

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



1 H Hydrogen 1.00794																	2 He Helium 4.003																												
3 Li Lithium 6.941	4 Be Beryllium 9.012182	<div style="border: 1px solid red; border-radius: 50%; width: 40px; height: 40px; display: flex; align-items: center; justify-content: center; margin: 0 auto;"> REE </div> <div style="background-color: yellow; padding: 2px; margin: 2px; display: inline-block;">LREE</div> <div style="background-color: blue; padding: 2px; margin: 2px; display: inline-block;">HREE</div>										5 B Boron 10.811	6 C Carbon 12.0107	7 N Nitrogen 14.00674	8 O Oxygen 15.9994	9 F Fluorine 18.9984032	10 Ne Neon 20.1797																												
11 Na Sodium 22.989770	12 Mg Magnesium 24.3050																	13 Al Aluminum 26.981538	14 Si Silicon 28.0855	15 P Phosphorus 30.973761	16 S Sulfur 32.066	17 Cl Chlorine 35.4527	18 Ar Argon 39.948																						
19 K Potassium 39.0983	20 Ca Calcium 40.078	21 Sc Scandium 44.955910	22 Ti Titanium 47.867	23 V Vanadium 50.9415	24 Cr Chromium 51.9961	25 Mn Manganese 54.938049	26 Fe Iron 55.845	27 Co Cobalt 58.933200	28 Ni Nickel 58.6934	29 Cu Copper 63.546	30 Zn Zinc 65.39	31 Ga Gallium 69.723	32 Ge Germanium 72.61	33 As Arsenic 74.92160	34 Se Selenium 78.96	35 Br Bromine 79.904	36 Kr Krypton 83.80																												
37 Rb Rubidium 85.4678	38 Sr Strontium 87.62	39 Y Yttrium 88.90585	40 Zr Zirconium 91.224	41 Nb Niobium 92.90638	42 Mo Molybdenum 95.94	43 Tc Technetium (98)	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.90550	46 Pd Palladium 106.42	47 Ag Silver 107.8682	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.710	51 Sb Antimony 121.760	52 Te Tellurium 127.60	53 I Iodine 126.90447	54 Xe Xenon 131.29																												
55 Cs Cesium 132.90545	56 Ba Barium 137.327	57 La Lanthanum 138.90547	72 Hf Hafnium 178.49	73 Ta Tantalum 180.9479	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platinum 195.078	79 Au Gold 196.96655	80 Hg Mercury 200.59	81 Tl Thallium 204.3833	82 Pb Lead 207.2	83 Bi Bismuth 208.98038	84 Po Polonium (209)	85 At Astatine (210)	86 Rn Radon (222)																												
87 Fr Francium (223)	88 Ra Radium (226)	89 Ac Actinium (227)	104 Rf Rutherfordium (261)	105 Db Dubnium (262)	106 Sg Seaborgium (263)	107 Bh Bohrium (262)	108 Hs Hassium (265)	109 Mt Meitnerium (266)	110 (269)	111 (272)	112 (277)	113	114																																
<div style="border: 1px solid red; border-radius: 50%; width: 80%; margin: 0 auto; padding: 5px;"> <table border="1" style="width: 100%; text-align: center;"> <tr> <td>58 Ce Cerium 140.116</td> <td>59 Pr Praseodymium 140.90768</td> <td>60 Nd Neodymium 144.24</td> <td>61 Pm Promethium (145)</td> <td>62 Sm Samarium 150.36</td> <td>63 Eu Europium 151.964</td> <td>64 Gd Gadolinium 157.25</td> <td>65 Tb Terbium 158.92534</td> <td>66 Dy Dysprosium 162.50</td> <td>67 Ho Holmium 164.93032</td> <td>68 Er Erbium 167.26</td> <td>69 Tm Thulium 168.93403</td> <td>70 Yb Ytterbium 173.054</td> <td>71 Lu Lutetium 174.967</td> </tr> <tr> <td>90 Th Thorium 232.0381</td> <td>91 Pa Protactinium 231.03588</td> <td>92 U Uranium 238.0289</td> <td>93 Np Neptunium (237)</td> <td>94 Pu Plutonium (244)</td> <td>95 Am Americium (243)</td> <td>96 Cm Curium (247)</td> <td>97 Bk Berkelium (247)</td> <td>98 Cf Californium (251)</td> <td>99 Es Einsteinium (252)</td> <td>100 Fm Fermium (257)</td> <td>101 Md Mendelevium (258)</td> <td>102 No Nobelium (259)</td> <td>103 Lr Lawrencium (262)</td> </tr> </table> </div>																		58 Ce Cerium 140.116	59 Pr Praseodymium 140.90768	60 Nd Neodymium 144.24	61 Pm Promethium (145)	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.92534	66 Dy Dysprosium 162.50	67 Ho Holmium 164.93032	68 Er Erbium 167.26	69 Tm Thulium 168.93403	70 Yb Ytterbium 173.054	71 Lu Lutetium 174.967	90 Th Thorium 232.0381	91 Pa Protactinium 231.03588	92 U Uranium 238.0289	93 Np Neptunium (237)	94 Pu Plutonium (244)	95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (251)	99 Es Einsteinium (252)	100 Fm Fermium (257)	101 Md Mendelevium (258)	102 No Nobelium (259)	103 Lr Lawrencium (262)
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Scandium

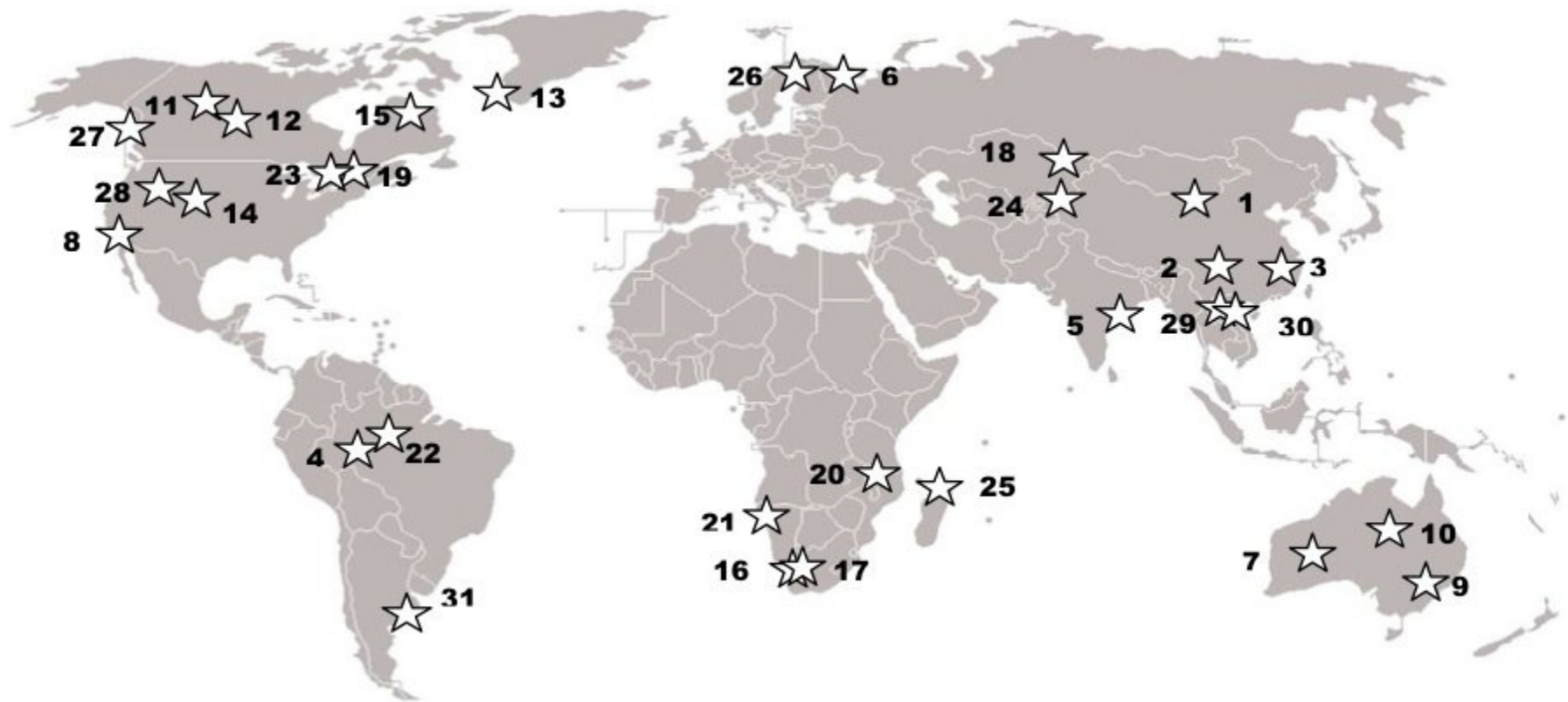


Yttrium

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

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),**



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

CREOs

HREOs

LREOs



Phosphors

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

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



Ceramics

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

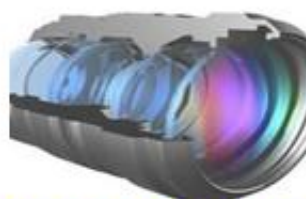
- Capacitors
- Sensors
- Colorants
- Scintillators
- Refractories



Metal Alloys

Nd, Y La, Ce, Pr

- NimH Batteries
- Fuel Cells
- Steel
- Super Alloys
- Aluminium / Magnesium



Glass & Polishing

Nd Gd, Er, Ho La, Ce, Pr

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



Catalysts

Nd La, Ce, Pr

- Petroleum Refining
- Catalytic Converter
- Fuel Additives
- Chemical Processing
- Air Pollution Controls



Defense

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

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

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 xenotime, apatite, yttrifluorite, 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

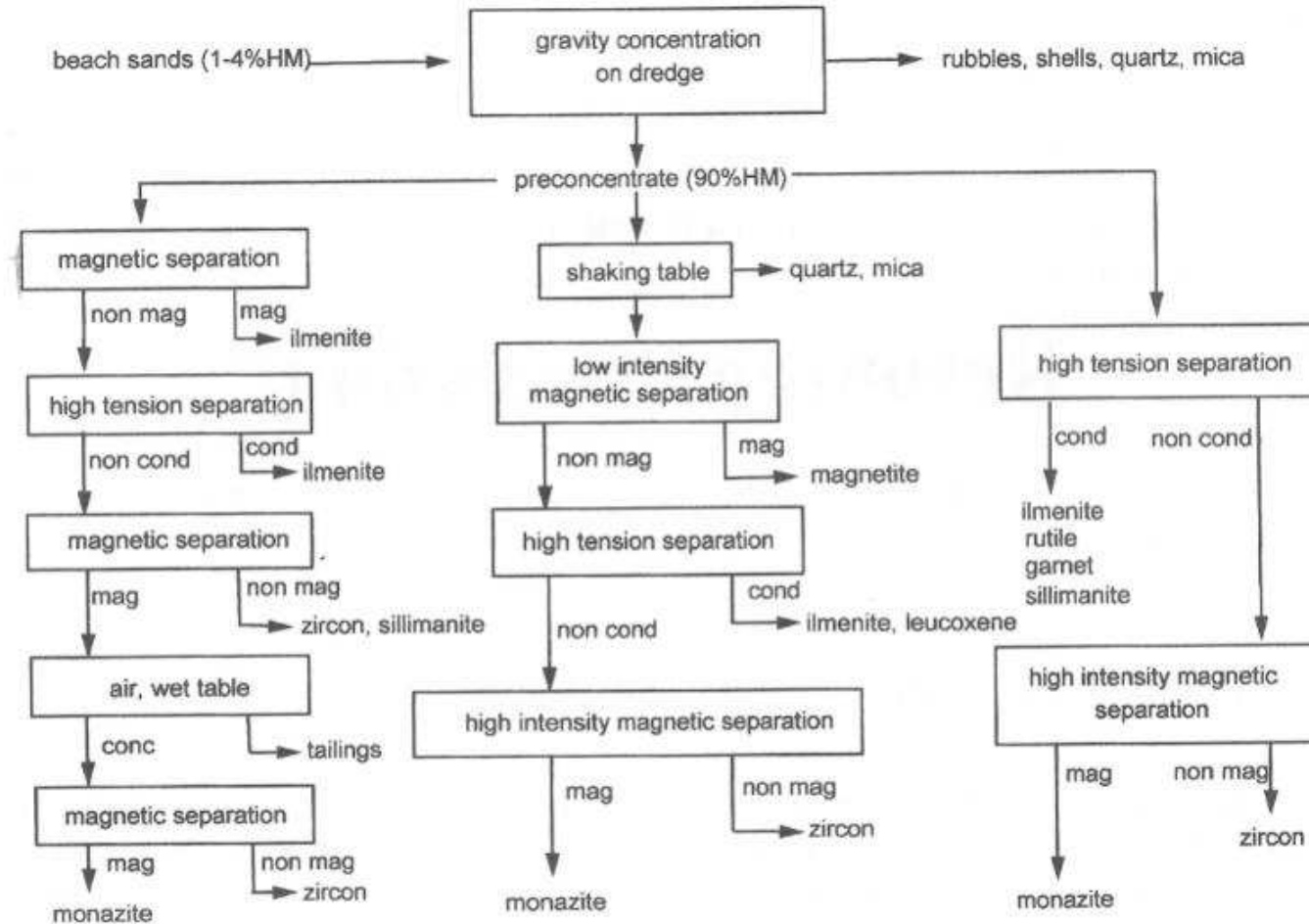


Figure 3.1 Physical beneficiation of beach sand minerals.

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°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.

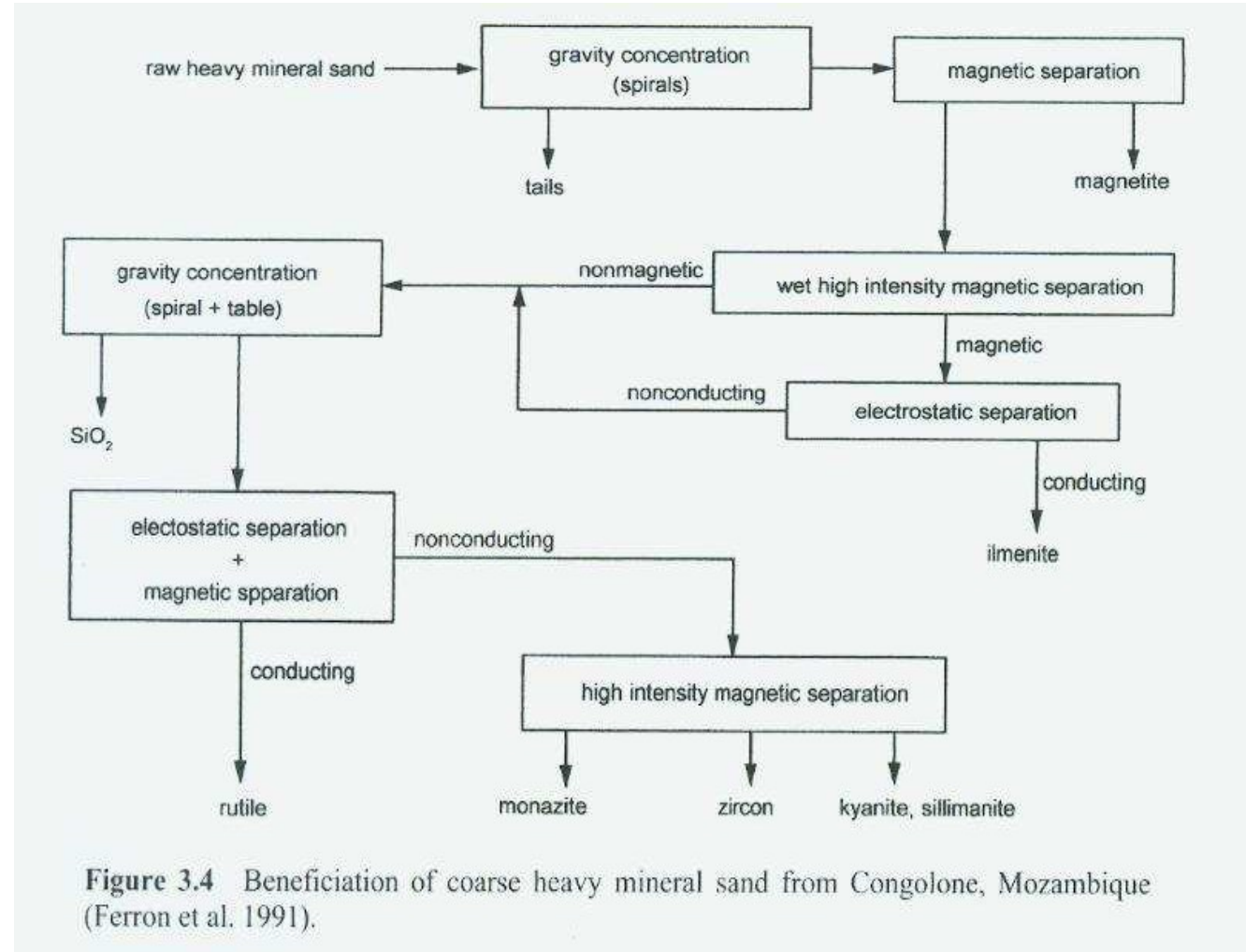


Figure 3.4 Beneficiation of coarse heavy mineral sand from Congolone, Mozambique (Ferron et al. 1991).

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 recirculated.
- 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%

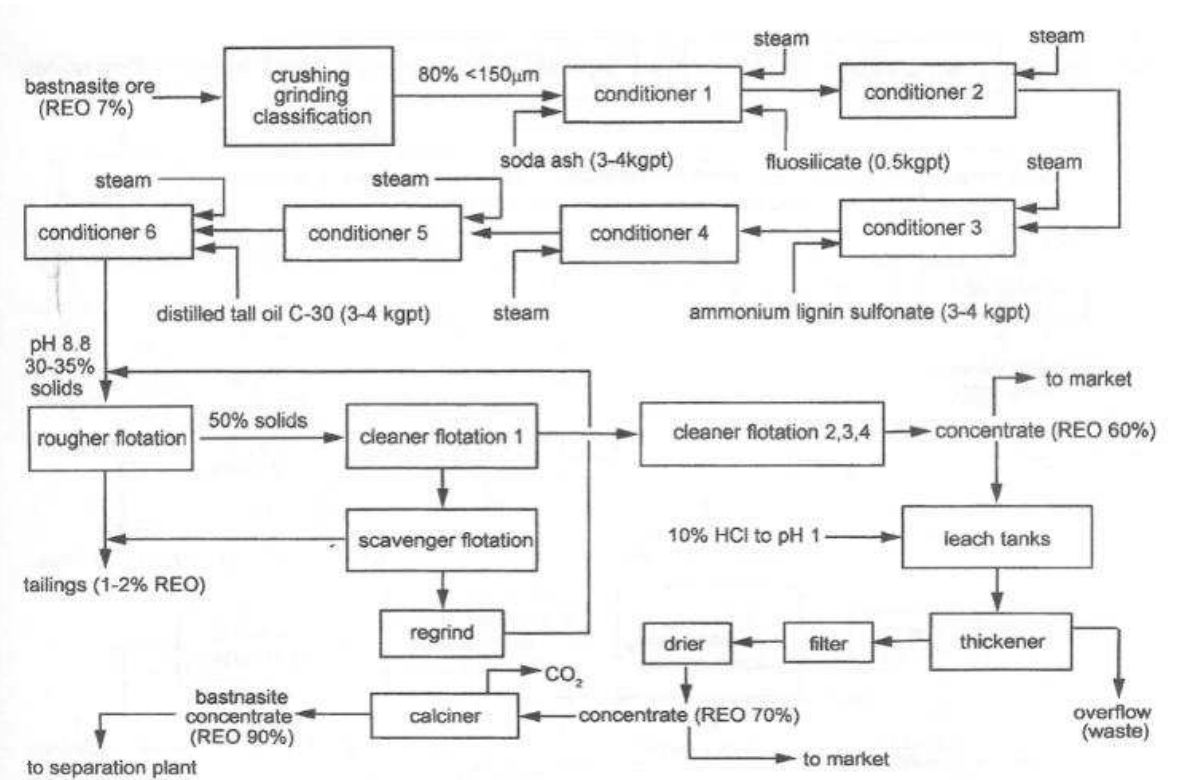


Figure 3.9 Simplified flowsheet for the recovery of bastnasite at the Molycorp plant (Aplan 1988).