the United States, and other areas to a lesser degree.**

- **Bastnasite is primarily mined in the United States and China.**

- **Several other ores are mined for the rare earths as well, including xenotine, apatite, yttrofluorite, cerite, and gadolinite.**

Mineral Processing

- **Covert the as-mined ore into a product that may be marketed or treated further.**

- **This involves the removal of impurity compounds from the material being processed.**

- **For Rare Earths, this is complicated by the special operations required to separate the rare earths from each other (chemically).**

Monazite

In placer deposits, monazite may occur as a

- minor constituent along with sillimanite, garnet, and magnetite, while the major minerals are ilmenite, rutile, zircon and quartz.

- Other minerals that may occur in some locations are: cassiterite, chromite, picotite, baddeleyite, cinnabar, gold and platinum.

- Beach sand deposits may exhibit considerable variation and thus their flow sheets may be variable in detail.

- The next figure shows a general overview of beach sand processing.

Example Flow Sheet – Mineral Processing – Gravity, Magnetic and – Electrostatic Separations

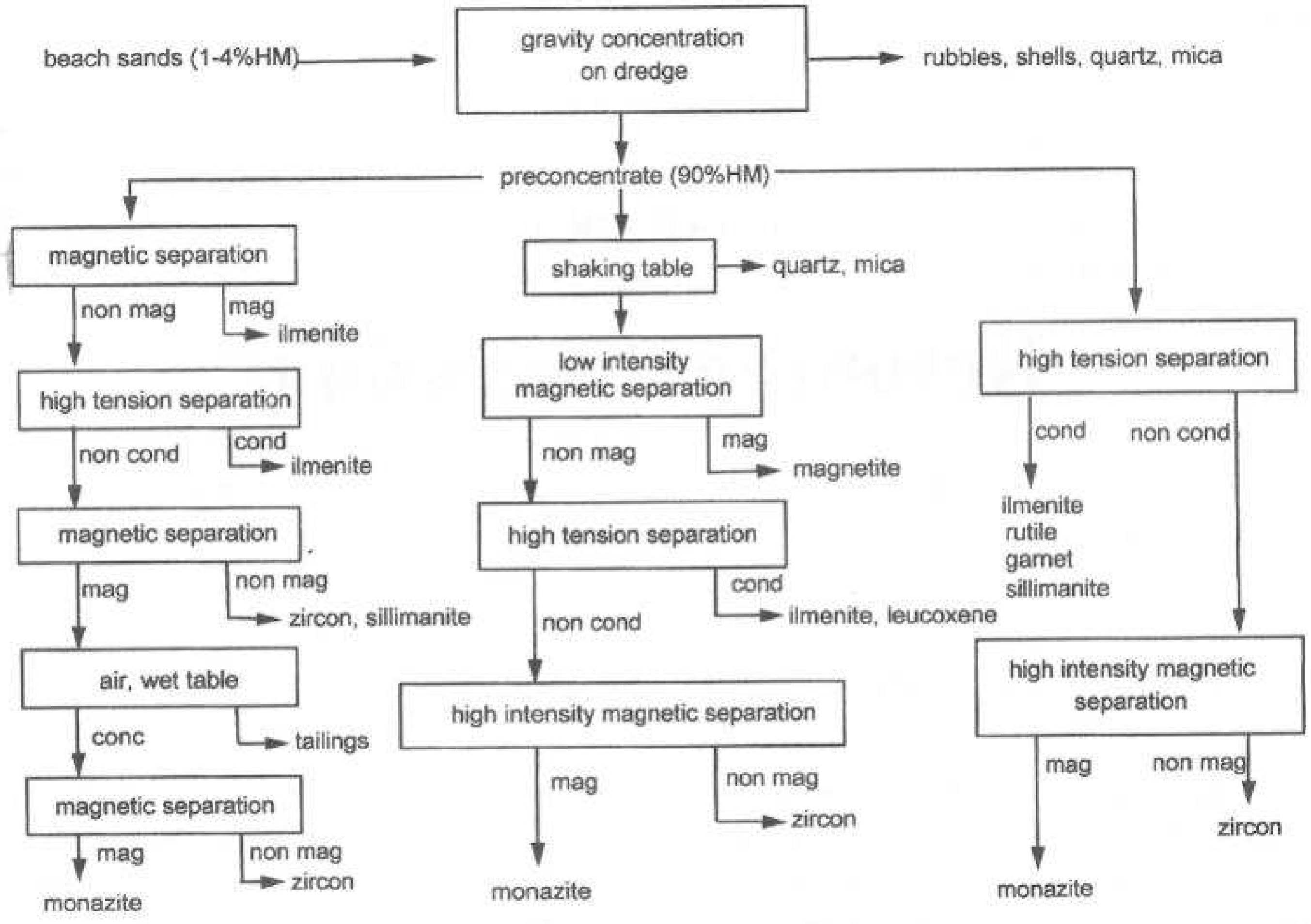


Figure 3.1 Physical beneficiation of beach sand minerals.

Monazite Ore Processing

- **The ore undergoes grinding, spiraling, or other similar operations for the initial coarse upgrading of the ore.**

- **Magnetic separation removes the magnetic ore constituents which can be processed separately or discarded as waste.**

- **The refined ore is then digested with sulfuric acid at 200- 220^{o}C.**

- **Rare earth sulfates and thorium sulfates are then dissolved and removed from the waste monazite solids by filtration.**

- **Rare earth elements are then precipitated as oxalates or sulfates. These precipitates undergo separations to form rare earth oxides.**

Mineral Separations

- The separation of heavy minerals exploits small differences in specific gravity, magnetic susceptibility and surface ionization potential (conductivity). Monazite is typically the heaviest.

- Ilmenite, garnet, xenotime and monazite, in decreasing order of magnetizability, behave as magnetic minerals. Xenotime is more strongly magnetic than monazite.

- In electrostatic separations, ilmenite and rutile act as conducting materials. Xenotime is a poor conductor and can be separated from ilmenite.

- Leucoxene can cause problems in the separation of monazite from ilmenite. A reduction roast of at 600 c converts the iron oxide in leucoxene into magnetite and enables easy separation.

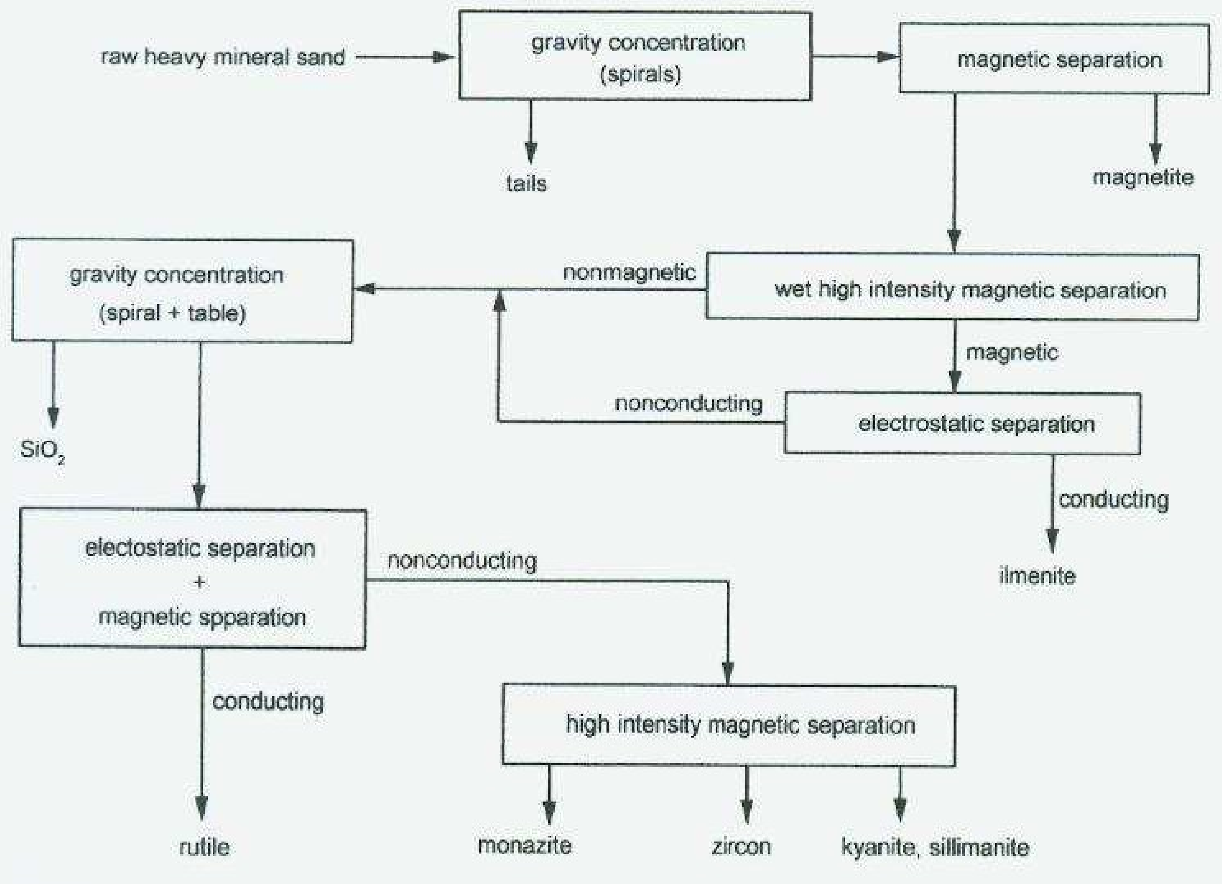


Figure 3.4 Beneficiation of coarse heavy mineral sand from Congolone, Mozambique (Ferron et al. 1991).

BASTNASITE ORE PROCESSING

- Bastnasite mining near Mountain Pass in southeastern California may be a the major source of rare earth metals in the U.S. again.
- The previous recovery process of the rare earths from this ore is shown in the following figure.
- The ore was initially crushed, ground, classified, and concentrated by flotation to increase the rare earth concentrations from about 5% to about 60% (REO).
- The concentrated bastnasite undergoes an acid (HCl) digestion to produce several rare earth chlorides.
- The resulting slurry is filtered and the solution is treated with sodium hydroxide to produce rare earth hydroxides.
- This rare earth hydroxide cake is chlorinated, converting the hydroxides to chlorides.
- Final filtration and evaporation yields the solid rare earth chloride products.

Mountain Pass Flotation

- 30-35% solids. Rougher flotation brings the grade from about 9% to 20% REO. Tails are 1-2% REO.
- Four stage cleaning is used – tailings are re circulated.
- The scavenger cons are reground and recirculated to roughers.
- After four stage cleaning, the final concentrate is thickened, filtered and dried
- The grade is 60% REO and the recovery is 65-70%

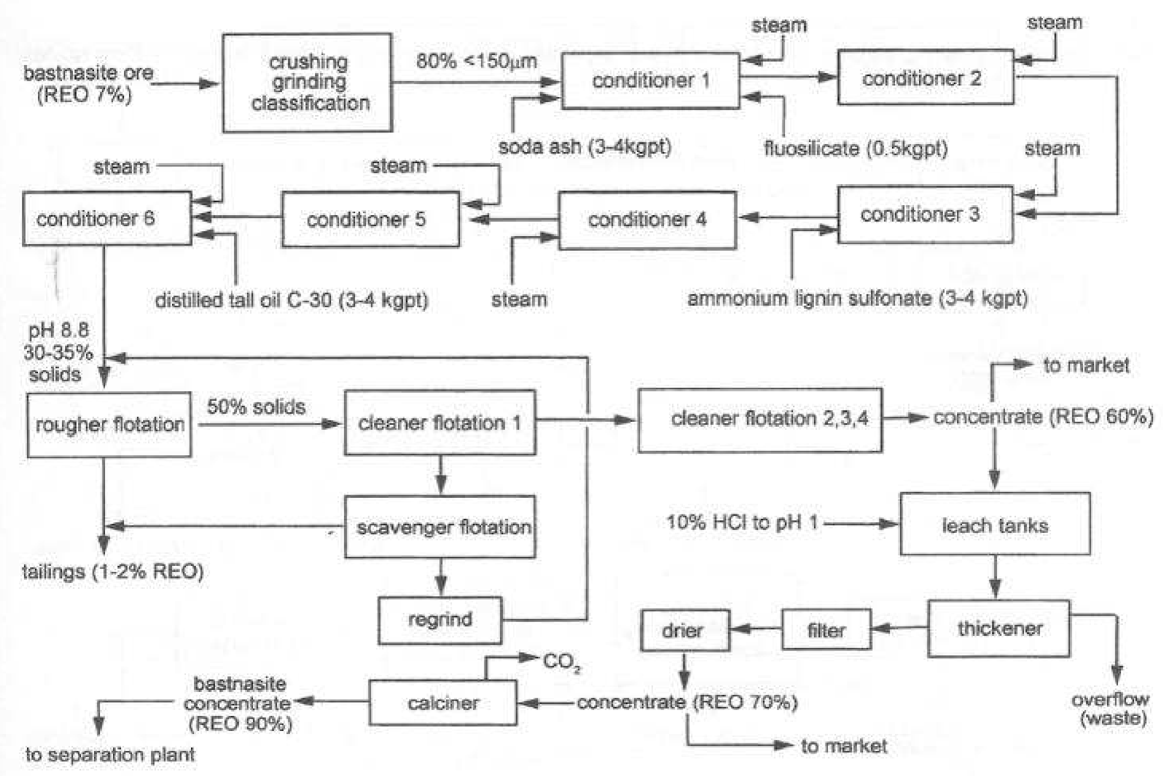


Figure 3.9 Simplified flowsheet for the recovery of bastnasite at the Molycorp plant (Aplan 1988).