# ME571/GEOL571 GEOLOGY AND ECONOMICS OF STRATEGIC AND CRITICAL MINERALS COMMODITIES: REE

Virginia T. McLemore

# ASSIGNMENT

- Field reports due April 9 (Lemitar)
- Special project, Caballo Mountains, report and presentation due April 29
- McLemore, V. T., 1986, Geology, geochemistry, and mineralization of syenites in the Red Hills, southern Caballo Mountains, Sierra County, New Mexico: MGS, Guidebook 37, p. 151-159.
- McMillan, N. J. and McLemore, V. T., 2004, Cambrian-Ordovician Magmatism and Extension in New Mexico and Colorado: NMBGMR, Bulletin 160, 12 p., http://geoinfo.nmt.edu/publications/bulletins/160/downloads/01mcmill.pdf
- McLemore, V.T., et all, 2012, Intermittent Proterozoic plutonic magmatism and Neoproterozoic cooling history in the Caballo Mountains, Sierra County, New Mexico; Preliminary Results: New Mexico Geological Society Guidebook 63, p. 235-248, https://nmgs.nmt.edu/publications/guidebooks/papers.cfml?v=63&file=63_p0235_p0248.pdf

# TYPES OF REE DEPOSITS

# TYPES OF REE DEPOSITS

- Alkaline/peralkaline Igneous Rocks
- Carbonatites
- Pegmatites
- Iron oxide Cu-Au (REE)
  - Magnetite ore bodies
- Porphyry Mo
- Metamorphic/ metasomatic
- Paleoplacer/placer/ beach sands
- Colluvial REE
- Residual
  - Stratiform phosphate residual
  - Ion adsorption clays/laterite/bauxite
- REE-Th-U Hydrothermal Veins
- Unconformity uranium deposits
- Quartz-pebble conglomerate deposits
- Collapse breccia pipes
- Sea floor muds
- Other REE-Bearing Deposits

# ALKALINE/PERALKALINE IGNEOUS ROCKS

# >791 Alkaline/peralkaline igneous rock complexes

# DEFINITION

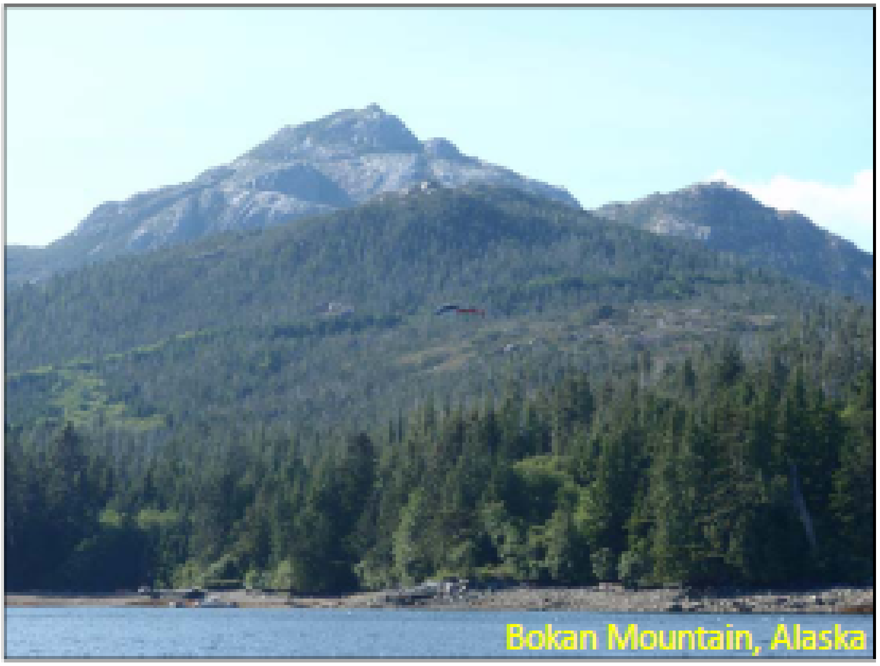
- Deficient in $SiO_2$ relative to $Na_2O$, $K_2O$, and CaO
- Peralkaline=$Na_2O+K_2O>Al_2O_3$ (excess Al)
- Peraluminous=$Al_2O_3>Na_2O+K_2O$

# Alkaline Intrusion-Related Deposits

- Associated with alkaline or peralkaline igneous complexes

  **Peralkaline:** $Na_2O + K_2O > Al_2O_3$

- Structural control on the veins, dikes & breccias
- In zoned alkaline intrusive complexes, REE veins, dikes, and breccia bodies are late phases.
- The REE are "incompatible elements", such as Th, Nb, and Zr, that do not tend to participate in the earlier mineral-forming events.

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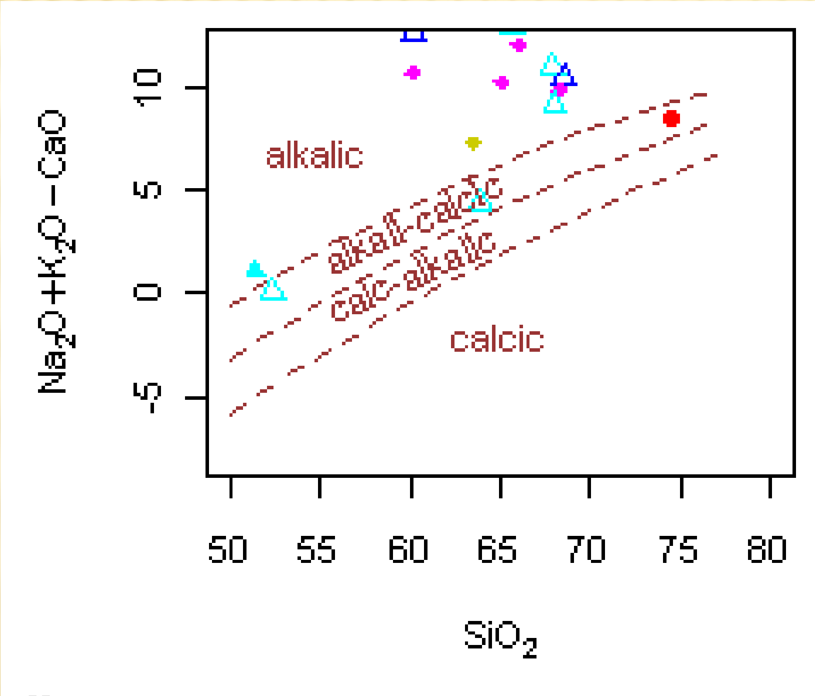
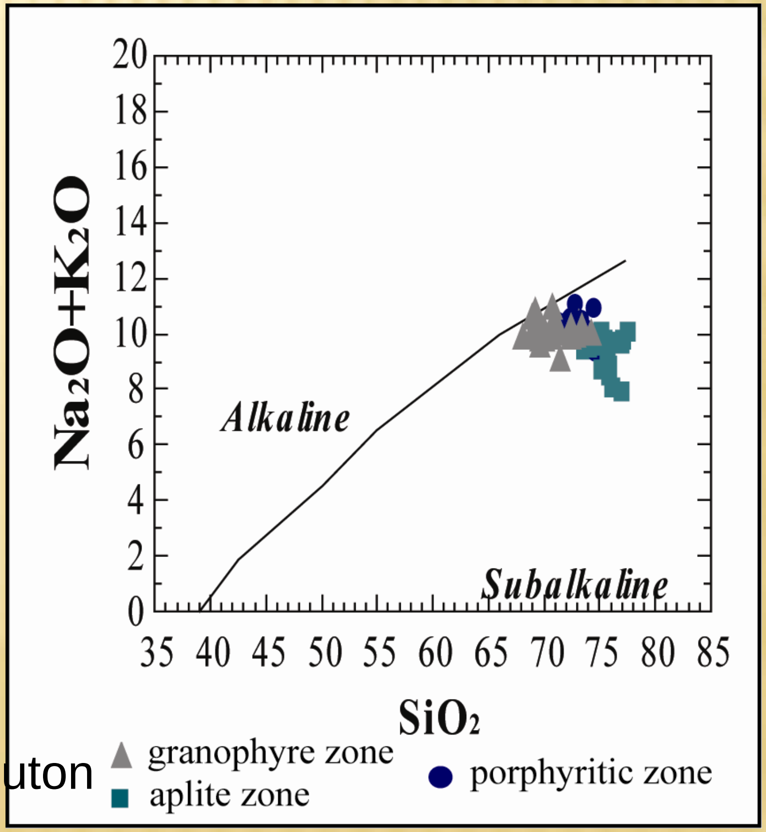
# ALKALINE IGNEOUS ROCKS

- Igneous rocks with $Na_2O+K_2O>0.3718(SiO_2)-14.5$
- Igneous rocks with mol $Na_2O$+mol $K_2O$>mol $Al_2O_3$




Gallinas Mountains




Capitan pluton

# ALKALINE/PERALKALINE IGNEOUS ROCKS

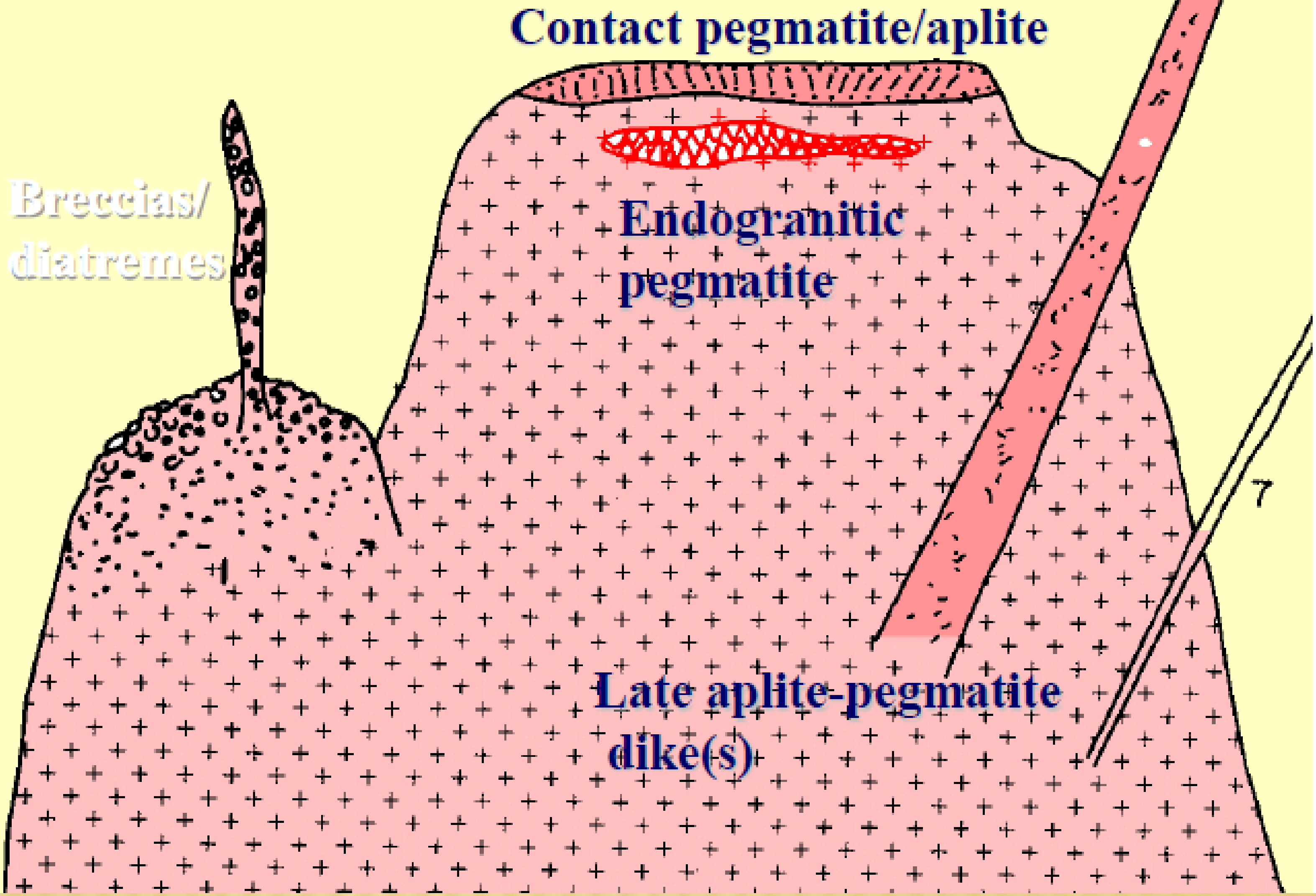
- Cooling of magmas derived by partial melting of rocks
- Enriched in Zr, Nb, Sr, Ba, Li, REE, U, Th
- None are currently being mined for REE
- Examples Bokan Mountain, southeastern Alaska; Thor Lake, Strange Lake and Kipawa Lake in Canada; Kola Peninsula, Russia; and Ilímaussaq, Greenland
- Contain a variety of ore minerals that are usually either REE-bearing carbonates, phosphates, or fluorates
- Complex replacements of minerals
- Associated with metasomatic alteration called fenitization
  - Alkali-rich fluids from the crystallizing magma, converts the host rock minerals to an assemblage of alkali-bearing minerals (either K- or Na-rich)

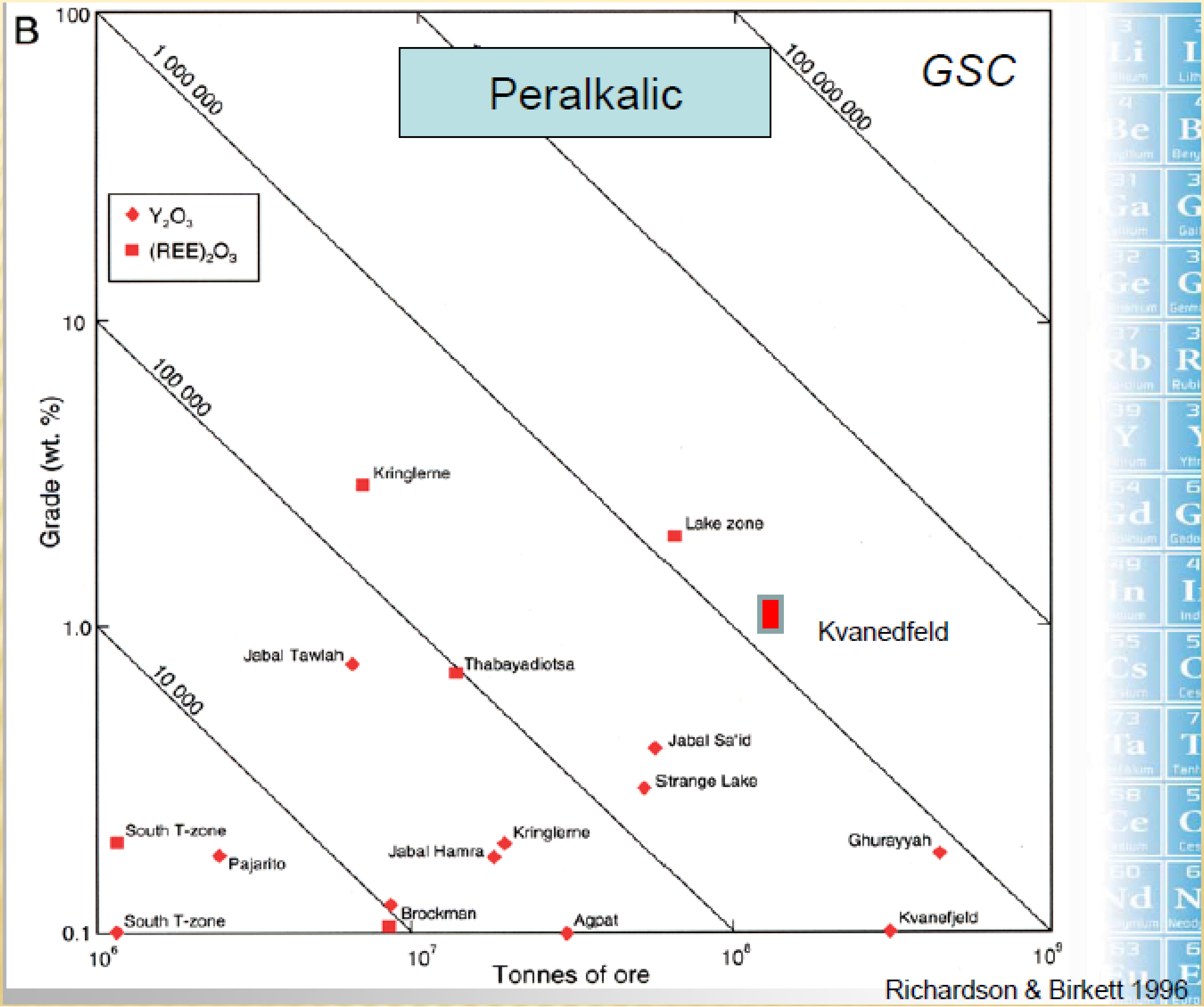
According to Richardson and Birkett (1996) other comparable rare metal deposits associated with peralkaline rocks include:

- Strange Lake, Canada (zircon, yttrium, beryllium, niobium, REE)
- Mann, Canada (beryllium, niobium)
- Illimausaq, Greenland (zircon, yttrium, REE, niobium, uranium, beryllium)
- Motzfeldt, Greenland (niobium, tantalum, zircon)
- Lovozero, Russia (niobium, zircon, tantalum, REE)
- Brockman, Australia (zircon, yttrium, niobium, tantalum)

# Model for Peralkalic Magma Systems

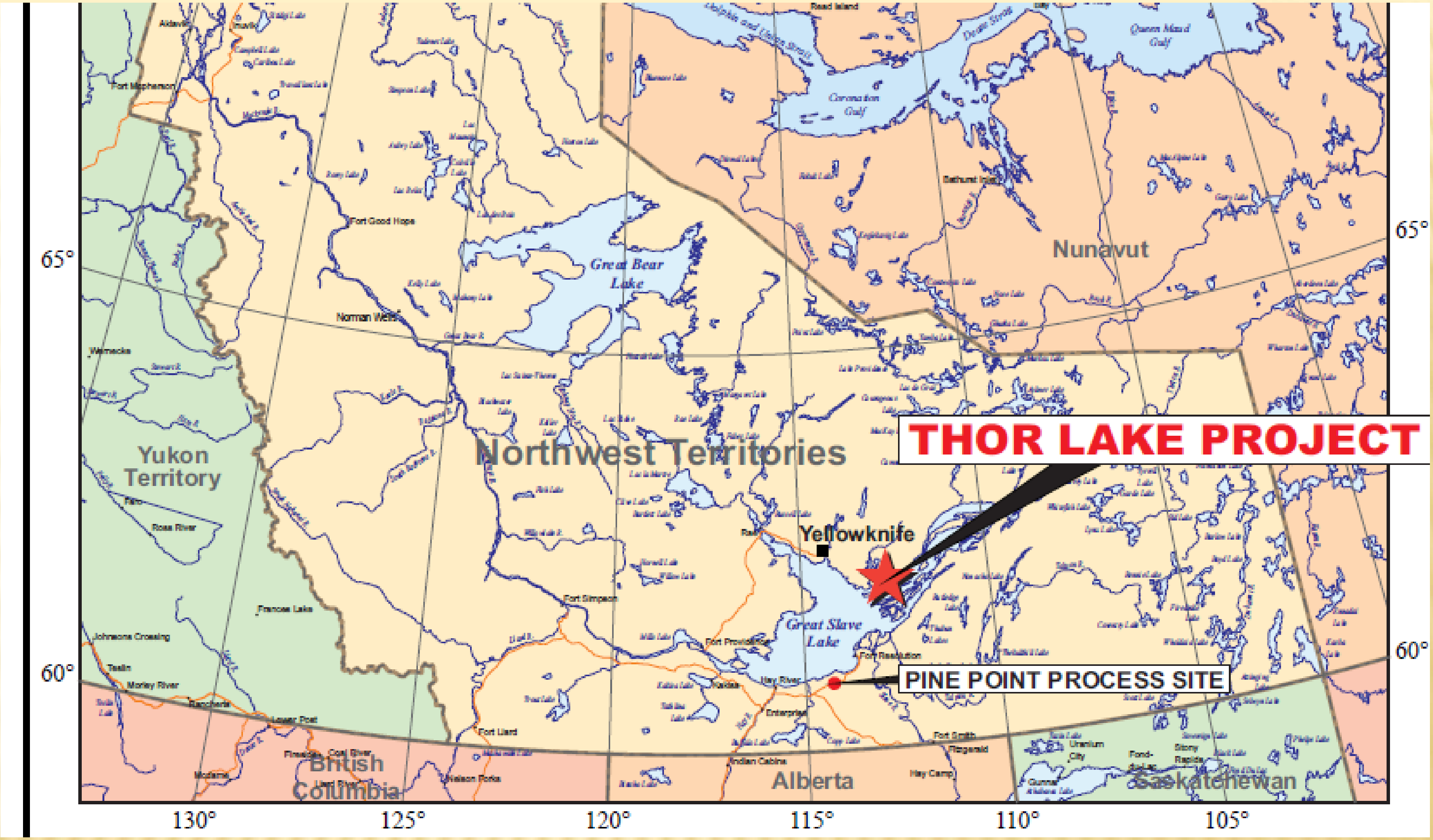
Jackson et al. 1985





Richardson & Birkett 1996

# THOR LAKE (NECHALACHO RARE EARTH ELEMENT PROJECT), NORTHWEST TERRITORIES, CANADA


THOR LAKE PROJECT
PINE POINT PROCESS SITE
Northwest Territories
Yukon Territory
Nunavut
British Columbia
Alberta
Saskatchewan
Yellowknife
Great Slave Lake
Great Bear Lake
Coronation Gulf
Queen Maud Gulf
Fort Good Hope
Norman Wells
Fort Simpson
Fort Providence
Fort Resolution
Hay River
Enterprise
Fort Smith
Fort Liard
Fort McPherson
Frances Lake
Johnsons Crossing
Teslin
Ross River
Faro
Uranium City
Fort McPherson
Bathurst Inlet
65°
60°
130°
125°
120°
115°
110°
105°

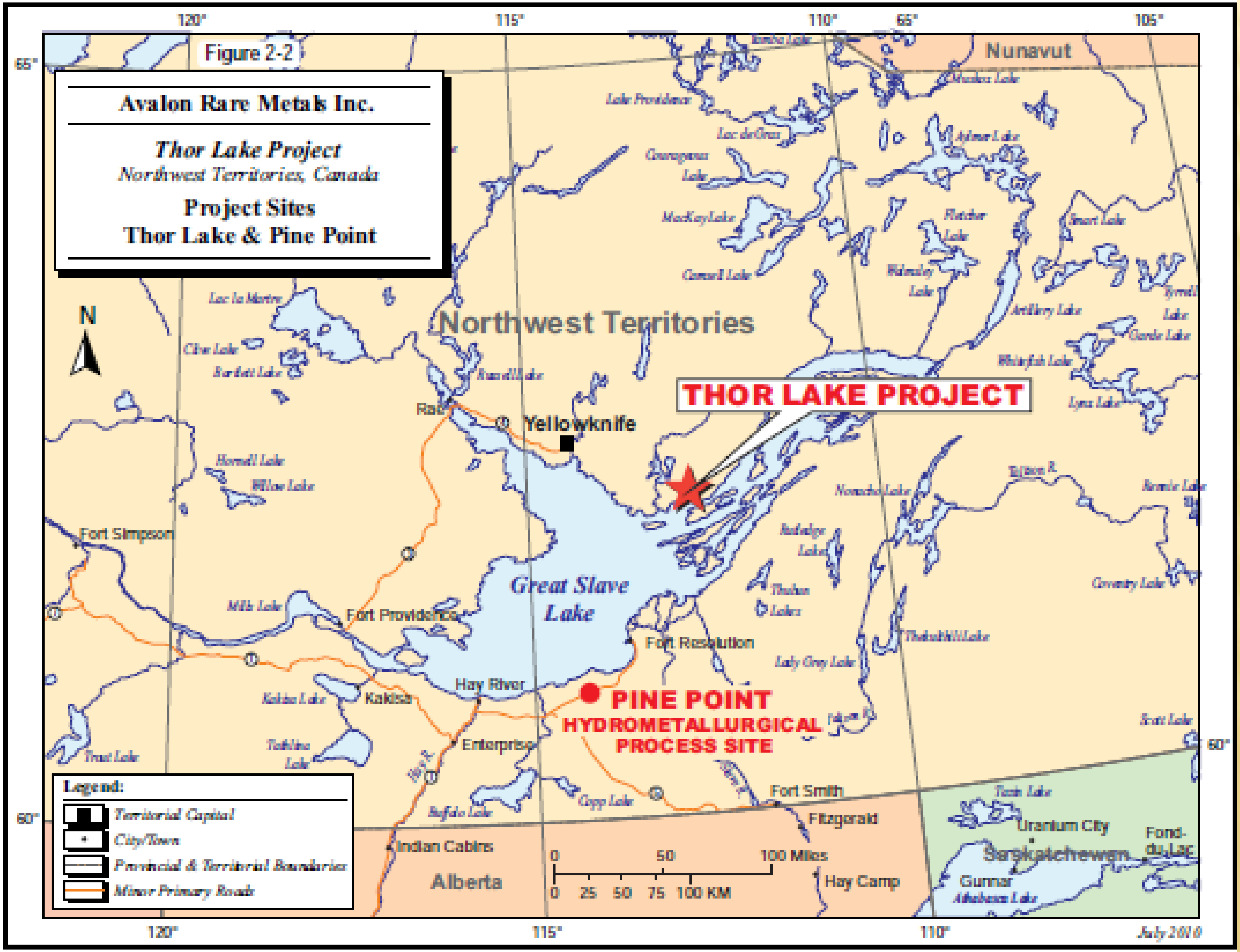


Figure 2-2
Avalon Rare Metals Inc.
Thor Lake Project
Northwest Territories, Canada
Project Sites
Thor Lake & Pine Point
Northwest Territories
Nunavut
THOR LAKE PROJECT
Yellowknife
Great Slave Lake
PINE POINT
HYDROMETALLURGICAL
PROCESS SITE
Fort Simpson
Fort Providence
Fort Resolution
Hay River
Kakisa
Enterprise
Fort Smith
Fitzgerald
Indian Cabins
Alberta
Saskatchewan
Uranium City
Fond-du-Lac
Gunnar
Hay Camp
Rae
N
0 50 100 Miles
0 25 50 75 100 KM
Legend:
Territorial Capital
City/Town
Provincial & Territorial Boundaries
Minor Primary Roads
120°
115°
110°
105°
65°
60°
July 2010

# THOR LAKE

- Discovered in 1976
- Highland Resources Ltd. 1976-2004 >$12 mill
- Placer Development Ltd (now Placer Dome Inc.) 1980-1981
- Highland 1983
- Hecla Mining Co of Canada 1986
- 2001 Navigator Exploration Corp 2001
- Avalon 2005 purchased

# THOR LAKE

- Peralkaline Blackford Lake intrusion, ~2.14 Ga
- Syenites, granites, and gabbros, with pegmatites and a core of nepheline-sodalite syenite
- 5 distinct zones (tabular zones)
  - Nechalacho
  - North T
  - South T
  - S
  - R
- Nepheline-sodalite syenite at Nechalacho
- complex interplay of magmatic and hydrothermal processes

SHEARD ET AL., 2012

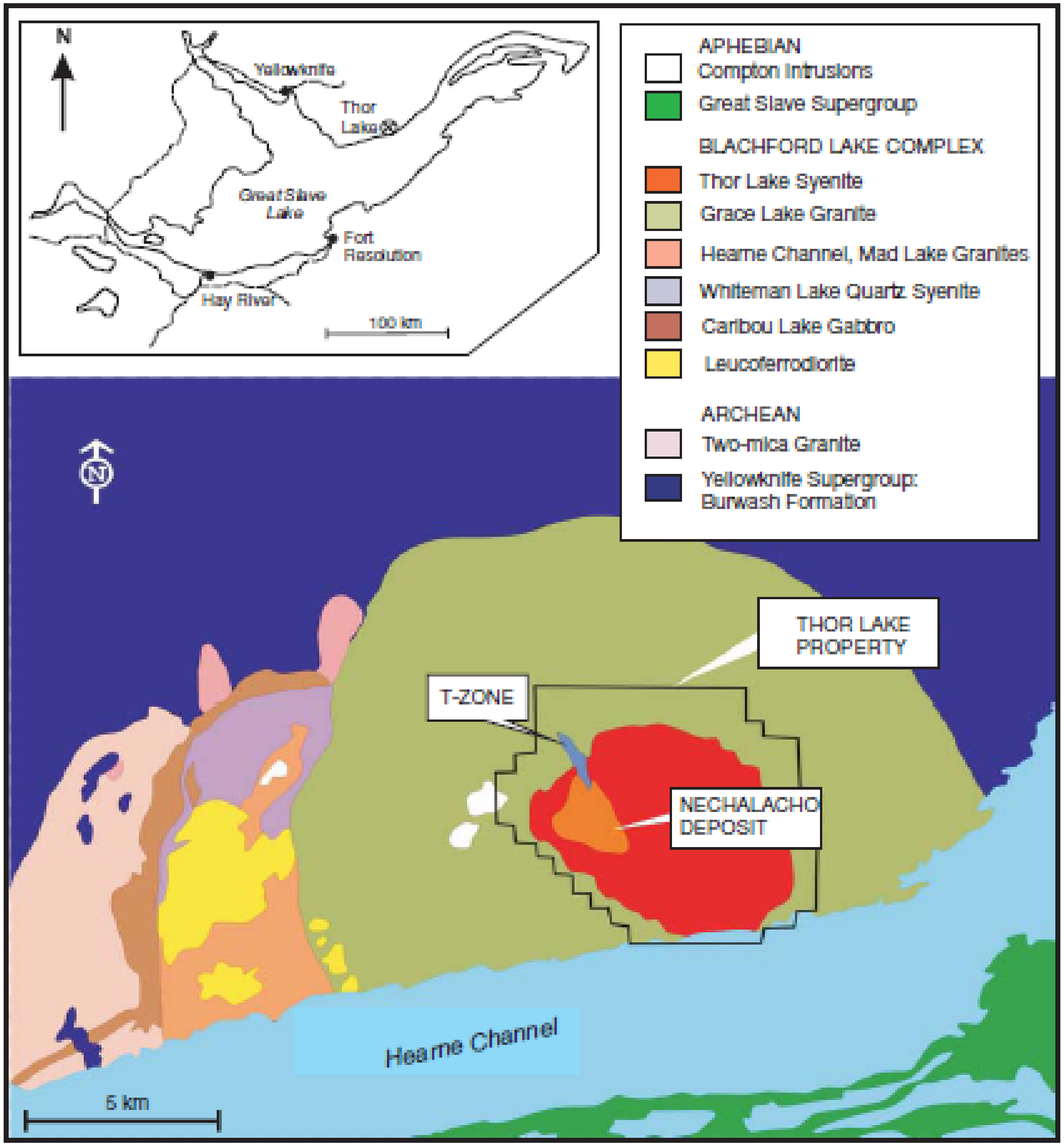
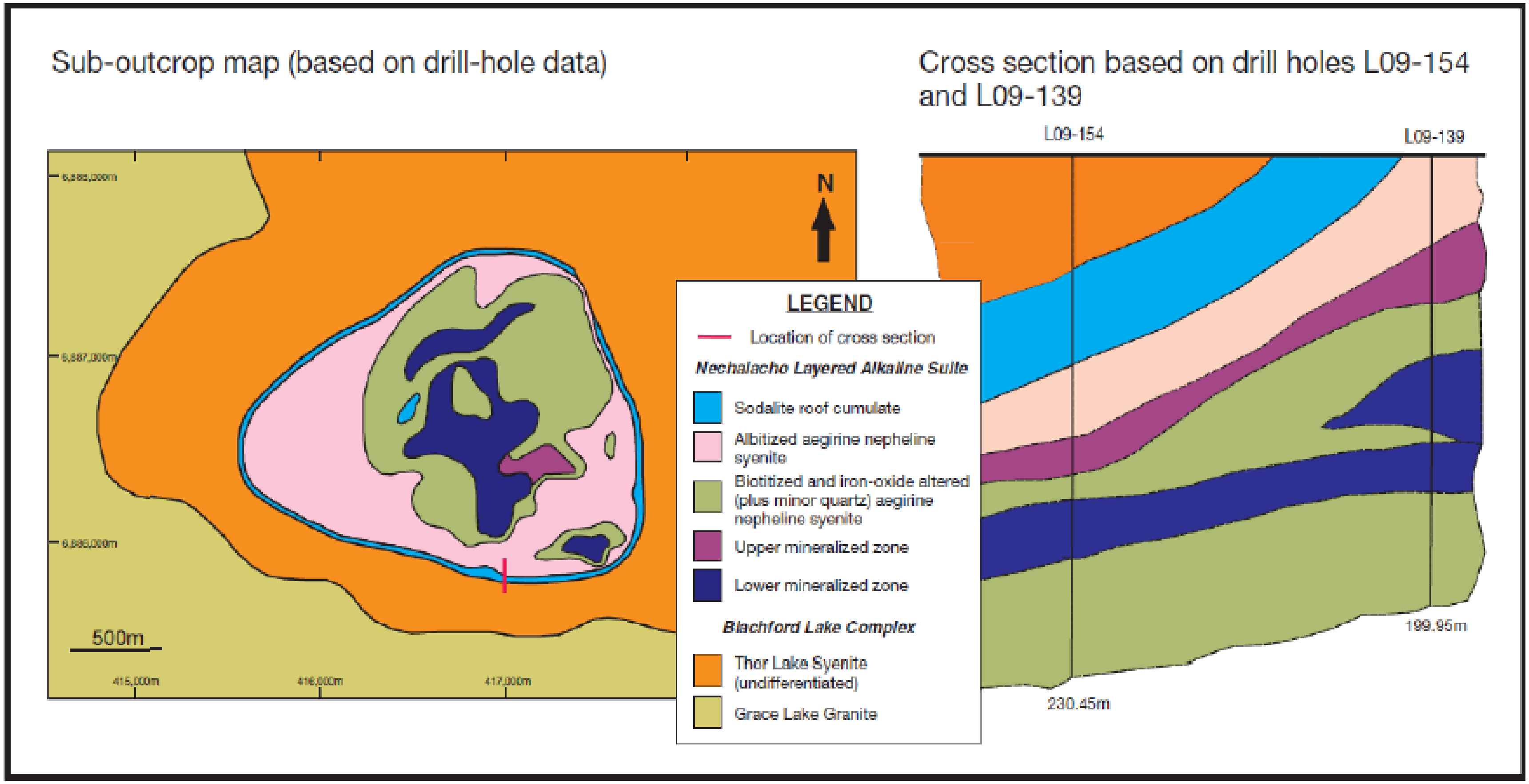



FIG. 1. Geologic map of the Blachford Lake Intrusive Complex, showing the location of the Nechalacho deposit and T zone within the Thor Lake rare metal deposit (modified after Davidson, 1982).

# Thor Lake, NWT, Canada




From: Sheard, E.R., Williams-Jones, A.E., Heiligmann, M., Pederson, C., and Trueman, D.L., 2012, Economic Geology, v. 107, p. 81-104.

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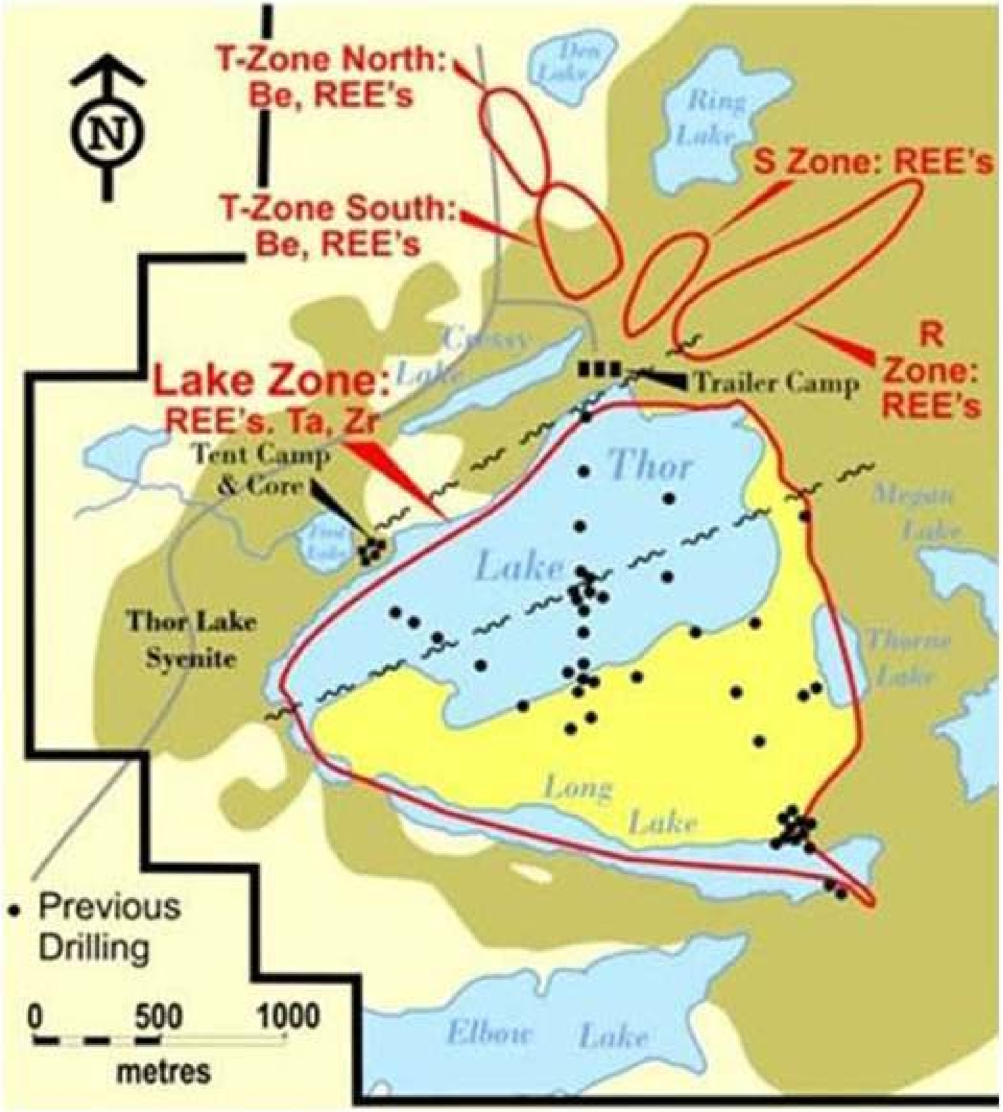
# Rare Metal Zones at Thor Lake

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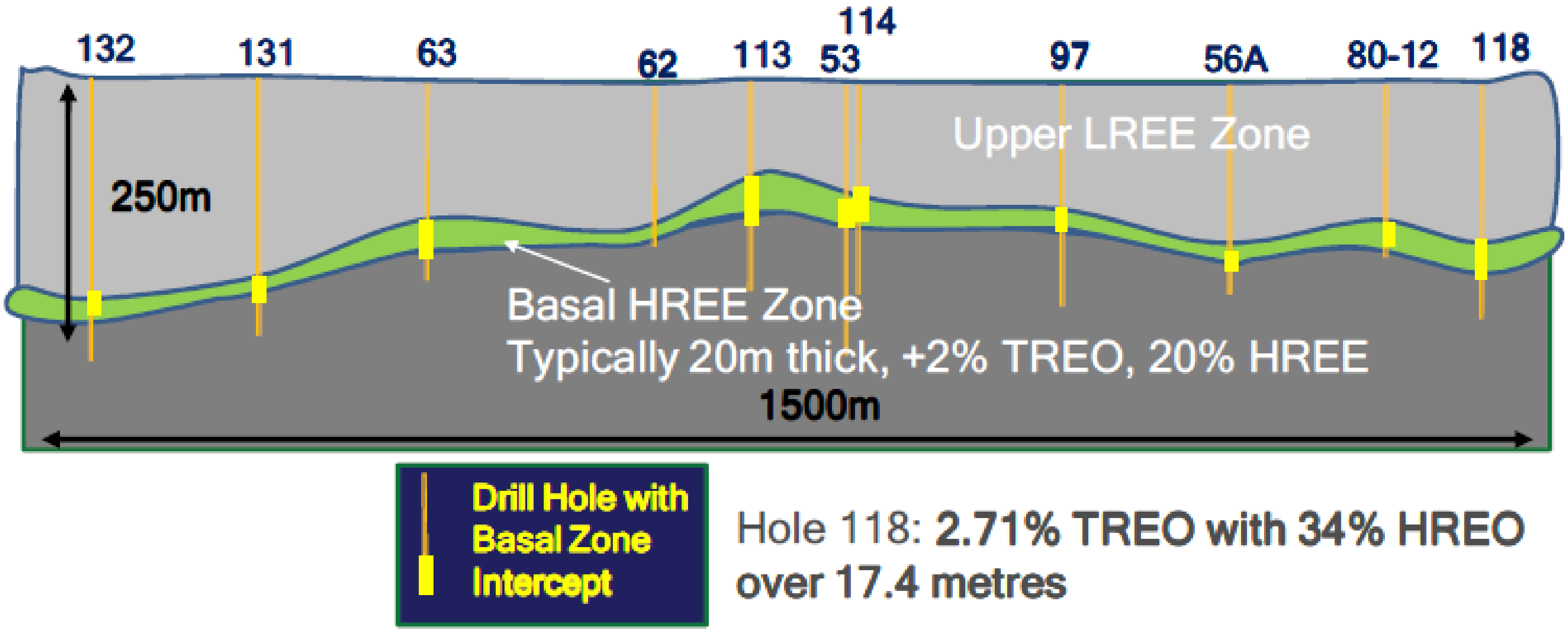
# THOR LAKE

- tabular hydrothermal alteration zone
- averages 100-150 m thick
- replacement of the primary mineral assemblage by chlorite, magnetite, biotite, zircon, monazite, allanite, bastnaesite and fergusonite
- distinct horizontal layering with HREE content generally increasing towards the base of the deposit

# Nechalacho (Thor Lake) REE Deposit

E-W Composite Section
(looking north, no vertical exaggeration)




Hole 118: **2.71% TREO with 34% HREO over 17.4 metres**

## TABLE 8-3 MINERALS OF PRINCIPAL ECONOMIC INTEREST IN THE T-ZONE

### Avalon Rare Metals Inc. – Thor Lake Project

| Element | T-Zone |
|---|---|
| Y + HREE | xenotime |
| LREE | bastnaesite, synchisite, parisite |
| Be | phenacite |
| Nb, Ta | columbite |
| Zr | zircon |
| Ga | albite (var. cleavelandite) |

# TABLE 9-1 AVERAGE PERCENT OF ORE MINERALS

## Avalon Rare Metals Inc. – Thor Lake Project

| | All Rock | Upper Zone | Basal Zone | Concentrate |
|---|---|---|---|---|
| Zircon | 65.3% | 62.8% | 66.2% | 63.0% |
| Fergusonite | 3.7% | 2.6% | 4.3% | 5.4% |
| Bastnaesite | 3.8% | 4.0% | 3.4% | 0.7% |
| Synchysite | 4.1% | 4.4% | 3.8% | 1.5% |
| Monazite | 6.4% | 9.4% | 5.2% | 5.5% |
| Allanite | 12.3% | 12.0% | 13.3% | 19.6% |
| Other REE | 0.1% | 0.1% | 0.0% | 0.1% |
| Columbite | 4.3% | 4.5% | 3.8% | 4.1% |
| Total | 100% | 100% | 100% | 100% |

**Nechalacho fergusonite and zircon (brown) compared to Illimaussaq eudialyte (pink).**

http://www.goldgeologist.com/mercenary_musings/musing-091103-Avalon-Rare-Metals-Inc-A-Real-Rare-Earth-Story.pdf

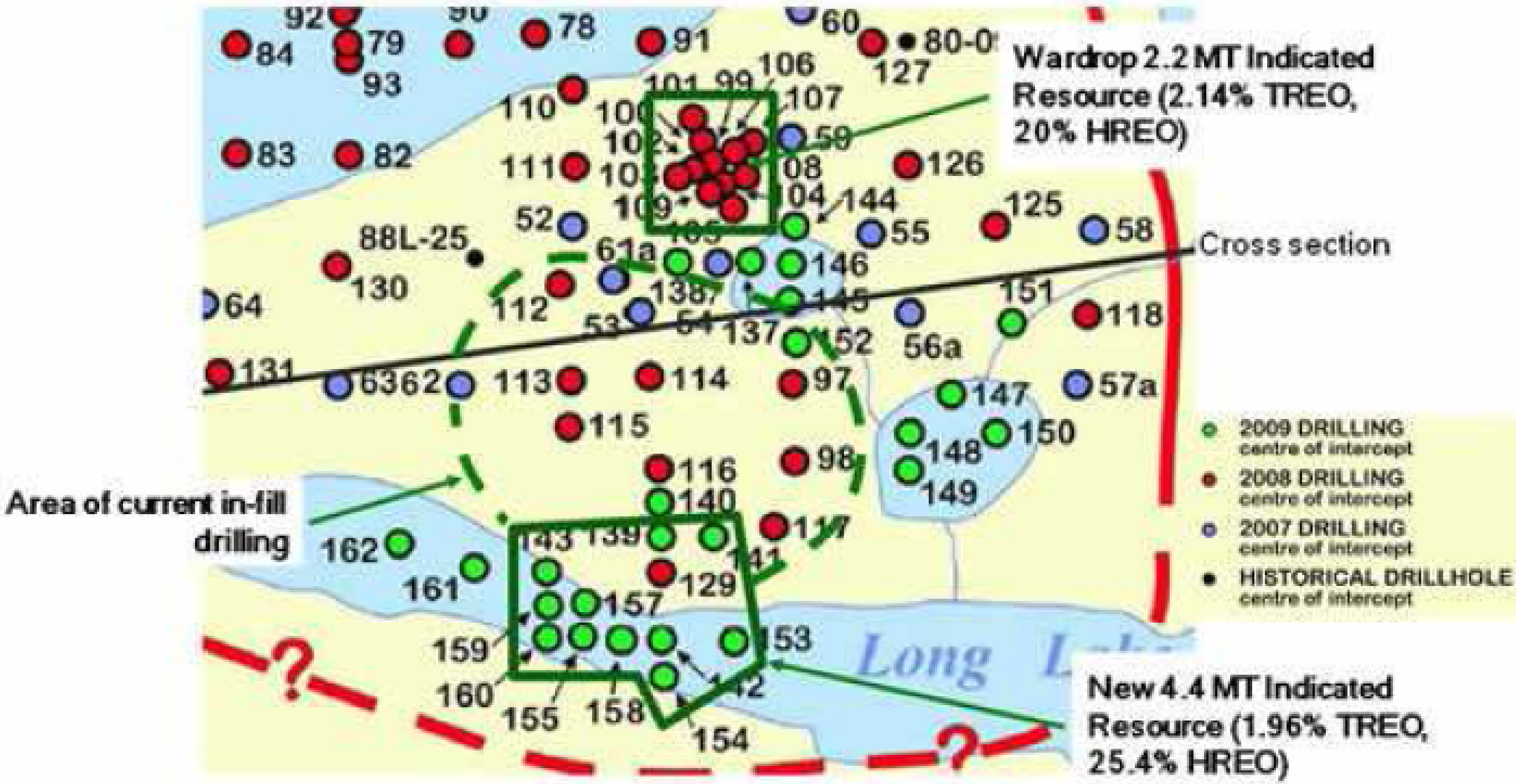
# THOR LAKE

- HREE in fergusonite ($(Y,HREE)NbO_4$) and zircon ($ZrSiO_4$)
- LREE in bastnaesite, synchysite, allanite and monazite
- Nb and Ta in columbite as well as zircon and fergusonite

# THOR LAKE

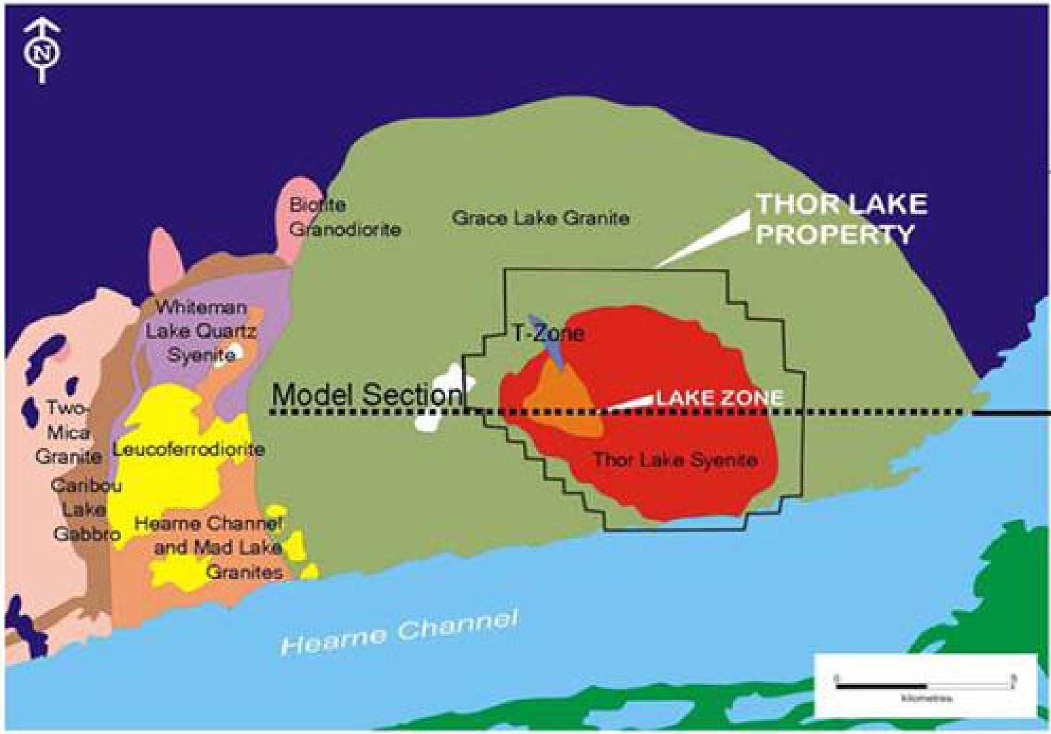
- “Basal Zone” contains between 1.5 and 2.5% total rare earth oxides 20 m thick
- Model=REE and rare metals being originally precipitated as cumulate minerals as part of the magmatic process
- Subsequent hydrothermal activity altered these to the presently seen assemblage of REE minerals
- 23 ppm U and 114 ppm Th

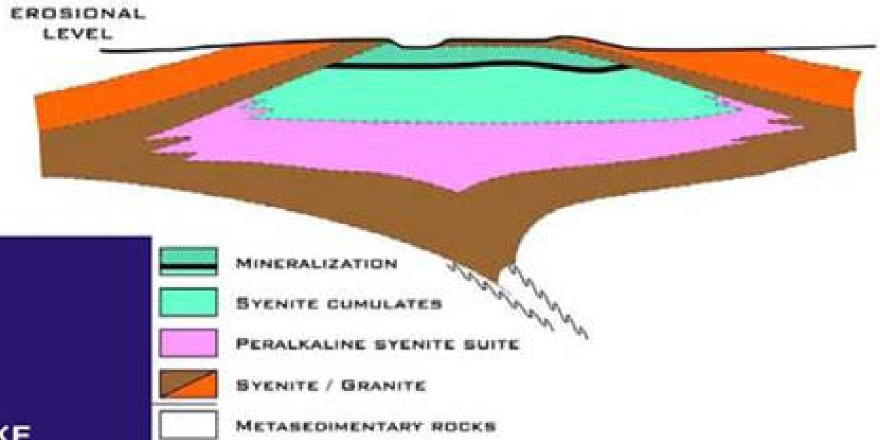
# South Part of Lake Zone: Indicated REE Resources



# Nechalacho Geological Model Evolving

Blachford Lake Peralkaline Intrusive Complex, NWT




Interpreted Geometry in Cross Section

*A unique example of a layered Peralkaline intrusive complex, with the upper, rare metal-rich part of the system readily accessible for mining.*

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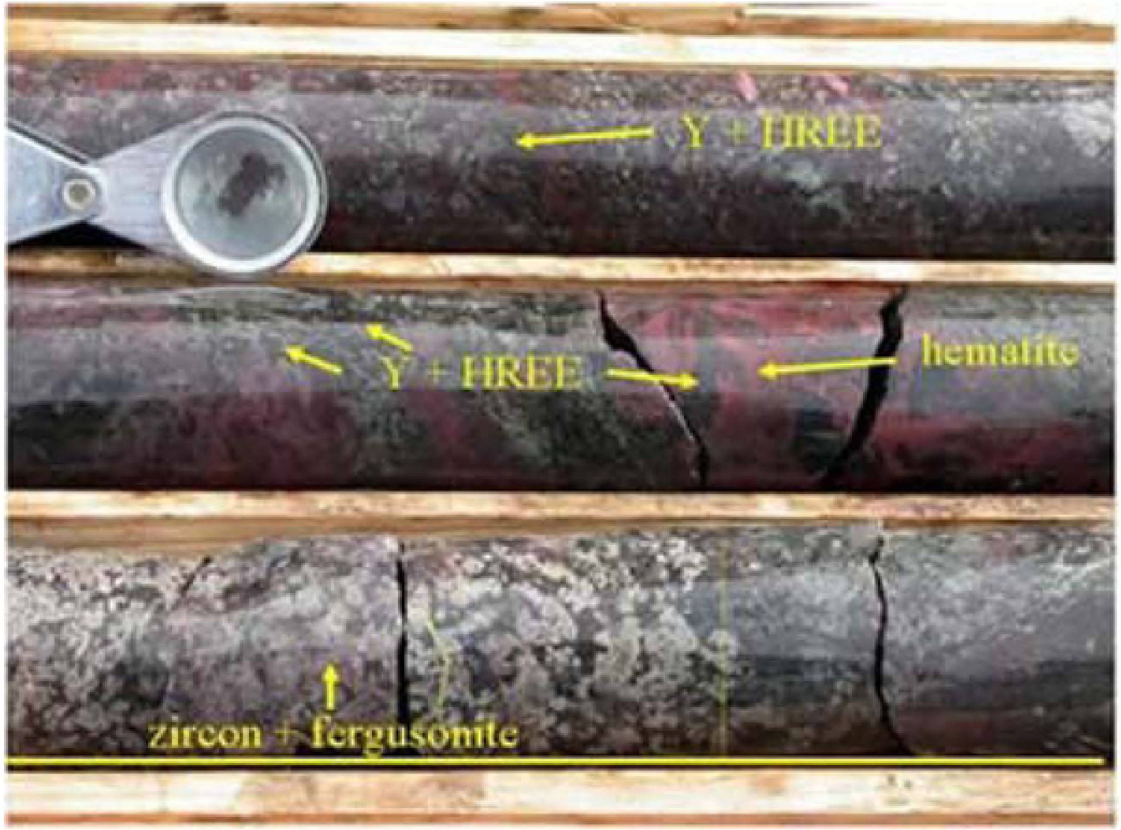
# Lake Zone Y + HREE Mineralization

AVALON RARE METALS INC.
TSX:AVL OTCQX:AVARF

## DDH L07-54

(Lake Zone - ~145 M - mineralized mafic replacement unit)



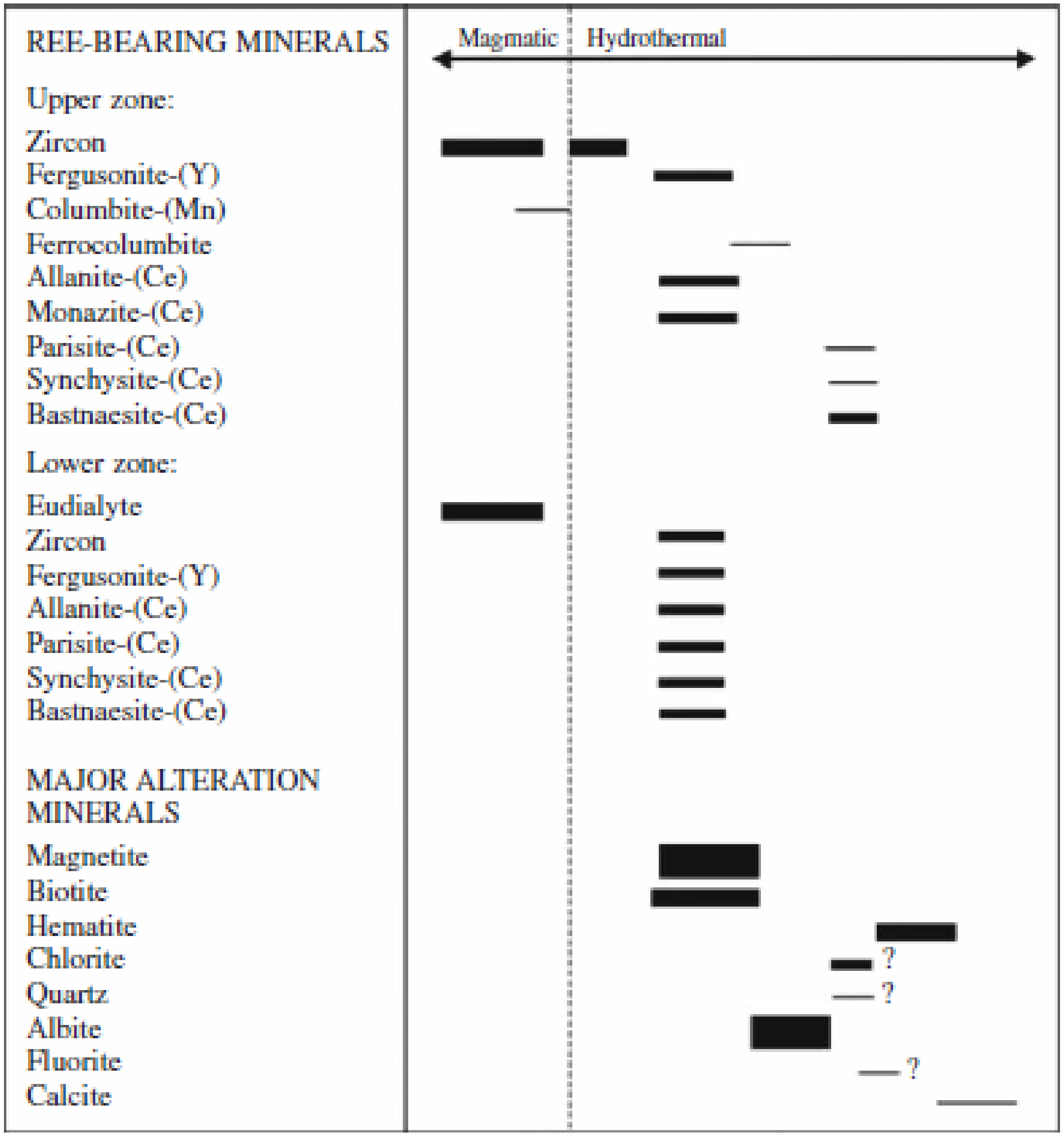



FIG. 9. Paragenetic sequence for the major REE-bearing and alteration minerals in the Nechalacho deposit. Line widths indicate relative abundances of phases. Uncertainty in the precise placement of a mineral within the paragenesis due to a lack of textural evidence is indicated by '?'.

# SHEARD, 2012

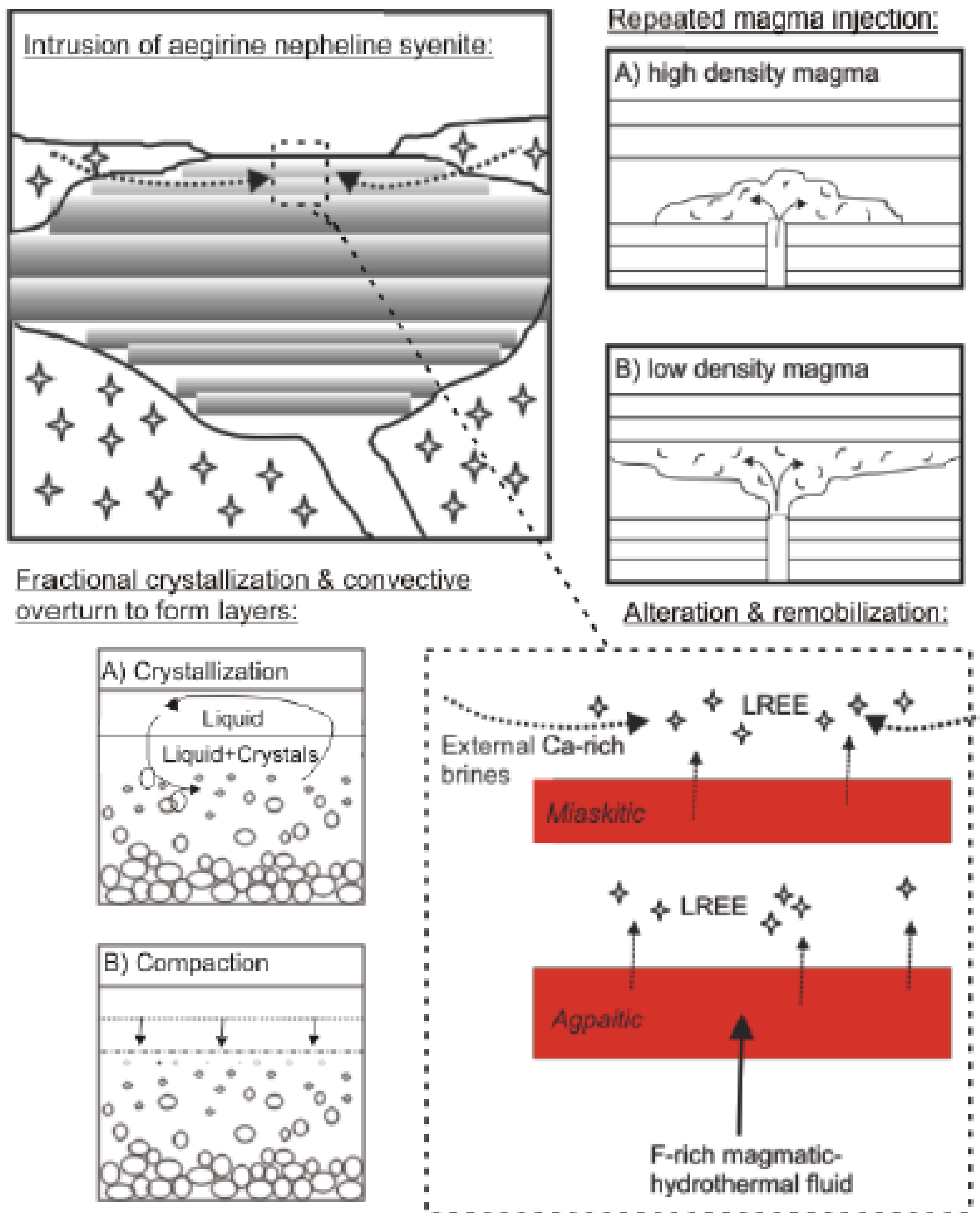



FIG. 17. Cartoon illustrating the intrusion of aegirine nepheline syenite into the Thor Lake Syenite. Repeated injections of magma, bottom upward crystallization due to gravity accumulation and convective overturn due to decreasing temperature, produce a layered igneous body. Hydrothermal alteration of the upper and lower mineralized zones leads to remobilization of a variety of elements, including the LREE.

| Items | Original 2010 Prefeasibility Study | Updated 2011 Prefeasibility Study |
|---|---|---|
| Mine life | 18 years | 20 years |
| Production schedule | 4 year ramp-up from 1,000 tpd to 2,000 tpd | Year 1 average of 1,833 tpd and years 2-20 at 2,000 tpd |
| Mill & Hydrometallurgical recoveries | ----- | No change |
| Labour costs | ----- | 5% increase |
| Reagent costs | ----- | 5% increase |
| Average operating costs per tonne | $267 or $5.93/kg | $269 or $5.54/kg |
| Total project capital costs | $900 million | $902 million |
| Hydrometallurgical Plant Tailings | Located on existing historic tailings @ Capex = $22.8 million | Located in historic open pit @ Capex = $8.8 million |
| Mine equipment capex | ----- | 15% increase |
| Exchange rates | CAD$1.00 = USD$0.90 | CAD$1.00 = USD$0.95 |
| Average TREO price | $21.94/kg | $46.33/kg |
| Niobium price | $45.00/kg | $55.86/kg |
| Zirconium price | $3.77/kg | $3.77/kg |
| Tantalum price | $130.00/kg | $255.63/kg |

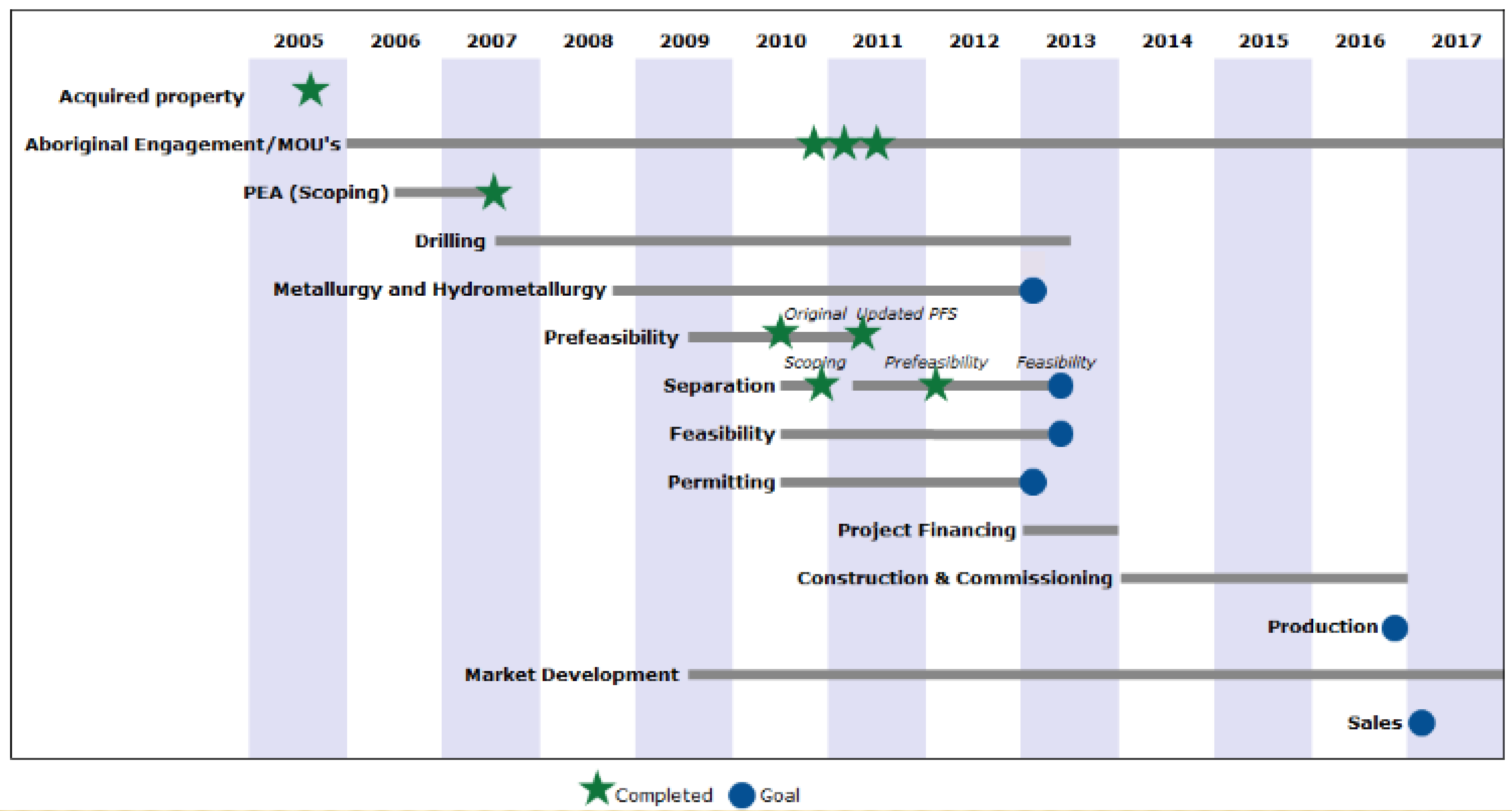
## TABLE 1-6 MINERAL RESOURCES

### Avalon Rare Metals Inc. – Thor Lake Project

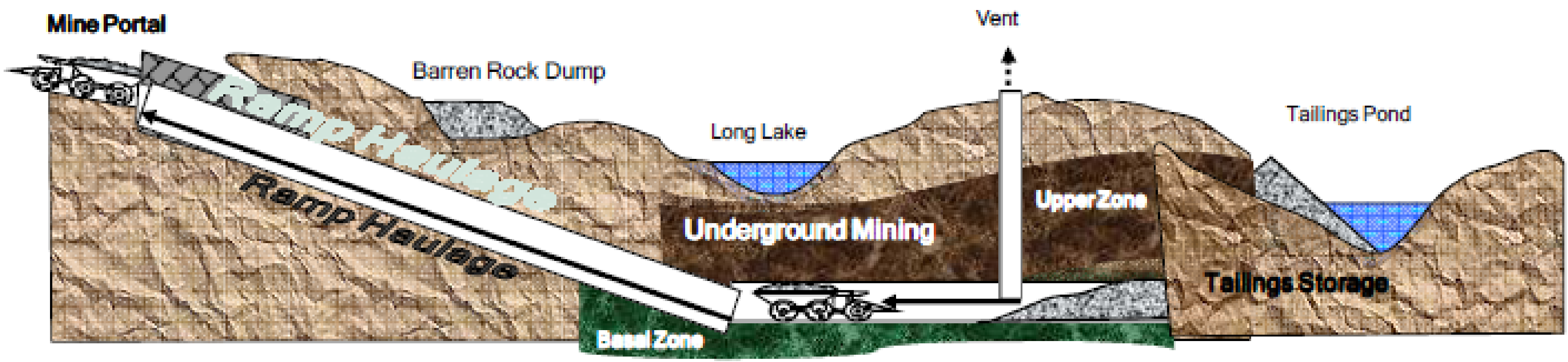
| | Tonnes (millions) | % TREO | % HREO | ppm $ZrO_2$ | ppm $Nb_2O_5$ | ppm $Ga_2O_3$ | ppm $Ta_2O_5$ |
|---|---|---|---|---|---|---|---|
| **Indicated** | | | | | | | |
| Upper Zone | 6.89 | 1.45 | 0.17 | 18,560 | 2,856 | 175 | 194 |
| Basal Zone | 14.48 | 1.82 | 0.40 | 33,843 | 4,370 | 144 | 430 |
| **Total Indicated** | **21.36** | **1.70** | **0.32** | **28,917** | **3,882** | **154** | **354** |
| **Inferred** | | | | | | | |
| Upper Zone | 99.06 | 1.29 | 0.12 | 24,371 | 3,640 | 172 | 210 |
| Basal Zone | 76.87 | 1.60 | 0.33 | 31,378 | 4,428 | 134 | 413 |
| **Total Inferred** | **175.93** | **1.43** | **0.21** | **27,433** | **3,985** | **155** | **298** |

Notes:

1. CIM definitions were followed for Mineral Resources.
2. Mineral Resources are estimated using price forecasts for 2014 for rare earth oxides (US$21.94/kg


2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
Acquired property
Aboriginal Engagement/MOU's
PEA (Scoping)
Drilling
Metallurgy and Hydrometallurgy
Original
Updated PFS
Prefeasibility
Scoping
Prefeasibility
Feasibility
Separation
Feasibility
Permitting
Project Financing
Construction & Commissioning
Production
Market Development
Sales
Completed
Goal

# Nechalacho REE Deposit Conceptual Mine Plan




Initial mine production rate: 1,000-2,000 t/day of ore through the mill.
To produce approx. 5,000-10,000 tpy TREO in chemical concentrates... equivalent to just 2-5% of est. 2014 market (5-10% of HREO demand).

Current forecast on operating costs: $200/tonne (mining & processing)

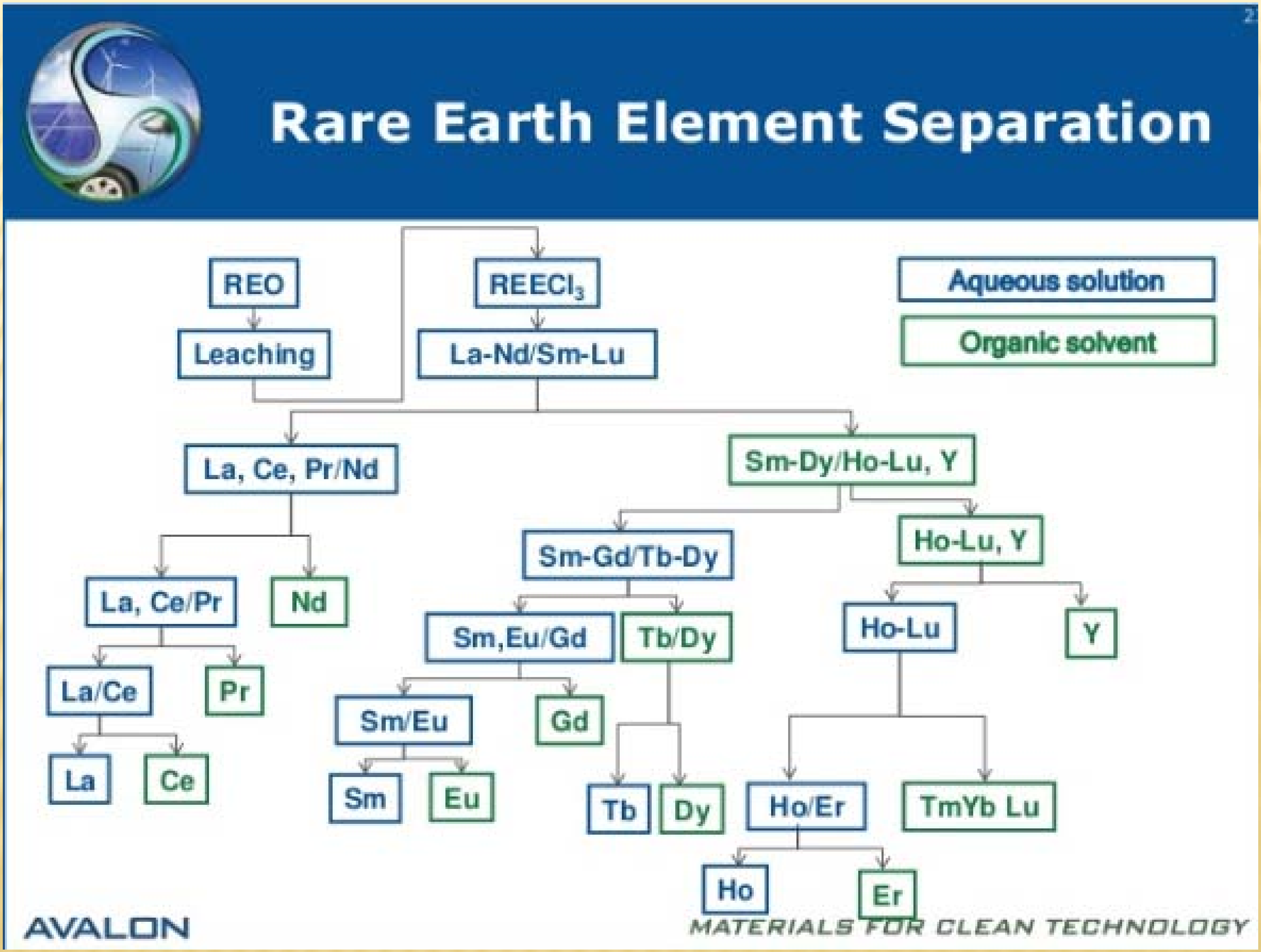
# Metallurgical Testwork Progress

- Flotation
  1. Benchscale - basically complete, optimization continuing
  2. Main Pilot Plant (40 tonne) - completed (SGS). 6 tonnes concentrate produced
  3. Follow up mini-pilot plant work at XPS in progress
- Hydrometallurgy (Sulphuric Acid Bake Process)
  1. Pilot plant trial and process optimization in progress (SGS)
  2. Produces mixed rare earth concentrate with zircon residue
  3. Zircon residues contain REE & require caustic or alkali cracking. Presently being marketed as an REE-enriched zirconium product
- Separation & Refining (HCl Solvent Extraction)
  1. Prefeasibility completed in April 2012 by SNC-Lavalin
  2. Feasibility Study underway for proposed plant site in Geismar, Louisiana, USA
  3. Pilot plant testwork set to begin. Identifying potential partners

## TABLE 16-1 FLOTATION AND HYDROMETALLURGICAL RECOVERIES

Avalon Rare Metals Inc. – Thor Lake Project

| | Feed to Concentrate | Concentrate to Product | Net Recovery |
|---|---|---|---|
| $ZrO_2$ | 89.7% | 90.0% | 80.7% |
| TREO | 79.5% | 93.0% | 73.9% |
| HREO | 79.5% | 93.0% | 73.9% |
| $Nb_2O_5$ | 68.9% | 80.0% | 55.1% |
| $Ta_2O_5$ | 63.0% | 50.0% | 31.5% |



Rare Earth Element Separation
REO
Leaching
REECl3
La-Nd/Sm-Lu
Aqueous solution
Organic solvent
La, Ce, Pr/Nd
Sm-Dy/Ho-Lu, Y
Sm-Gd/Tb-Dy
Ho-Lu, Y
La, Ce/Pr
Nd
Sm,Eu/Gd
Tb/Dy
Ho-Lu
Y
La/Ce
Pr
Sm/Eu
Gd
La
Ce
Sm
Eu
Tb
Dy
Ho/Er
TmYb Lu
Ho
Er
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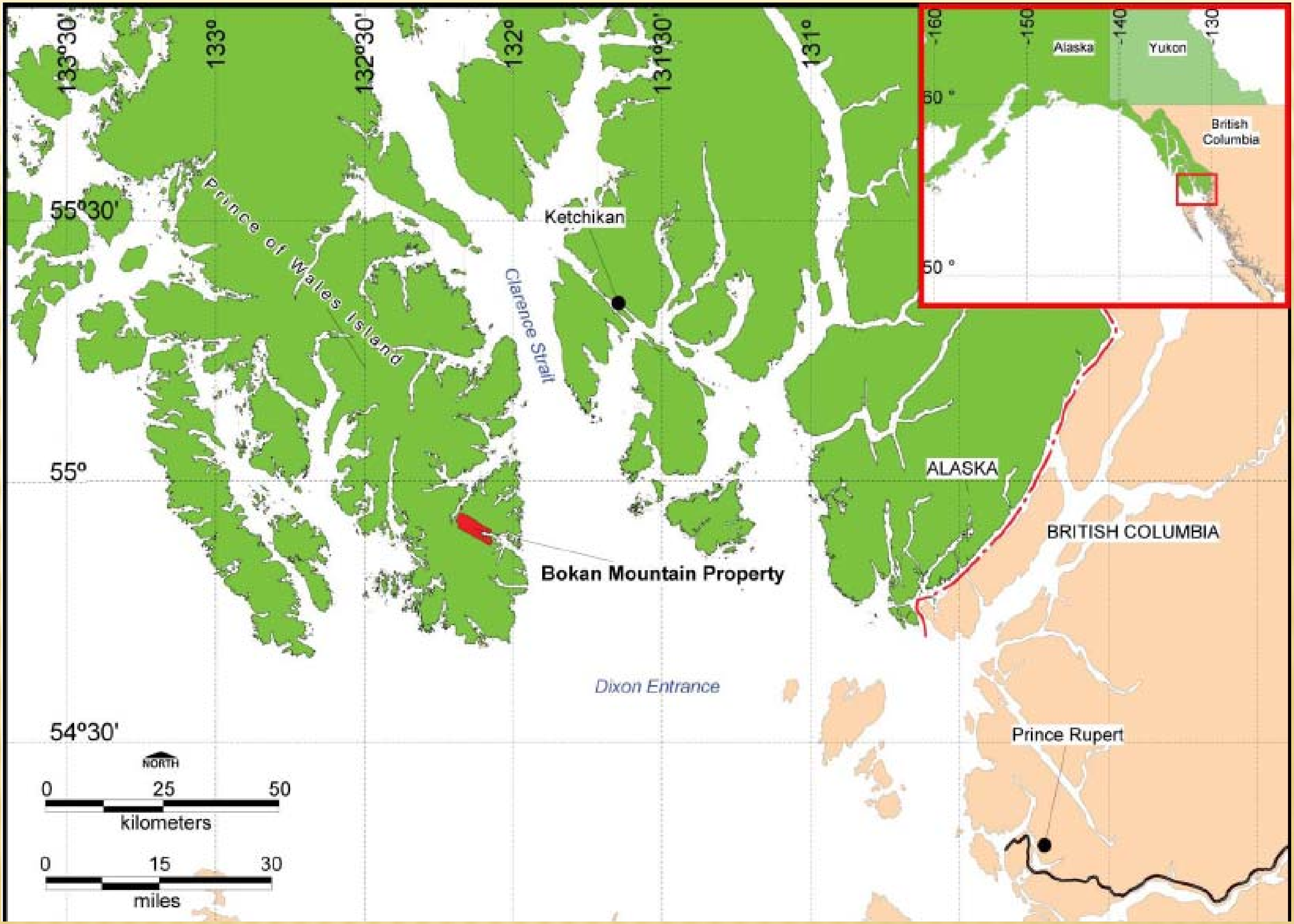
## TABLE 1-1 PROJECT ADVANCEMENT BUDGET

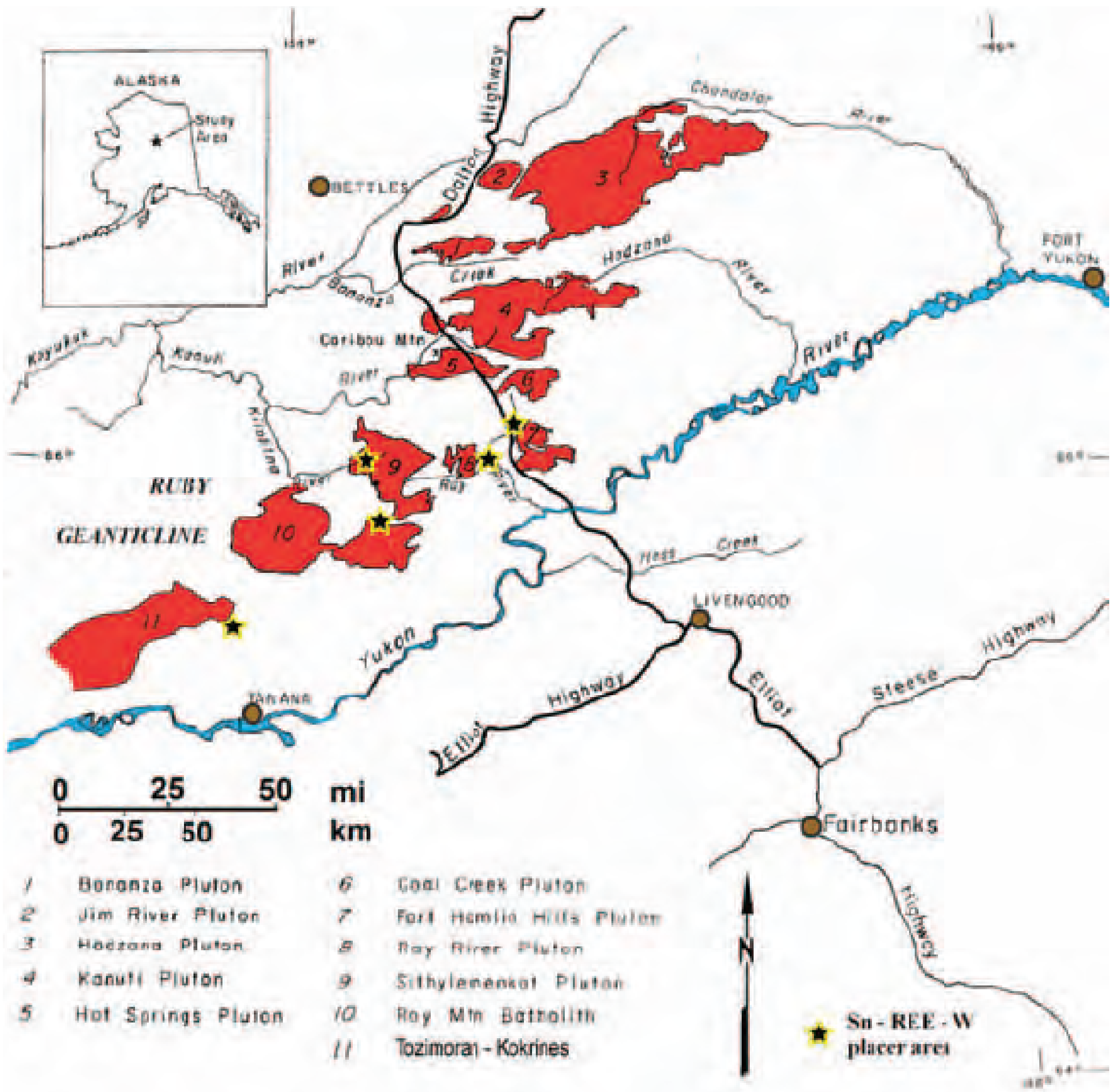
### Avalon Rare Metals Inc. – Thor Lake Project

| Item | Cost (C$ millions) |
|---|---|
| Exploration/Upgrade Drilling & Geology | 19.5 |
| Metallurgical Testwork | 5.0 |
| Technical Studies & Support | 4.0 |
| Environmental Work | 2.0 |
| Sales & Marketing | 1.5 |
| Administration | 11.5 |
| **Total** | **43.5** |

# BOKAN MOUNTAIN, ALASKA


133º30'
133º
132º30'
132º
131º30'
131º
55º30'
55º
54º30'
Prince of Wales Island
Clarence Strait
Ketchikan
Bokan Mountain Property
ALASKA
BRITISH COLUMBIA
Dixon Entrance
Prince Rupert
NORTH
0
25
50
kilometers
0
15
30
miles
-160
-150
-140
-130
Alaska
Yukon
60 °
50 °
British Columbia

Peraluminous plutons of the Ruby batholith associated with widespread alluvial Sn-REE-W occurrences. Figure modified from Barker and Foley (1986).




MINING ENGINEERING, 2012, HTTP://UCORE.COM/MININGENGINEERING%20JAN2012.PDF

## HISTORY

**Ross Adams Mine**

- Disc. Don Ross & Kelly Adams 1955 (uranium)
- 1.3 million lbs. $U_3O_8$ produced 1957-1971
- Remaining resources, historic, (non NI 43-101 compliant) est'd 365,000 st at 0.17% $U_3O_8$
- 1950s-60s USGS geological mapping projects, presence of REE-Nb noted in Bokan area

http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=12&ved=0CDgQFjABOAo&url=http%3A%2F%2Fwww.legis.state.ak.us%2Fbasis%2Fget_documents.asp%3Fsession%3D26%26docid%3D7452&ei=sWM2UY7PMuLRyAGjh4Ao&usg=AFQjCNHfwV6sj77hCvqlL07GZx_hg_KjTA&sig2=vaFBys12VGB2VfhEoUo3-A


http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=12&ved=0CDgQFjABOAo&url=http%3A%2F%2Fwww.legis.state.ak.us%2Fbasis%2Fget_documents.asp%3Fsession%3D26%26docid%3D7452&ei=sWM2UY7PMuLRyAGjh4Ao&usg=AFQjCNHfwV6sj77hCvqlL07GZx_hg_KjTA&sig2=vaFBys12VGB2VfhEoUo3-A

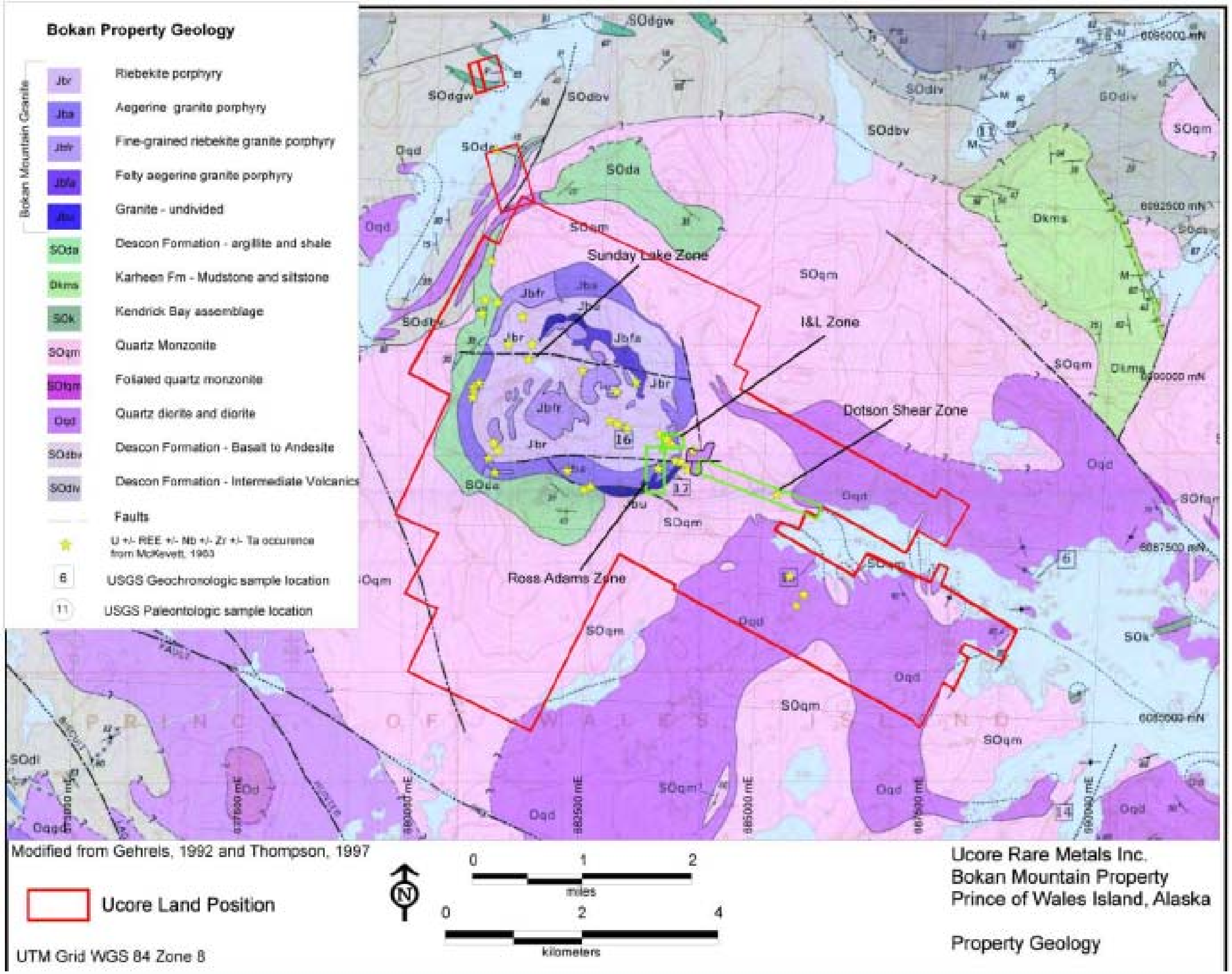
# 2007-present

**Rare Earth One, LLC (wholly owned Alaska subsidiary)**

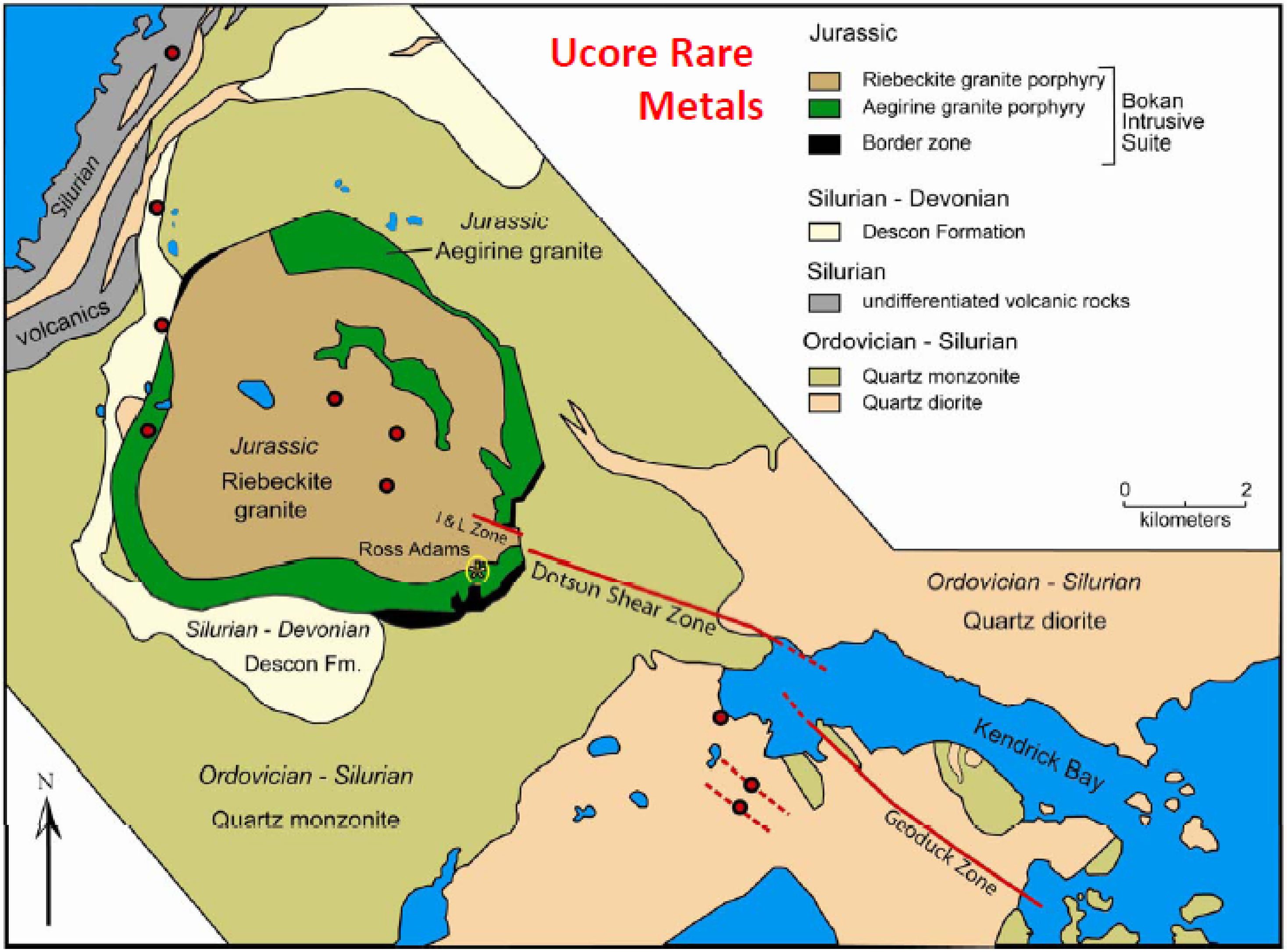
**Ucore Uranium Inc.**

**Over 17,500 feet of drilling thru Nov. 2009, on Bokan area prospects**

rare earth ONE


Bokan Property Geology
Bokan Mountain Granite
Jbr Riebekite porphyry
Jba Aegerine granite porphyry
Jbfr Fine-grained riebekite granite porphyry
Jbfa Felty aegerine granite porphyry
Jbu Granite - undivided
SOda Descon Formation - argillite and shale
Dkms Karheen Fm - Mudstone and siltstone
SOk Kendrick Bay assemblage
SOqm Quartz Monzonite
SOfqm Foliated quartz monzonite
Oqd Quartz diorite and diorite
SOdbv Descon Formation - Basalt to Andesite
SOdiv Descon Formation - Intermediate Volcanics
Faults
U +/- REE +/- Nb +/- Zr +/- Ta occurrence from McKevett, 1963
USGS Geochronologic sample location
USGS Paleontologic sample location
Sunday Lake Zone
I&L Zone
Dotson Shear Zone
Ross Adams Zone
PRINCE OF WALES ISLAND
Modified from Gehrels, 1992 and Thompson, 1997
Ucore Land Position
UTM Grid WGS 84 Zone 8
miles
kilometers
Ucore Rare Metals Inc.
Bokan Mountain Property
Prince of Wales Island, Alaska
Property Geology

# Bokan Mountain, Alaska



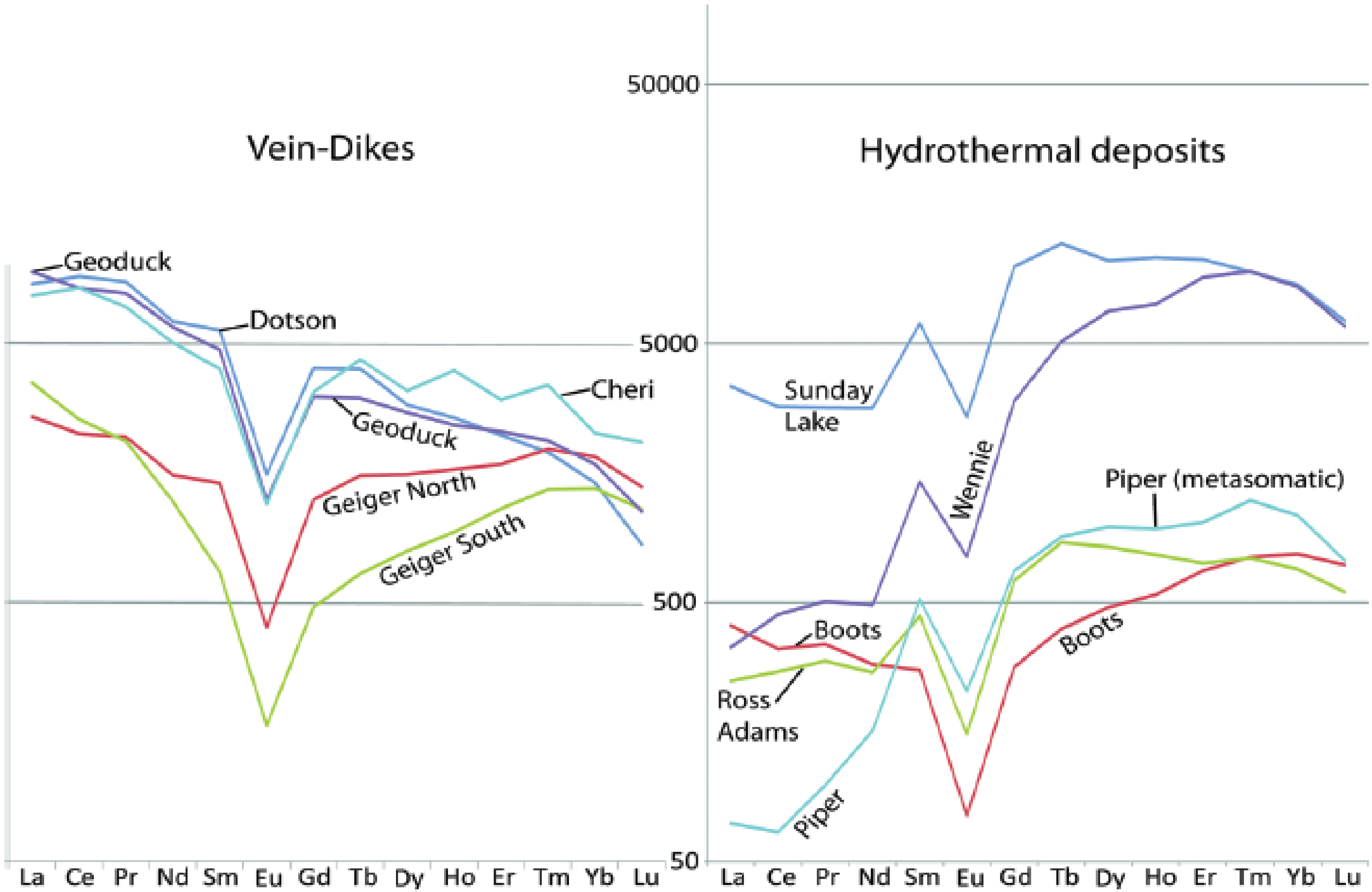

USGS
science for a changing world

Inferred resource estimates by varying cutoff grade for the Dotson dike system, Bokan Mountain, Alaska.

| % TREO Cut-off | Tonnes | % TREO | HREO/TREO | Contained TREO (lbs) |
|---|---|---|---|---|
| 0.8 | 1,021,000 | 1.054 | 36.80% | 23,718,000 |
| 0.7 | 1,549,000 | 0.951 | 37.70% | 32,467,000 |
| 0.6 | 2,489,000 | 0.834 | 39.60% | 45,751,000 |
| 0.5 | 3,669,000 | 0.746 | 38.60% | 60,325,000 |
| 0.4 | 5,276,000 | 0.654 | 40.00% | 76,049,000 |
| 0.3 | 6,126,000 | 0.613 | 40.80% | 82,765,000 |
| 0.2 | 6,702,000 | 0.58 | 41.30% | 85,673,000 |

• All intercepts with a true width of less than 1.5 m were diluted to a potential minimum mining width of 1.5 m.
• Additional details at www.ucore.com.

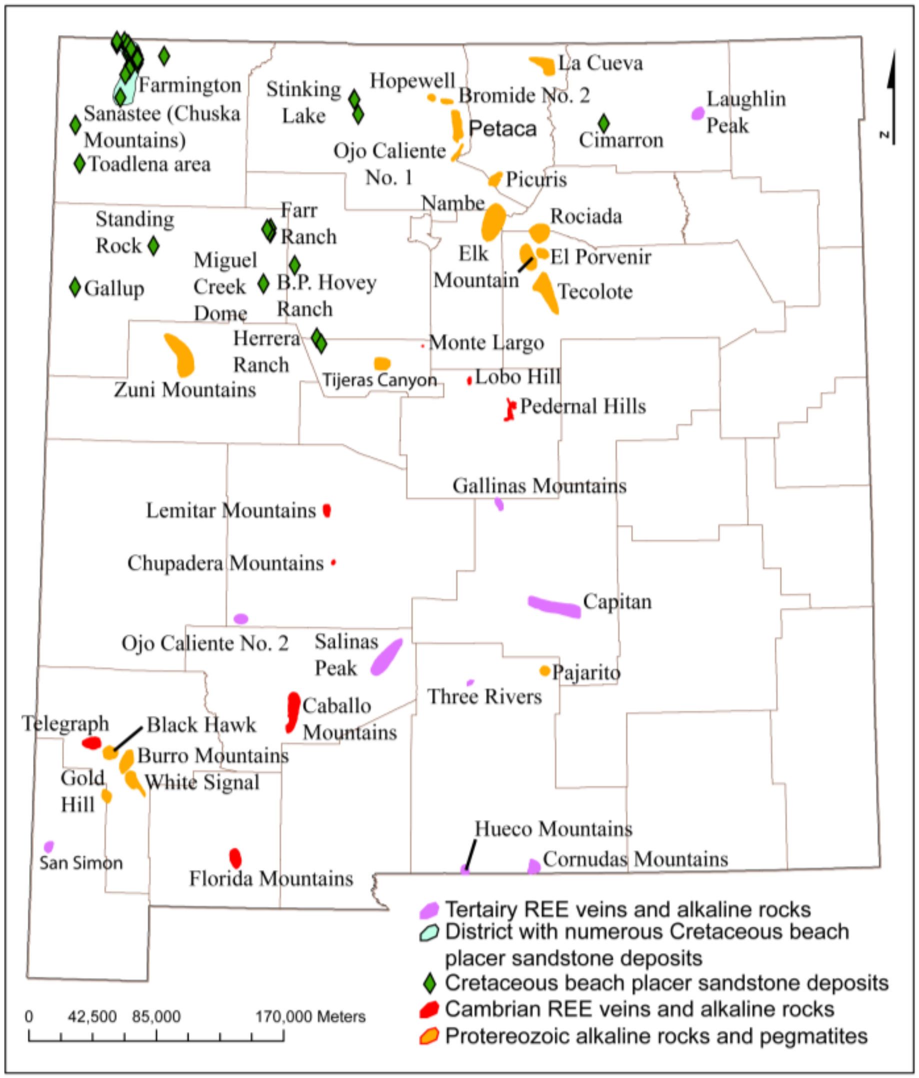
## Normalized REE plots comparing vein-dikes (typically with 40% HREE) to more evolved hydrothermal REE prospects at Bokan Mountain (>80% HREE).



# DEVELOPMENT ISSUES- *Bokan Project*

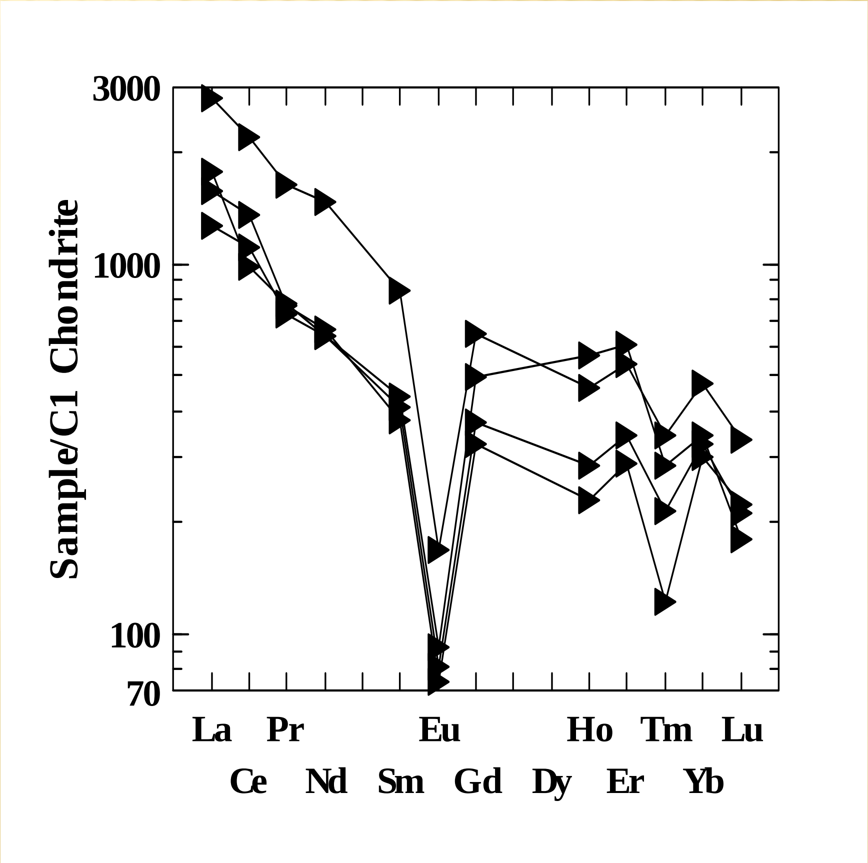
- Federal land- Tongass Nat'l Forest Management Plan completed, area zoned for mineral development
- State of Alaska Prince of Wales Area Plan completed, Kendrick Bay area classified for mineral and forestry access/development
- No overland access/transport requirements: Immediate access to property by ocean transport
- Native Land claims issues resolved
- Labor and services locally available

# PAJARITO MOUNTAIN, MESCALERO APACHE INDIAN RESERVATION NEAR RUIDOSO



# PAJARITO MOUNTAIN, MESCALERO APACHE INDIAN RESERVATION NEAR RUIDOSO

- In 1990, Molycorp, Inc. reported historic resources of 2.7 million short tons grading 0.18% $Y_2O_3$ and 1.2% $ZrO_2$ as disseminated eudialyte



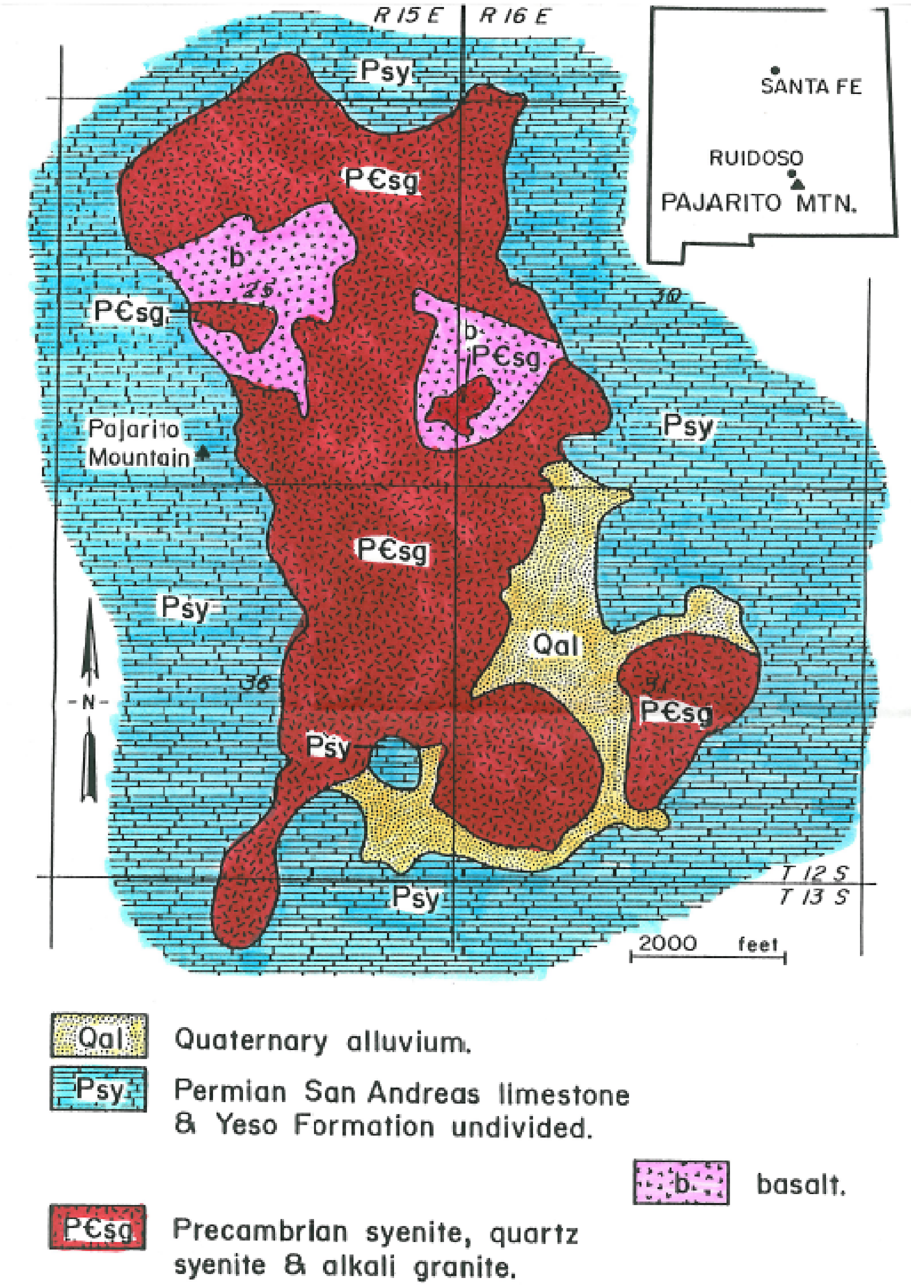
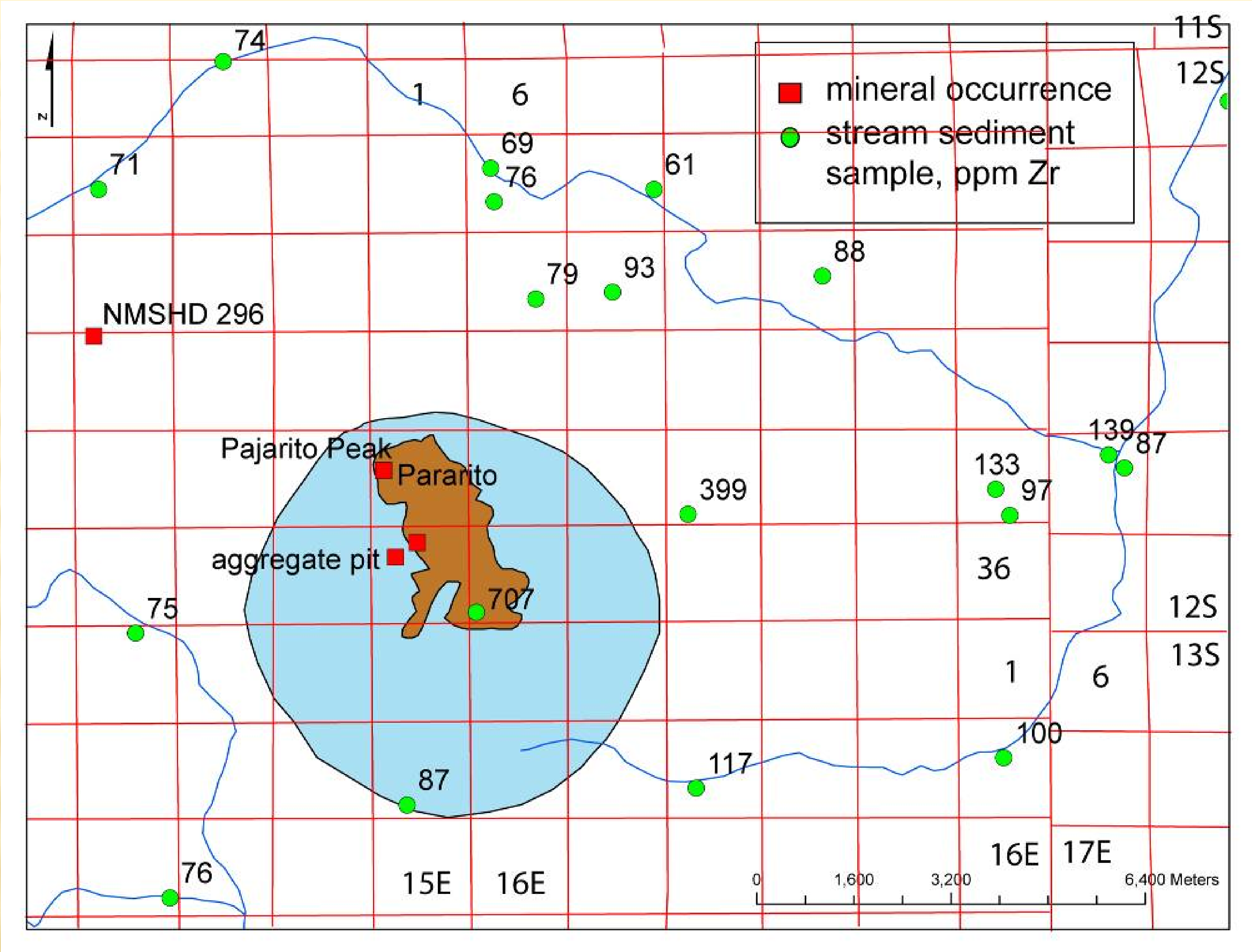



FIGURE 1—Location and generalized geology of the yttrium–zirconium deposit at Pajarito Mountain. SHERER (1990)




Samples also are high in Y (as much as 106 ppm) and Ce (as much as 138 ppm)

# CARBONATITES

# >330 Carbonatites

# Carbonatites

- An igneous intrusive or extrusive rock containing more than 50% carbonate (calcite, dolomite, ankerite) (Bell, 1989)
- intrusive igneous rocks rich in carbonate minerals that form central plugs within alkaline intrusive complexes, or dykes, sills and veins (Barker, 1989)

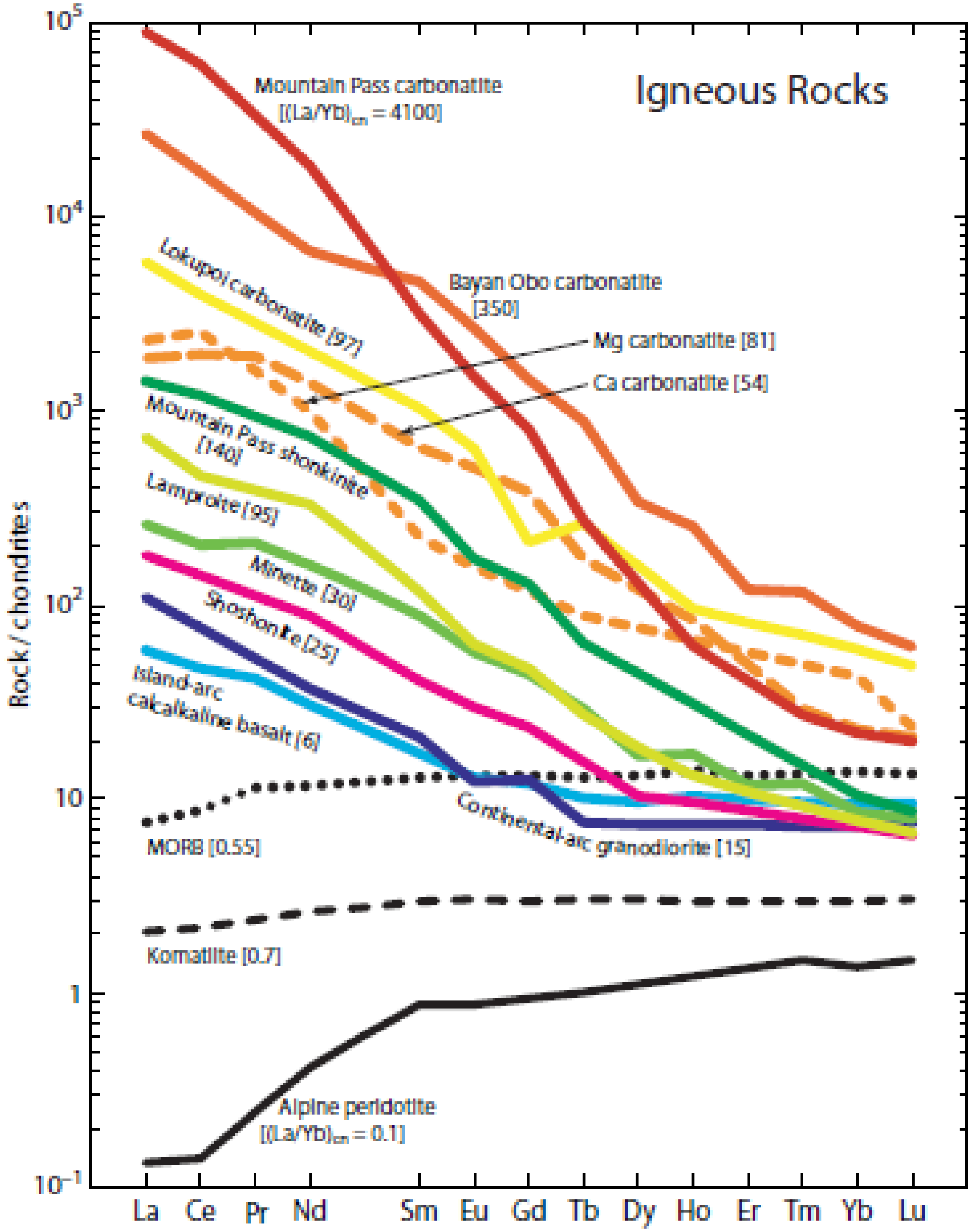
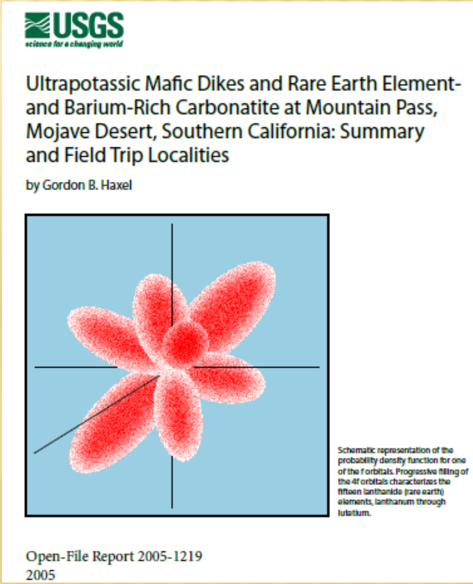
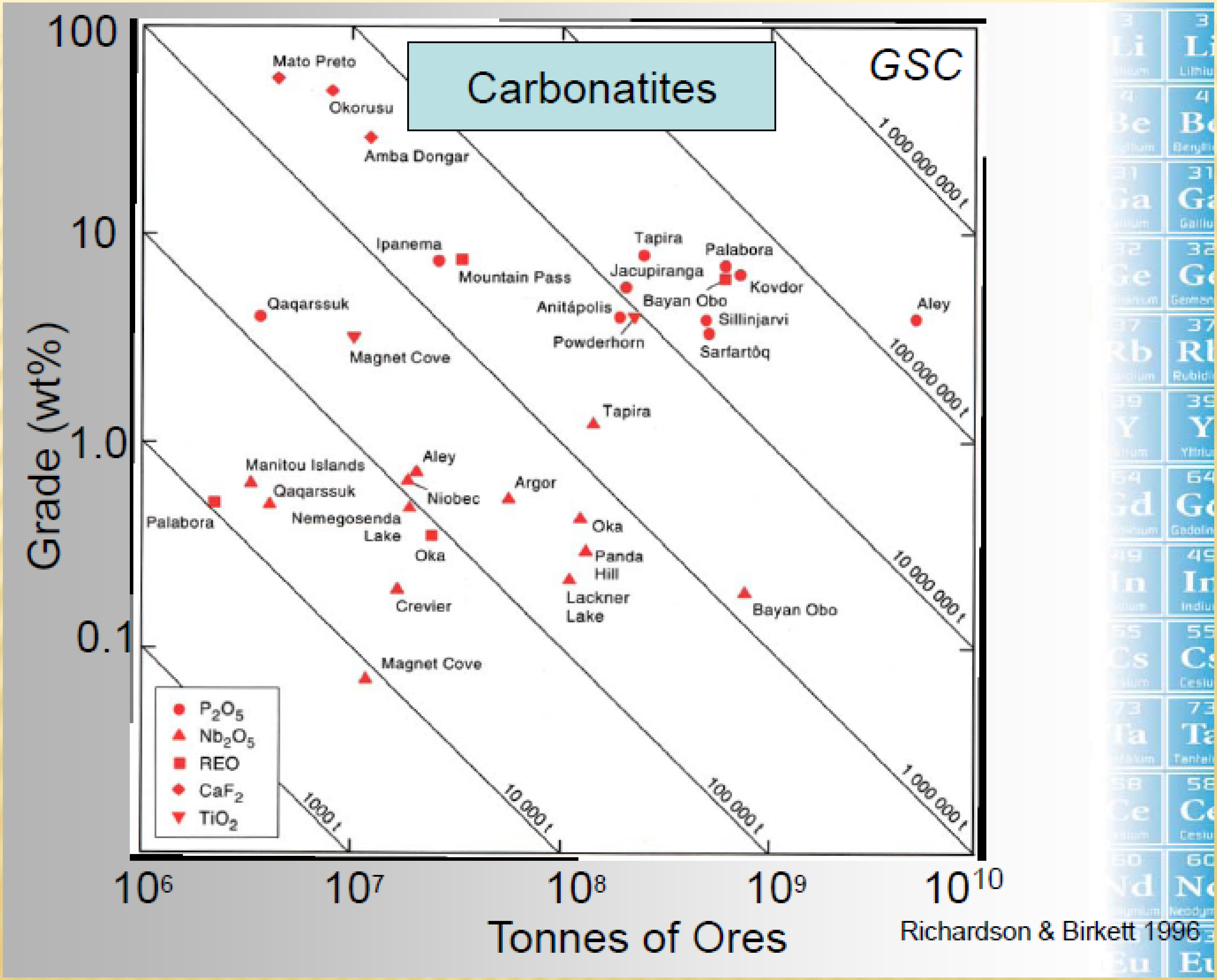



Figure 3. Chondrite-normalized (Table 1; Nakamura, 1974) REE spectra for average (labeled in italic) or representative compositions (labeled in upright type) of several common suites of ultramafic to intermediate, tholeiitic and calcalkaline






Richardson & Birkett 1996

# BAYAN OBO, CHINA

# BAYAN OBO, CHINA

- Largest in the world
- Discovered in 1927, mined for Fe ore
  - 1500 Mt 35% Fe
- REE discovered in 1936
  - 100) million tonnes at 6% $REE_2O_3$
- Nb discovered in 1950s
- Dolphins harmed by mine tailings in the Yellow River

# MINERALOGY

- Bastnasite
- Monazite
- Aeschynite
- Orthite
- apatite
- Parisite
- Huanghoite
- Fergusonite
- Fersmite
- Xenotime
- Daqingshanite
- Cordylite
- Chevkinite
- britolite

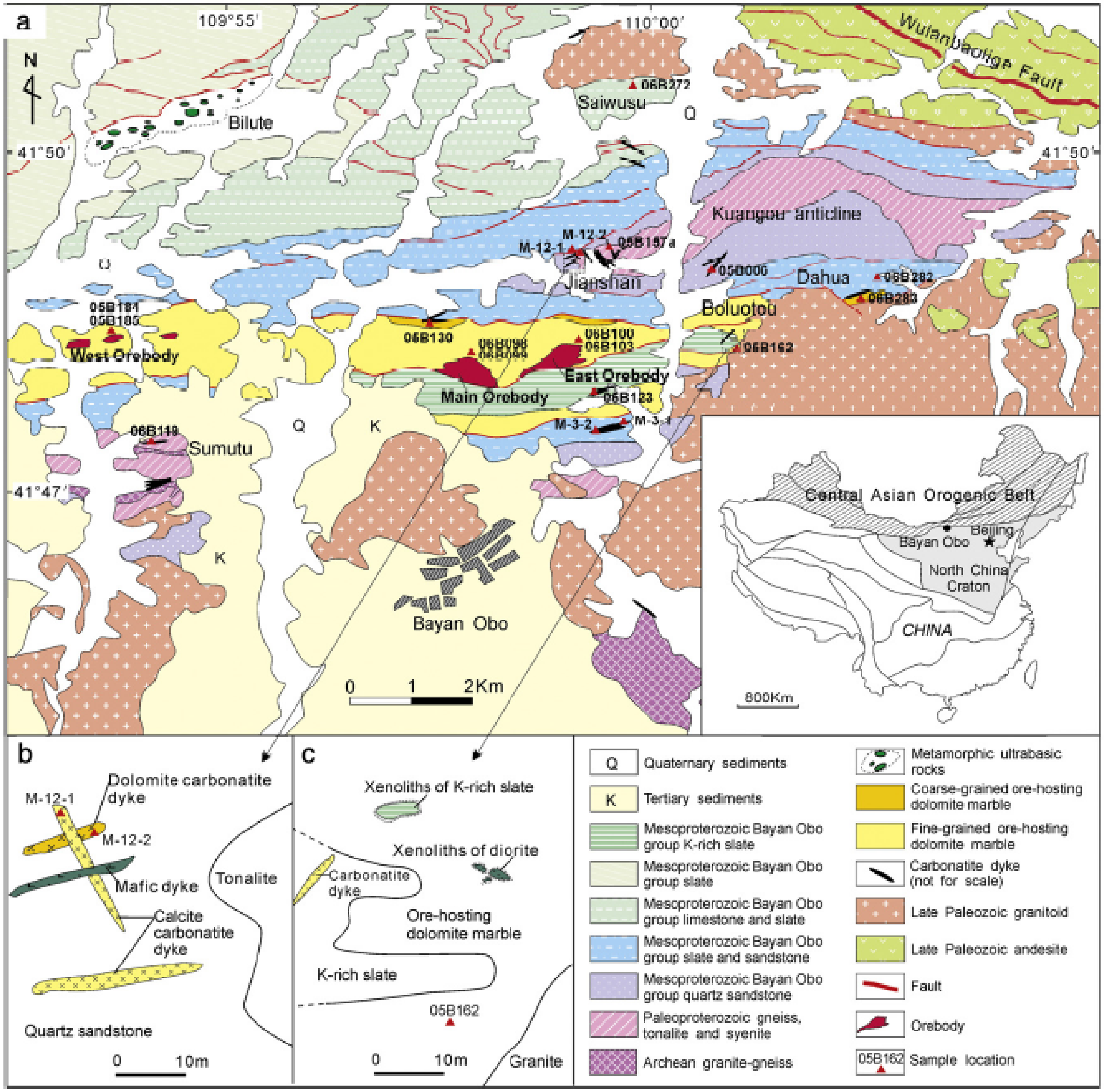



**Fig. 1.** Geological map of the Bayan Obo REE deposit (a). Intrusive contact between dolomite and calcite carbonatite dykes (b). Xenoliths of K-rich slate and diorite in fine-grained ore-hosting dolomite marble with extensive fenitization and flow structure around them (c).

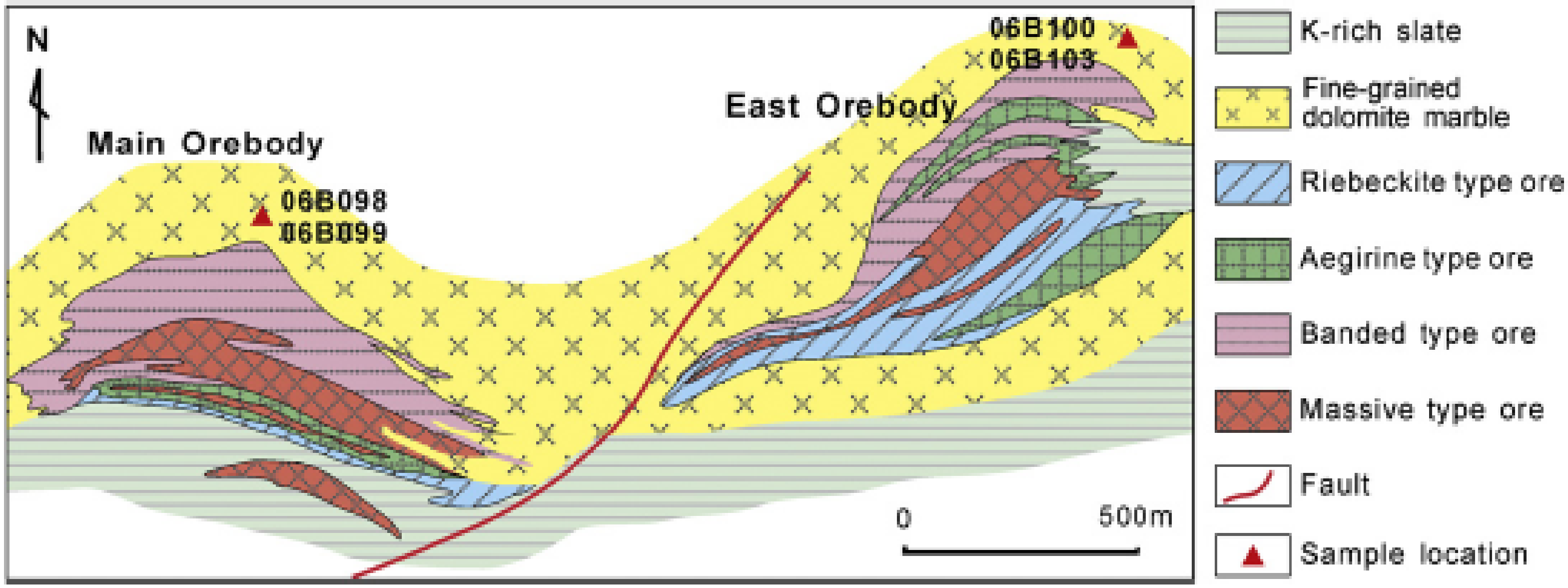



**Fig. 2.** Structural map of the Main and East Orebody. (Modified after Institute of Geology and Guiyang Geochemistry Chinese Academy of Sciences, 1974).

http://www.igg.cas.cn/rssdy/201108/W020110824363804401800.pdf

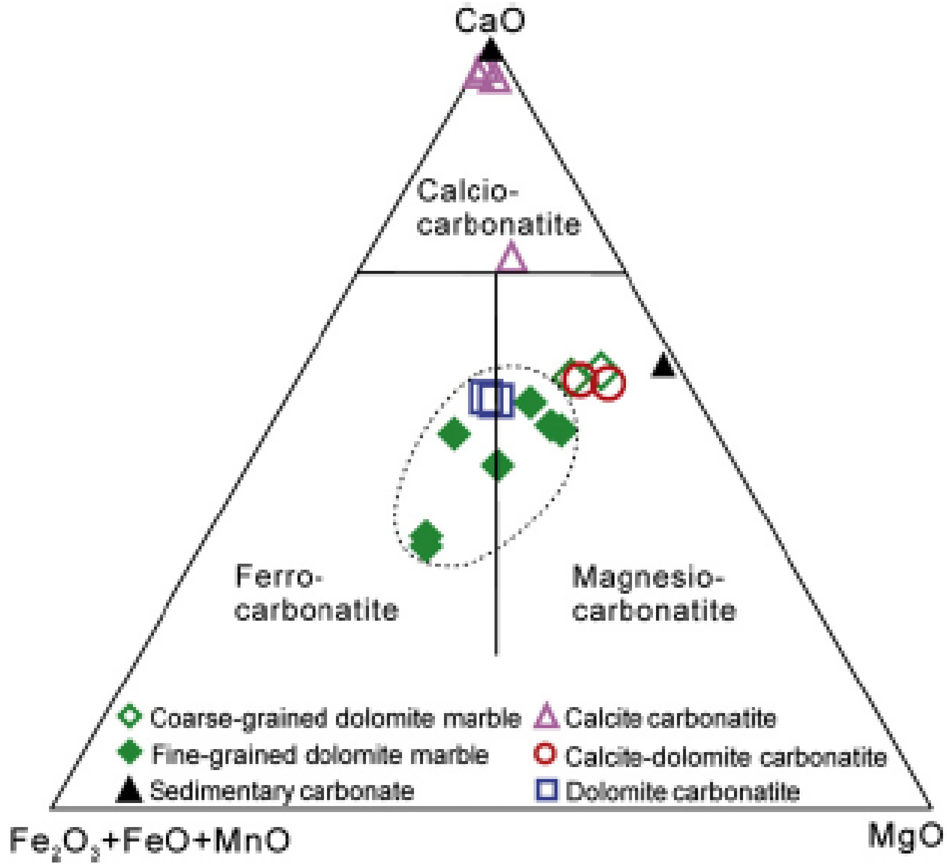



**Fig. 3.** CaO-MgO-(FeO + $Fe_2O_3$ + MnO) classification diagram (Woolley and Kempe, 1989) for the carbonatite dykes, ore-hosting dolomite marble and sedimentary carbonate rocks from Bayan Obo district.



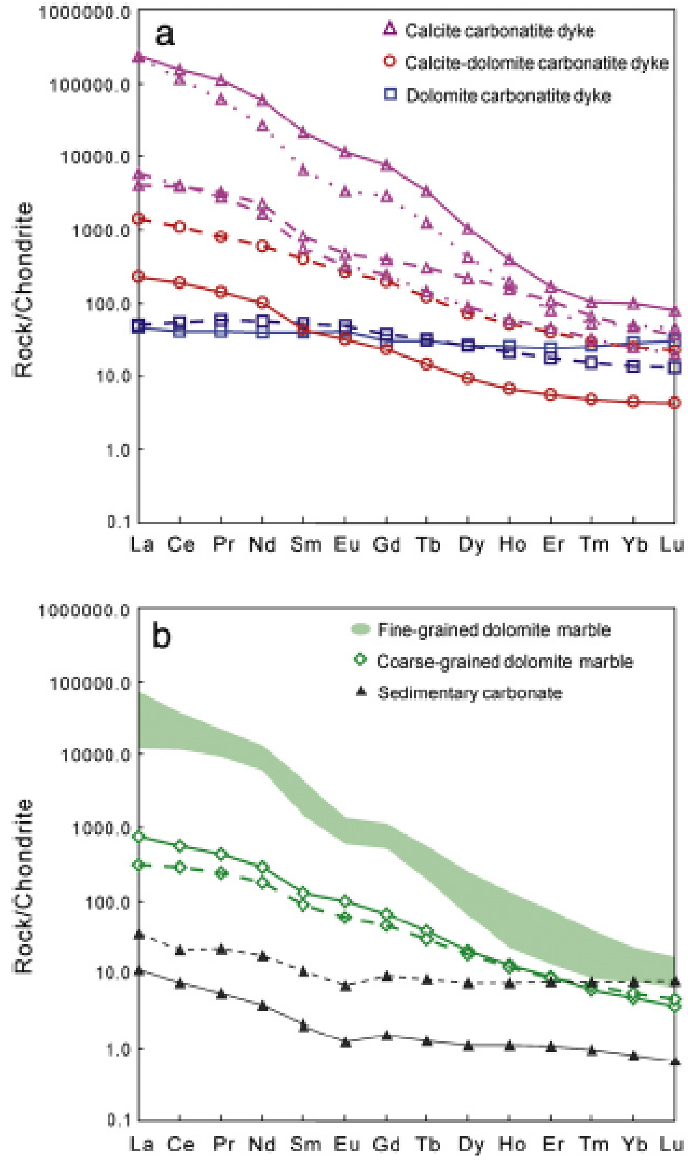



**Fig. 6.** Chondrite-normalized REE abundance diagram for carbonatite dykes, ore-hosting dolomite marble and sedimentary carbonate rocks from Bayan Obo district. Chondrite values are from Taylor and McLennan (1985).

# KYNICKY ET AL. 2012

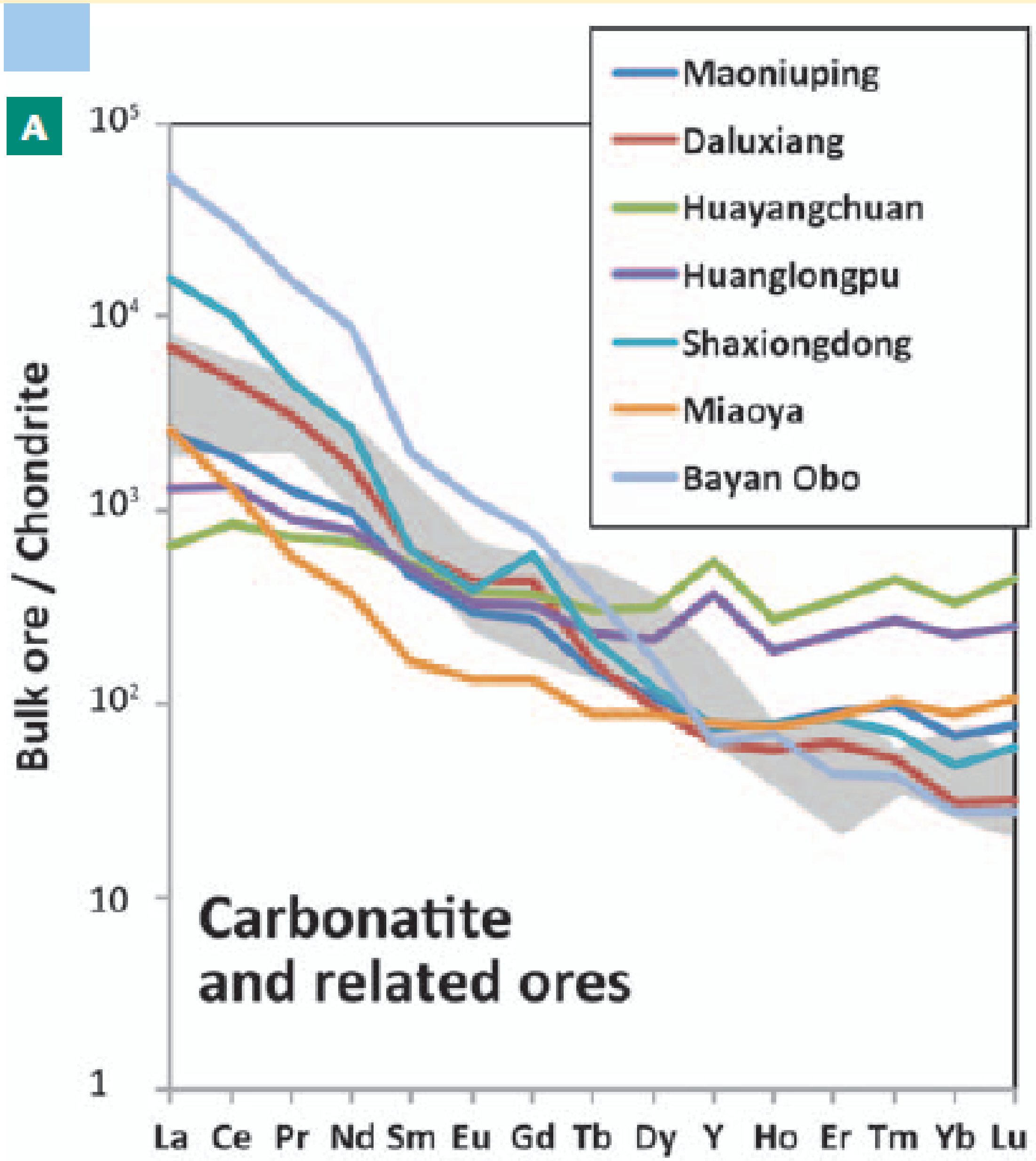



**FIGURE 2** Representative chondrite-normalized plots showing the distribution of REEs in the deposits discussed in the text. Yttrium is plotted as a pseudo-lanthanide between Dy

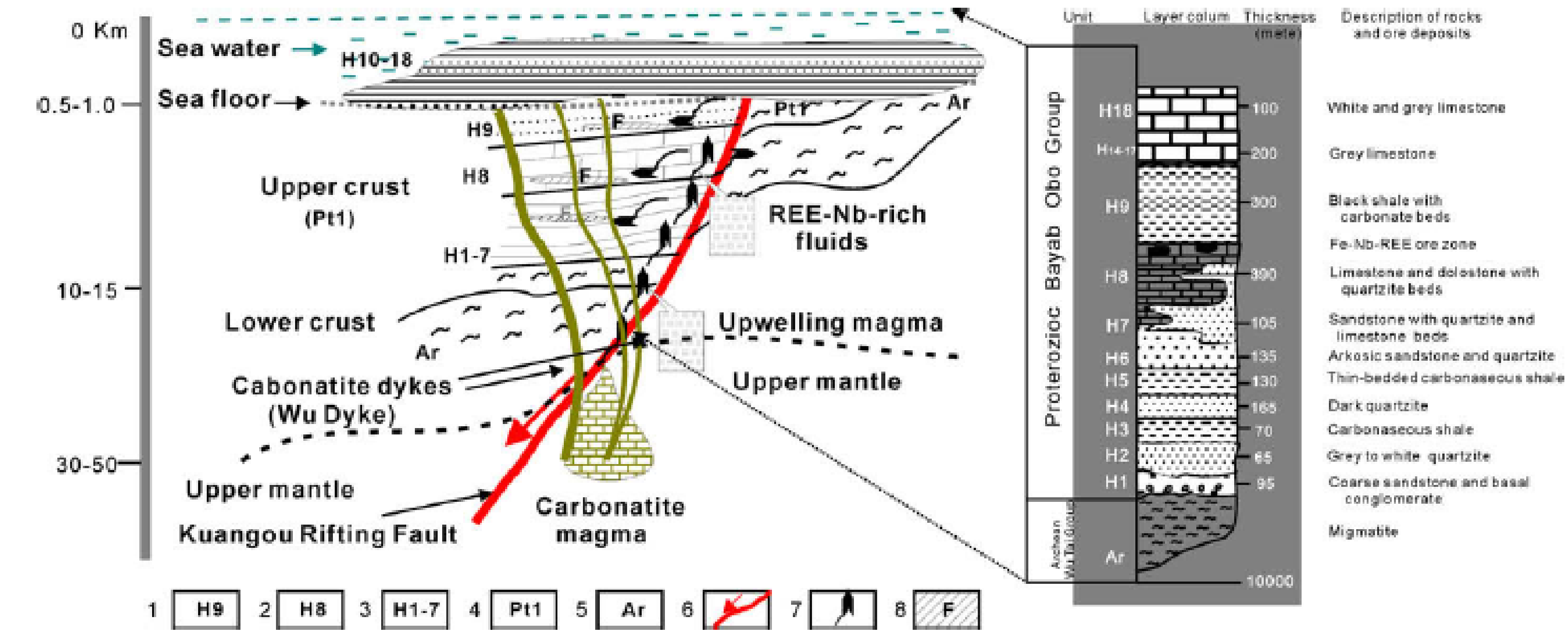
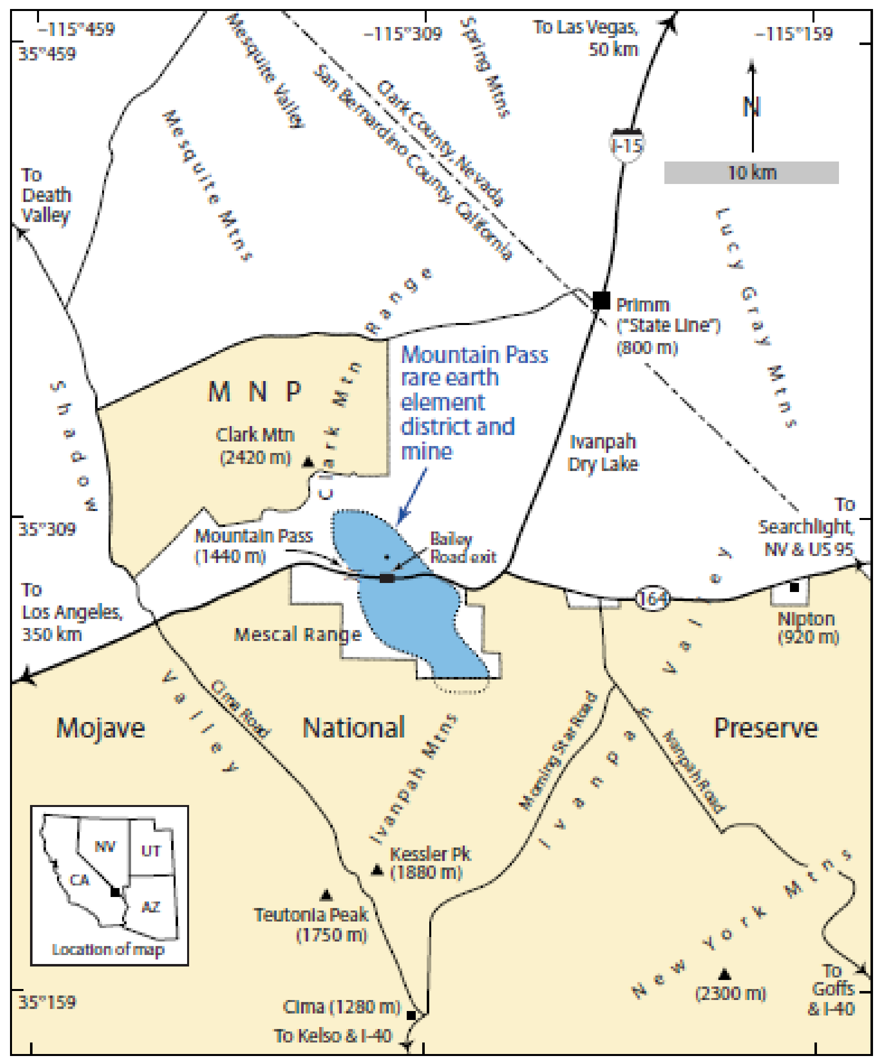



Fig. 10. The proposed model for metasomatism related to the intrusion of carbonatite magma and resulting profiles from the H1–H18 layers in the Bayan Obo region. (1) Carbon slate (H9). (2) Calcite and dolomite carbonates (H8). (3) Sedimentary rocks of Bayan Obo Group (H1–H7). (4) Granitic migmatite of the Wutai formation (Pt1) (Wang et al., 2002). (5) Archean basement gneiss (Ar). (6) Proterozoic rift at Bayan Obo. (7) Path of fluid and magma. (8) Fenitization in sedimentary rocks.

# MOLYCORP MOUNTAIN PASS

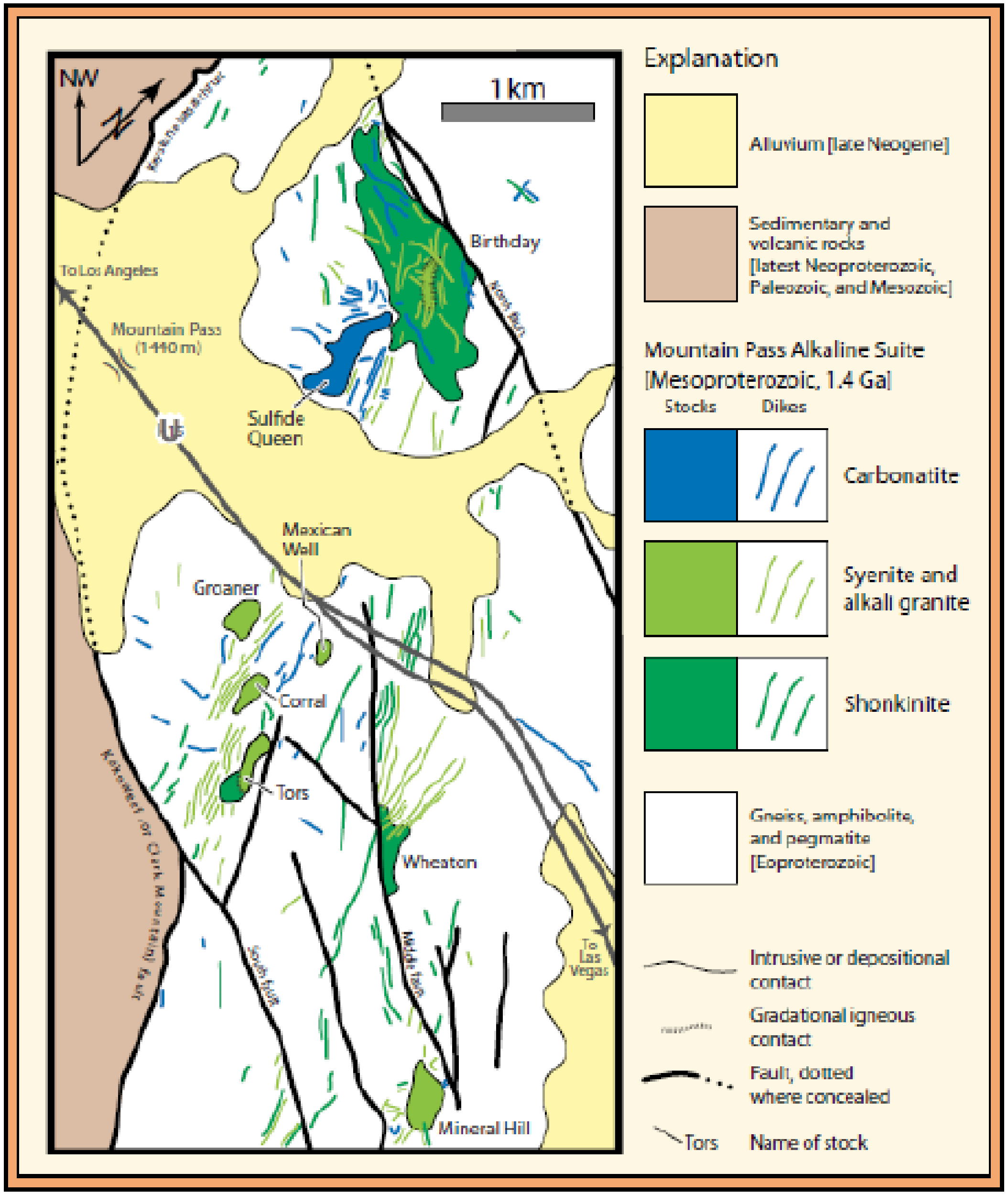


# MOLYCORP MOUNTAIN PASS

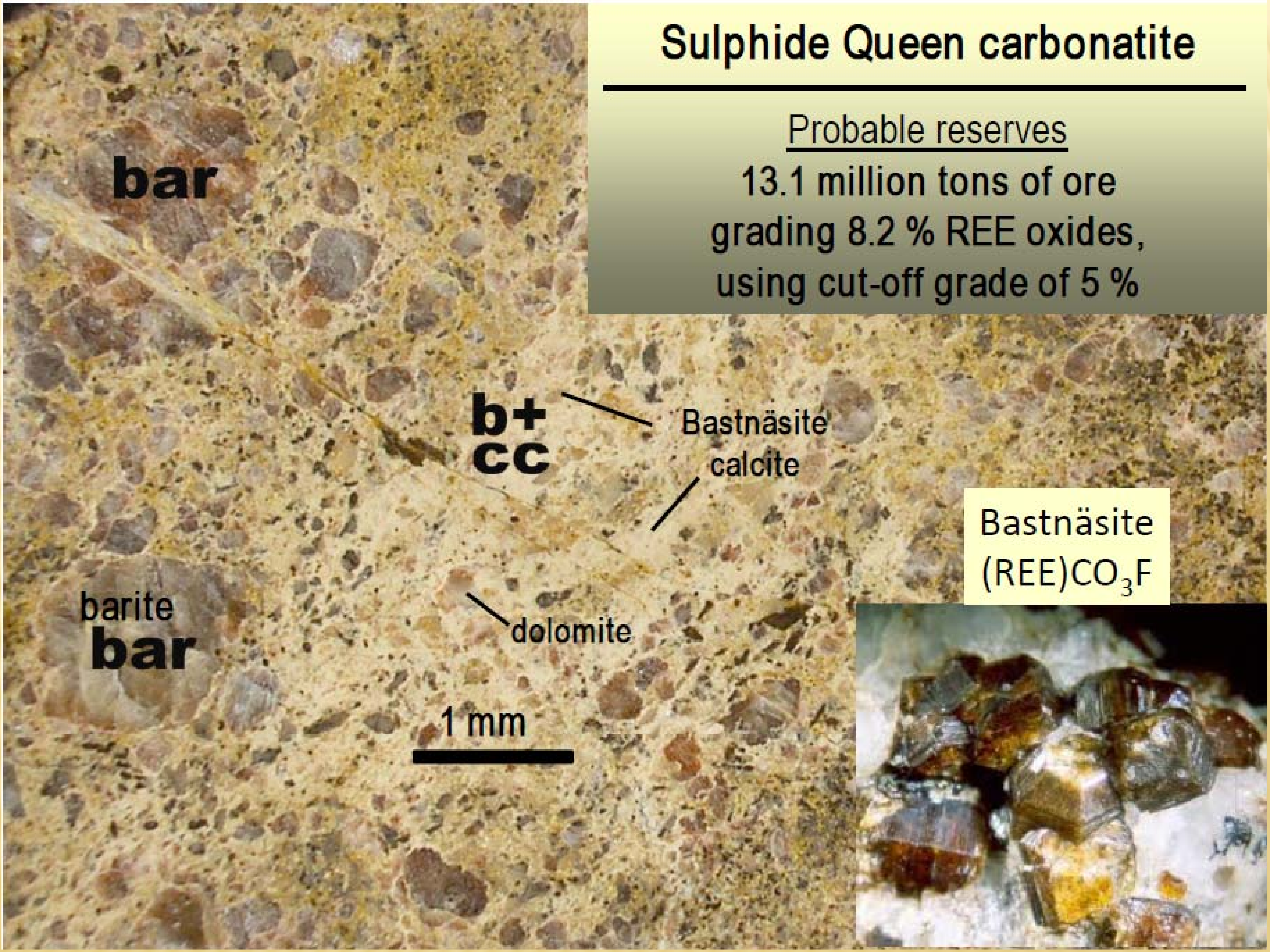
- Mojave Desert
- Discovered in 1949 during exploration for U
- 1.4 Ga

Birthday vein


0 10 20 30 40 50 60 70 80 mm
Mineralium Deposita
SGA
Society for Geology
Applied to Mineral Deposits
0 1 2 Inch 3




From: Haxel (2005)


Sulphide Queen carbonatite
Probable reserves
13.1 million tons of ore
grading 8.2 % REE oxides,
using cut-off grade of 5 %
bar
b+
cc
Bastnäsite
calcite
barite
bar
dolomite
1 mm
Bastnäsite
(REE)$CO_3F$

Molycorp

# A World-Class Resource: Mountain Pass

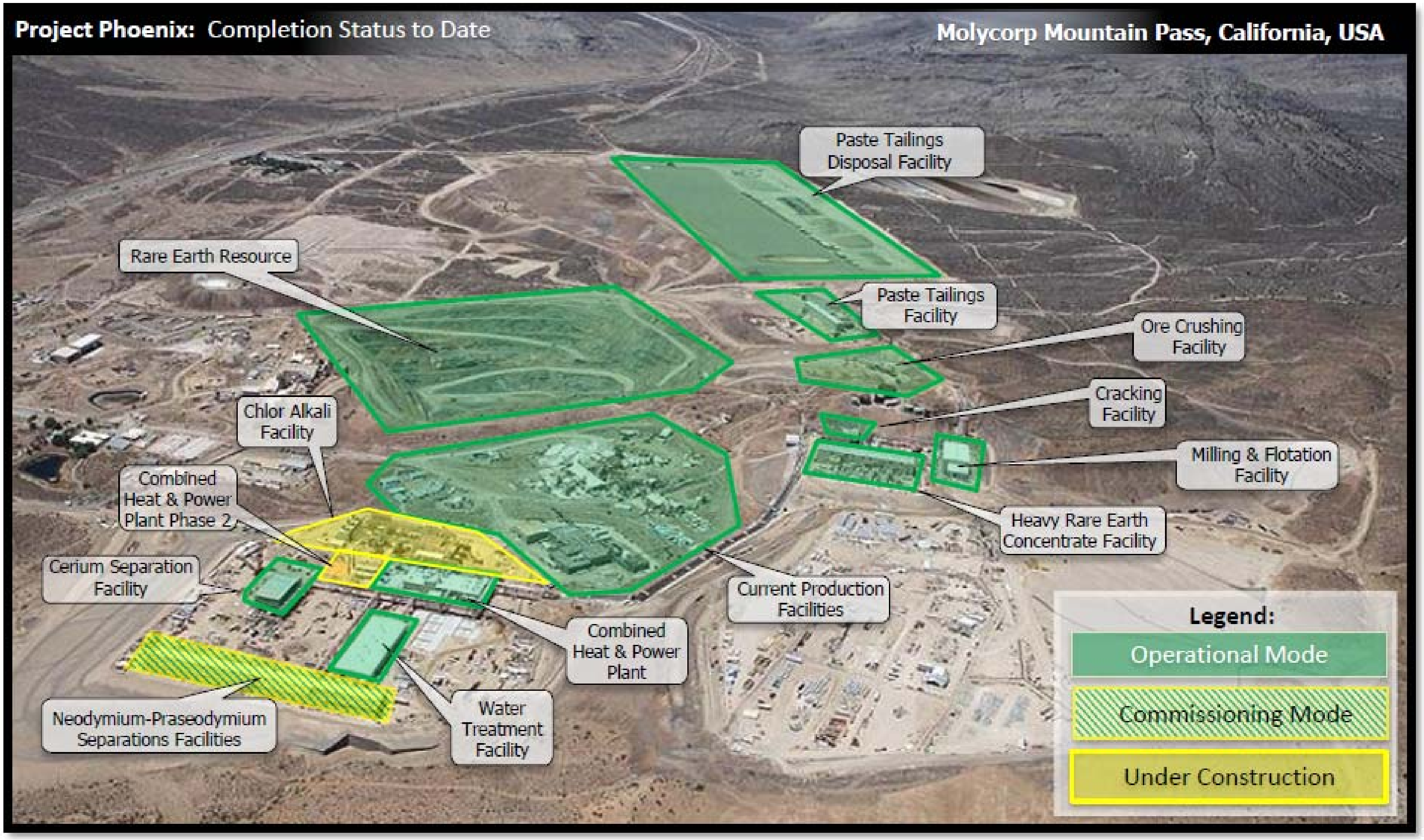
**Reserves & Resources**

| Category | REO% | kMT | M lbs |
|---|---|---|---|
| SEC Guide 7: Proven & Probable | 7.98 | 18,400 | **2,993** |
| NI 43-101: Measured & Indicated | 6.68 | 24,341 | **3,251** |
| NI 43-101: Inferred | 6.32 | 10,446 | **1,320** |
| NI 43-101 Totals | | 34,787 | **4,571** |

- 60 years of operating history
- More than seven years without a Lost Time Incident
- Current government permits allow operations through 2042
- Phase 1 production rate (19,050 mt/year of REO equivalent) will be achieved in Q4 2012
- Phase 2 production capacity (40,000 mt / year) to be mechanically complete by year end 2012
- Very low occurrence of Th (.02%) and U (.002%) in the ore body. Th and U are removed and permanently deposited onsite in Molycorp's environmentally superior paste tailings disposal facility.

Molycorp

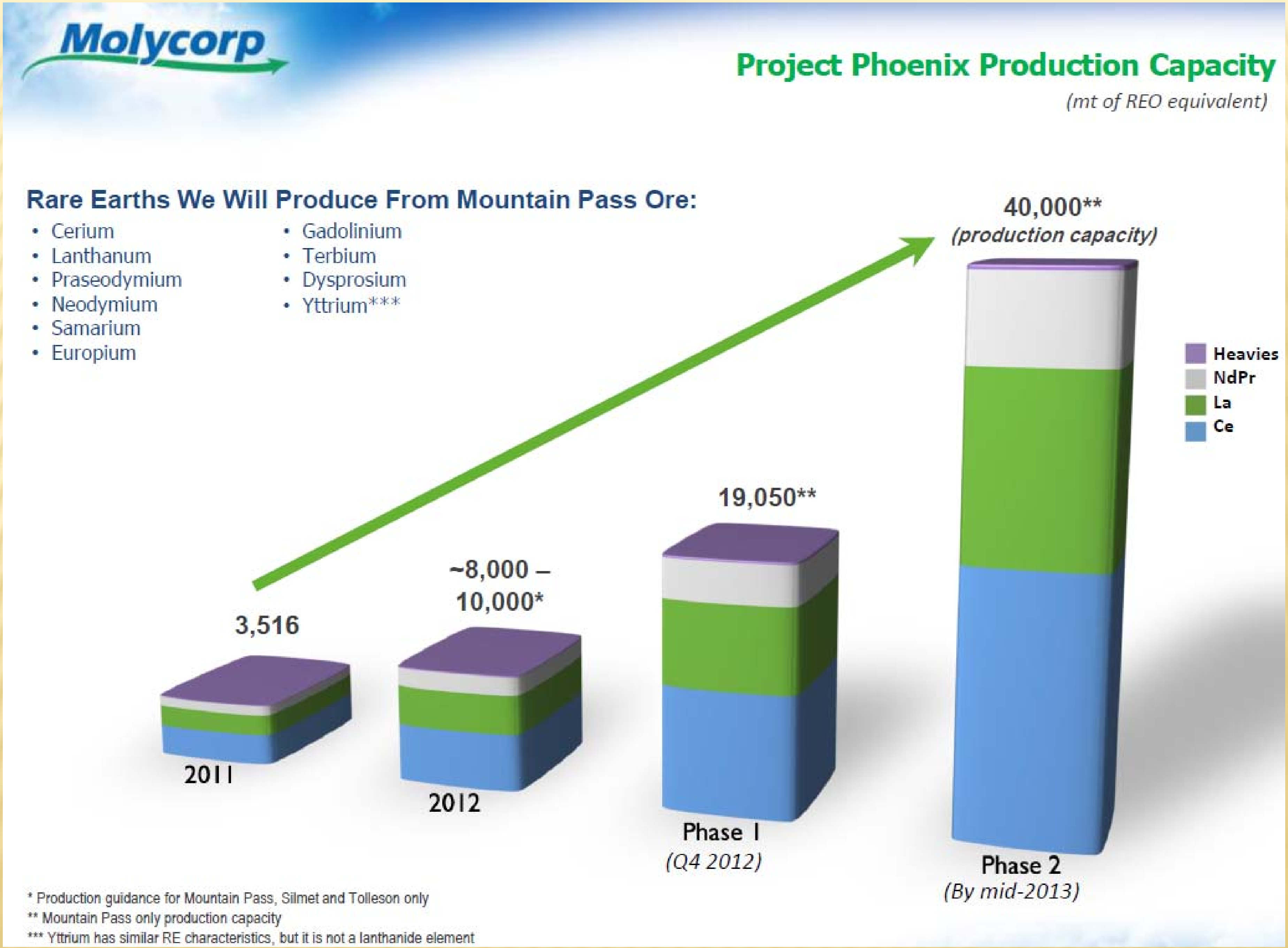
# The Project Phoenix Modernization And Expansion of Mountain Pass



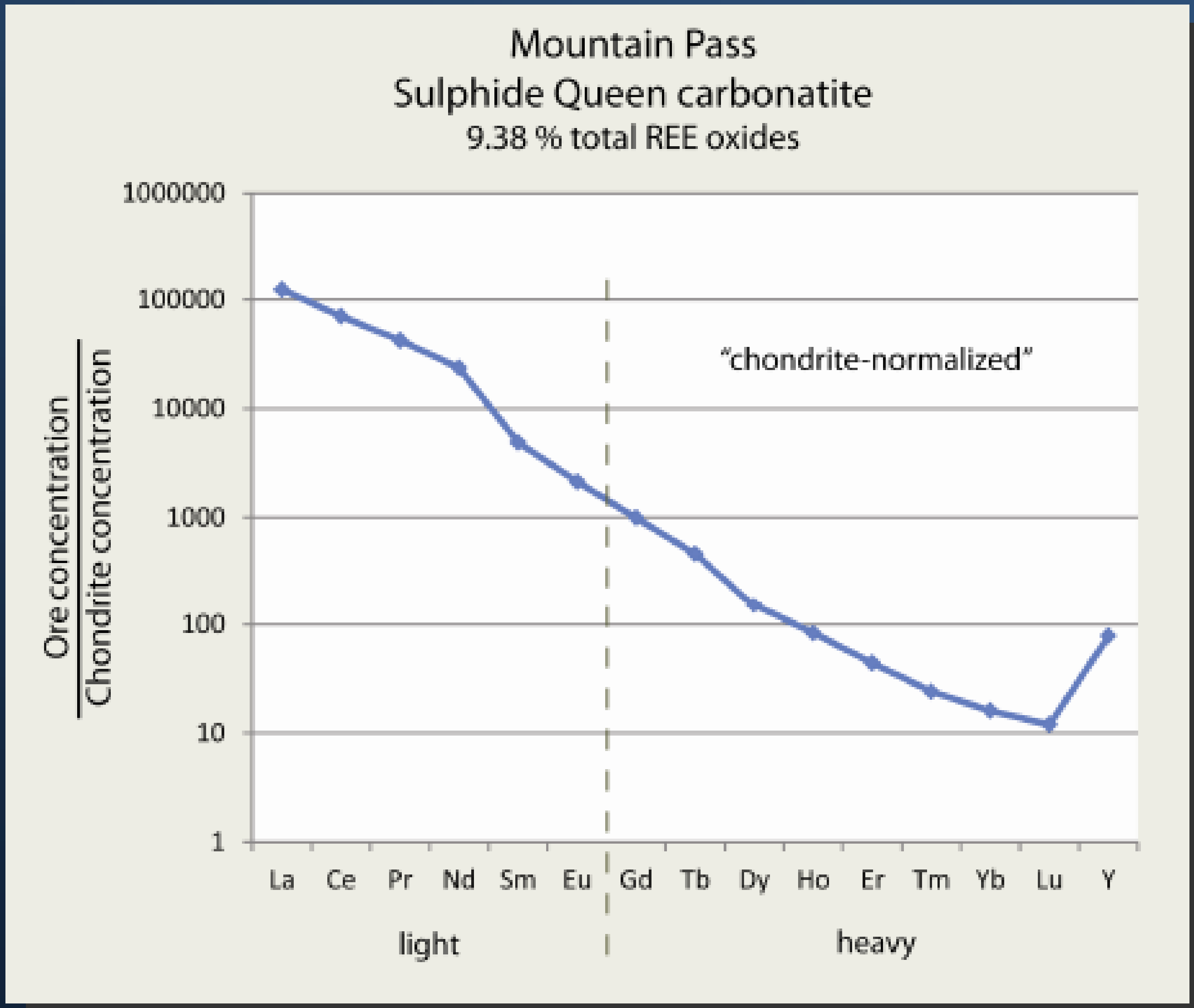
Molycorp

# Project Phoenix Completion Status

| Facility | Phase 1 Construction | In Commissioning | Phase 1 Operational Status | % Complete for Phase 1 Ramp |
|---|---|---|---|---|
| Mining Operations | | | Operating at *Greater* Than Phase 1 Rate | 100% |
| Crushing | | | Operating at *Greater* Than Phase 1 Rate | 100% |
| Milling | | | Operating at *Greater* Than Phase 1 Rate | 100% |
| Flotation | | | Operating at *Greater* Than Phase 1 Rate | 100% |
| Paste Tailings Plant | | | Operating at *Greater* Than Phase 1 Rate | 100% |
| Paste Tailings Disposal Facility | | | Operating at *Greater* Than Phase 1 Rate | 100% |
| Combined Heat & Power Plant | | | Operational at Phase 1 Rate | 100% |
| Water Treatment | | | Operational at Phase 1 Rate | 100% |
| SX-H / SX-I | | | Operational at Phase 1 Rate | 100% |
| Cerium | | | Operational at Phase 1 Rate | 90% |
| Crack | | | Operational at 25% Phase 1 Rate | 70% |
| NdPr | | | | 80% |


Molycorp
Project Phoenix Production Capacity
(mt of REO equivalent)
Rare Earths We Will Produce From Mountain Pass Ore:
• Cerium
• Lanthanum
• Praseodymium
• Neodymium
• Samarium
• Europium
• Gadolinium
• Terbium
• Dysprosium
• Yttrium***
3,516
~8,000 – 10,000*
19,050**
40,000**
(production capacity)
2011
2012
Phase 1
(Q4 2012)
Phase 2
(By mid-2013)
Heavies
NdPr
La
Ce
* Production guidance for Mountain Pass, Silmet and Tolleson only
** Mountain Pass only production capacity
*** Yttrium has similar RE characteristics, but it is not a lanthanide element

# Mountain Pass Sulphide Queen Carbonitite




USGS

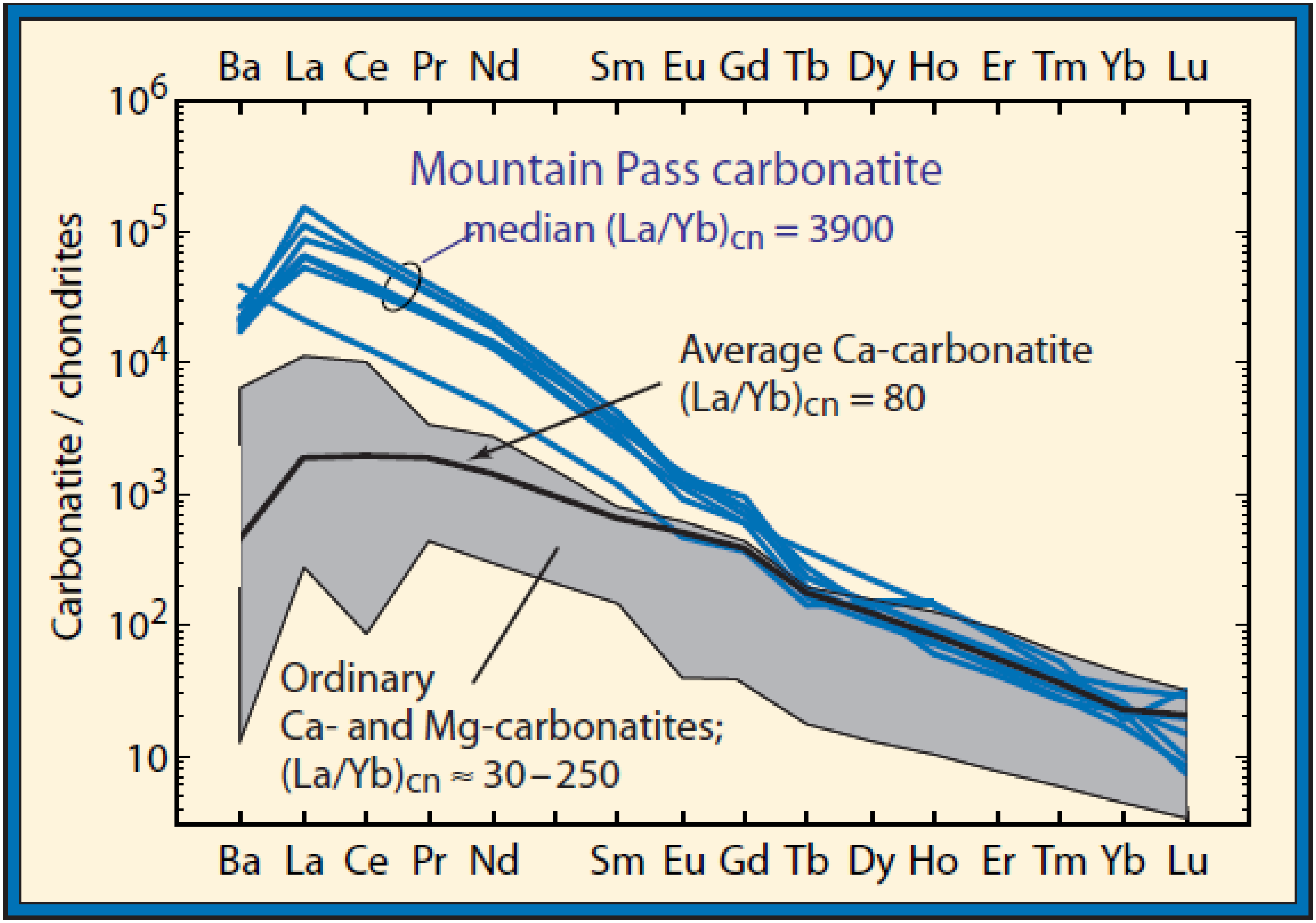
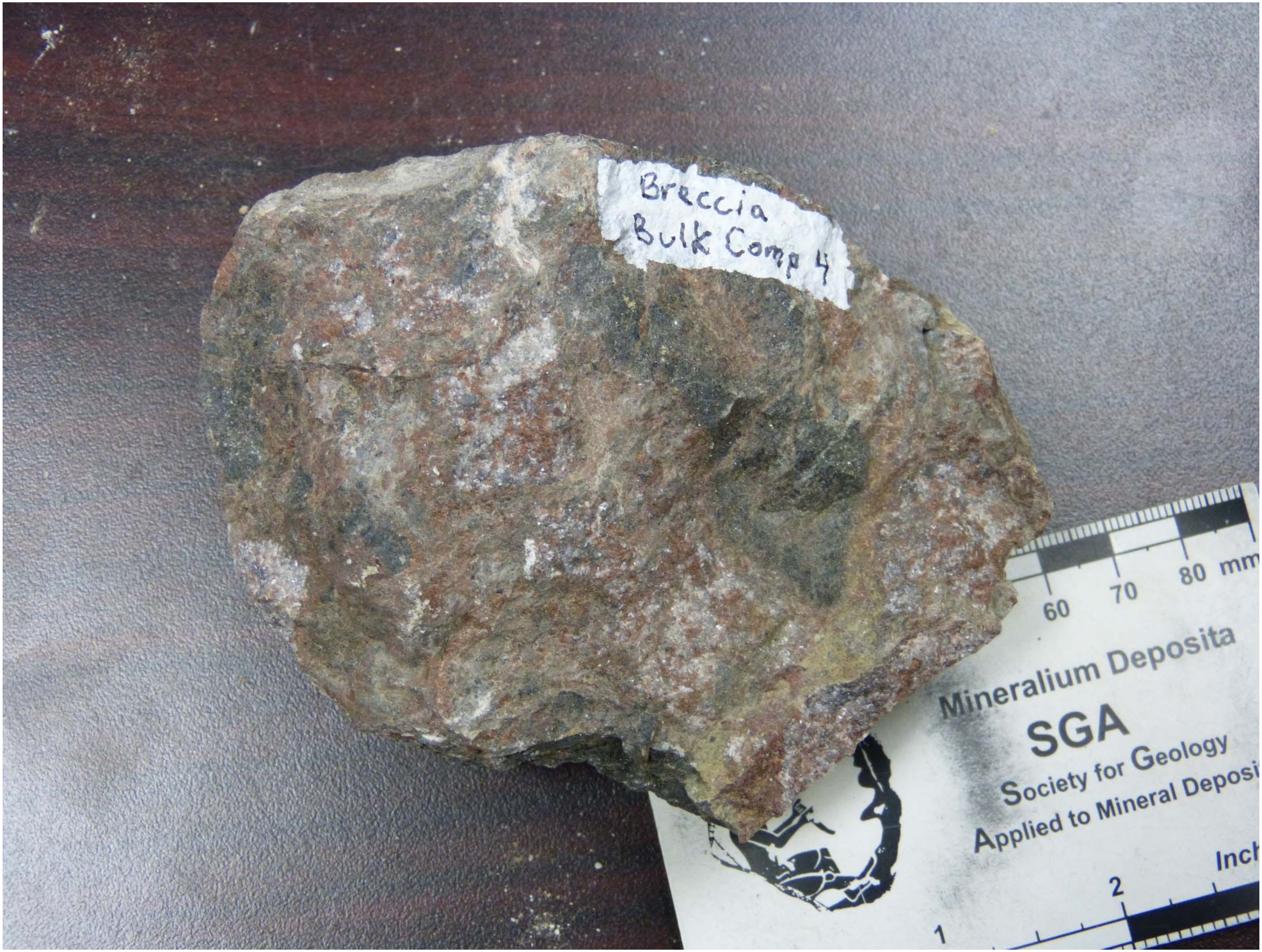


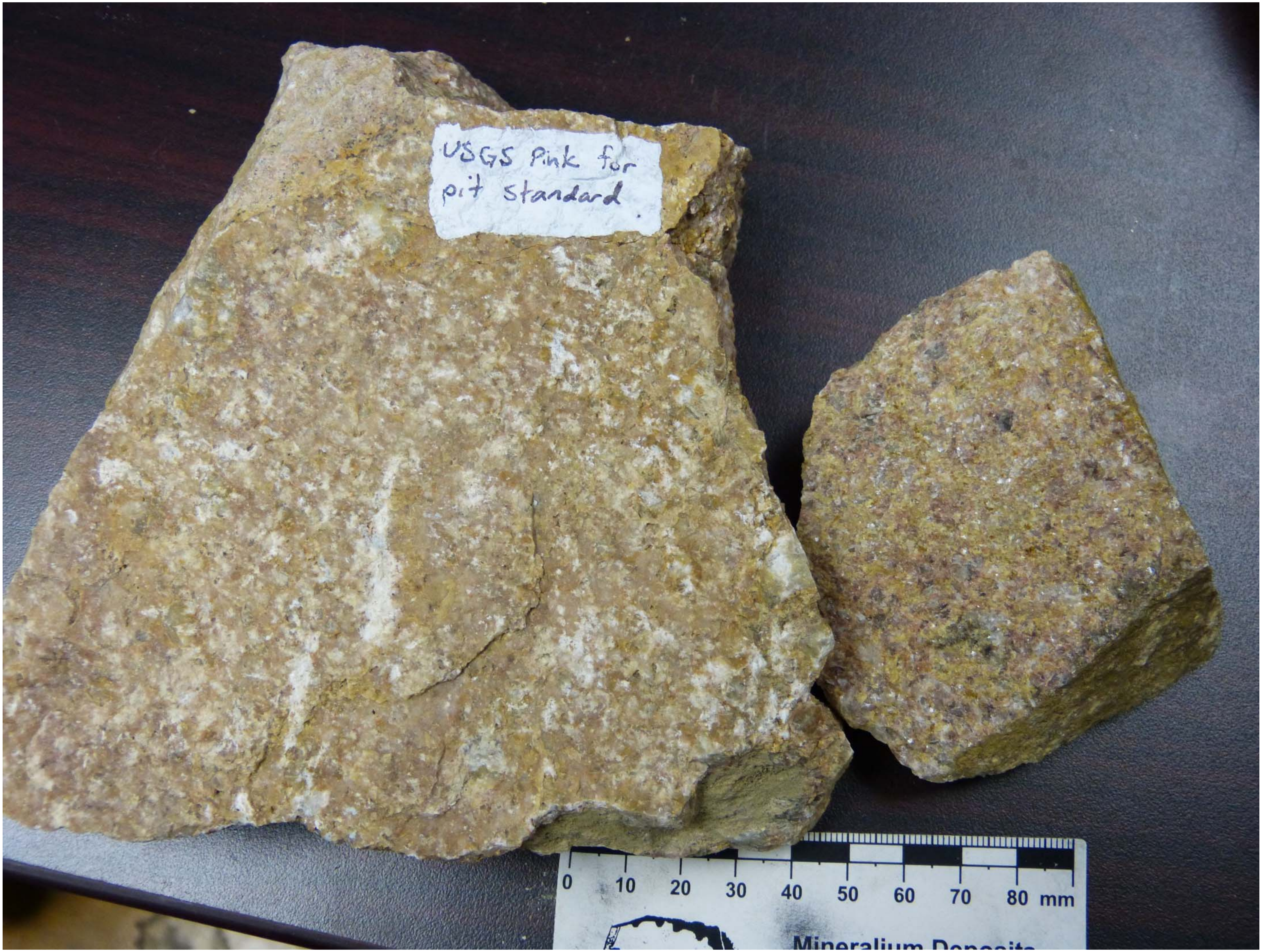

Figure 15. Extended REE spectra (lanthanides plus Ba) of Mountain Pass carbonatite (including one analysis from Johnson and Sisneros, 1982), compared with ordinary carbonatites (Woolley and Kempe, 1989); chondrite normalized (Table 1; Nakamura, 1974). See also Figures 3, 13, and 14.

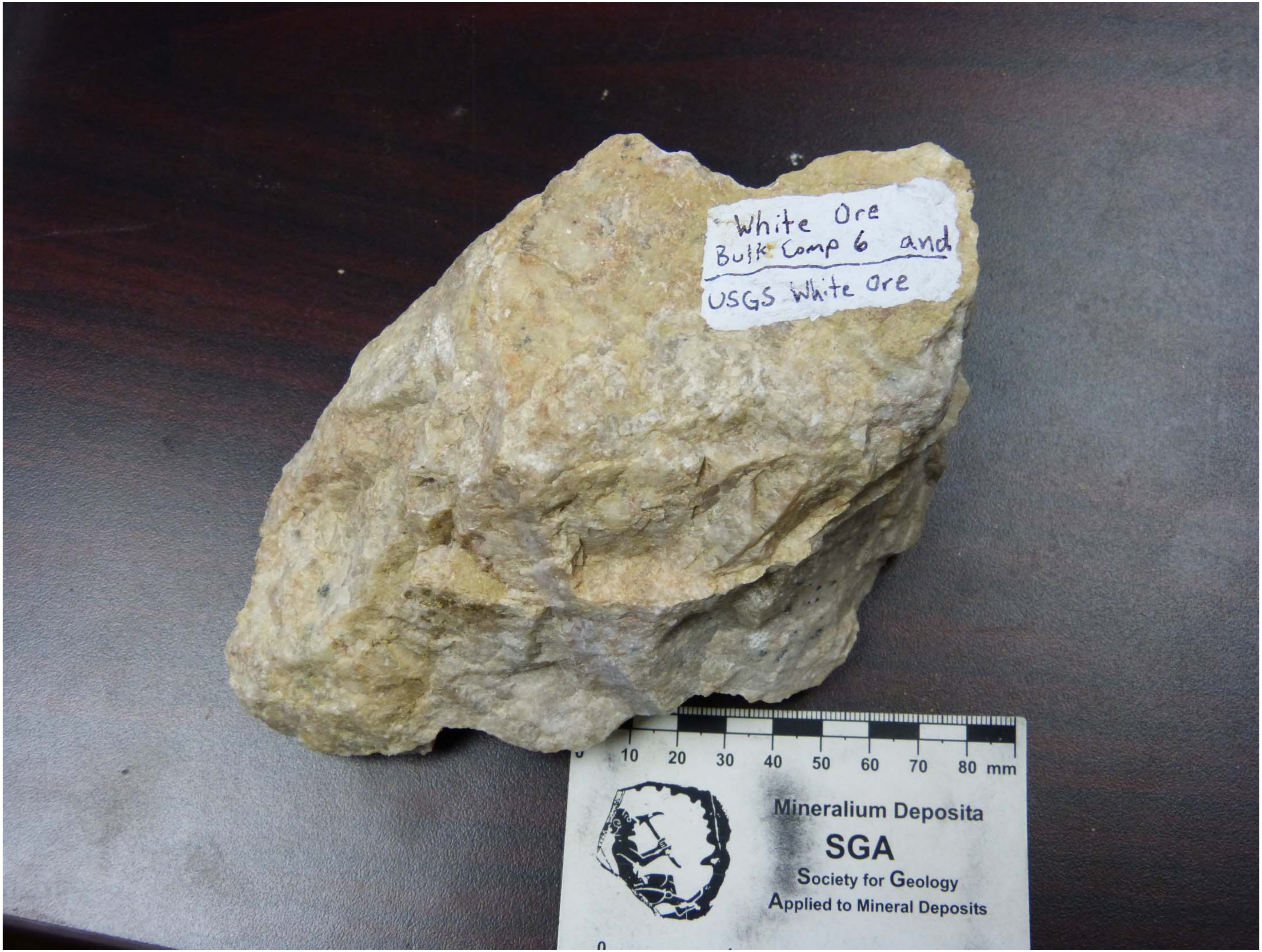

Black Ore
Bulk Comp 2
0 10 20 30 40 50 60 70 80 mm
Mineralium Deposita
SGA

20
30
40
50
60
70
Mineralium De
SGA
Society for
Applied to Min

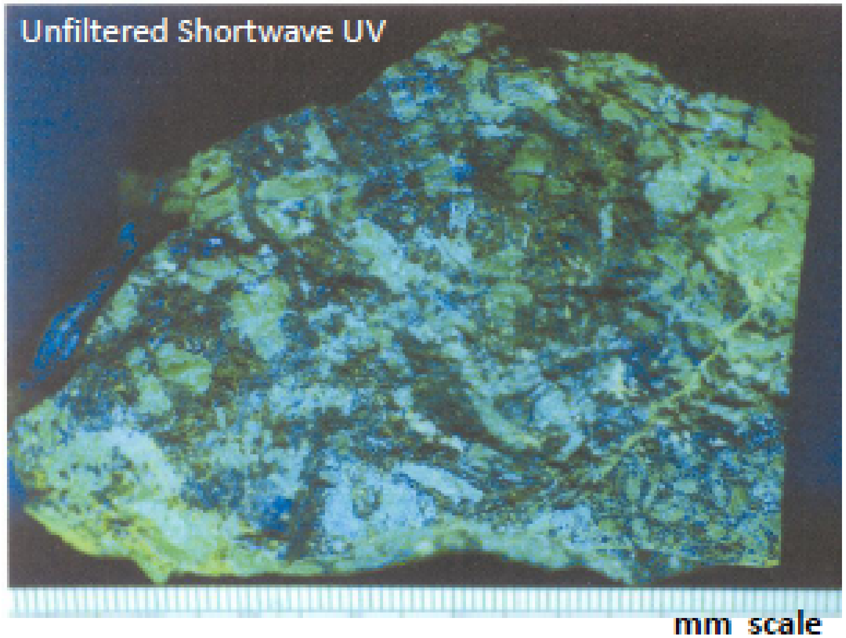

USGS Brown
for pit standard
20 30 40 50 60 70 80 mm
Mineralium Deposita
SGA
Society for Geology


Breccia
Bulk Comp 4
60
70
80 mm
Mineralium Deposita
SGA
Society for Geology
Applied to Mineral Deposi
Inch
1
2

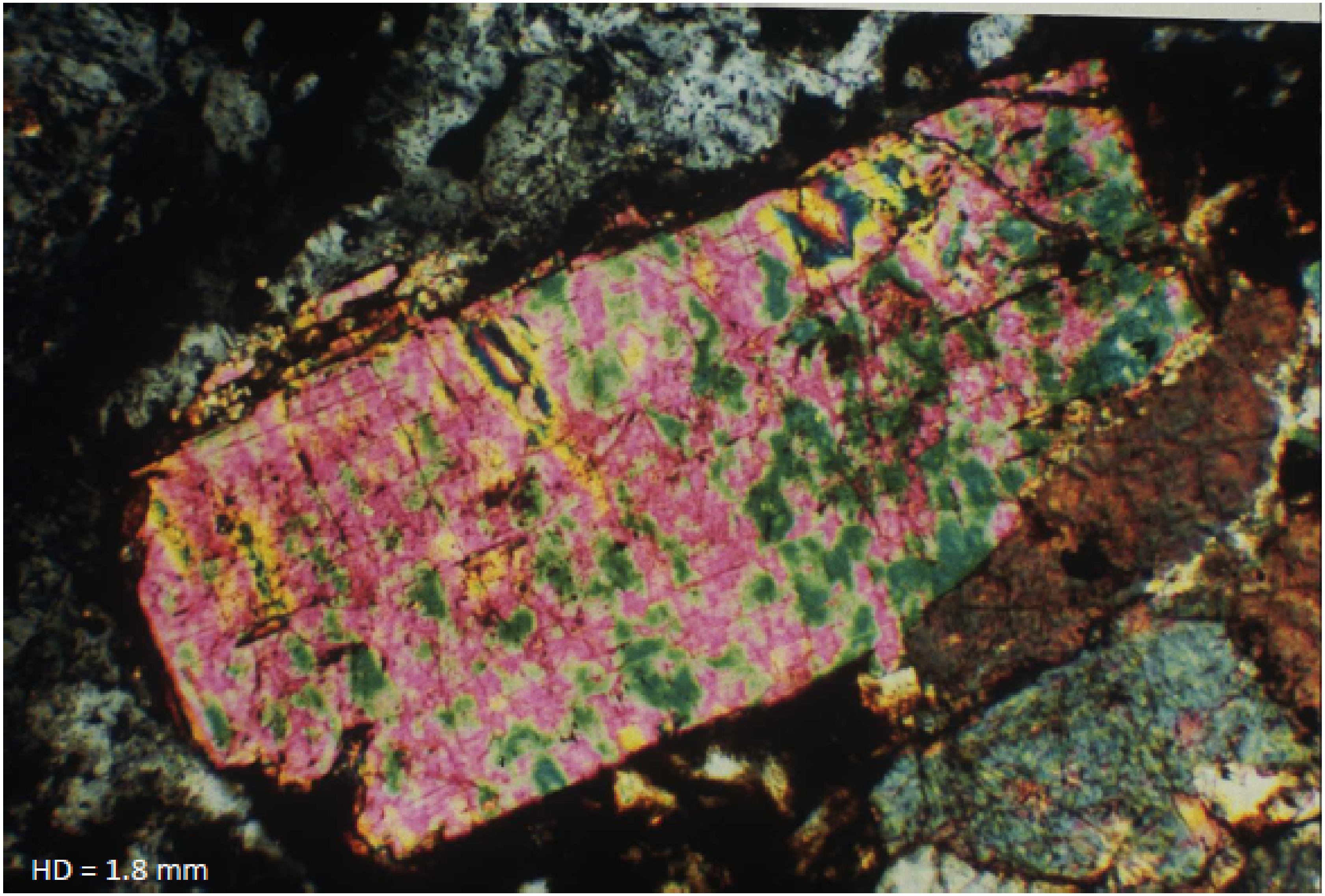

USGS Pink for
pit standard.
0 10 20 30 40 50 60 70 80 mm


White Ore
Bulk Comp 6 and
USGS White Ore
10 20 30 40 50 60 70 80 mm
Mineralium Deposita
SGA
Society for Geology
Applied to Mineral Deposits

# Bastnäsite, Mountain Pass, CA

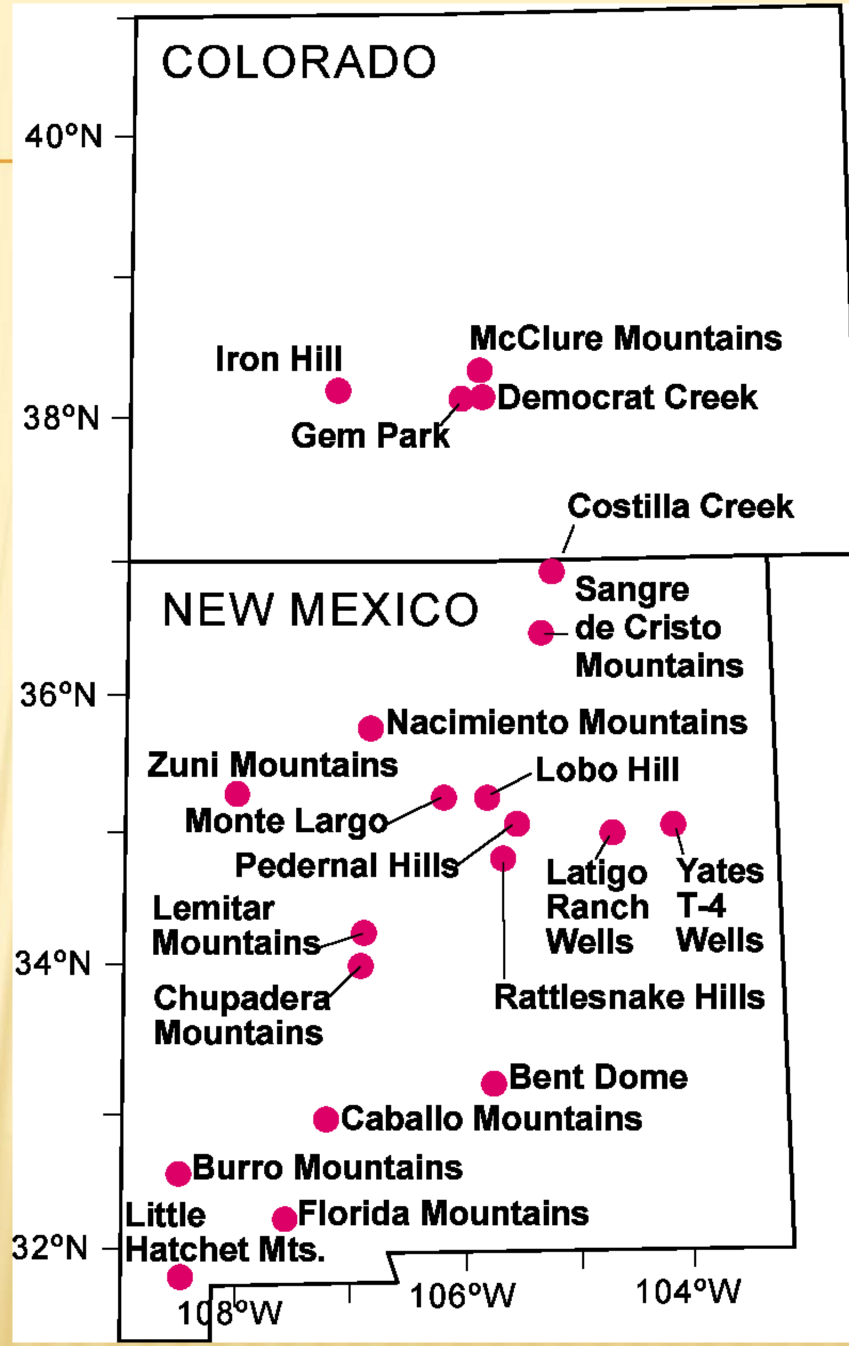
# Parisite - $Ca(REE)_2(CO_3)_3F_2$ Mountain Pass, CA



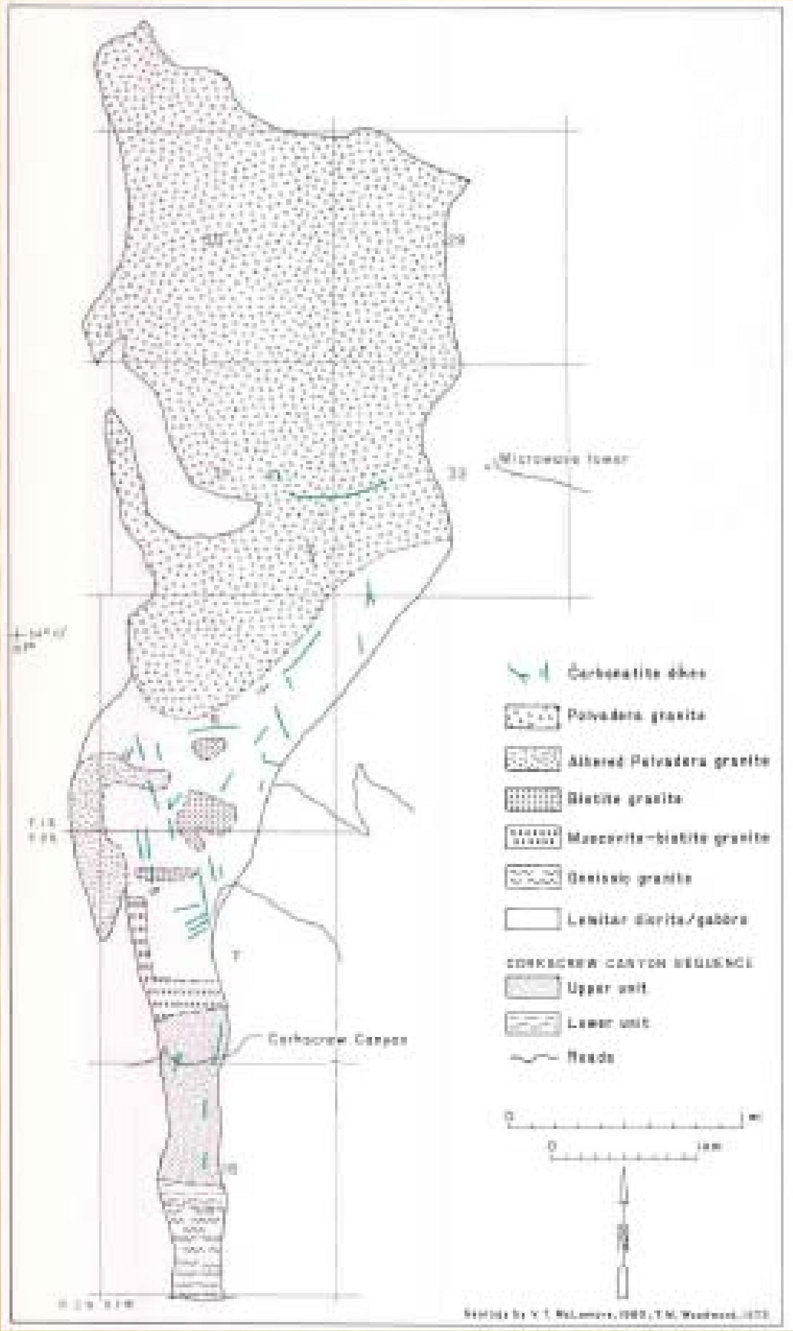

Mineralium Deposita
SGA
Society for Geology
Applied to Mineral Deposits

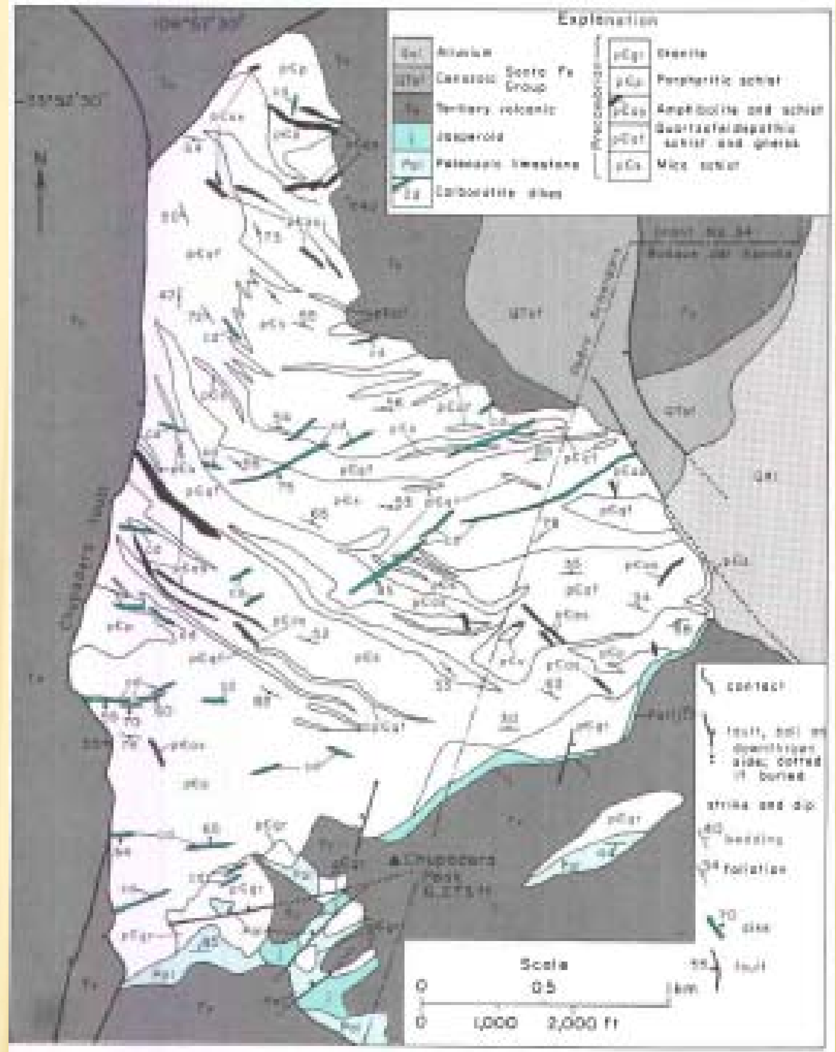
0 10 20 30 40 50 60 70 80 mm
Mineralium Deposita
SGA
Society for Geology
Applied to Mineral Deposits
Inch
0 1 2 3

# CAMBRIAN-ORDOVICIAN CARBONATITES, SYENITES, ALKALI GRANITES, EPISYENITES



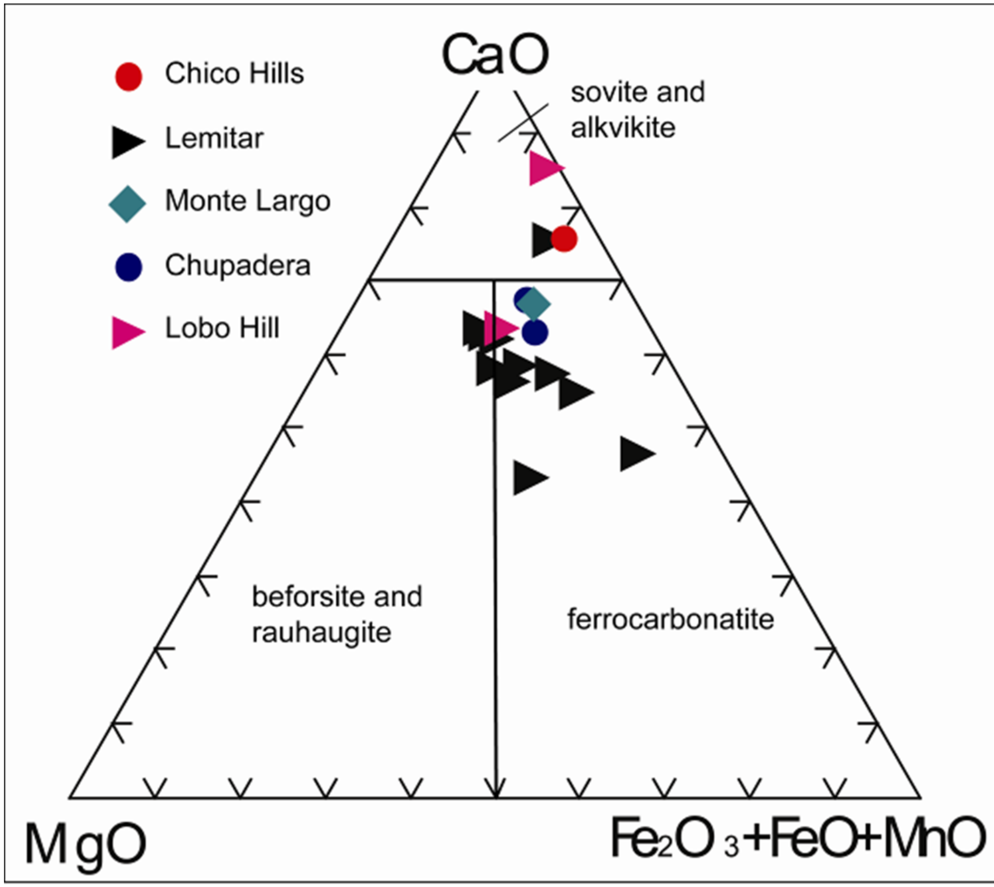

# Lemitar carbonatite

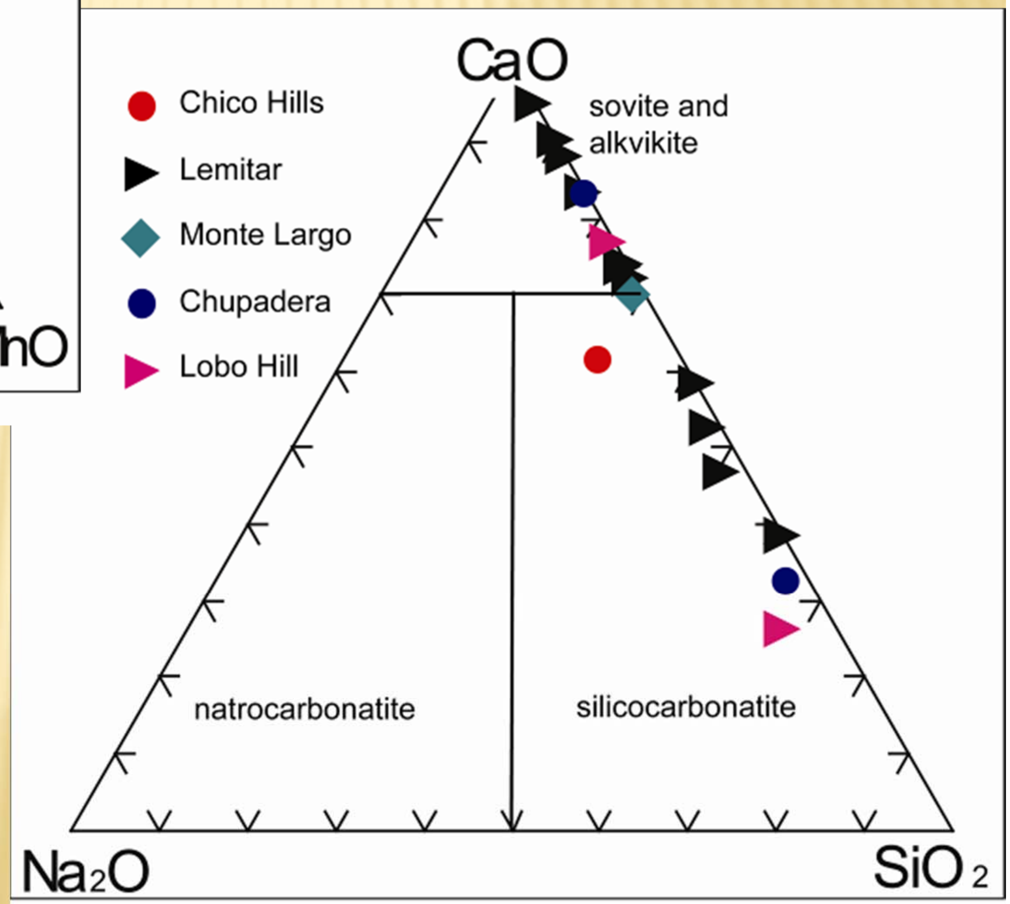


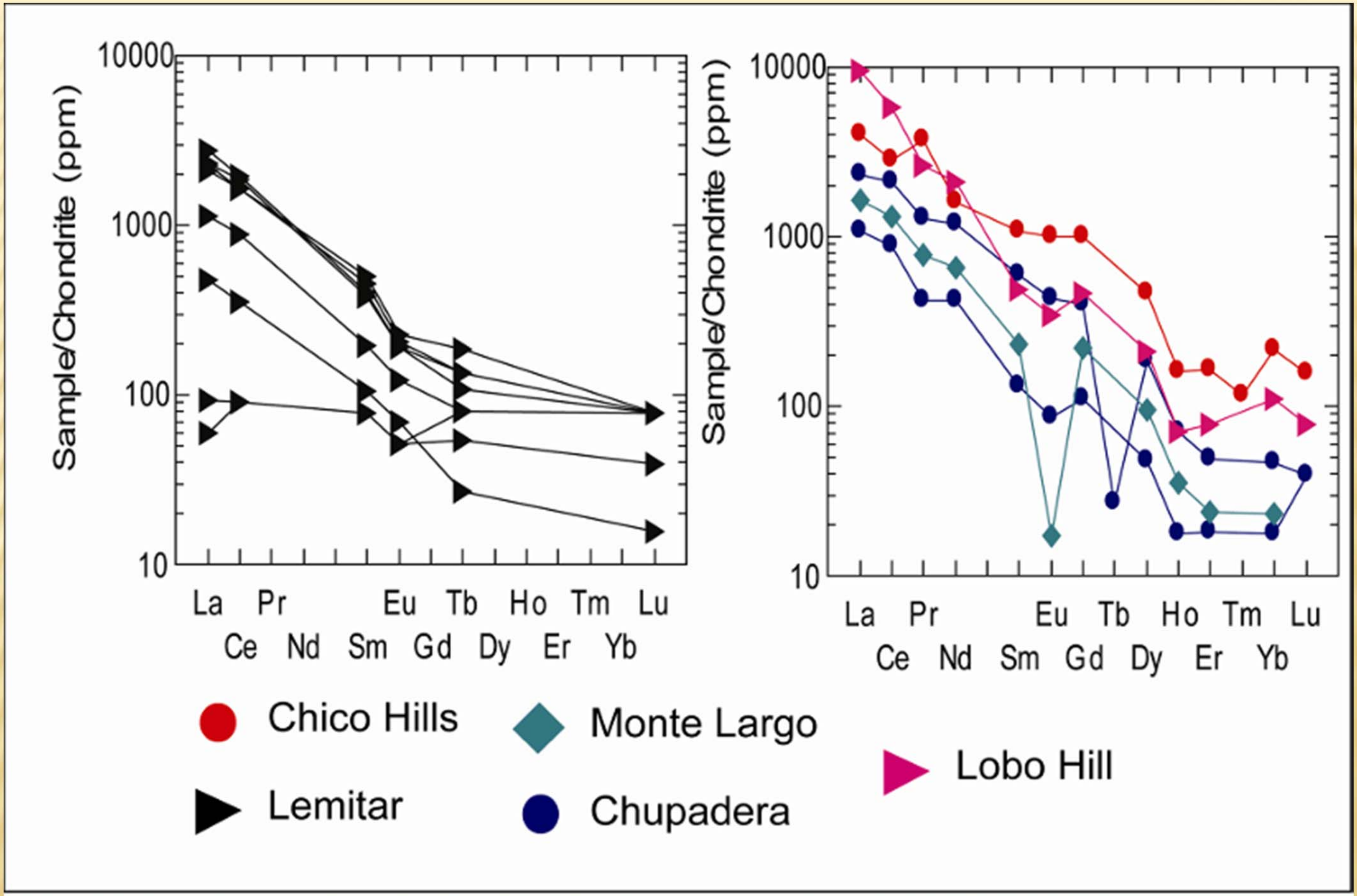




Chupadera carbonatites (van Allen et al., 1986)

Lemitar carbonatites (McLemore, 1983)

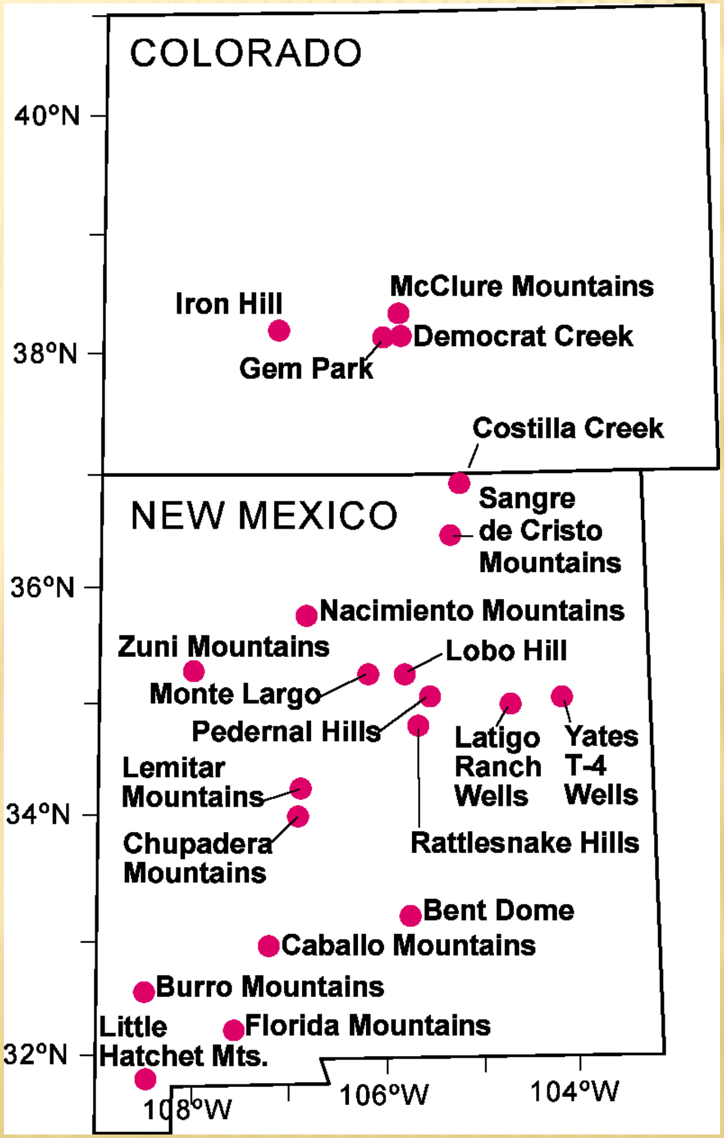

Chico Hills
Lemitar
Monte Largo
Chupadera
Lobo Hill
CaO
sovite and alkvikite
beforsite and rauhaugite
ferrocarbonatite
MgO
$Fe_2O_3$+FeO+MnO


Chico Hills
Lemitar
Monte Largo
Chupadera
Lobo Hill
CaO
sovite and alkvikite
natrocarbonatite
silicocarbonatite
$Na_2O$
$SiO_2$

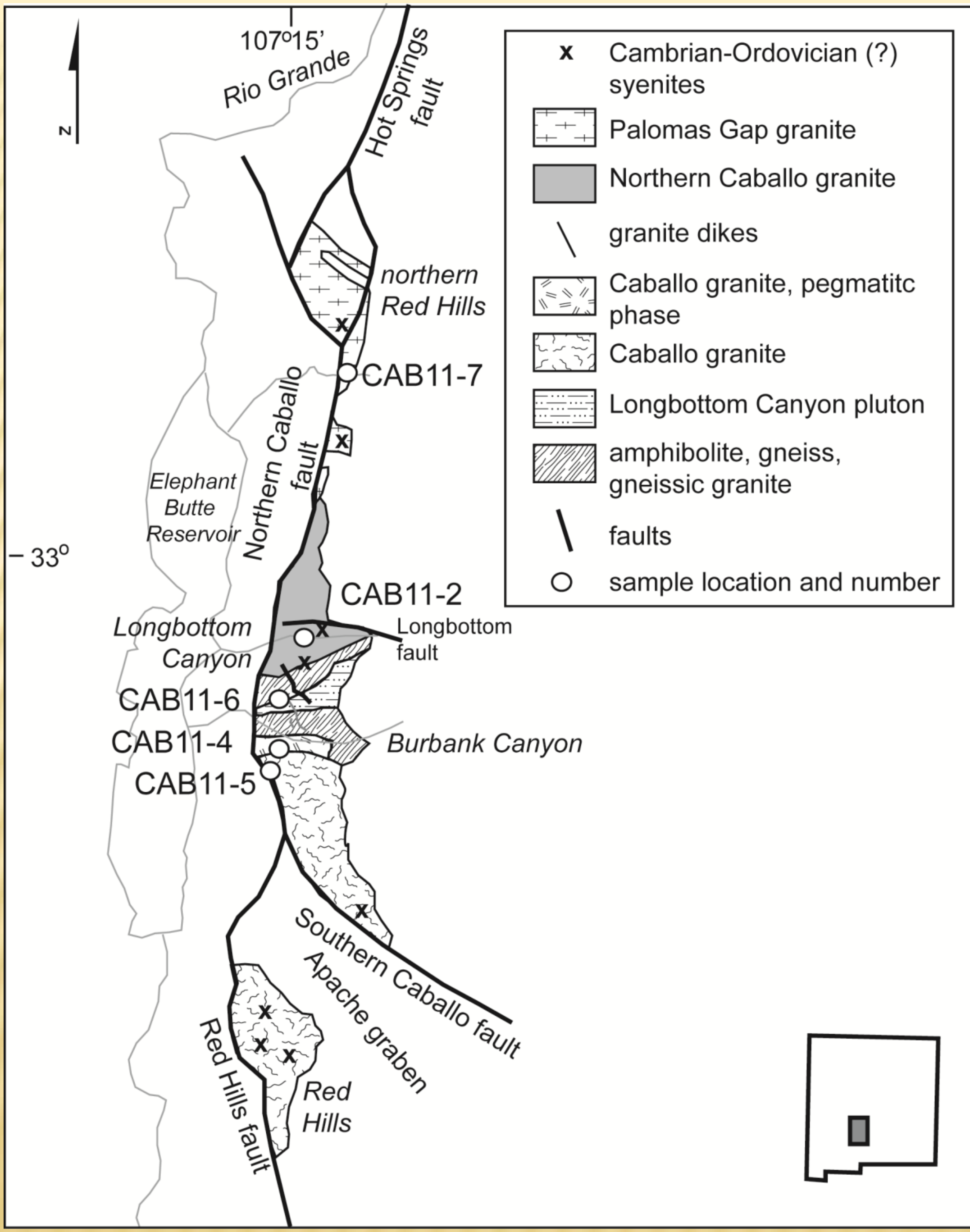


Sample/Chondrite (ppm)
10000
1000
100
10
La
Ce
Pr
Nd
Sm
Eu
Gd
Tb
Dy
Ho
Er
Tm
Yb
Lu
Chico Hills
Monte Largo
Lobo Hill
Lemitar
Chupadera

# METAMORPHIC/METASOMATIC

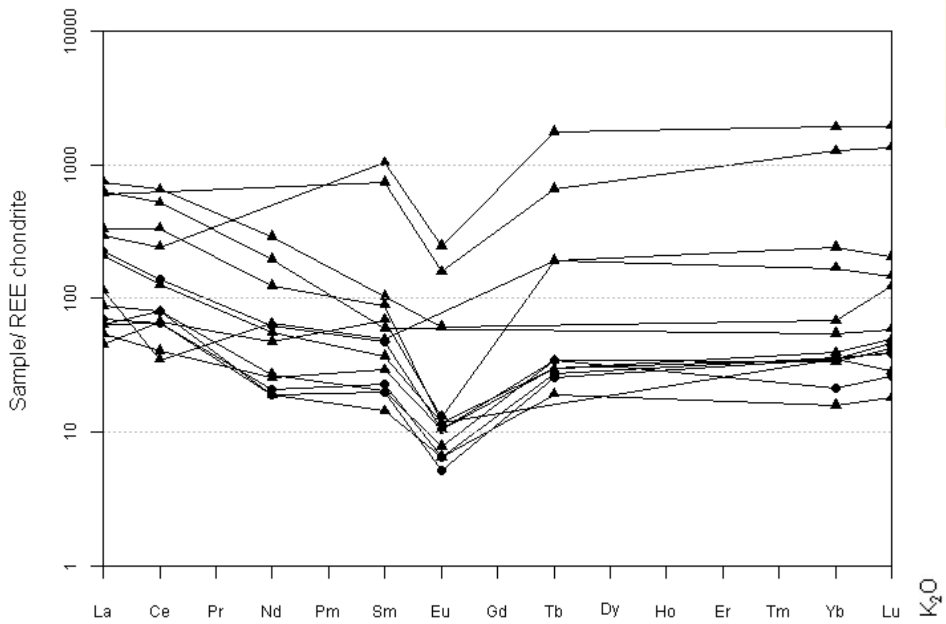


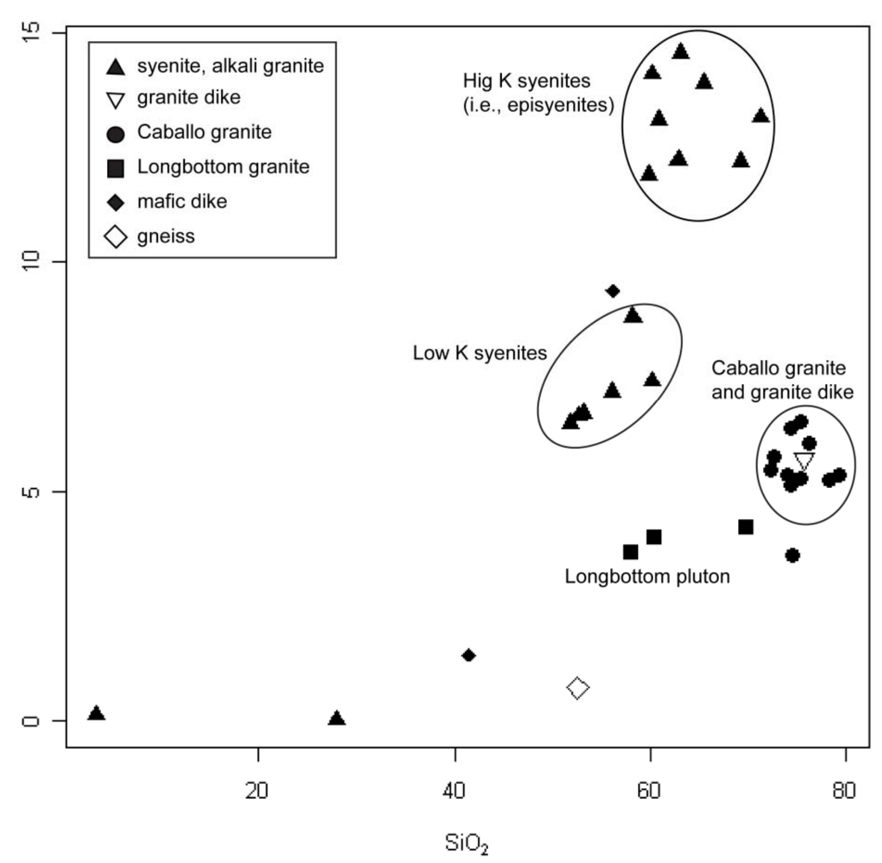
# Episyenites in Longbottom Canyon, Caballo Mountains

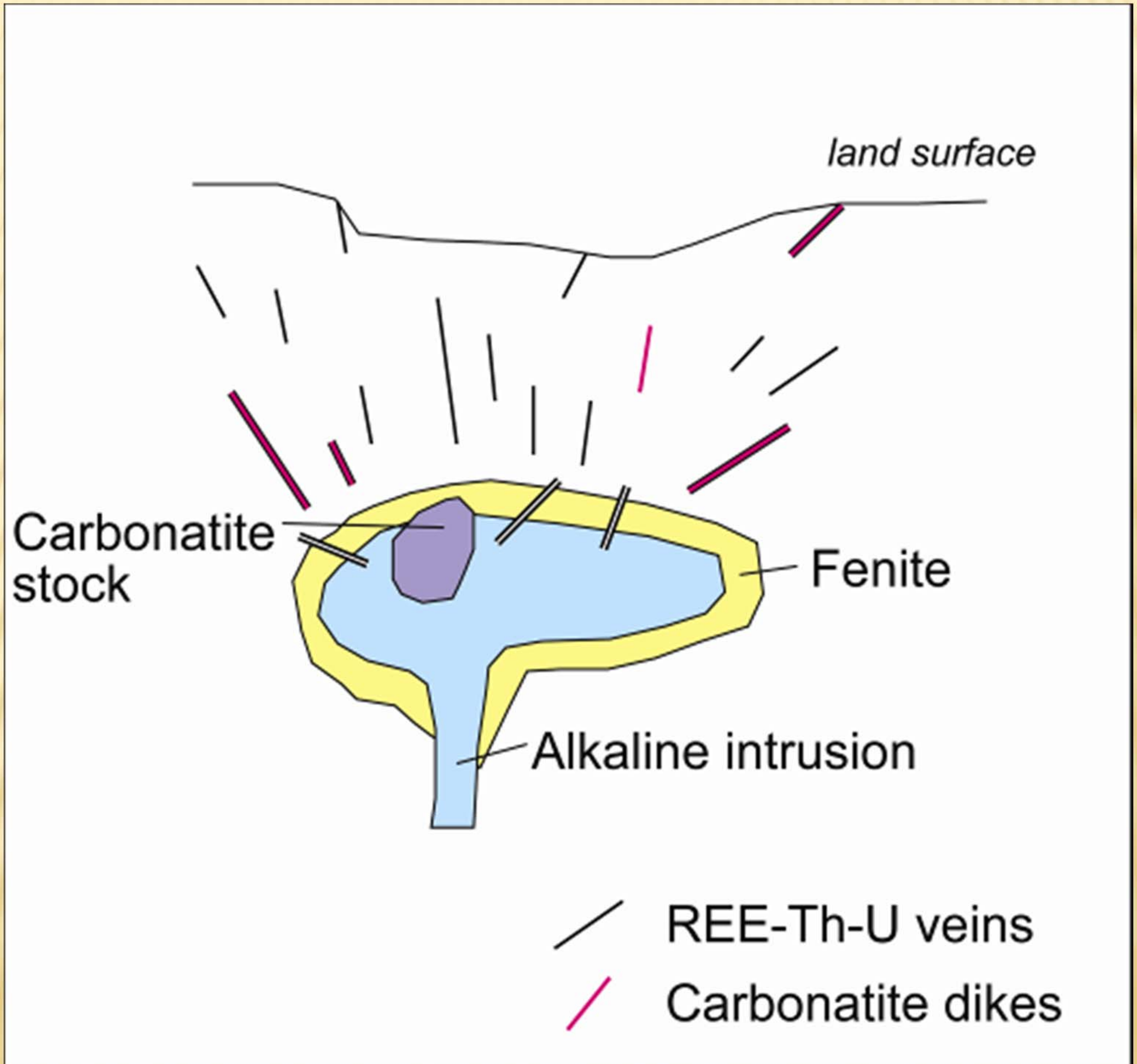



# EPISYENITES IN CABALLO MOUNTAINS

# CHEMISTRY OF CABALLO EPISYENITES



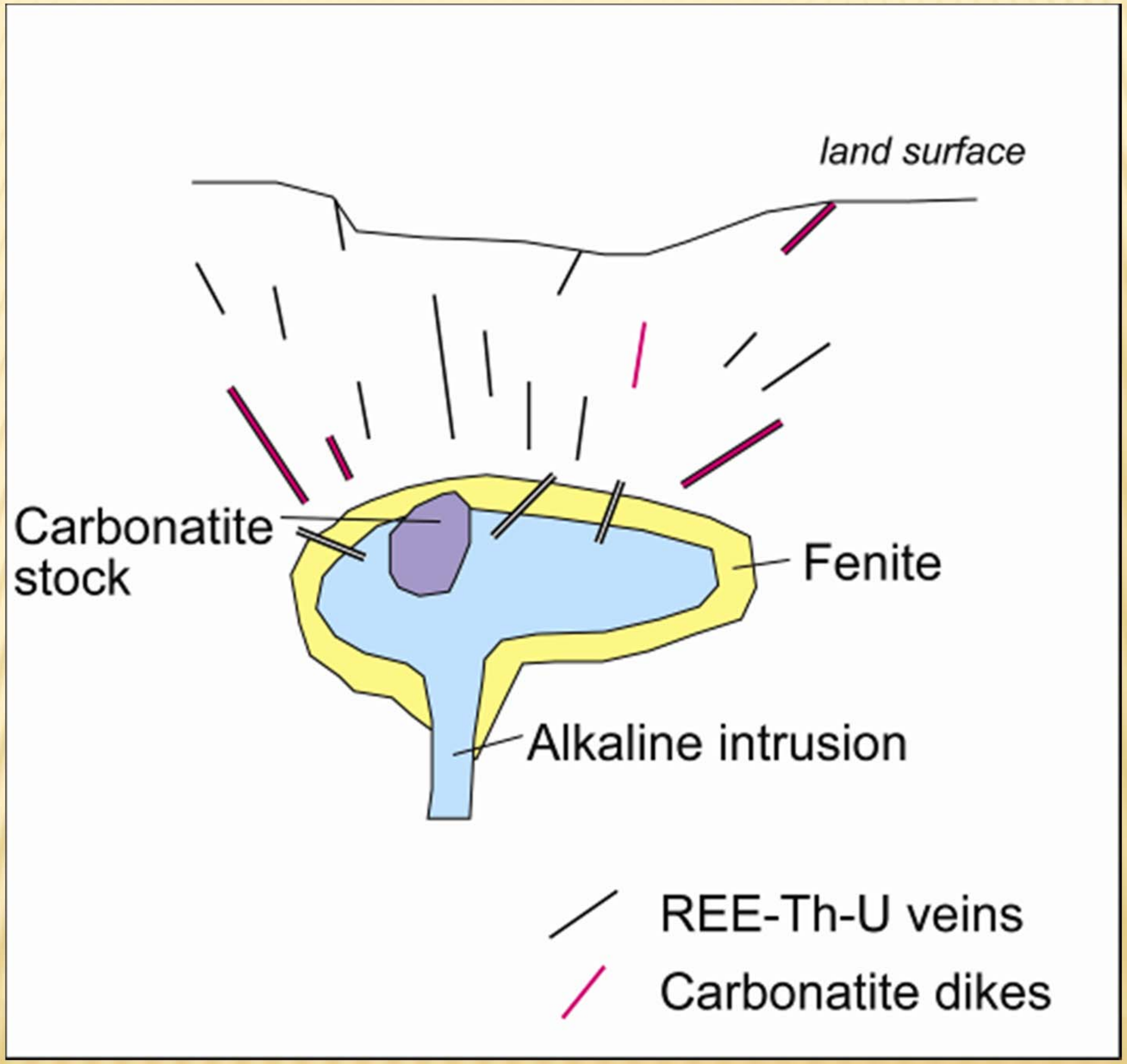


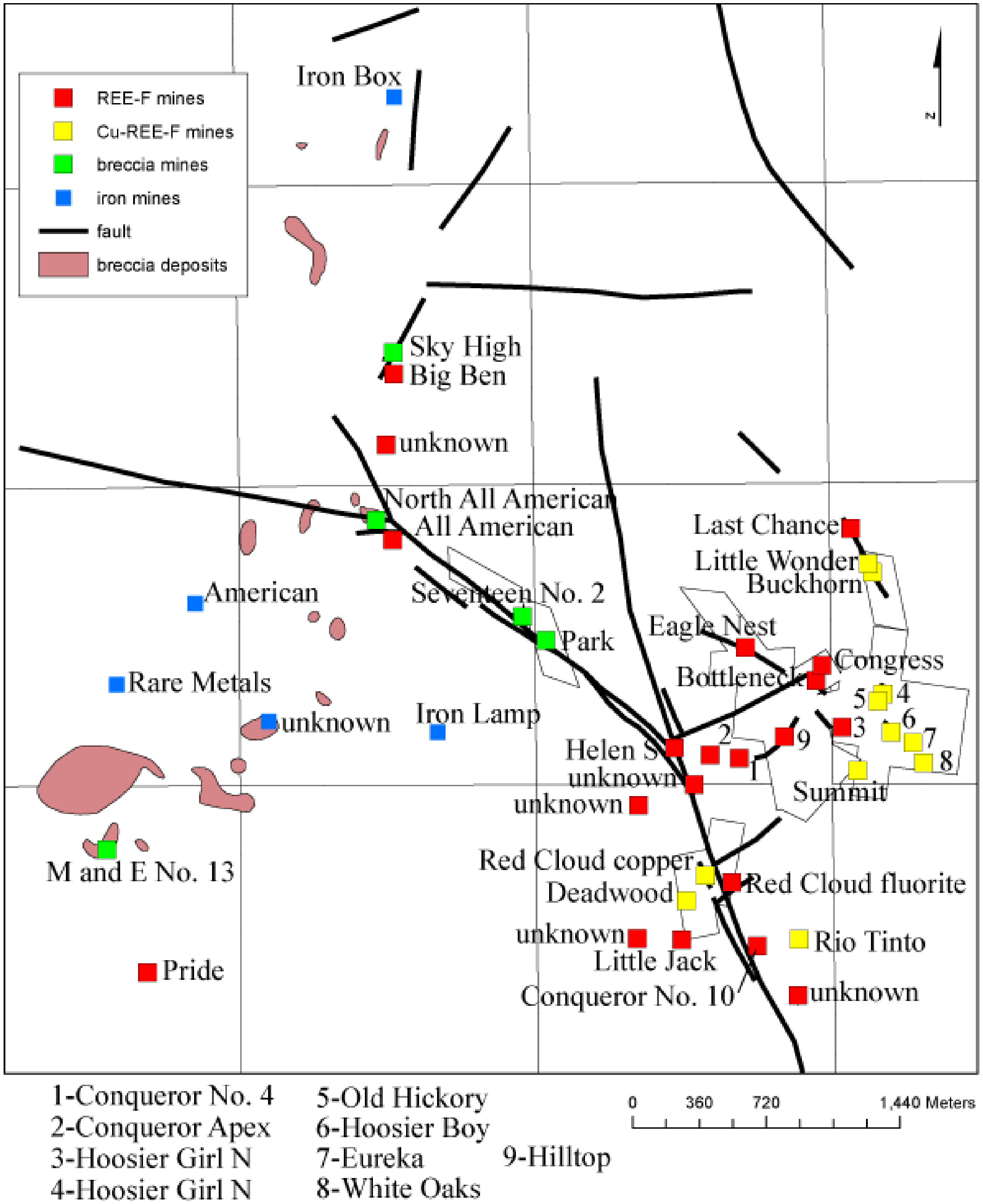
land surface
Carbonatite stock
Fenite
Alkaline intrusion
REE-Th-U veins
Carbonatite dikes

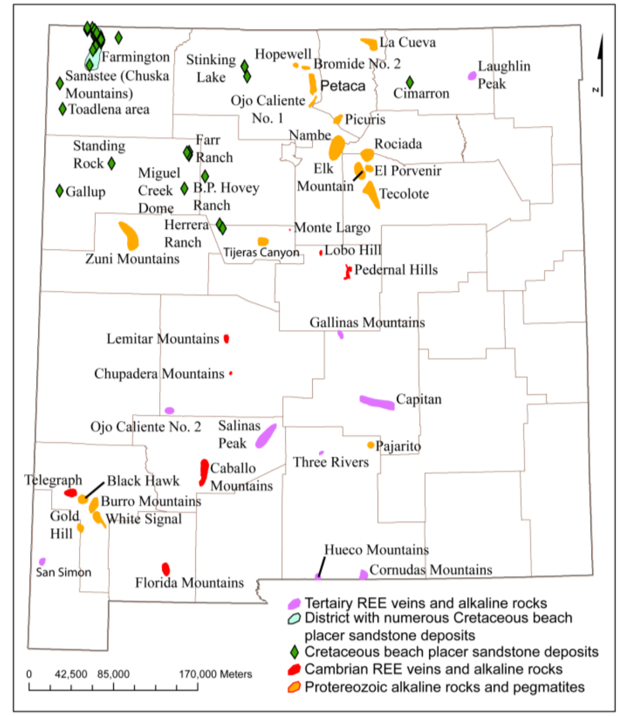
# REE-TH-U HYDROTHERMAL VEINS

# REE-TH-U HYDROTHERMAL VEINS

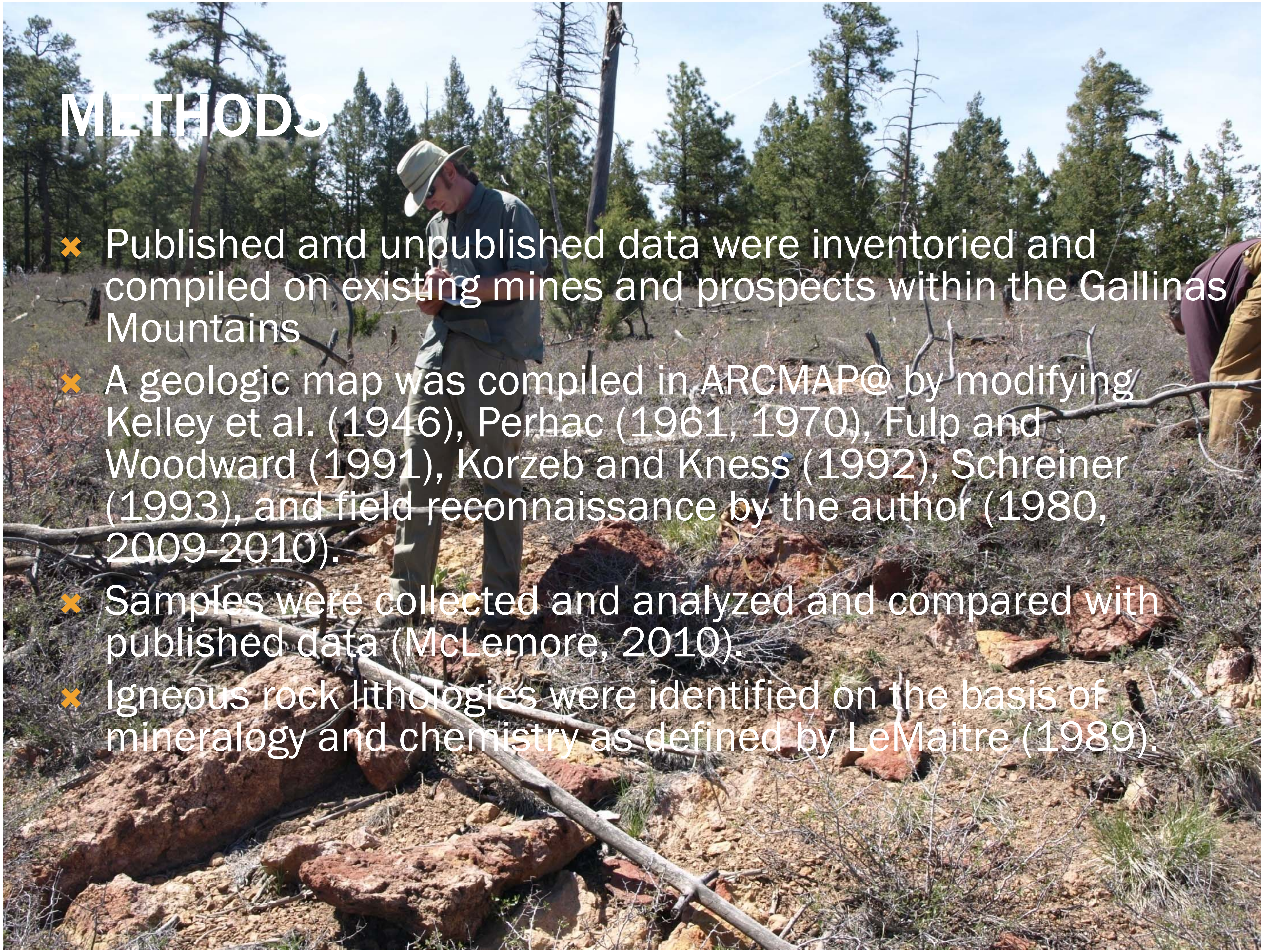
- various Th and REE minerals found in hydrothermal veins and are commonly associated with alkaline igneous rocks and carbonatites
- tabular bodies, narrow lenses, and breccia zones along faults, fractures and shear zones


land surface
Carbonatite stock
Fenite
Alkaline intrusion
REE-Th-U veins
Carbonatite dikes




# Mines and prospects in the Gallinas Mountains, Lincoln County



# METHODS

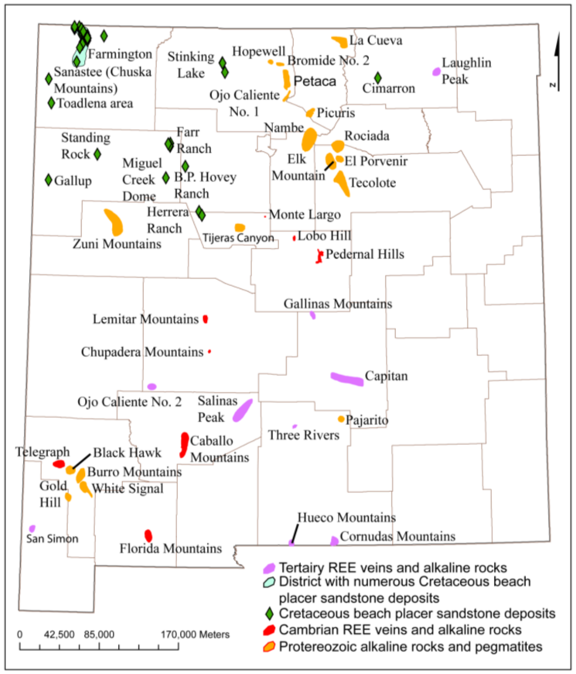
- Published and unpublished data were inventoried and compiled on existing mines and prospects within the Gallinas Mountains
- A geologic map was compiled in ARCMAP@ by modifying Kelley et al. (1946), Perhac (1961, 1970), Fulp and Woodward (1991), Korzeb and Kness (1992), Schreiner (1993), and field reconnaissance by the author (1980, 2009-2010).
- Samples were collected and analyzed and compared with published data (McLemore, 2010).
- Igneous rock lithologies were identified on the basis of mineralogy and chemistry as defined by LeMaitre (1989).

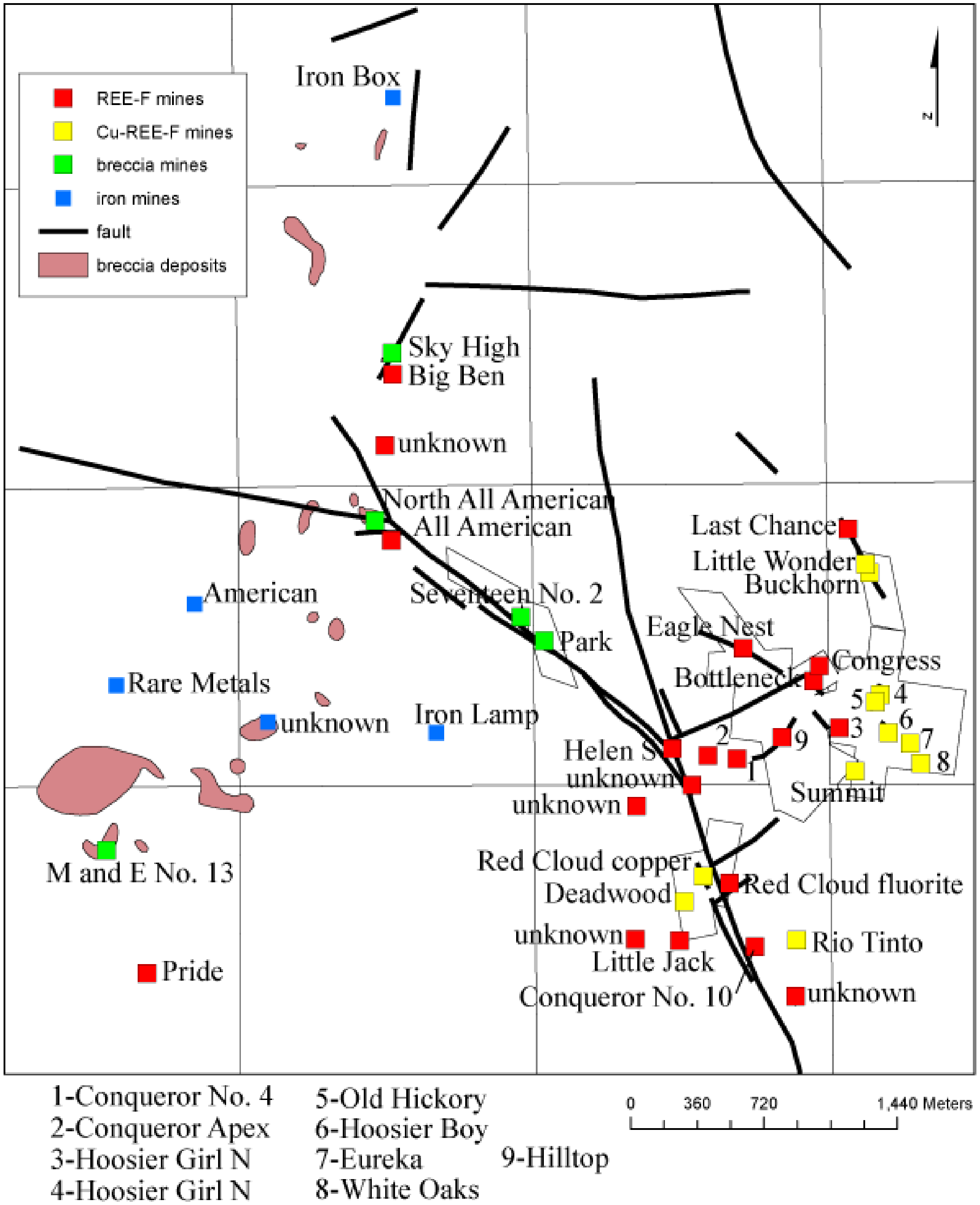
# MINERAL PRODUCTION

| Mineral Produced | Mine name | Years of production | Amount (short tons) | Grade % |
|---|---|---|---|---|
| Copper | various | 1909-1953 | 192.7 | |
| Gold | various | 1913-1955 | 6.58 ounces | |
| Silver | various | 1909-1955 | 23,723 ounces | |
| Lead | various | 1909-1055 | 863.4 | |
| Zinc | various | 1948-1953 | 8.7 | |
| Iron ore | American | 1942-1943 | 3,944 | 55.7 |
| | Gallinas | 1942 | 6,410 | 48.7 |
| | Other mines | | 3,326 | |
| Total iron ore | | 1942-1943 | 11, 540 | |
| Fluorite | All American | 1951-1954 | 129 | |
| | Conqueror ( Tinto) | 1951-1954 | 300 | |
| | Red Cloud | 1951-1954 | 1,000 | |
| Total fluorite | | 1951-1954 | 1,608 | |
| Bastnaesite | Conqueror No. 9 | 1954-1955 | 60 | |
| | Conqueror No. 10 | 1956 | 11 | |
| Total bastnaesite | | 1954-1956 | 71 | |

| DISTRICT NAME | PRODUCTION |
|---|---|
| Gallinas Mountains | 146,000 lbs of bastnasite concentrate |
| Petaca | 112 lbs of samarskite, few hundred lbs of monazite, 12,000 lbs of Ta-Nb-REE ore |
| Elk Mountain | 500 lbs of Ta-U-REE concentrate |
| Rociada | Several thousand tons of REE-Ta ore |
| Tecolote | $10,000 worth of beryl, tantalite-columbite and monazite |
| Gold Hill | REE production in the 1950s |

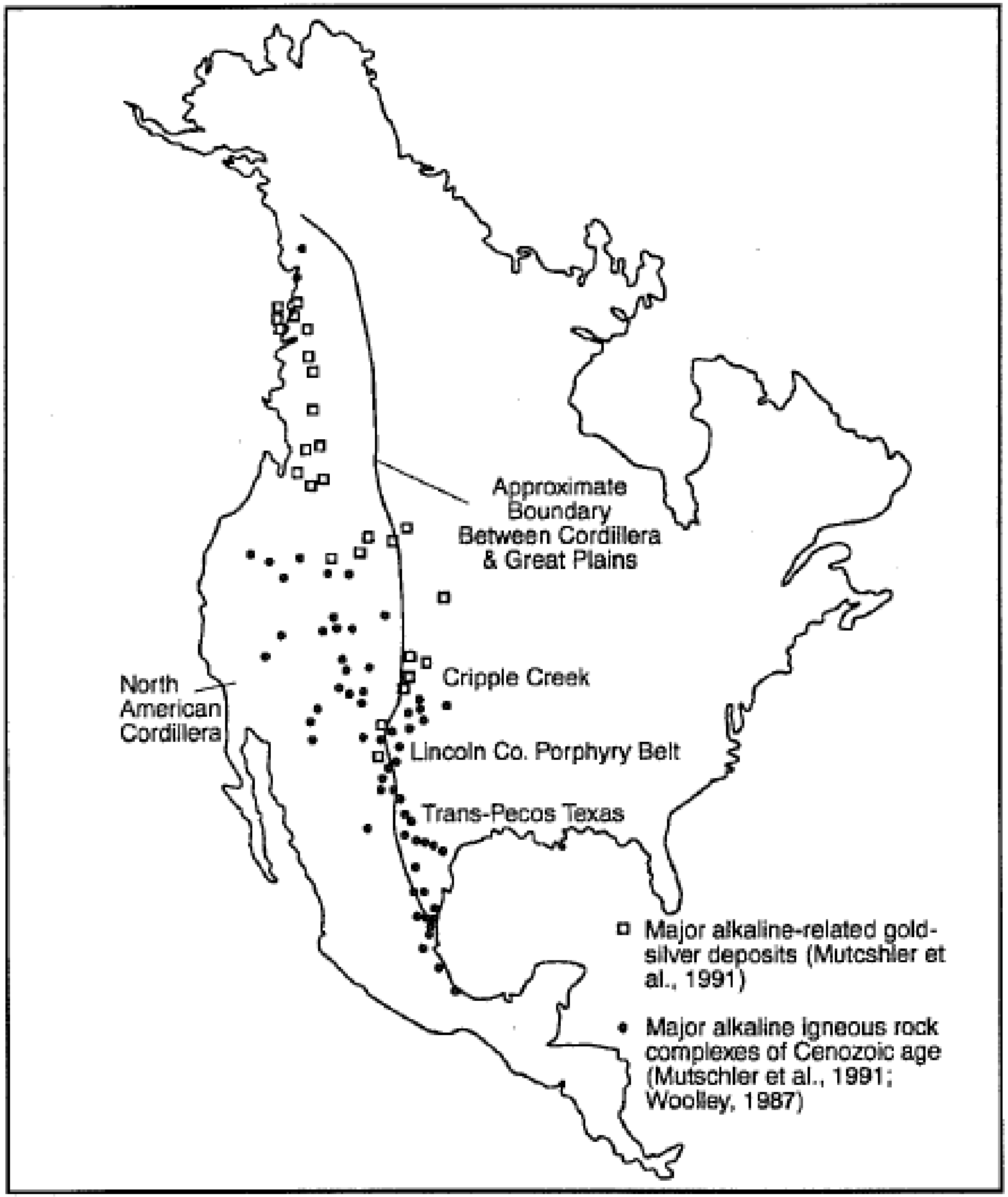
*Production of rare earth elements (REE) in New Mexico, to date.*

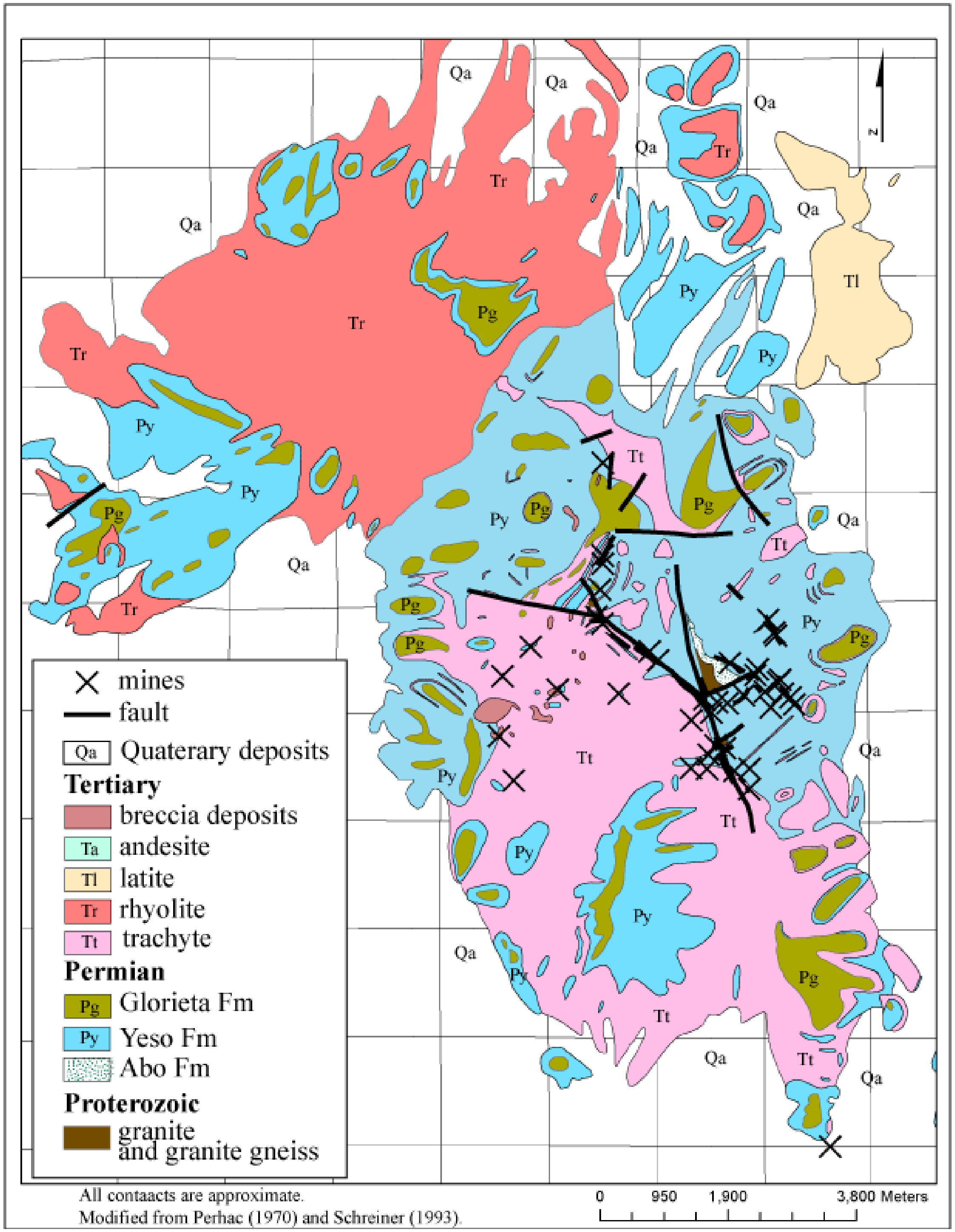





## Mines and prospects in the Gallinas Mountains, Lincoln County

# North American Cordilleran Belt of Alkaline Igneous Rocks



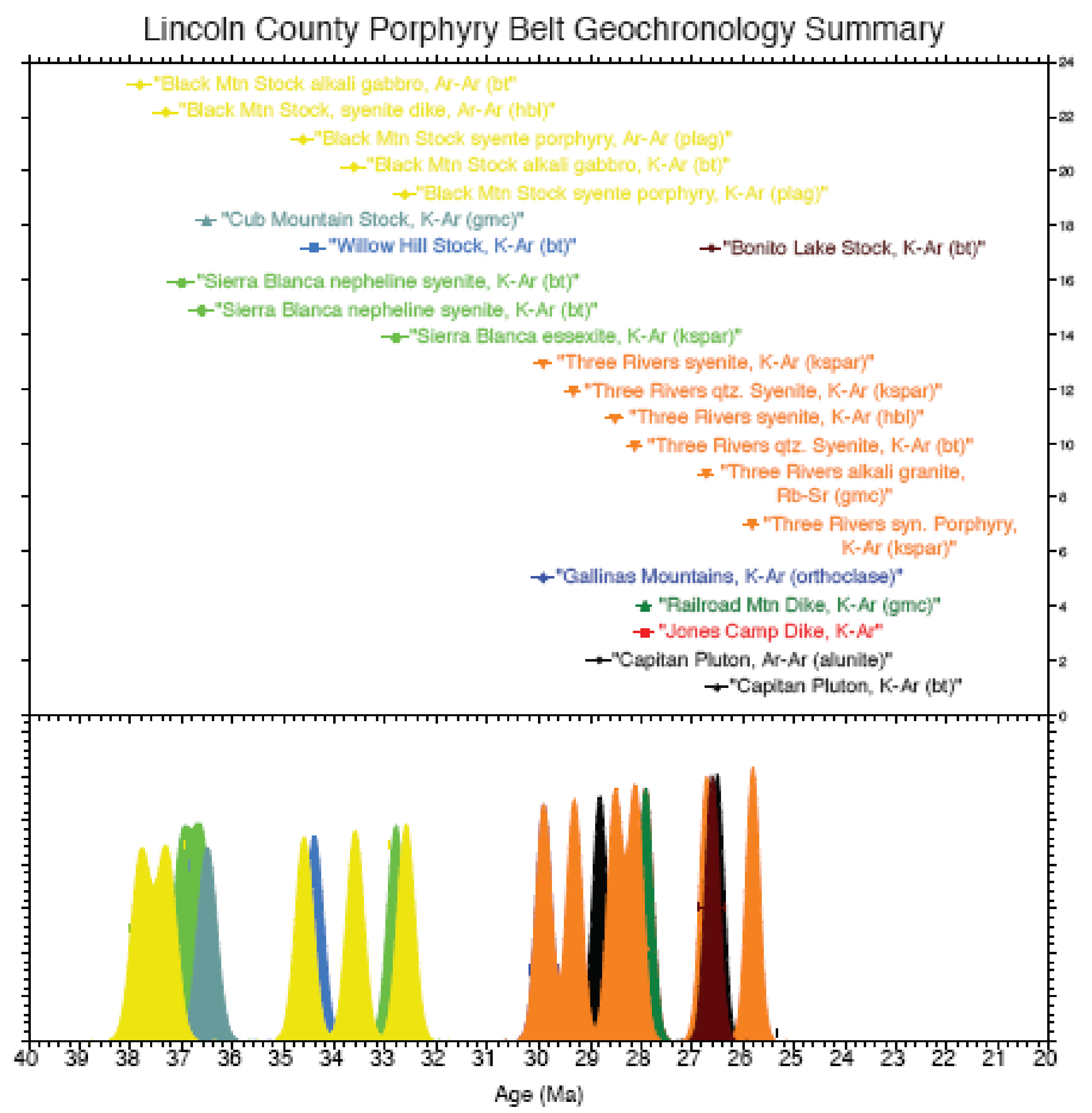



Geologic Map of the Gallinas Mountains, Lincoln and Torrance Counties, New Mexico (Modified From Kelley et al., 1946; Kelley, 1949, 1971; Perhac, 1961, 1970; Woodward and Fulp, 1991; Schreiner, 1993; Field Reconnaissance by the Author)

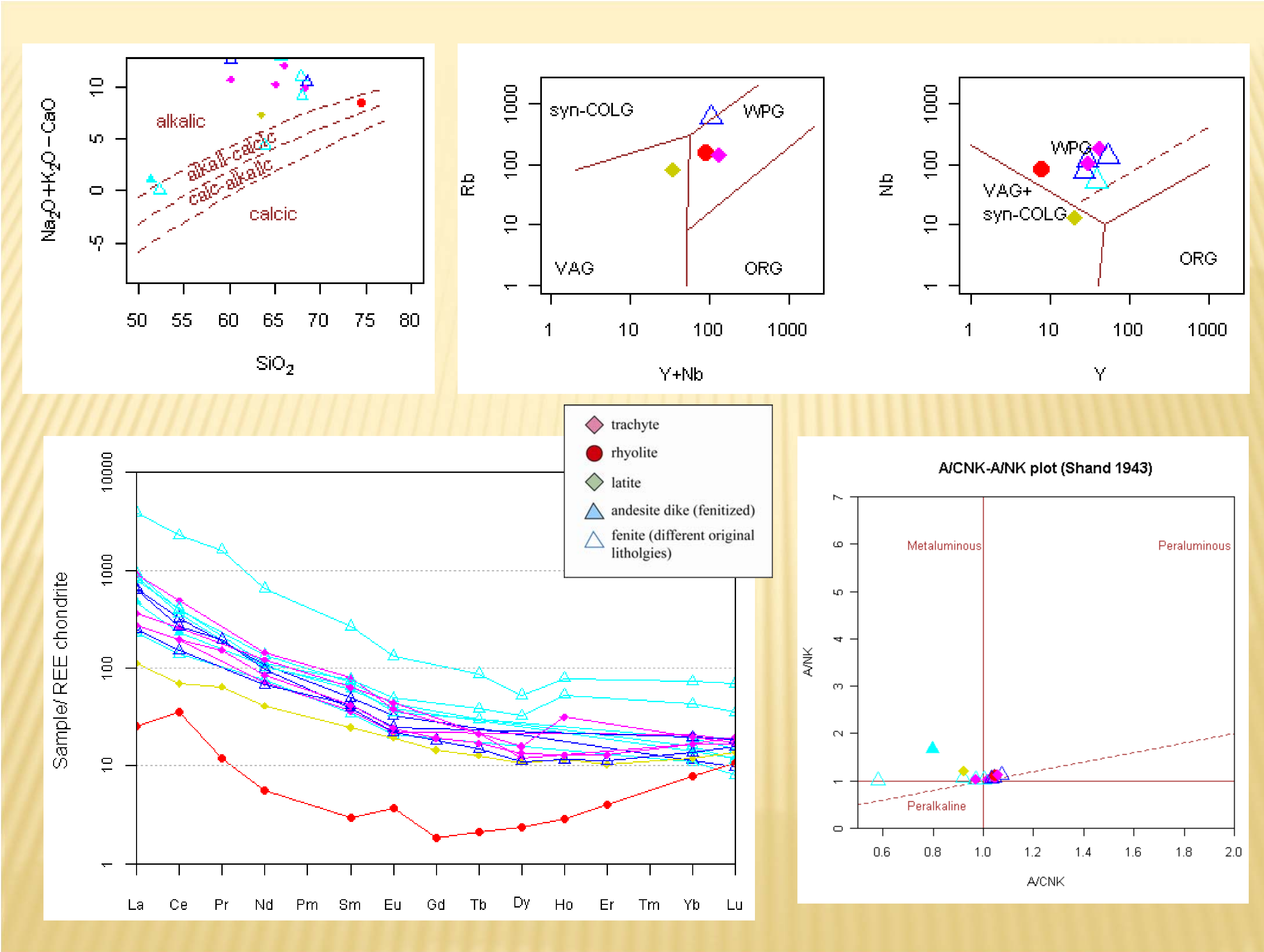

Photograph of the porphyritic latite (sample GM10-6).


Photograph of the trachyte (sample GM10-9).

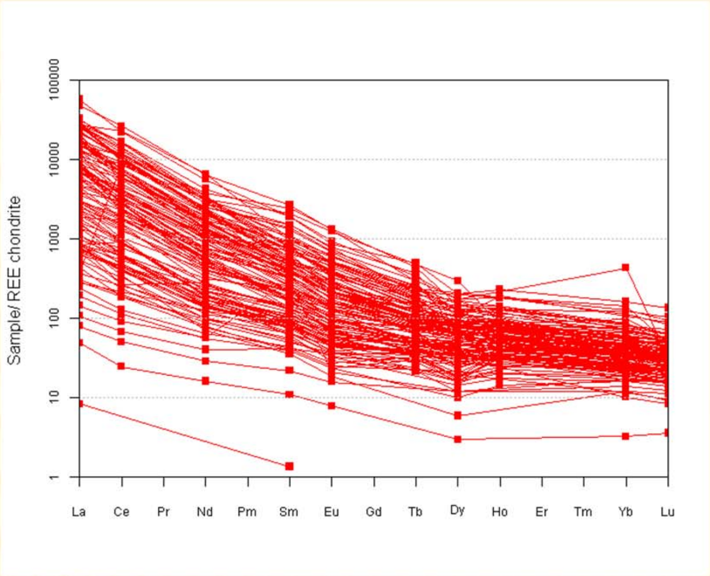

Photograph of the rhyolite (sample GM10-7).



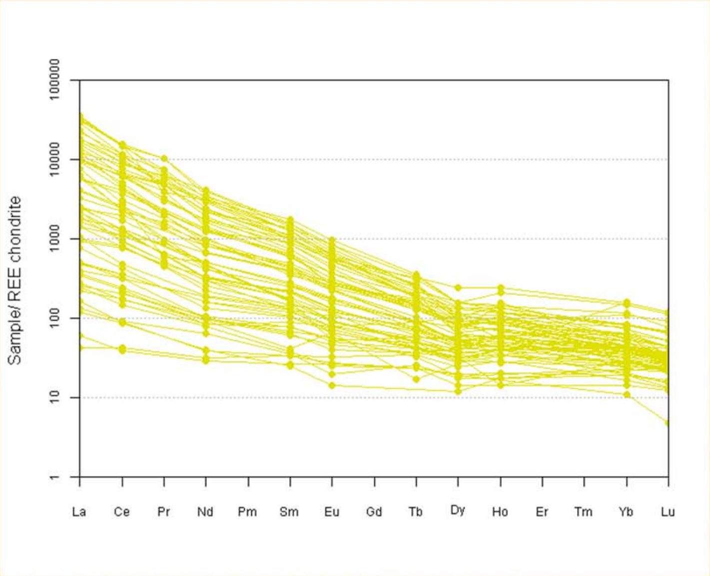

THE GALLINAS MOUNTAINS TRACHYTE WAS DATED BY K/AR METHODS AS 29.9 MA (PERHAC, 1970).



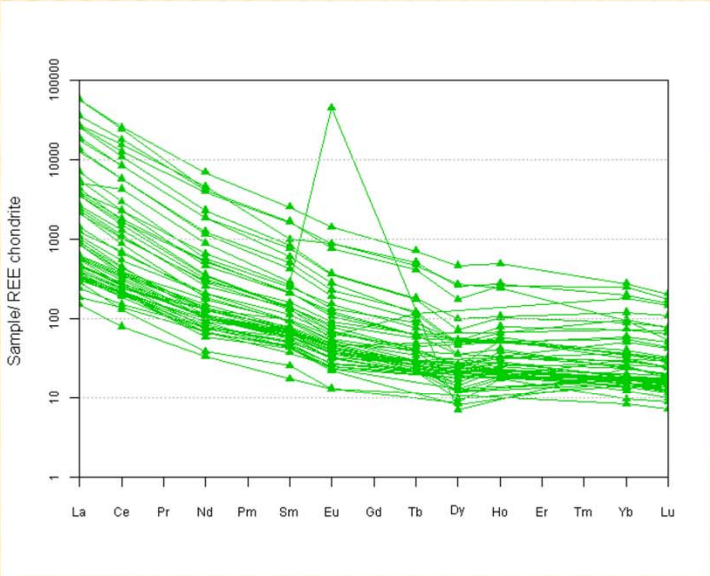
$Na_2O+K_2O-CaO$
$SiO_2$
alkalic
alkali-calcic
calc-alkalic
calcic
Rb
Y+Nb
syn-COLG
WPG
VAG
ORG
Nb
Y
WPG
VAG+
syn-COLG
ORG
Sample/ REE chondrite
La
Ce
Pr
Nd
Pm
Sm
Eu
Gd
Tb
Dy
Ho
Er
Tm
Yb
Lu
trachyte
rhyolite
latite
andesite dike (fenitized)
fenite (different original litholgies)
A/CNK-A/NK plot (Shand 1943)
A/NK
A/CNK
Metaluminous
Peraluminous
Peralkaline



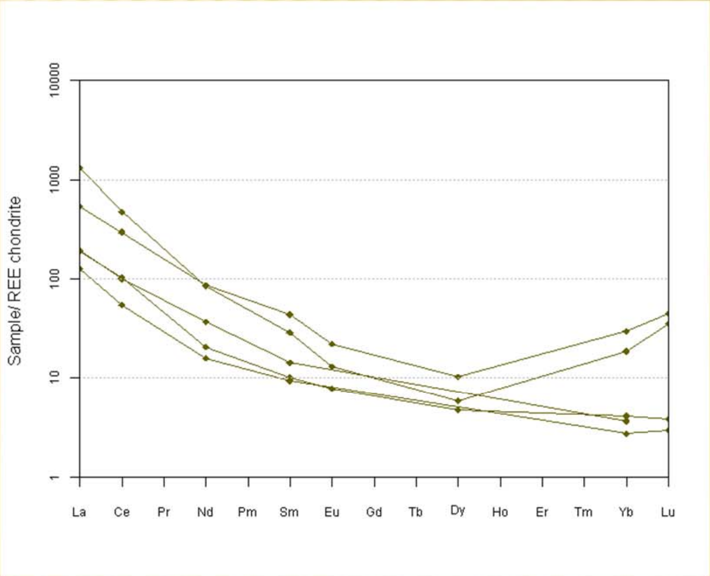

REE-F veins (131 samples)




Cu-REE-F veins (65 samples)




Breccia pipe deposits (58 samples)




Iron skarns (6 samples)

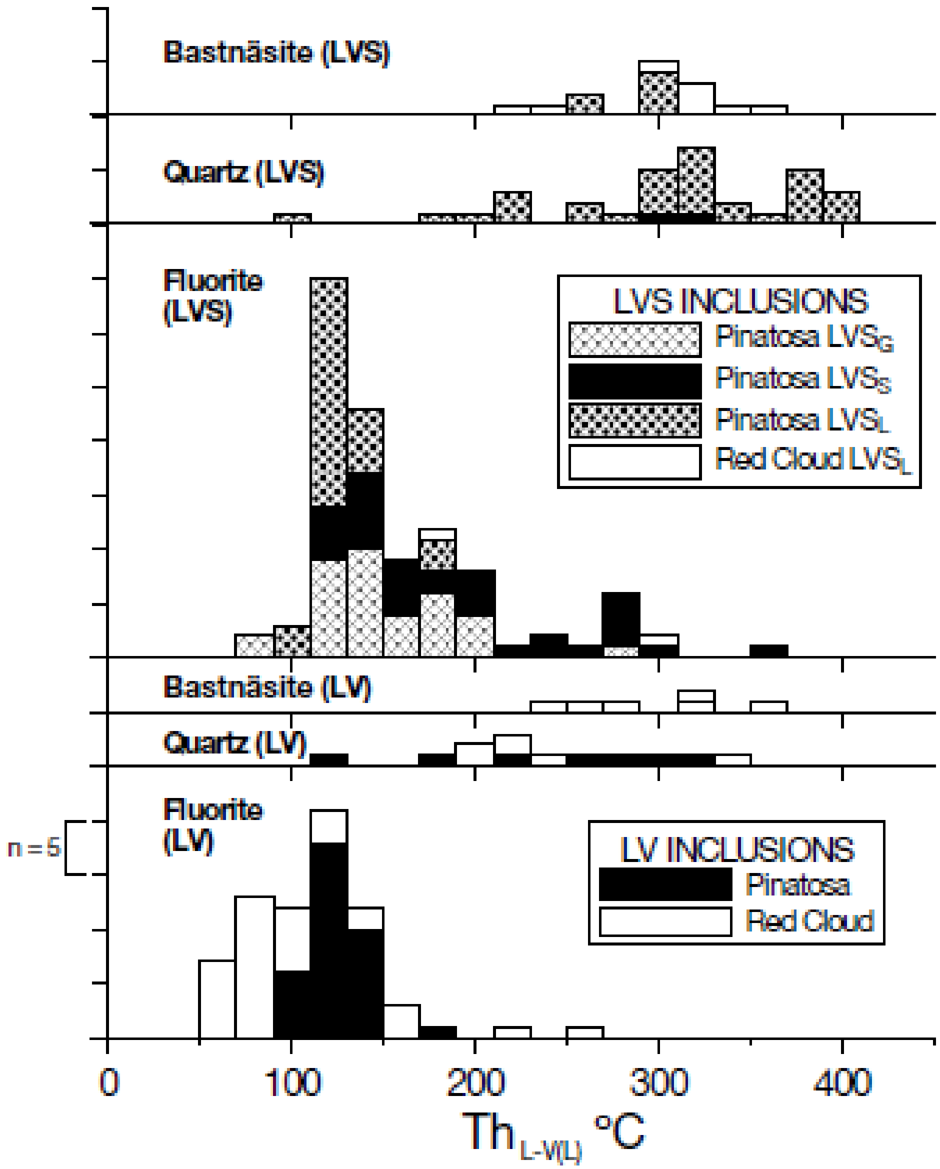



FIG. 10. Histogram depicting liquid-vapor homogenization temperatures for L-V and L-V-S fluid inclusions.

# QUARTZ AT 200- 400°C (WILLIAM-JONES ET AL., 2000)

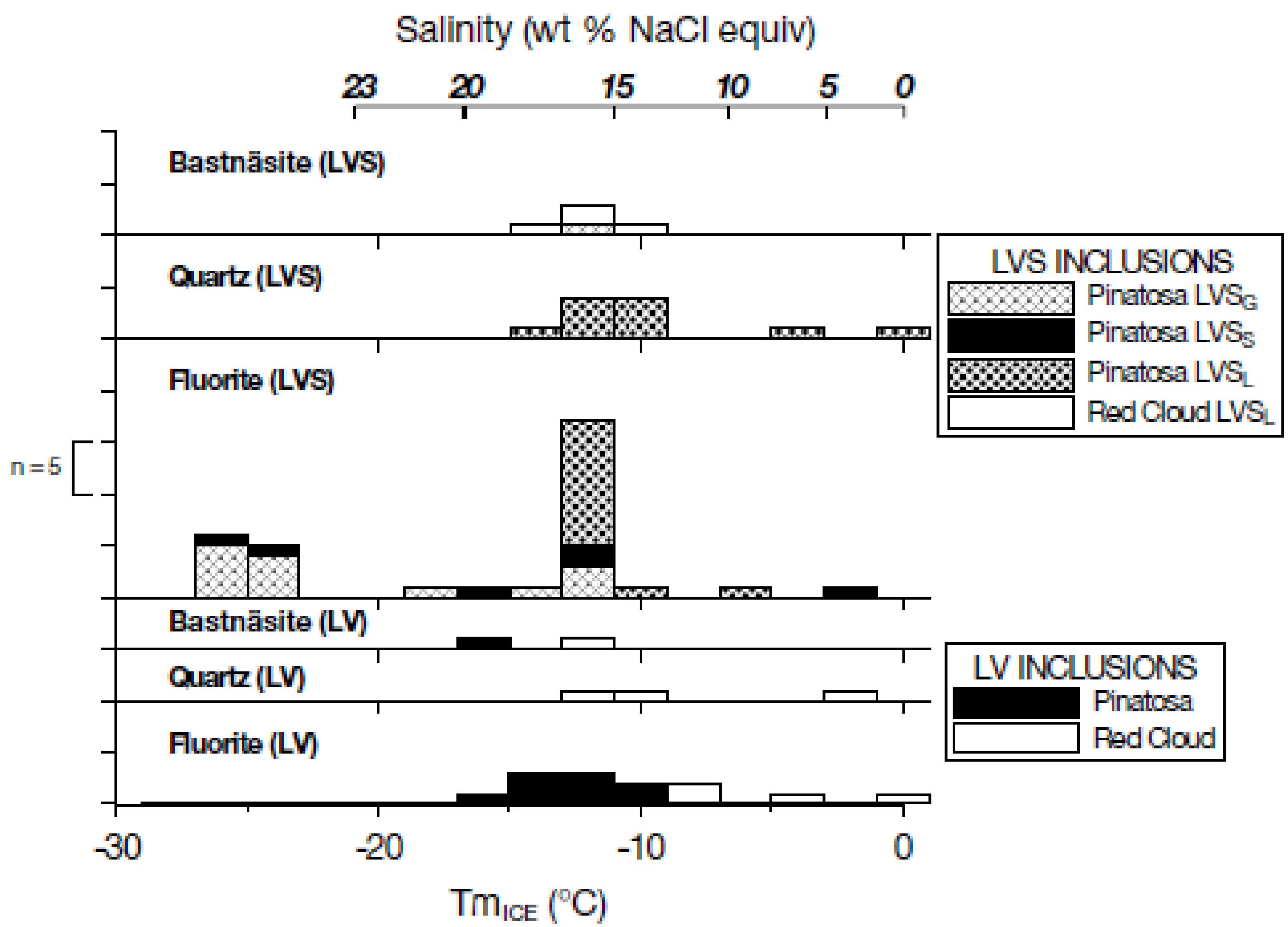
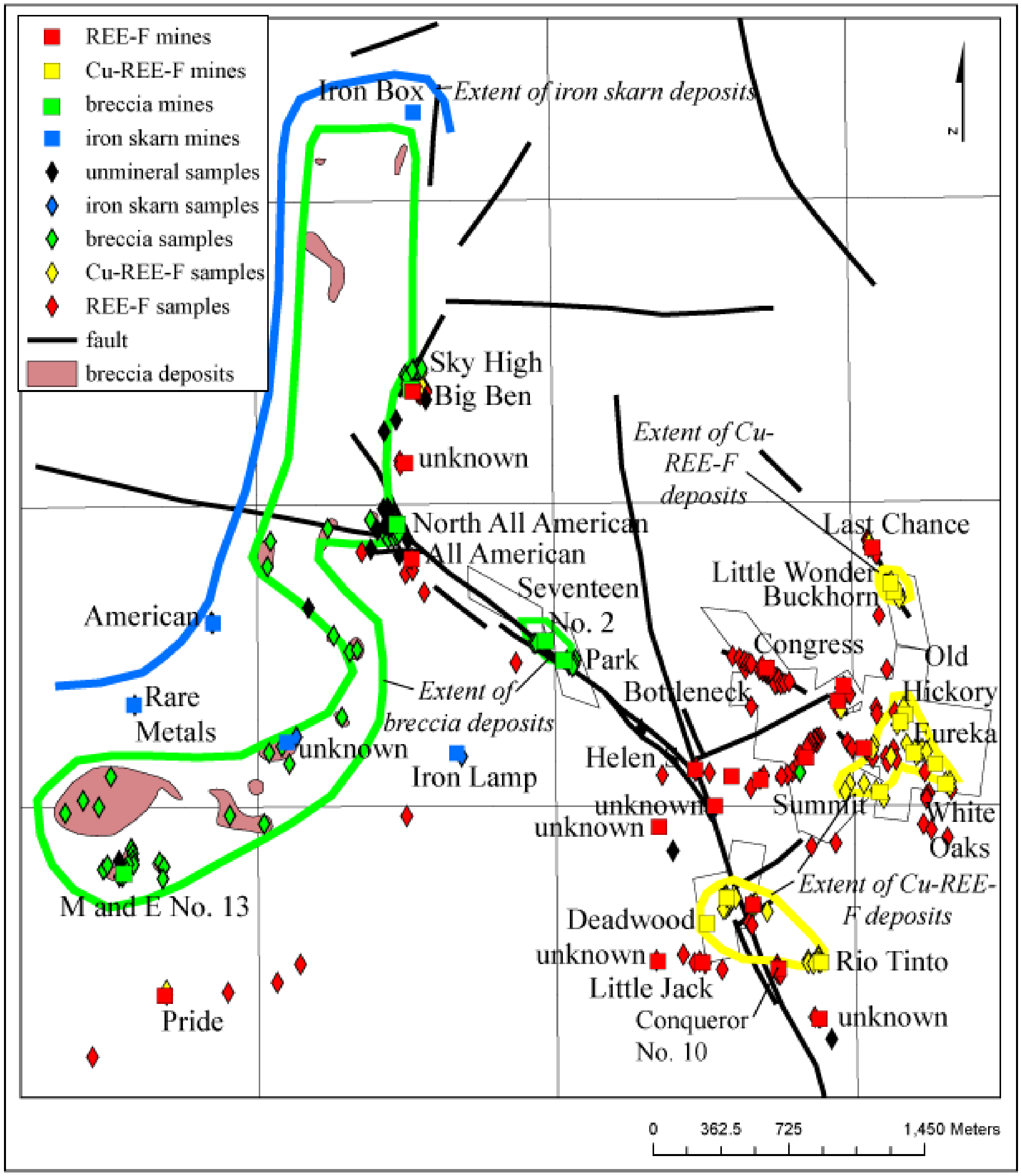


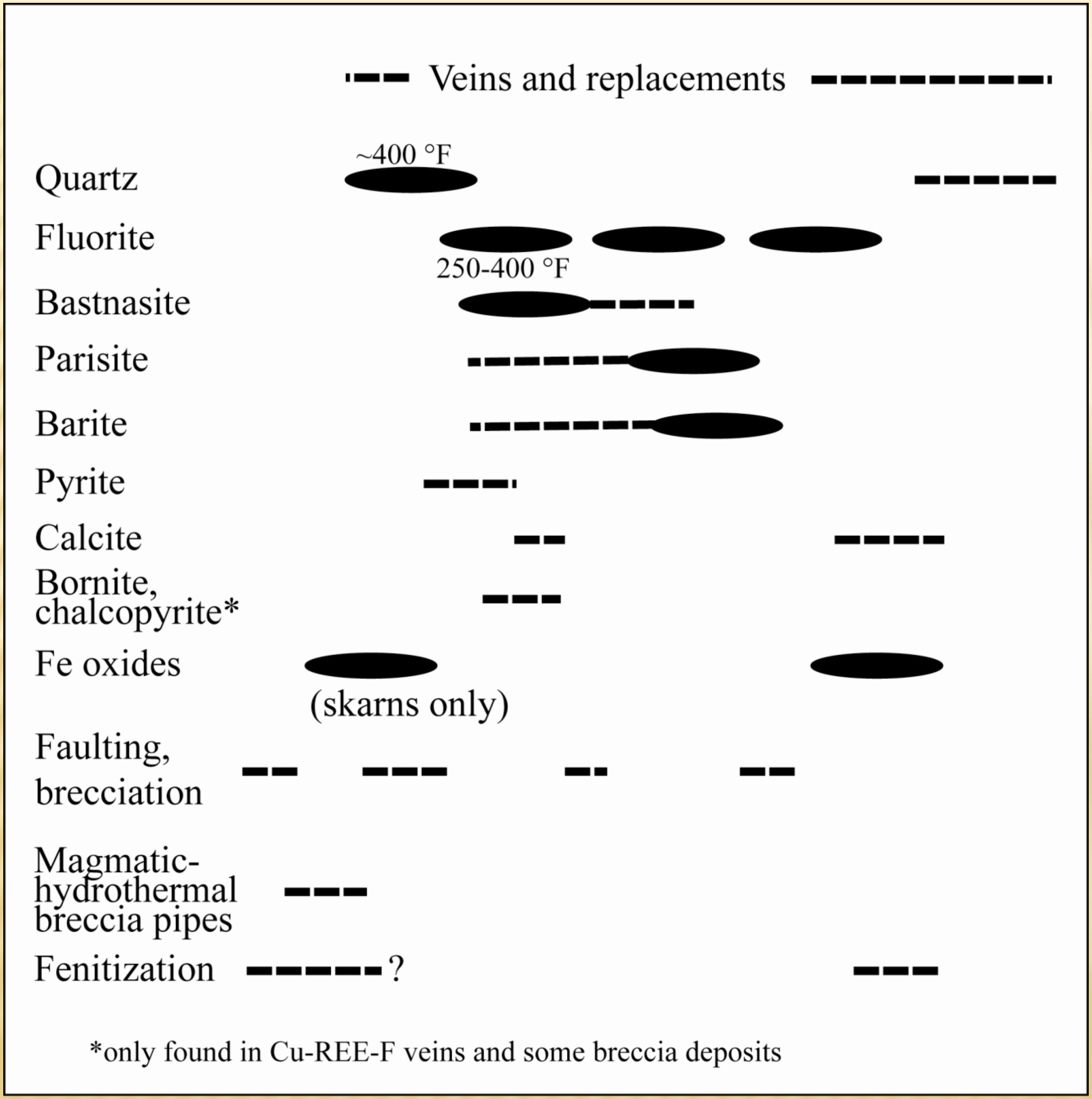

FIG. 11. Histogram depicting final ice melting temperatures for L-V and L-V-S fluid inclusions. A salinity scale (nonlinear) is also shown at the top of the figure.

~15 WT PERCENT NACL EQUIV (WILLIAM-JONES ET AL., 2000)

# MINERAL ZONING

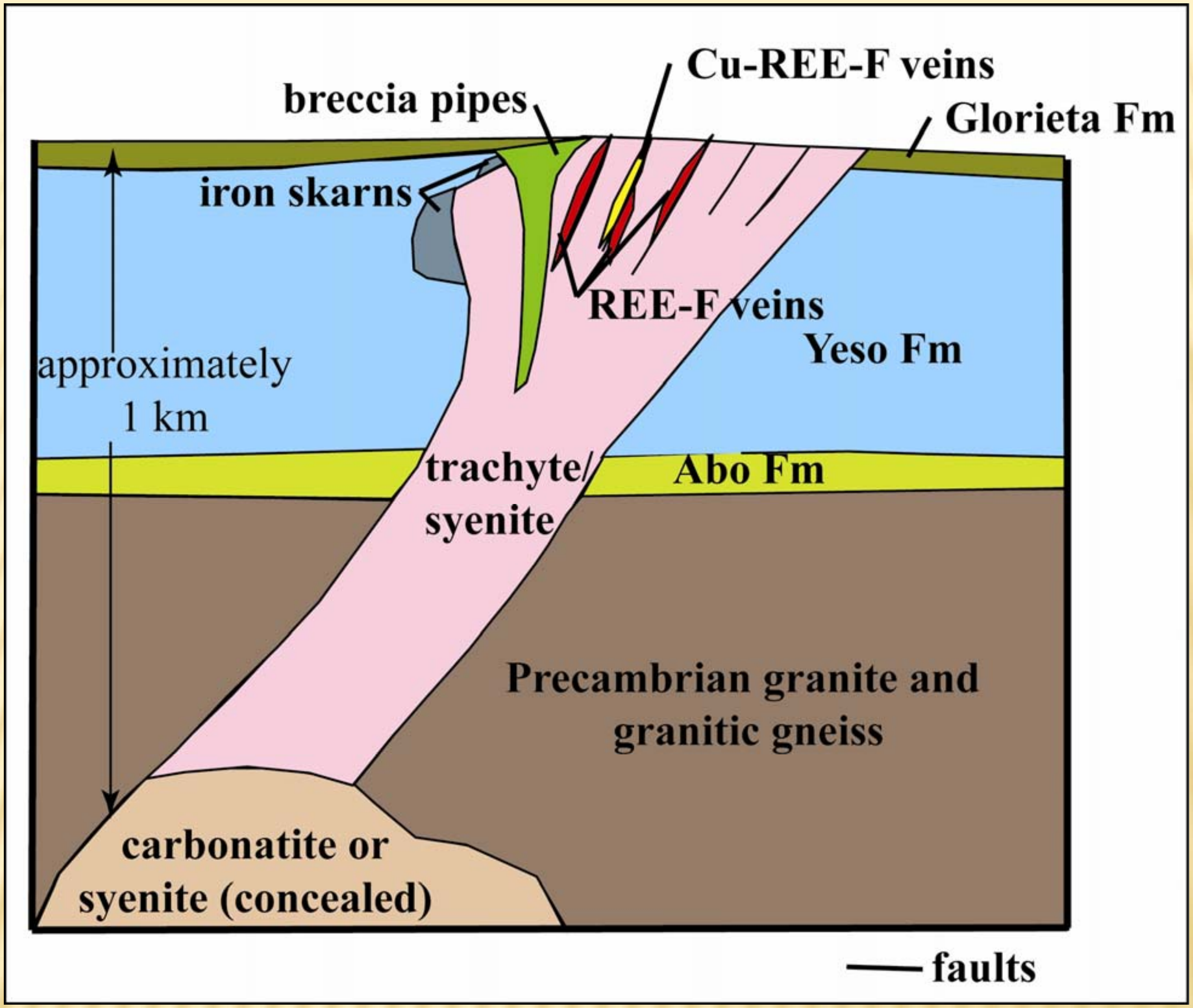


# PARAGENESIS



# SEQUENCE OF EVENTS

- Emplacement of the trachyte/syenite ~30 Ma
- Sodic fenitization
- Deposition of the iron skarns
- Faulting and brecciation
- Formation of the magmatic-hydrothermal breccia pipes
- Potassic fenitization
- Additional brecciation
- Deposition of the REE-F and Cu-REE-F veins
- Late stage deposition of quartz and calcite




SCHEMATIC MODEL OF FORMATION OF THE MINERAL DEPOSITS IN THE GALLINAS MOUNTAINS, LINCOLN COUNTY, NEW MEXICO (MODIFIED IN PART FROM SCHREINER 1993; RICHARDS, 1995; WILLIAMS-JONES ET AL., 2000).

# COLLAPSE BRECCIA PIPES

# COLLAPSE BRECCIA PIPES

- Circular, vertical (up to 1000 metres in vertical extent) pipes filled with down-dropped coarse and fine fragments stopped from the overlying sediments
- Mineralized pipes range from 30 to 200 metres in diameter
- Orphan mine, Arizona, USA

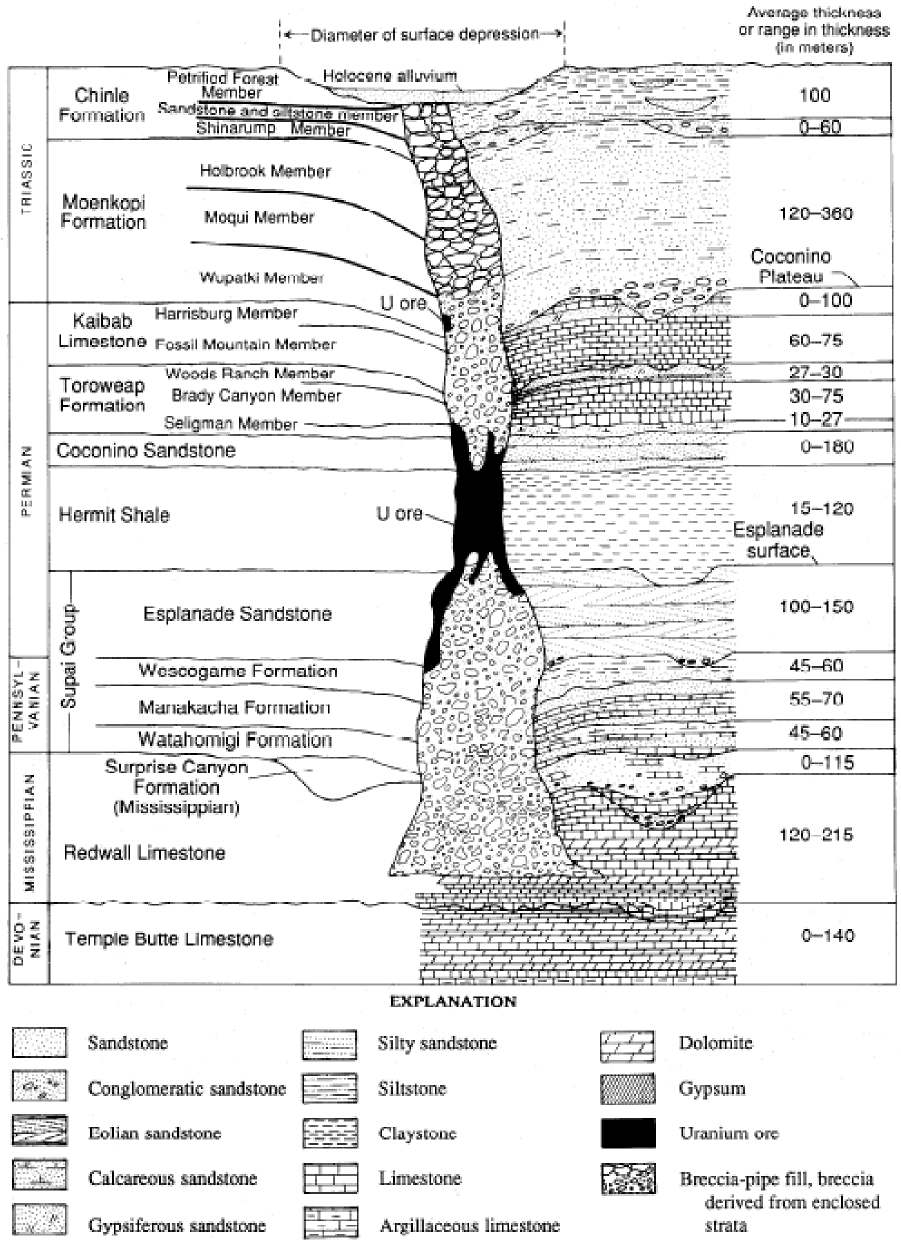
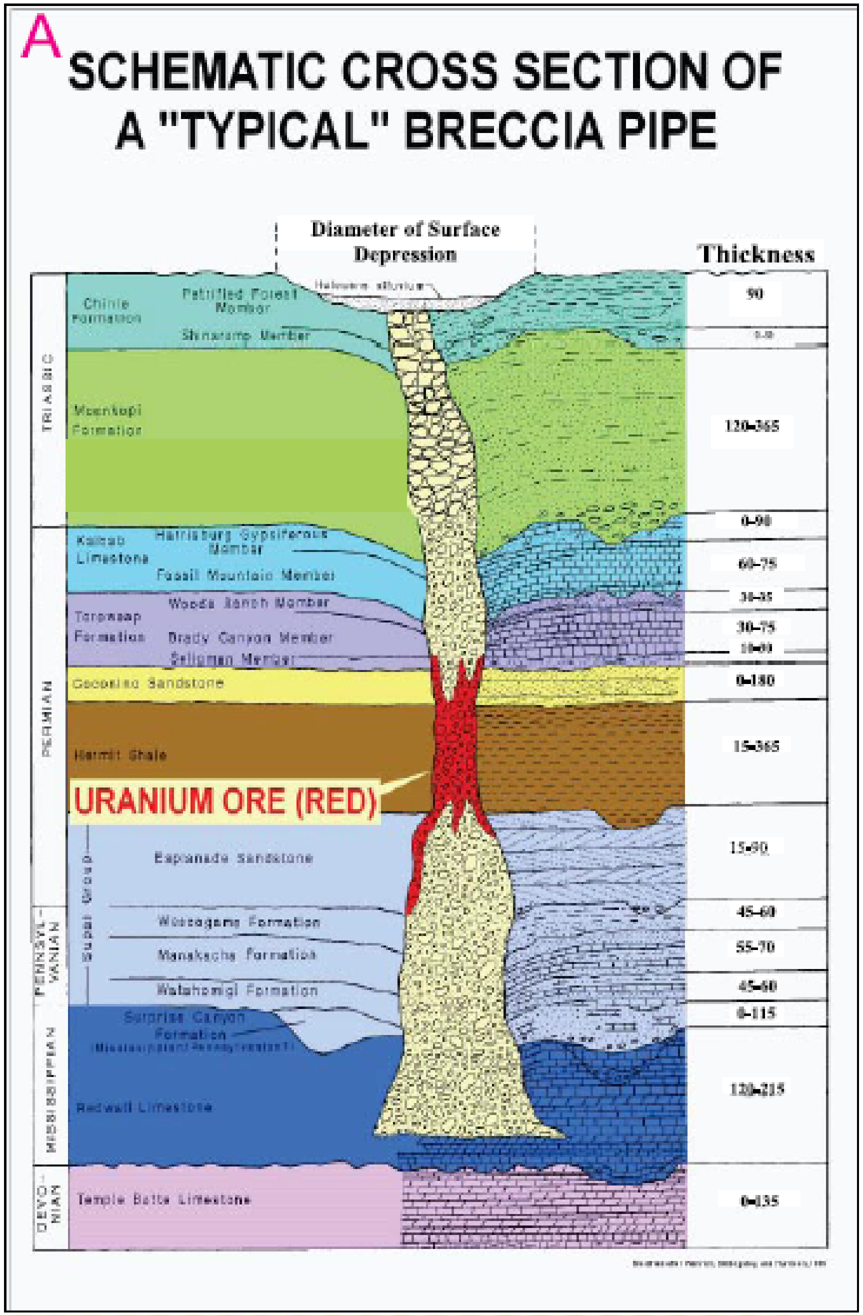
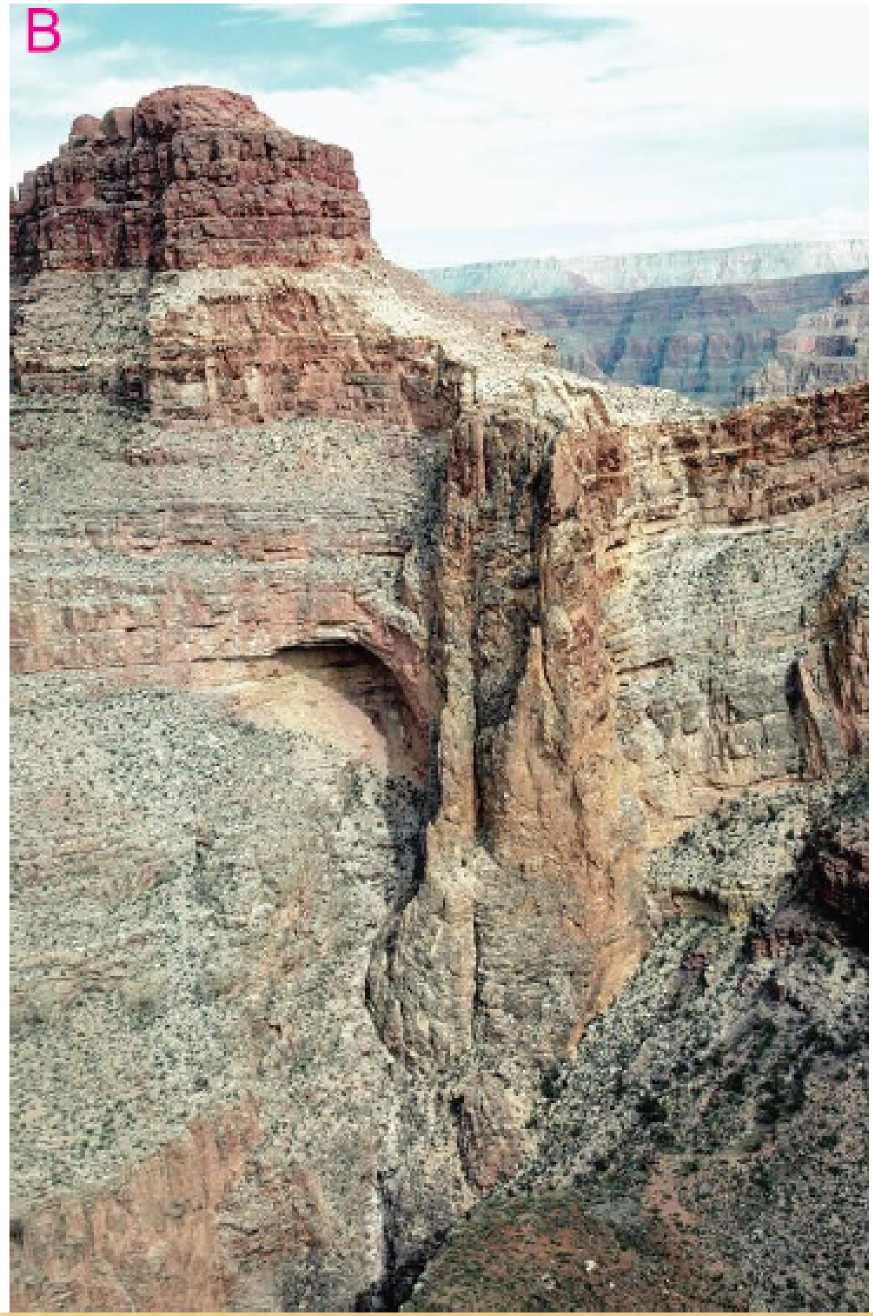



**Figure 20.** Schematic cross section of a solution-collapse breccia pipe in the Grand Canyon region, showing the general distribution of uranium ore within the pipe (stratigraphic section modified after Van Gosen and Wenrich, 1989).


A
SCHEMATIC CROSS SECTION OF A "TYPICAL" BRECCIA PIPE
Diameter of Surface Depression
Thickness
TRIASSIC
PERMIAN
PENNSYL-VANIAN
MISSISSIPPIAN
DEVO-NIAN
Chinle Formation
Petrified Forest Member
Shinarump Member
Moenkopi Formation
Kaibab Limestone
Harrisburg Gypsiferous Member
Fossil Mountain Member
Toroweap Formation
Woods Ranch Member
Brady Canyon Member
Seligman Member
Coconino Sandstone
Hermit Shale
URANIUM ORE (RED)
Supai Group
Esplanade Sandstone
Wescogame Formation
Manakacha Formation
Watahomigi Formation
Surprise Canyon Formation
Redwall Limestone
Temple Butte Limestone
90
120-365
0-90
60-75
30-75
0-180
15-365
15-90
45-60
55-70
45-60
0-115
120-215
0-135


B

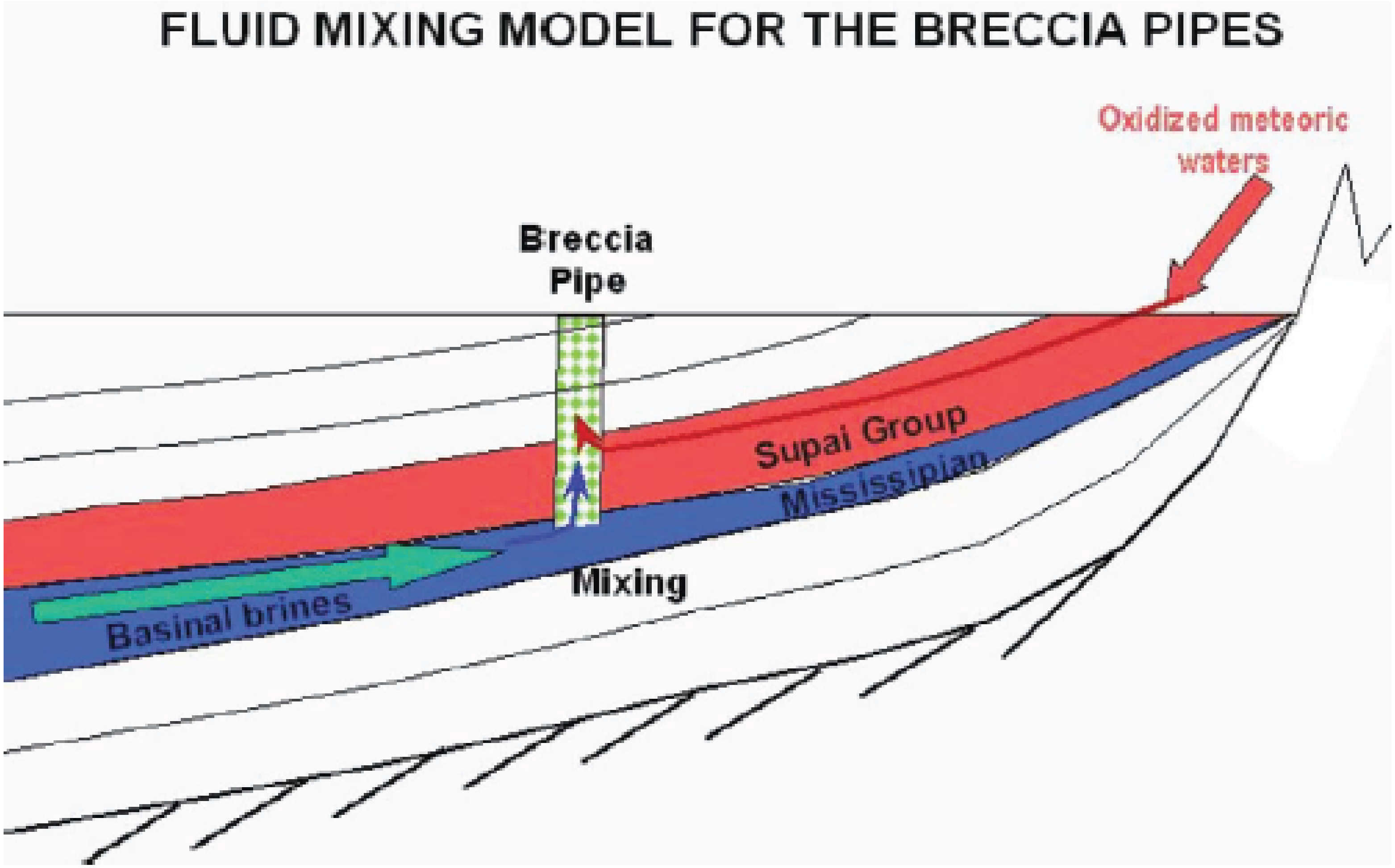



Figure 41. Fluid-mixing model for the breccia pipe ore genesis.

http://www.libertystaruranium.com/wp-content/uploads/2012/04/23AGS22WenrichandTitleyfinal-Protect.pdf

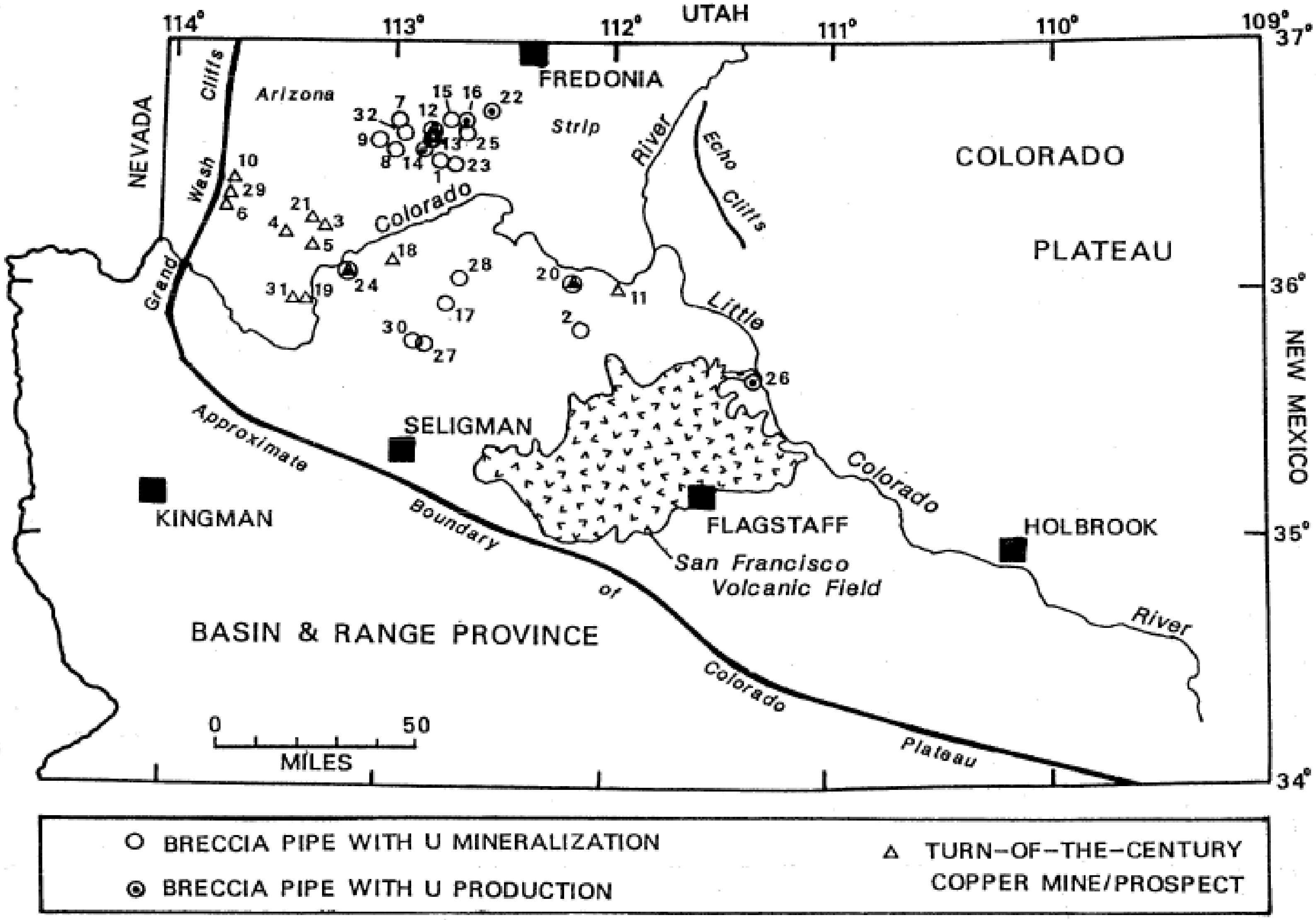



**Figure 1.** Index map of northern Arizona showing locations of mineralized breccia pipes, and San Francisco volcanic field that buries terrane with high potential for breccia pipes (Wenrich and others, 1989). Numbers refer to the following mines: (1) Arizona 1, (2) Canyon, (3) Chapel, (4) Copper House, (5) Copper Mountain, (6) Cunningham, (7) DB-1, (8) EZ-1, (9) EZ-2, (10) Grand Gulch, (11) Grandview, (12) Hack 1, (13) Hack 2, (14) Hack 3, (15) Hermit, (16) Kanab North, (17) Lynx, (18) Mohawk Canyon, (19) Old Bonnie Tunnel, (20) Orphan, (21) Parashant, (22) Pigeon, (23) Pinenut, (24) Ridenour, (25) Rim, (26) Riverview, (27) Rose, (28) Sage, (29) Savannic, (30) SBF, (31) Snyder, (32) What.

**Table 1.** Breccia pipe production data for all eight previously producing mines.

| **Mine*** | **Average Grade (% $U_3O_8$)** | **Production (Pounds $U_3O_8$)** |
|---|---|---|
| Hack 1, 2, & 3 | 0.643 | 9,542,000 |
| Pigeon | 0.695 | 5,652,000 |
| Kanab North | 0.582 | 2,728,000 |
| Pinenut | 1.020 | 526,350 |
| Hermit | 0.760 | 552,500 |
| Orphan | 0.420 | 4,200,000 |
| **Total** | | **23,200,850** |

*All mines except the Orphan mine produced between 1980 and 1994—production figures for those 7 mines are from Donn Pillmore of Energy Fuels Nuclear (written commun., 2008).

# OTHER REE-BEARING DEPOSITS

# OTHER REE-BEARING DEPOSITS

- REE could be recovered as a by-product of Uranium, thorium, and phosphate deposits
  - Examine sandstone U deposits for REE contents
- Other placer deposits (fluvial, alluvial placers) could carry anomalous amounts of REE.
- Fluorite veins can carry high concentrations of REE, especially Y.
- Coal??

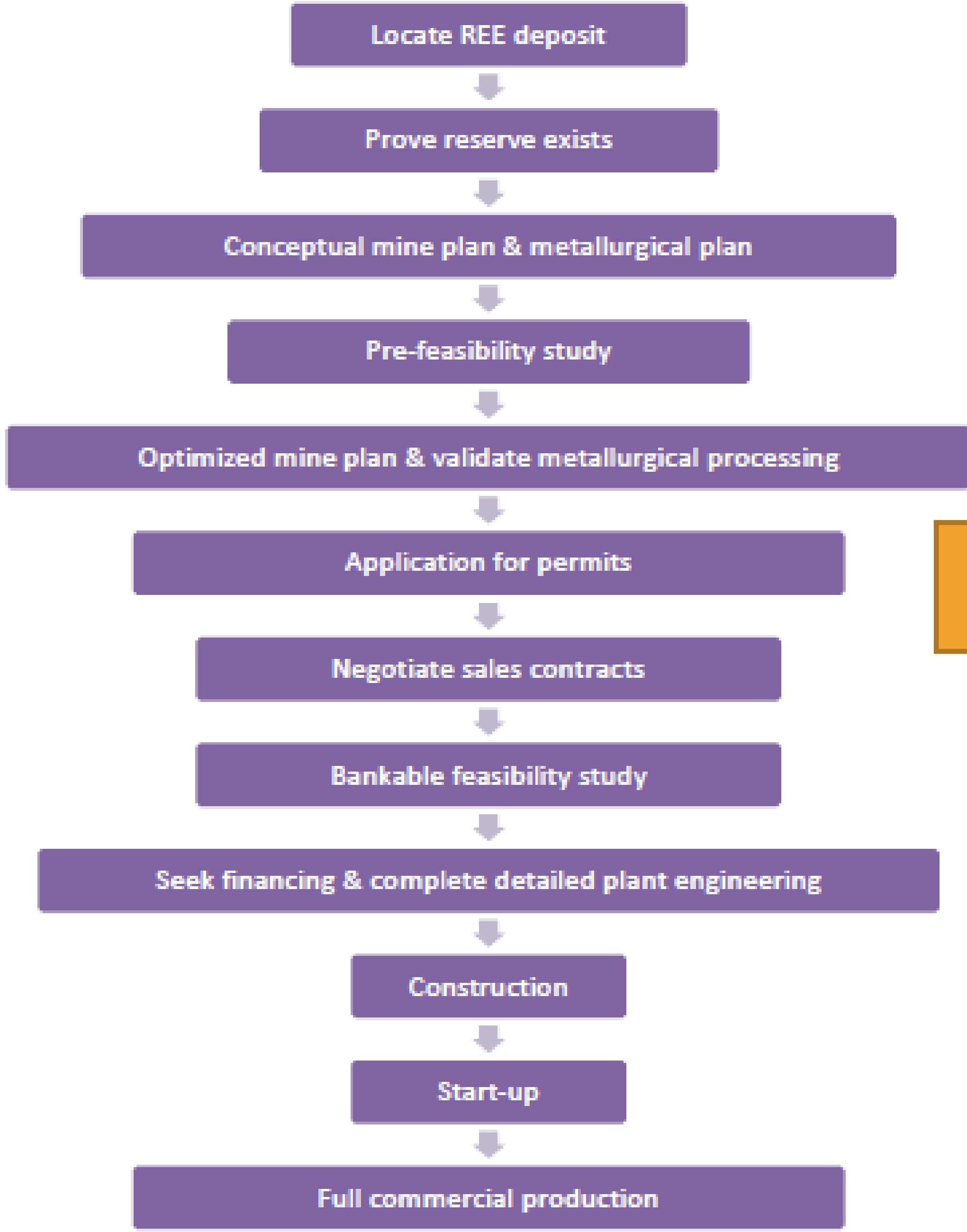
# PROJECTS

- Due April 29
  - Report and class presentation
- Group report/presentation encouraged
- Read
  - Naumov, A.V., 2010, Selenium and tellurium: State of the markets, the crisis, and its consequences: Metallurgist, v. 54, p. 197-200

# MINE LIFE CYCLE

# CLOSURE

Figure 16: Major Steps Taken In Developing A Rare Earth Elements Mine



# The Kingsnorth 8: steps in developing rare-earths projects

1. Resource: grade, REO distribution
2. Mineralogy : which minerals; liberation not too fine; beneficiate to > 30% REO
3. Scoping study
4. Pilot plant (beneficiation, extraction, separation)
   - Demonstrate technical viability/flexibility

Source: Kingsnorth 2011

COLORADO SCHOOL OF MINES
EARTH • ENERGY • ENVIRONMENT

# The Kingsnorth 8 (cont'd)

5. <u>Environmental approval</u>: government, social
6. <u>Marketing plan</u>: recognizing the 'balance' issue
7. <u>Definitive feasibility study and financing</u>
8. <u>Construction & start-up</u>

Source: Kingsnorth 2011

# EXPLORATION METHODS

# EXPLORATION METHODS

- Radiometric
  - Most occur with U and Th
- Gravimetric
  - Many are surrounded by mafic alkaline rocks (gravity high) or sedimentary rocks (gravity low)
- Geochemical
- Drilling, trenching

# MINING

# Mine Design Sequence

Iterative Evaluation Process

- Geologic Analysis & Sampling
  - Resource Characterization
  - Geomechanics
  - Metallurgy
- Reserve Estimation & Cutoff Grade Assessment
- Mine Size & Mining Rate
- Closure, Reclamation & Post Mining Uses
- Mining Method & Systems
- Equipment, Infrastructure, Mine Layout, Labor Estimates
- Sequencing & Production Optimization
- Cost Estimation (Operating and Capital Costs)
- Financial Analysis
- Corporate Evaluation

# Mining Method Selection

- Traditional Approach: Use designs and systems that have successfully work at mines with similar geologic and operating characteristics.
- Very conservative approach usually mandated by regulatory process and external financing, often is employed at the expense of technical innovations and improved labor practices.
- Mitigates risk: Mining history littered with examples of mines heavily reliant on new technology failing because of over estimated performance.
- Any Mining Method Considers Ore to Waste Ratios !

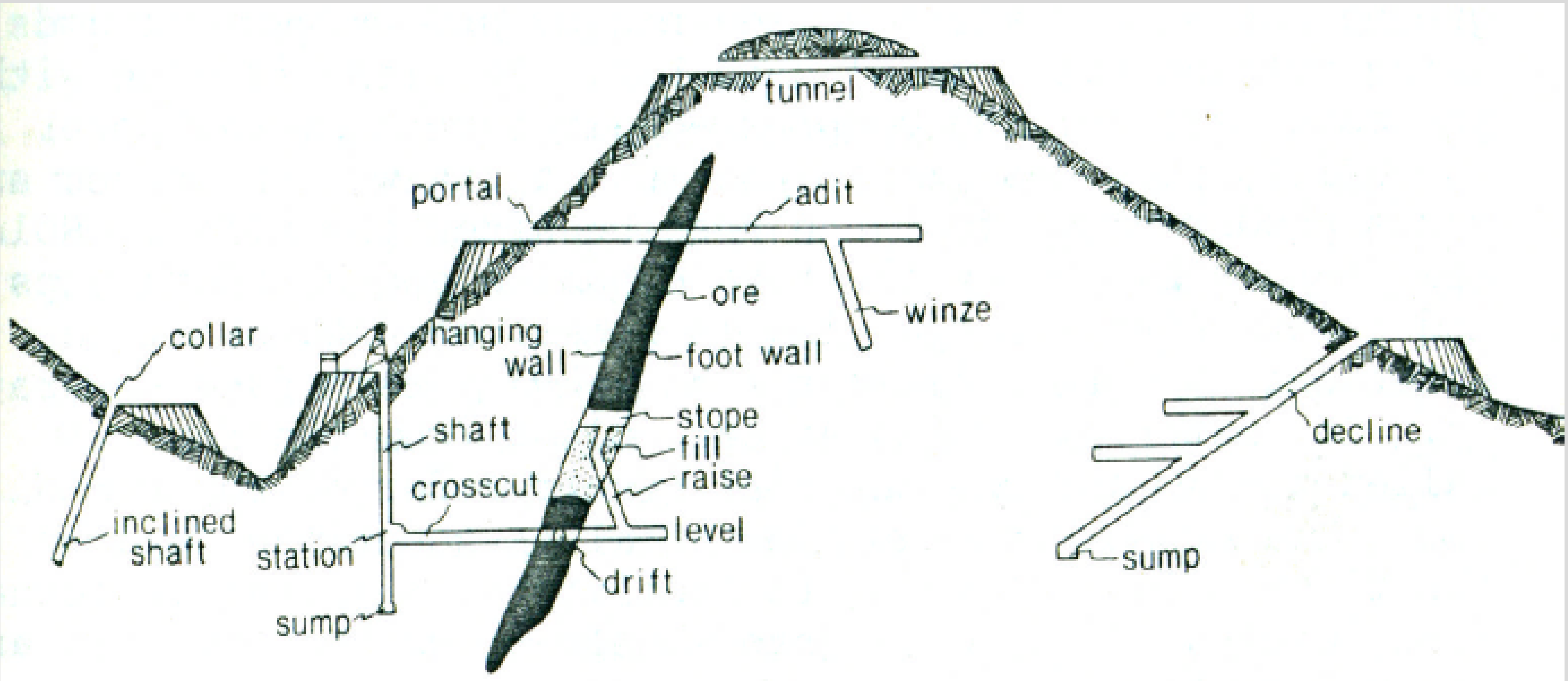
Open Pit Factors – Strip Ratio :: Underground Factors – Dilution Factor

# Surface Mining Methods & Systems

- Open Pit Mining – Massive & Disseminated Deposits
- Strip Mining – Bedded & Flat Laying Deposits
- Quarry/Aggregate Mining – Common to Place-Value Mineral Commodities
- Placer Mine – Minerals in Alluvium

# Underground Mining Terms

(U.S. Forest Service, Anatomy of a Mine, Pg. 75)



# PROCESSING

# MINERAL PROCESSING

- The processes focused on physically separating the grains of valuable minerals from the gangue minerals to produce an enriched portion, or concentrate, and a discard portion, or tailings.
- Two major functions
  - Liberation
  - Separation

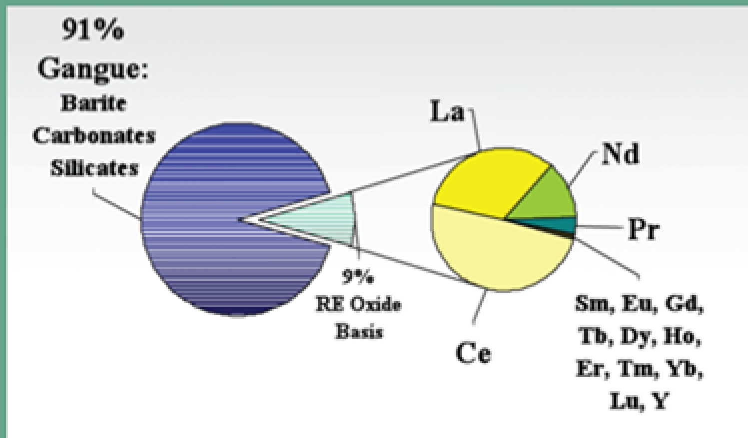
***Comminution*** **is from the Latin word** ***comminuere*** **meaning to make small and is needed to achieve <u>Liberation</u>.**

**Crushing and grinding of the ore to a particle size such that the product is a mixture of relatively free particles of valuable mineral and gangue.**

**Do not want to grind beyond the liberation size (wastes energy) or minimum size that unit operations do not function well at (reduces recovery and/or grade).**

## Mineral Processing

Source: Molycorp, Inc.

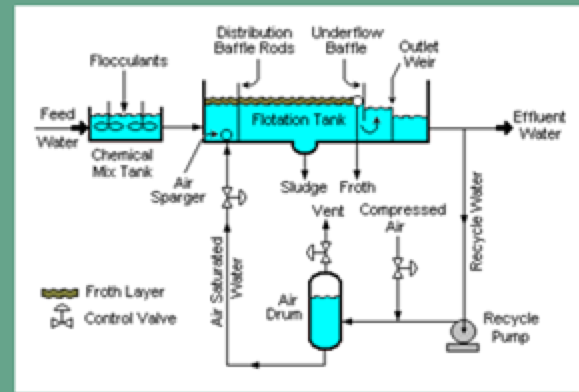


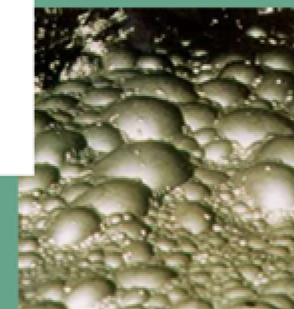

Mountain Pass, CA

Requires two steps: (1) separate REE minerals from other minerals; (2) separate individual REE.

USGS

## Separating Rare Earth Minerals

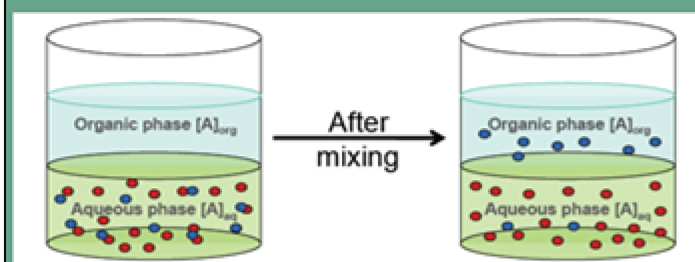


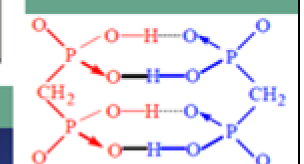



Froth flotation is the most common method for separation of rare earth minerals from other minerals in ore.

USGS

## Separating Individual REE



Solvent extraction uses small differences in solubility between individual REE. REE minerals are leached with an acid or base, then mixed with an organic chemical that strips a selected REE.

USGS

# SEPARATION

- Gravity
- Magnetic
- Flotation
- Electrostatic Separation

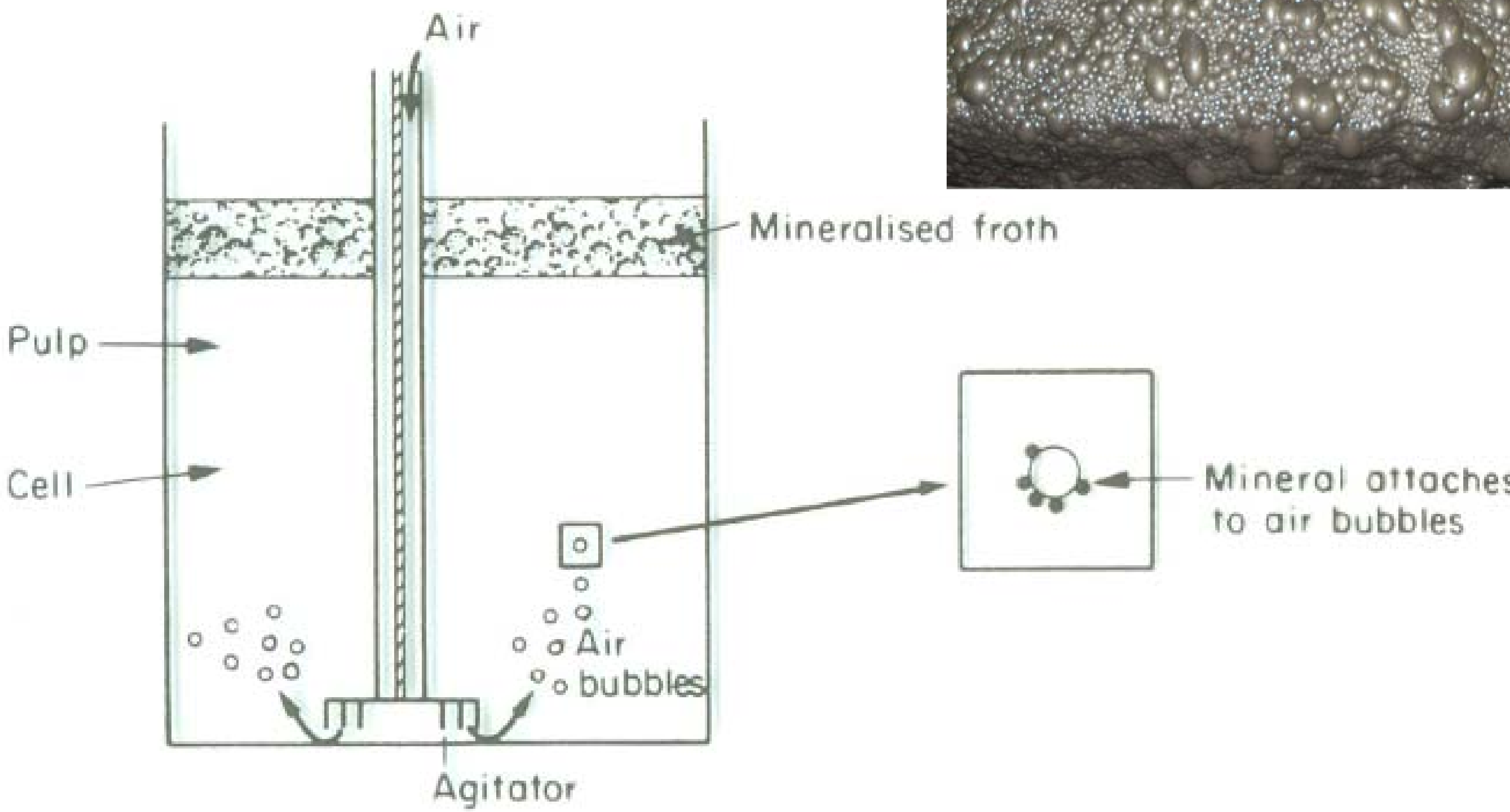
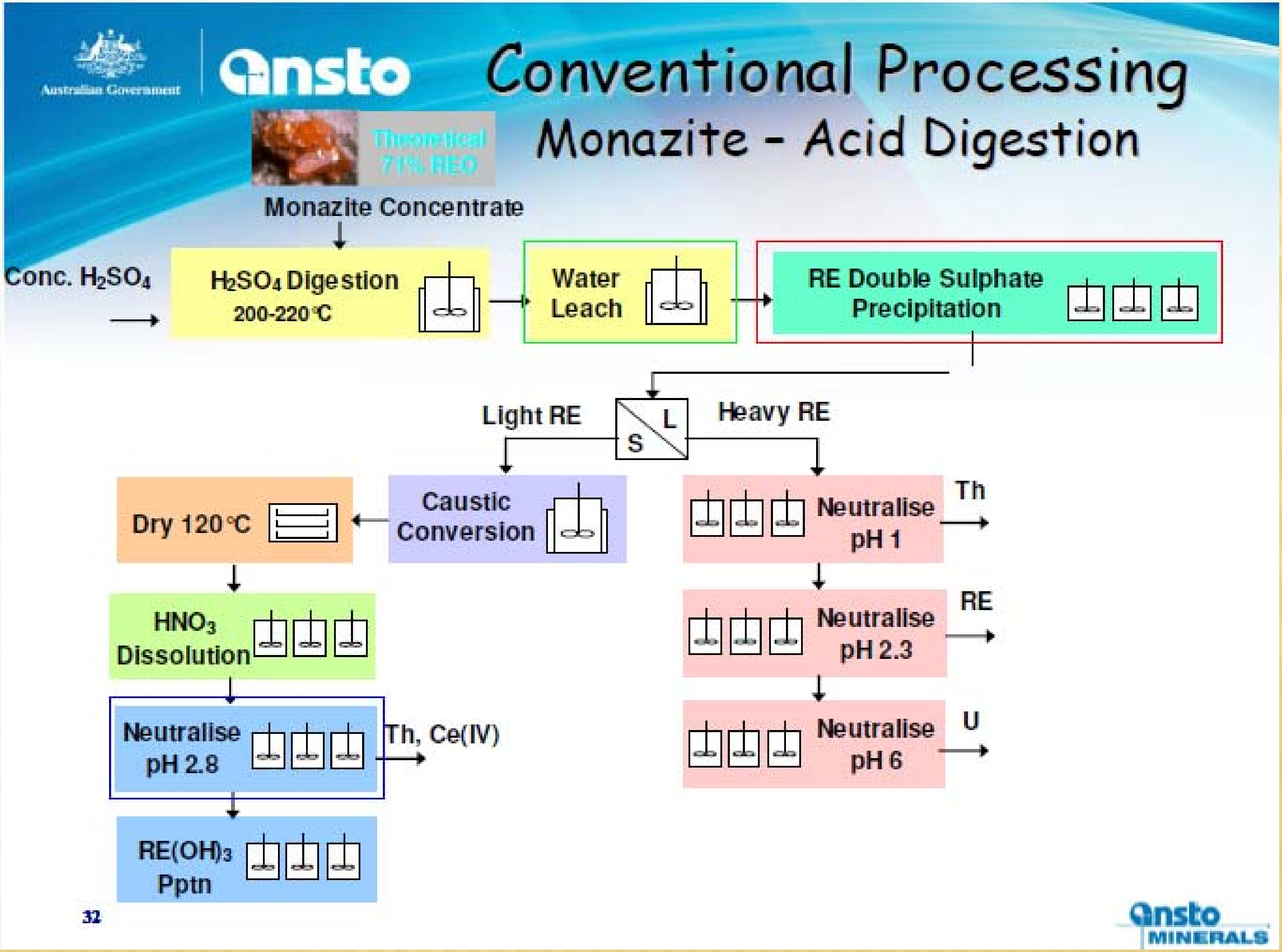


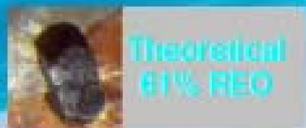

FIG. 12.1. Principle of froth flotation.

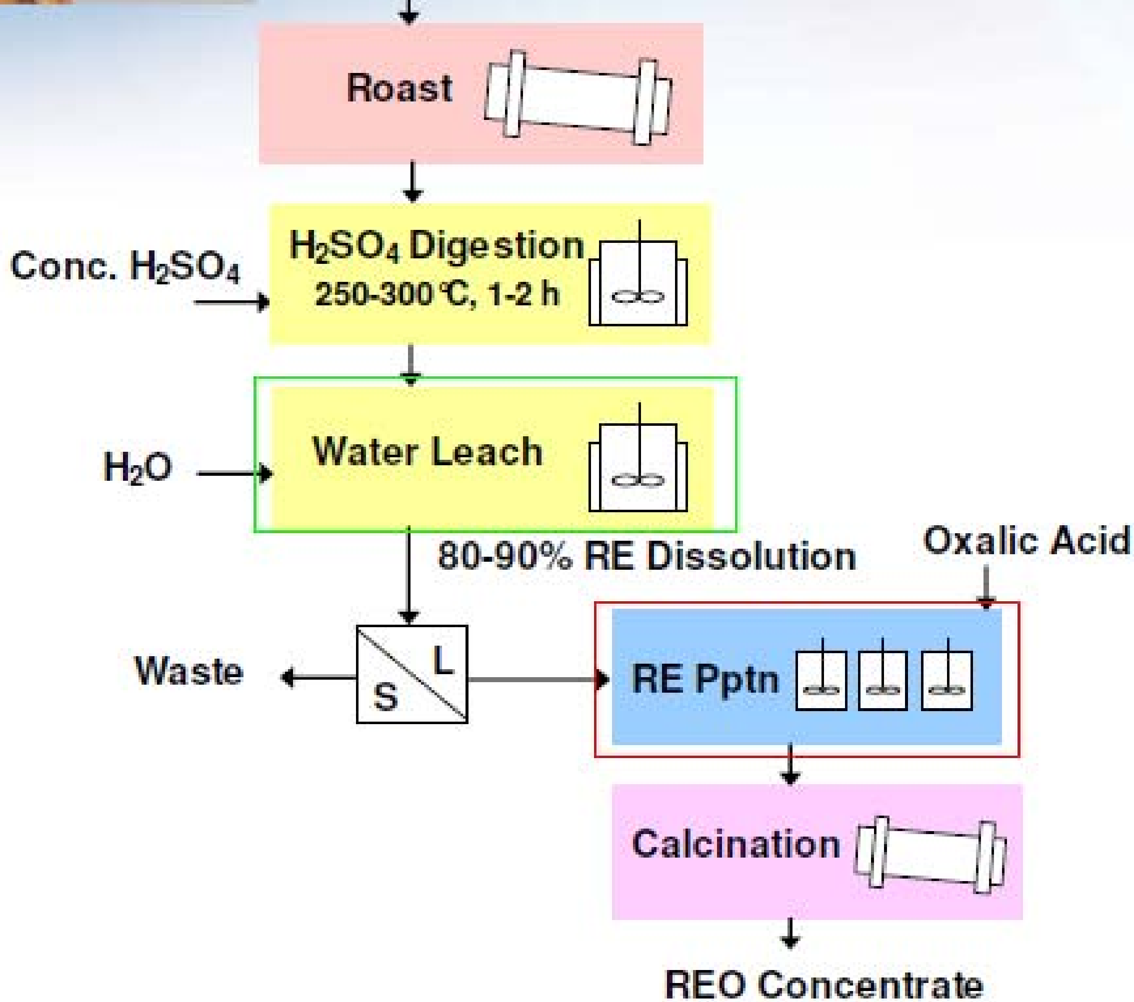
# Monazite Ore Processing

- 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.


Australian Government
ansto
Conventional Processing
Monazite - Acid Digestion
Theoretical
71% REO
Monazite Concentrate
Conc. $H_2SO_4$
$H_2SO_4$ Digestion
200-220°C
Water
Leach
RE Double Sulphate
Precipitation
Light RE
L
S
Heavy RE
Dry 120°C
Caustic
Conversion
Neutralise
pH 1
Th
Neutralise
pH 2.3
RE
Neutralise
pH 6
U
$HNO_3$
Dissolution
Neutralise
pH 2.8
Th, Ce(IV)
$RE(OH)_3$
Pptn
32
ansto
MINERALS

# Conventional Processing
## Xenotime - Acid Digestion

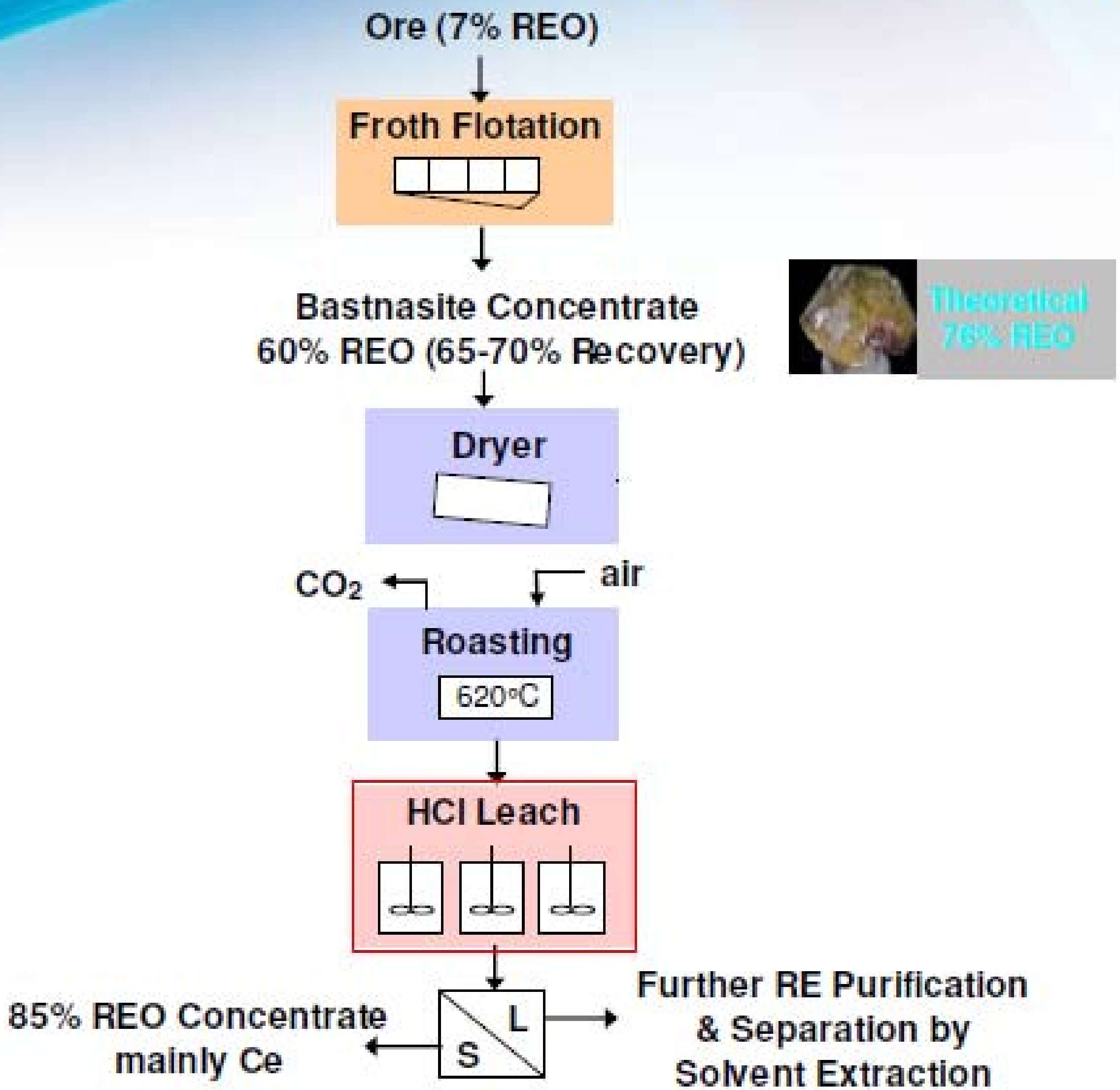


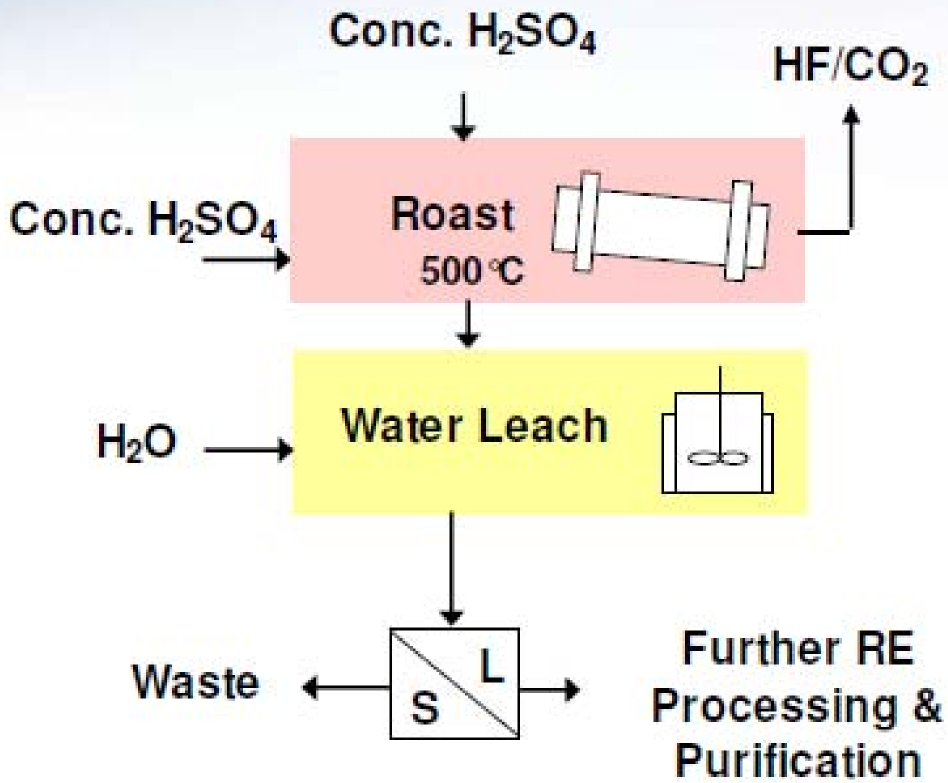
# BASTNASITE ORE PROCESSING

- Bastnasite mining near Mountain Pass in southeastern California will 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.
- 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, 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.

# Conventional Processing
## Bastnasite - HCl Acid Leach



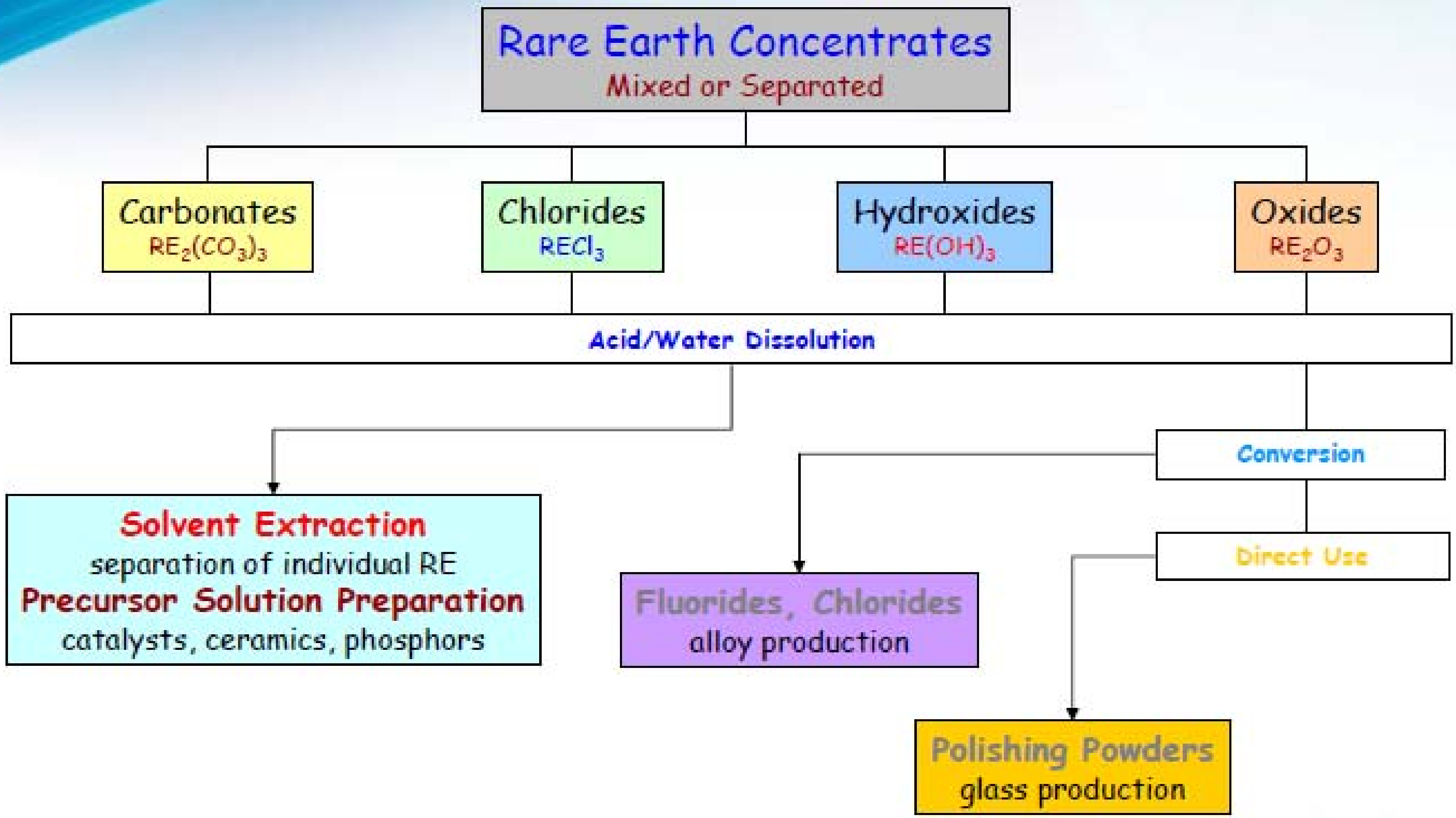
# Conventional Processing
## Bastnasite - $H_2SO_4$ Roast-Leach



# Processing of the Products

- The rare earth hydroxides and chlorines which are recovered from monazite and bastnasite are, respectively, typically would undergo further processing to produce and recover individual rare earth metal compounds for a variety of applications.
- Several processes are used to produce rare earth fluorides, nitrates, carbonates, oxides, and pure metals.
- Processes used include fractional crystallization, fractional precipitation, solvent extraction, ion exchange, and reduction.

# RE Products/Concentrates

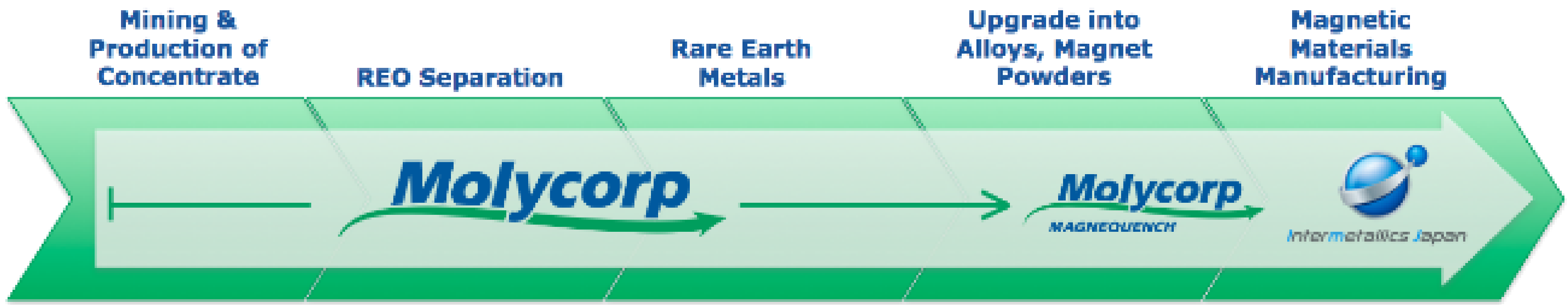


# Rare Earth Processing

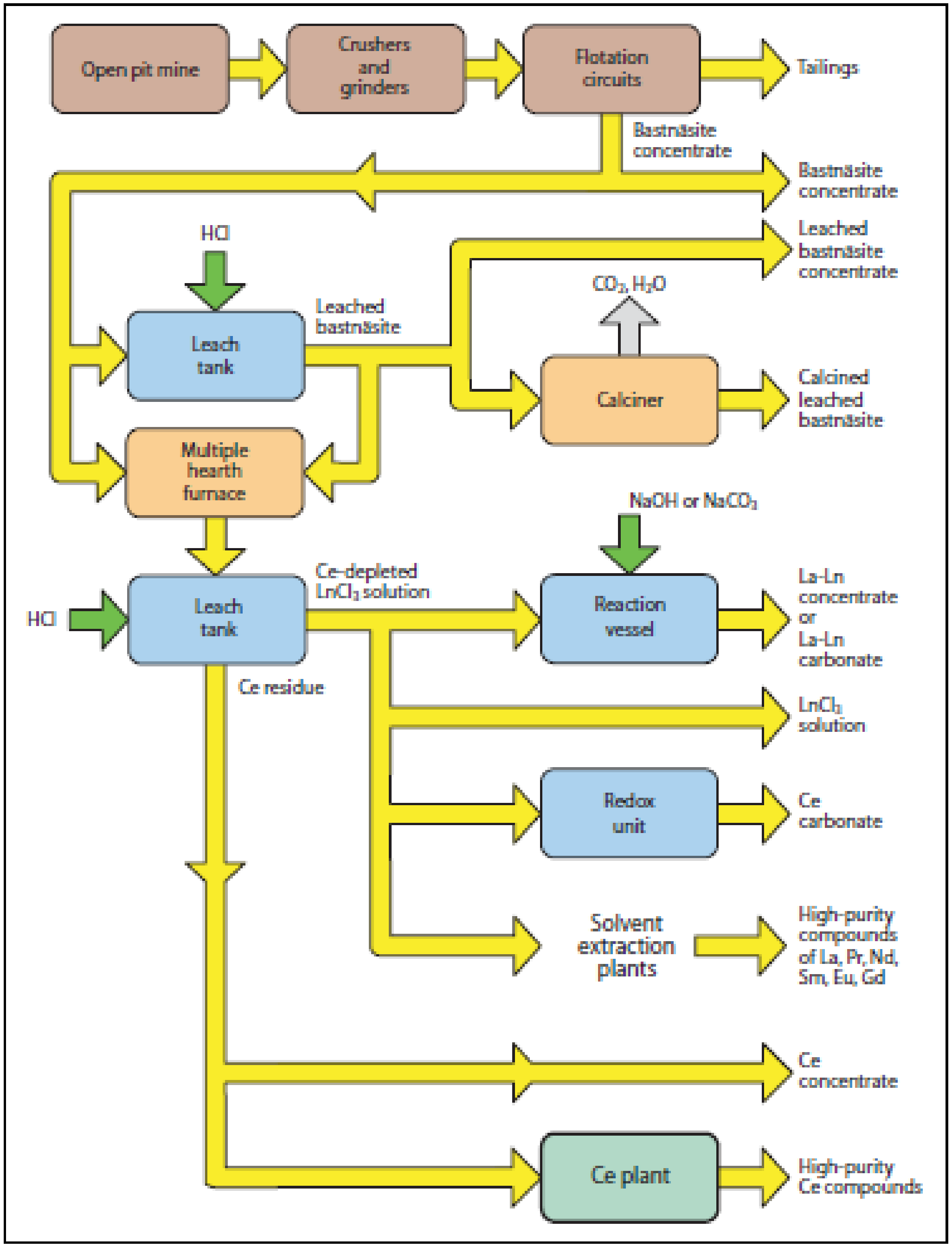
Key Points

1. Processing of conventional RE sources is well established but processing of other sources is NOT;
2. The mineralogy of RE is complex and 'a specific process is needed for a specific ore';
3. Multiple unit processes are required to reject the elemental and radioactive impurities associated with the RE;
4. There is an exponential increase in the complexity where the RE are trying to be recovered as a by-product and multiple processing options need to be explored.

# MOLYCORP

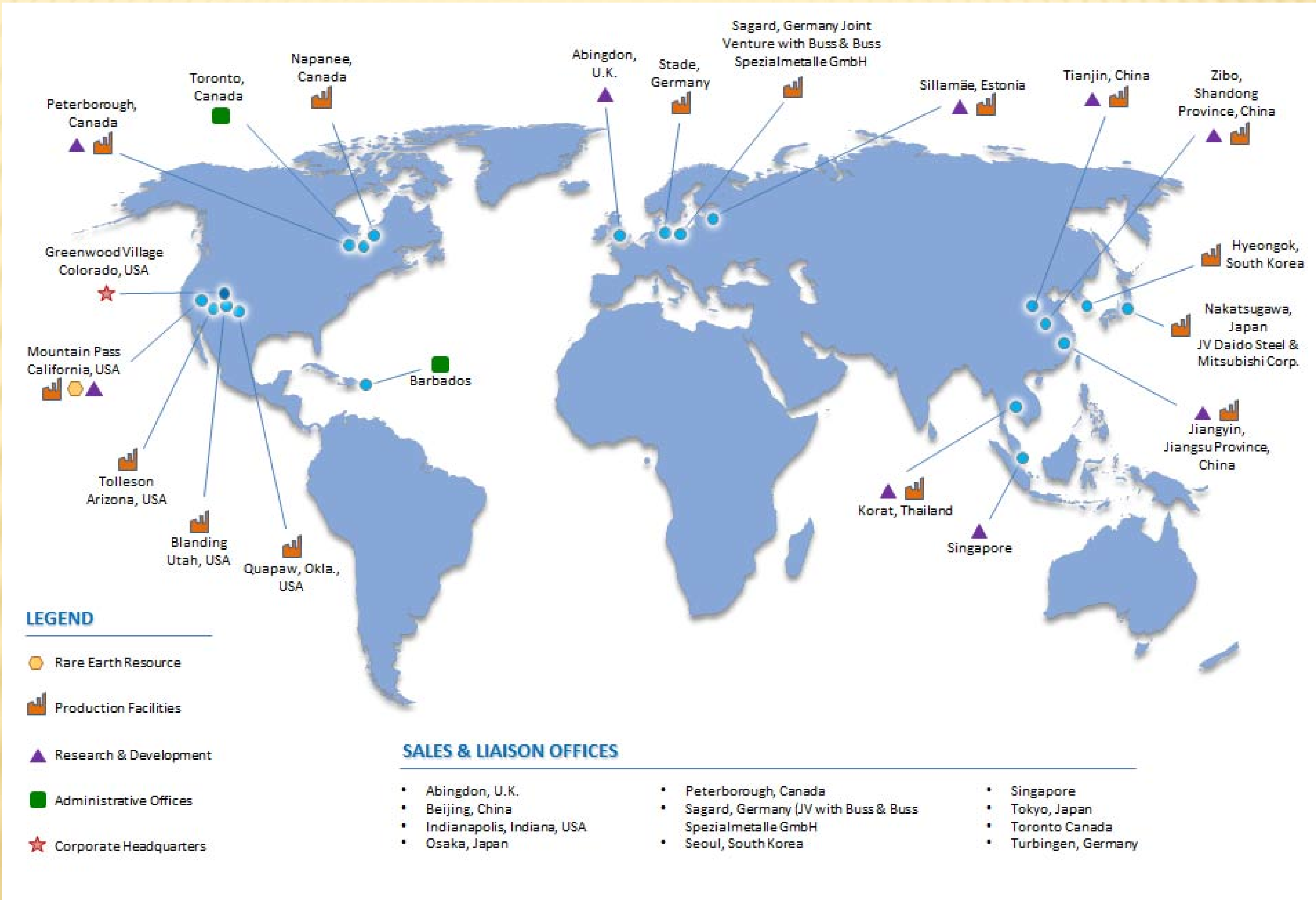



Molycorp's Mine-To-Magnetics Supply Chain

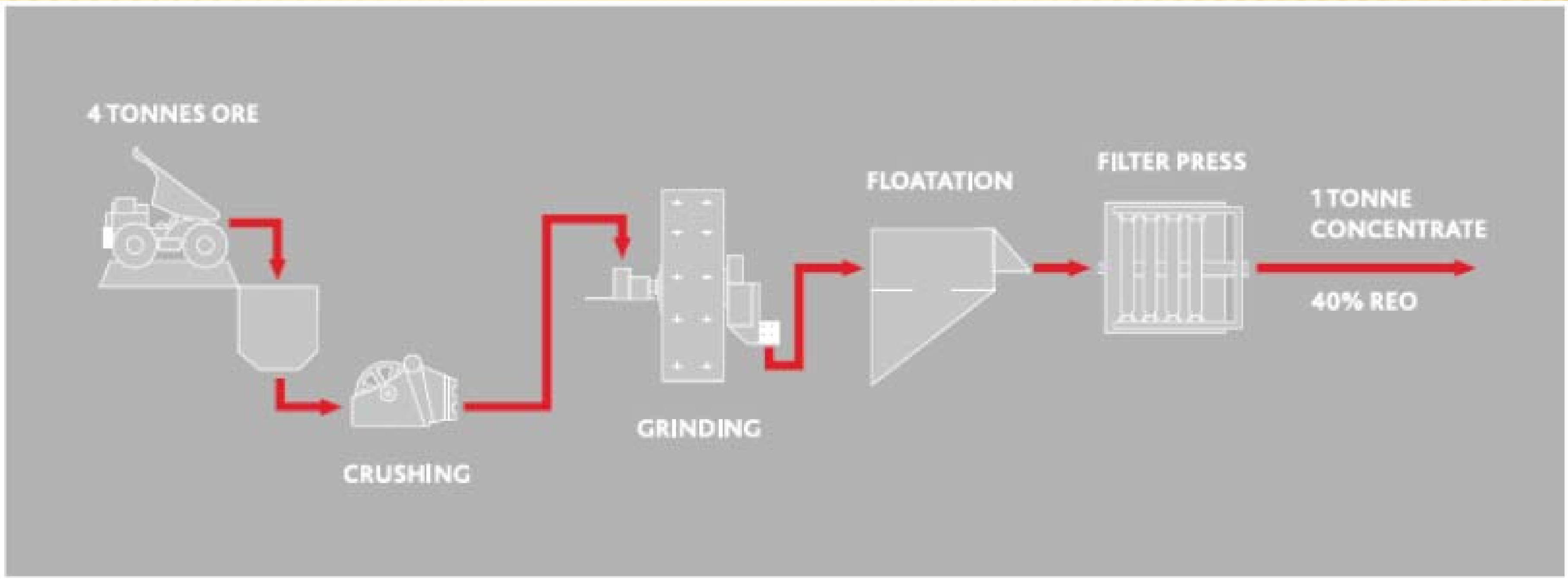


Open pit mine
Crushers and grinders
Flotation circuits
Tailings
Bastnäsite concentrate
Bastnäsite concentrate
Leached bastnäsite concentrate
HCl
Leach tank
Leached bastnäsite
$CO_2$, $H_2O$
Calciner
Calcined leached bastnäsite
Multiple hearth furnace
NaOH or $NaCO_3$
HCl
Leach tank
Ce-depleted $LnCl_3$ solution
Reaction vessel
La-Ln concentrate or La-Ln carbonate
Ce residue
$LnCl_3$ solution
Redox unit
Ce carbonate
Solvent extraction plants
High-purity compounds of La, Pr, Nd, Sm, Eu, Gd
Ce concentrate
Ce plant
High-purity Ce compounds

# MOLYCORP FACILITIES



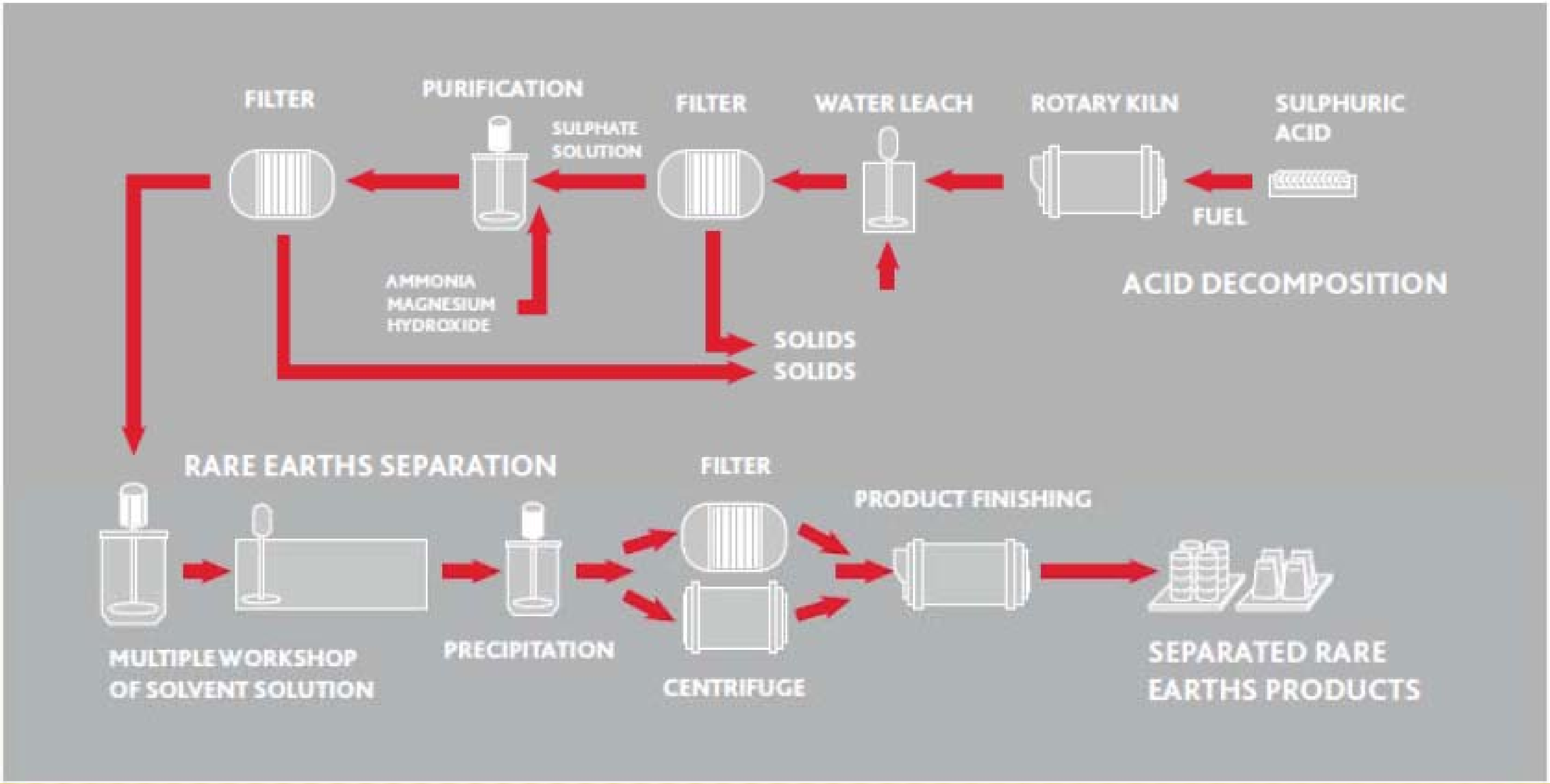
# LYNAS PLANT


4 TONNES ORE
CRUSHING
GRINDING
FLOATATION
FILTER PRESS
1 TONNE
CONCENTRATE
40% REO

# LYNAS PLANT

- Mine
- Mill produces a concentrate (REE phosphate)
- Cracking and leaching using sulfuric acid to yield a REE-rich solution
- Solvent extraction
  - Upstream solvent extraction separates LREE (La-Nd) and HREE (Sm-Gd and other HREE)
  - Downstream solvent extraction separates REE into groups and individual elements

# LYNAS PLANT

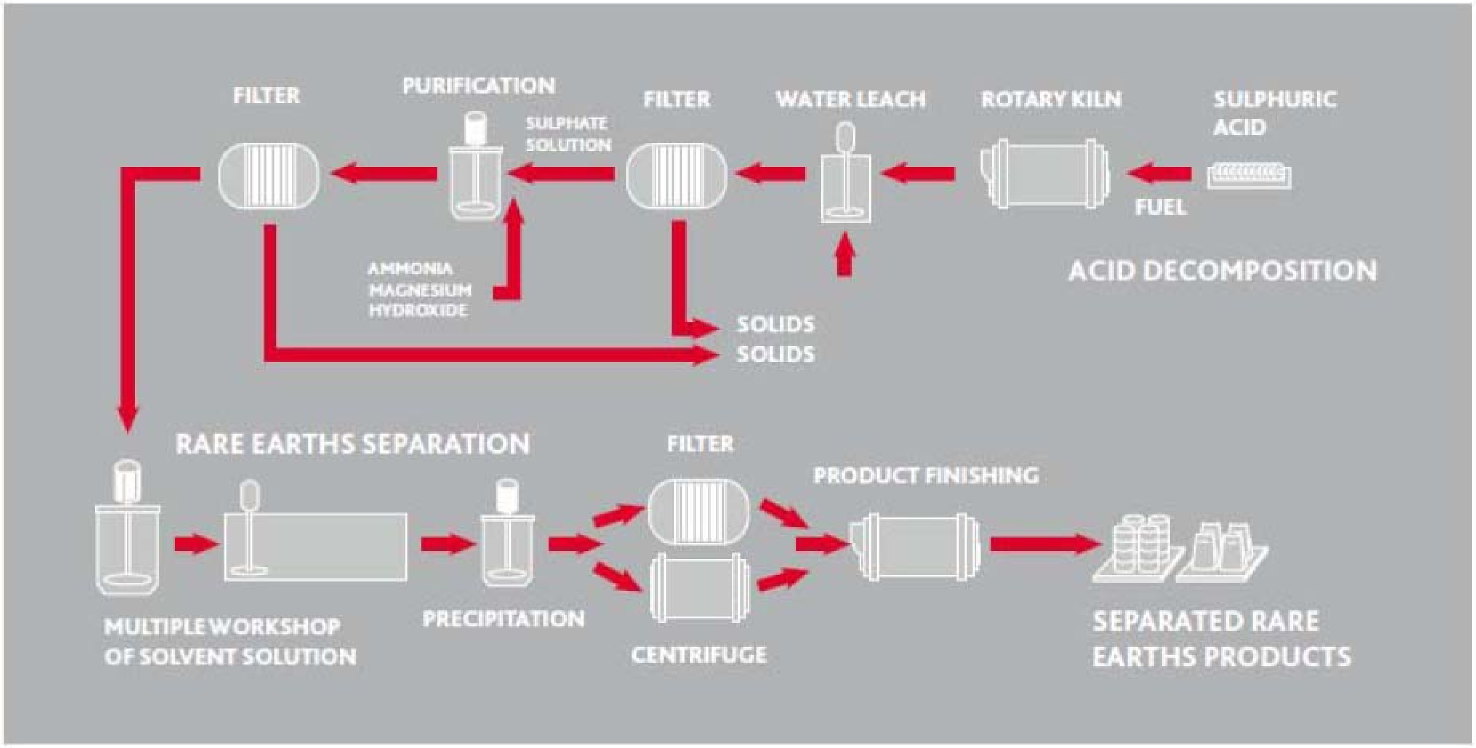


FILTER
PURIFICATION
SULPHATE SOLUTION
FILTER
WATER LEACH
ROTARY KILN
SULPHURIC ACID
FUEL
AMMONIA MAGNESIUM HYDROXIDE
ACID DECOMPOSITION
SOLIDS
SOLIDS
RARE EARTHS SEPARATION
FILTER
PRODUCT FINISHING
MULTIPLE WORKSHOP OF SOLVENT SOLUTION
PRECIPITATION
CENTRIFUGE
SEPARATED RARE EARTHS PRODUCTS

# LYNAS PLANT

- Product finishing
  - La-Ce carbonate
  - La carbonate
  - Ce carbonate
  - Sm-Eu-Gd (SEG)+heavy REE carbonate
  - Nd-Pd oxide
- Products derived from processing (plan to develop a market)
  - Gas from cracking and leaching treated to yield a synthetic gypsum
  - Water leaching yields an iron phospogypsum

# Schematic - Lynas Advanced Materials Plant core process, which uses mature industry technology




Lynas CORPORATION LTD

# The Lynas Advanced Materials Plant (LAMP) is 0.8km wide (N-S) and 1.4 km long (E-W)

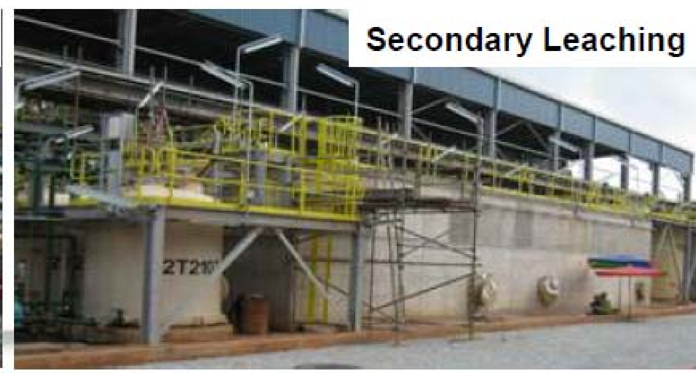
**OVERVIEW OF UP AND DOWNSTREAM SEPARATION AND PRODUCT FINISHING WORKSHOPS**

# LAMP construction is more than 98% complete


Cracking (Rotary Kiln)


Gas Treatment


Primary Leaching


Secondary Leaching



Lynas CORPORATION LTD

# LAMP construction is more than 98% complete

Upstream Extraction

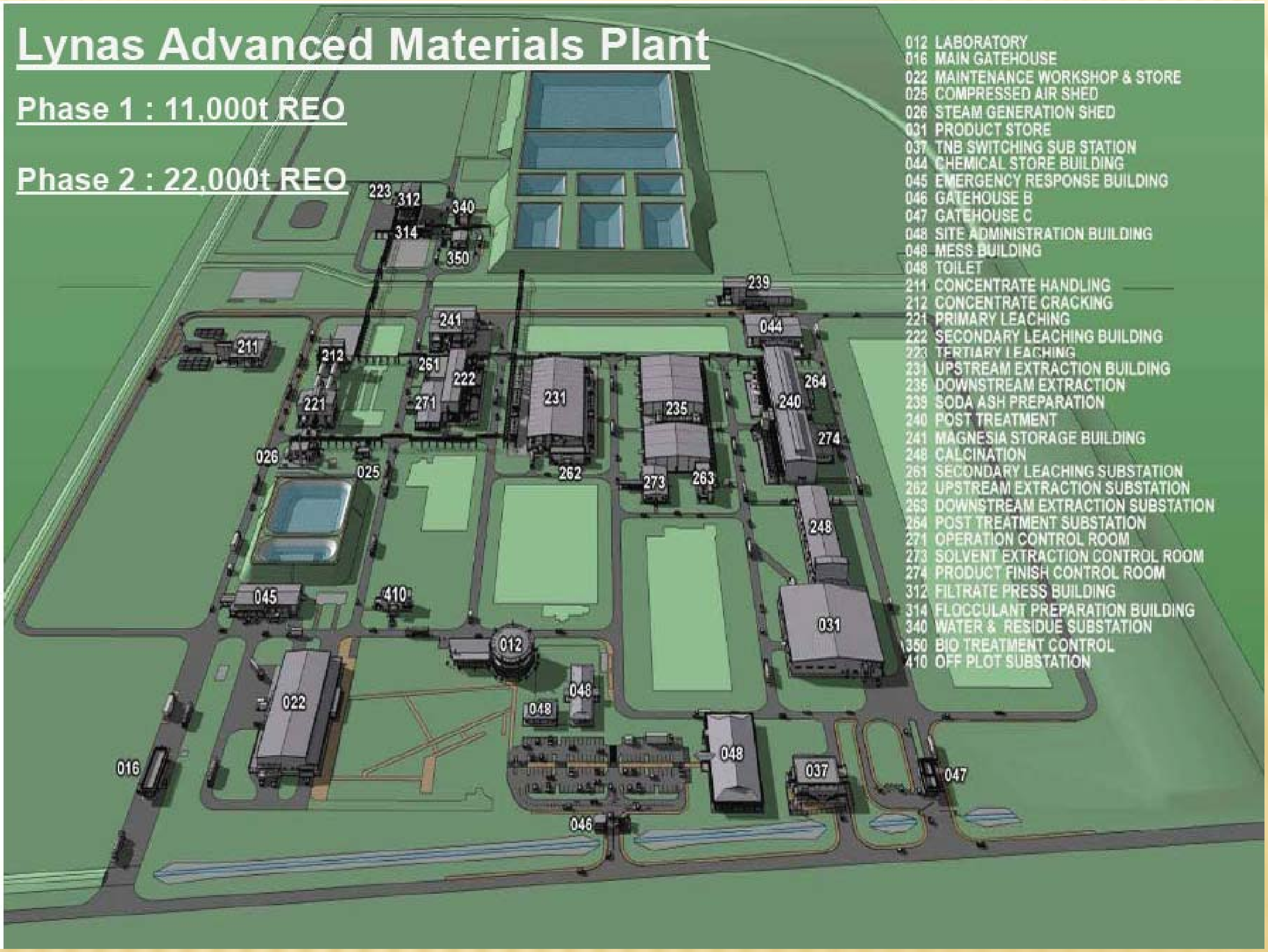
Downstream Extraction

Post Treatment

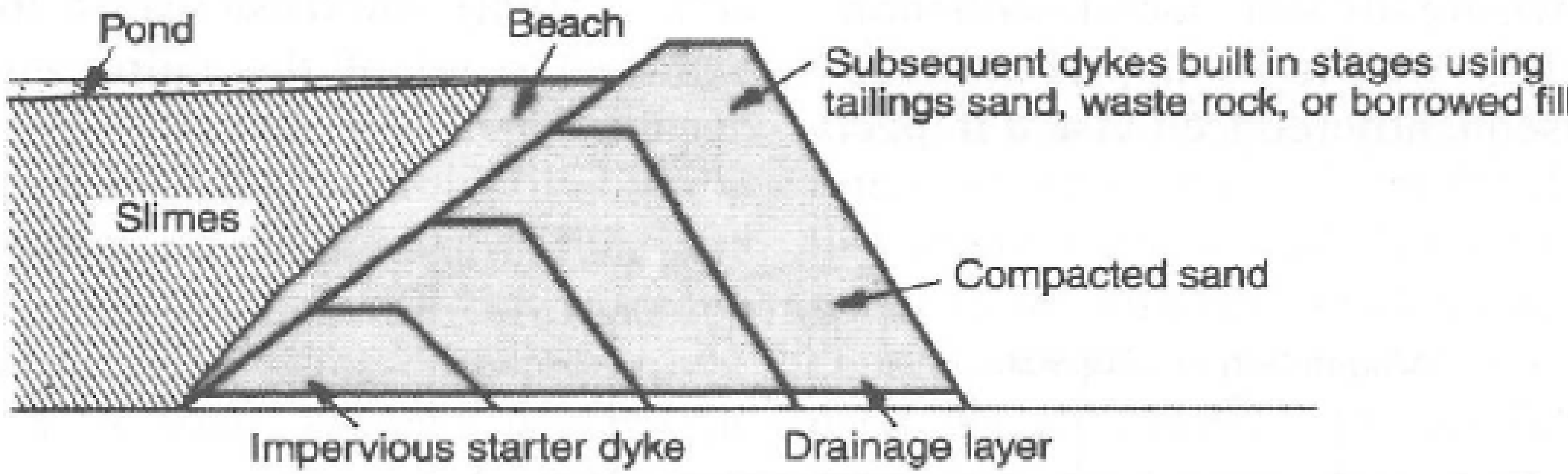
Tunnel Furnaces



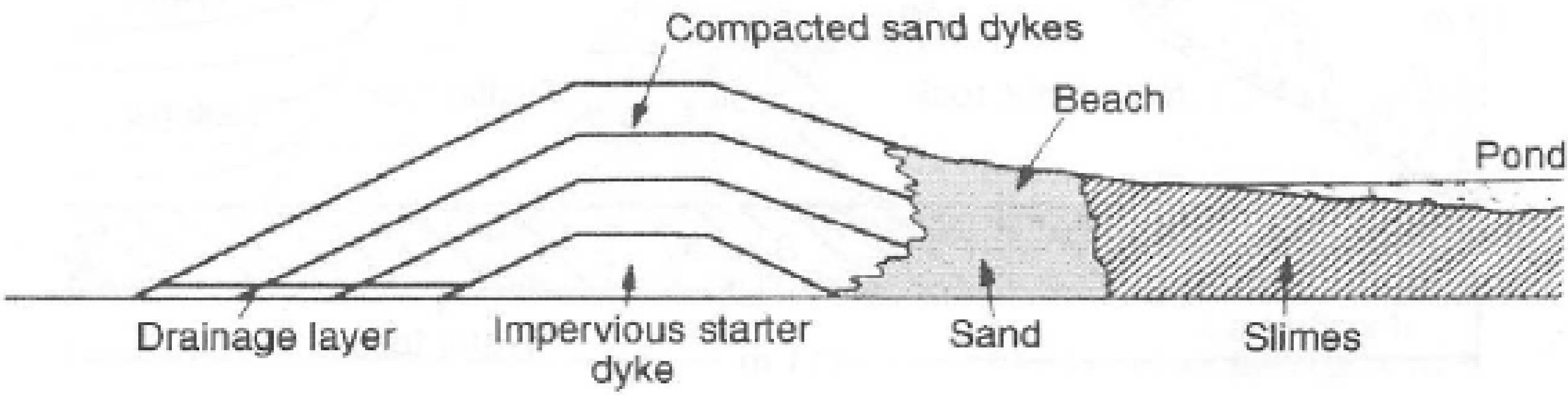
Lynas CORPORATION LTD



Lynas Advanced Materials Plant
Phase 1 : 11,000t REO
Phase 2 : 22,000t REO
012 LABORATORY
016 MAIN GATEHOUSE
022 MAINTENANCE WORKSHOP & STORE
025 COMPRESSED AIR SHED
026 STEAM GENERATION SHED
031 PRODUCT STORE
037 TNB SWITCHING SUB STATION
044 CHEMICAL STORE BUILDING
045 EMERGENCY RESPONSE BUILDING
046 GATEHOUSE B
047 GATEHOUSE C
048 SITE ADMINISTRATION BUILDING
048 MESS BUILDING
048 TOILET
211 CONCENTRATE HANDLING
212 CONCENTRATE CRACKING
221 PRIMARY LEACHING
222 SECONDARY LEACHING BUILDING
223 TERTIARY LEACHING
231 UPSTREAM EXTRACTION BUILDING
235 DOWNSTREAM EXTRACTION
239 SODA ASH PREPARATION
240 POST TREATMENT
241 MAGNESIA STORAGE BUILDING
248 CALCINATION
261 SECONDARY LEACHING SUBSTATION
262 UPSTREAM EXTRACTION SUBSTATION
263 DOWNSTREAM EXTRACTION SUBSTATION
264 POST TREATMENT SUBSTATION
271 OPERATION CONTROL ROOM
273 SOLVENT EXTRACTION CONTROL ROOM
274 PRODUCT FINISH CONTROL ROOM
312 FILTRATE PRESS BUILDING
314 FLOCCULANT PREPARATION BUILDING
340 WATER & RESIDUE SUBSTATION
350 BIO TREATMENT CONTROL
410 OFF PLOT SUBSTATION

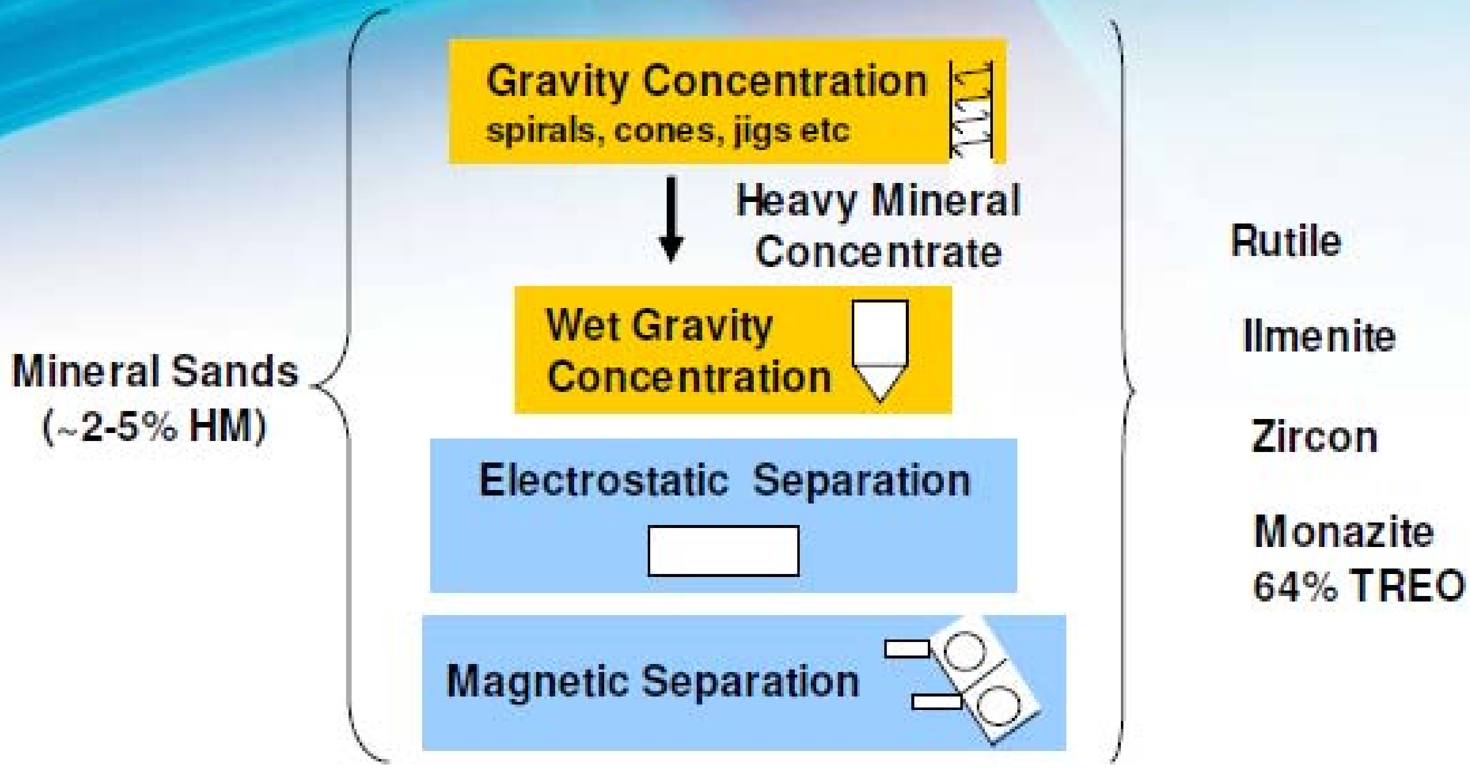



Downstream tailings dam




Centre-line tailings dam

# Beneficiation – Mineral Sands




- Well known, widely used technology – lowers risk
- Applicability of methods dependent on mineralogy
- *Includes flotation

# ENVIRONMENTAL ISSUES

# ENVIRONMENTAL ISSUES

- Limited case studies
- Knowedge is limited
- Environmental risks likely vary among deposit types
- U, Th issues
- Other trace elements (Cd, Ni, Se????)
- Acid drainage is probably low, but monitor it
  - Few sulfide minerals
  - Abundant carbonates

# Rare Earth Element Minerals & Chemistry

| Group-Mineral | Formula | REO Wt% | $ThO_2$ Wt% | $UO_2$ Wt% |
|---|---|---|---|---|
| **Oxides** | | | | |
| Aeschynite | $(Ln,Ca,Fe)(Ti,Nb)_2(O,OH)_6$ | | | |
| Euxenite | $(Y,Ln,Ca)(Nb,Ta,Ti)_2(O,OH)_6$ | | | |
| Fergusonite | $YNbO_4$ | | | |
| **Carbonates** | | | | |
| Bastnäsite | $(Ln,Y)CO_3F$ | 70 - 74 | 0 - 0.3 | 0.09 |
| Parisite | $Ca(Ln)_2(CO_3)_3F_2$ | 59 | 0 – 0.5 | 0 – 0.3 |
| Synchisite | $Ca(Ln,Y)(CO_3)_2F$ | 49 – 52 | 1.6 | |
| Tengerite | $Y_2(CO_3)_3 \bullet n(H_2O)$ | | | |
| **Phosphates** | | | | |
| Apatite | $(Ca,Ln)_5(PO_4)_3(OH,F,Cl)$ | 0 -20 | | |
| Monazite | $(Ln,Th)PO_4$ | 35 - 71 | 0 - 20 | 0 - 16 |
| Xenotime | $YPO_4$ | 52 – 67 | 0 - 3 | 0 -5 |
| **Silicates** | | | | |
| Allanite | $(Ln,Y,Ca)_2(Al,Fe^{3+})_2(SiO_4)_3(OH)$ | 3 – 51 | 0 -3 | |
| Eudialyte | $Na_4(Ca,Ce)_2(Fe^{2+},Mn^{2+},Y)ZrSi_8O_{22}(OH,Cl)_2$ | 1 - 10 | | |
| Thalenite | $Y_2Si_2O_7$ | | | |
| Zircon | $(Zr,Ln)SiO_4$ | 0 – 0.7 | 0.1 – 0.8 | |

Ln: Lanthanide (a.k.a. REE)

USGS science for a changing world

# Scarred landscape from small REE mines in China and pipeline spill (Tien, 2013)

Every ton of REE produced generates approximately 8.5 kg (18.7 lb) of F and 13 kg (28.7lb) of dust. Using concentrated sulfuric acid high temperature calcination techniques to produce approximately 1 ton of calcined REE ore generates 9,600 to 12,000 m3 of waste gas containing dust concentrate, hydrofluoric acid, sulfur dioxide and sulfuric acid,

approximately 75 m3 of acidic wastewater, and about 1 ton of radioactive waste residue (containing water). (Chinese Society of Rare Earths)

1 ton of REES creates 2,000 tons of mine tailings

# Rare Earth Element Minerals & Chemistry

| Group-Mineral | Formula | REO Wt% | $ThO_2$ Wt% | $UO_2$ Wt% |
|---|---|---|---|---|
| **Oxides** | | | | |
| Aeschynite | $(Ln,Ca,Fe)(Ti,Nb)_2(O,OH)_6$ | | | |
| Euxenite | $(Y,Ln,Ca)(Nb,Ta,Ti)_2(O,OH)_6$ | | | |
| Fergusonite | $YNbO_4$ | | | |
| **Carbonates** | | | | |
| Bastnäsite | $(Ln,Y)CO_3F$ | 70 - 74 | 0 - 0.3 | 0.09 |
| Parisite | $Ca(Ln)_2(CO_3)_3F_2$ | 59 | 0 – 0.5 | 0 – 0.3 |
| Synchisite | $Ca(Ln,Y)(CO_3)_2F$ | 49 – 52 | 1.6 | |
| Tengerite | $Y_2(CO_3)_3 \bullet n(H_2O)$ | | | |
| **Phosphates** | | | | |
| Apatite | $(Ca,Ln)_5(PO_4)_3(OH,F,Cl)$ | 0 -20 | | |
| Monazite | $(Ln,Th)PO_4$ | 35 - 71 | 0 - 20 | 0 - 16 |
| Xenotime | $YPO_4$ | 52 – 67 | 0 - 3 | 0 -5 |
| **Silicates** | | | | |
| Allanite | $(Ln,Y,Ca)_2(Al,Fe^{3+})_2(SiO_4)_3(OH)$ | 3 – 51 | 0 -3 | |
| Eudialyte | $Na_4(Ca,Ce)_2(Fe^{2+},Mn^{2+},Y)ZrSi_8O_{22}(OH,Cl)_2$ | 1 - 10 | | |
| Thalenite | $Y_2Si_2O_7$ | | | |
| Zircon | $(Zr,Ln)SiO_4$ | 0 – 0.7 | 0.1 – 0.8 | |

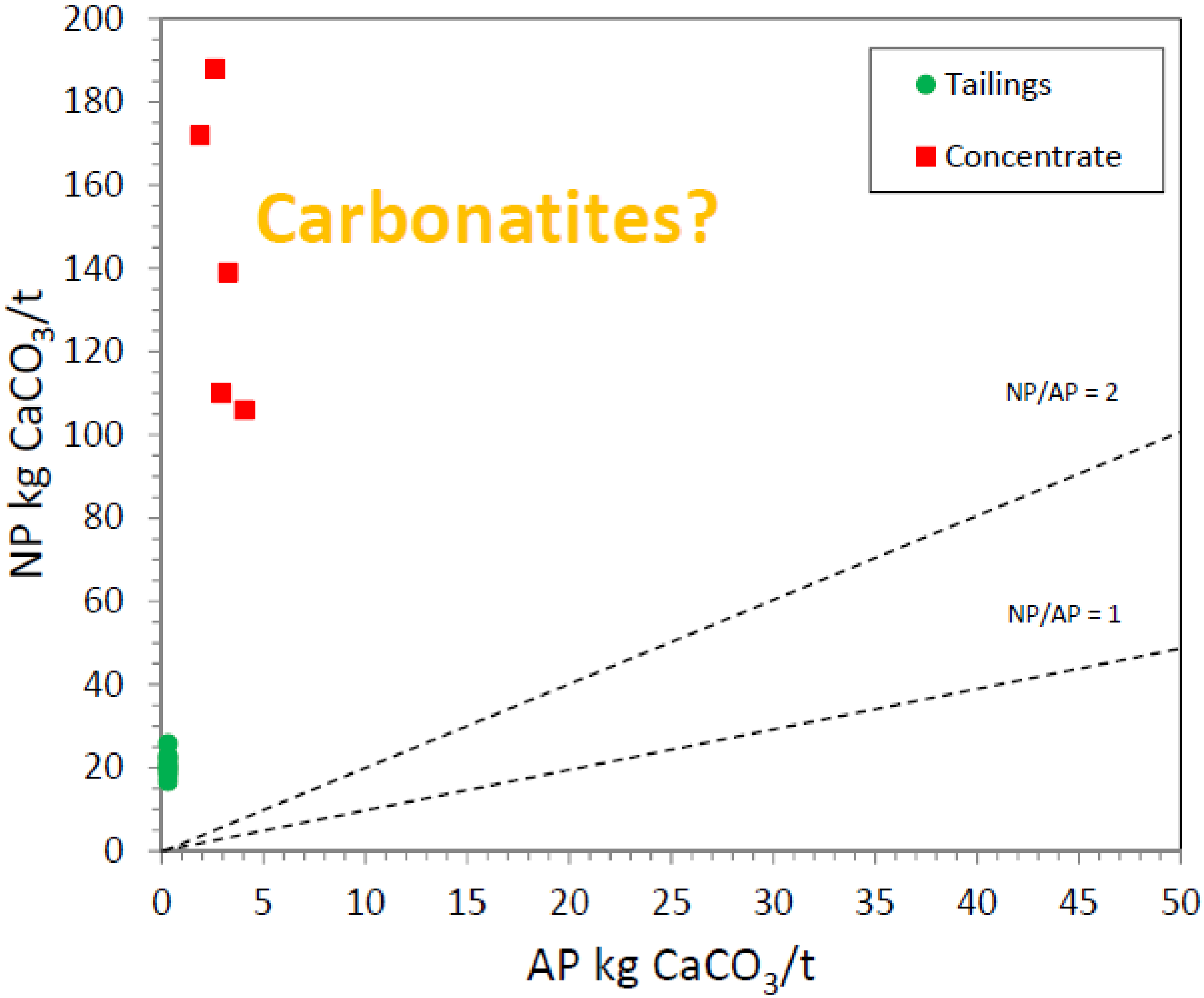
Ln: Lanthanide (a.k.a. REE)

USGS science for a changing world

# MOLYCORP MOUNTAIN PASS

- Th and Ra contamination of waste water spills in 1990s closed the mine
- Desert tortoise
- Evaporating ponds
- Water use
- Th, Ra in waste materials

# Acid-Generating Potential - Thor Lake, NWT, Canada




- Despite lack of data, carbonatite-hosted REE deposits would be expected to be strongly net alkaline.

Thor Lake data: http://www.reviewboard.ca/registry/project.php?project_id=87

USGS science for a changing world

# Rare Earth Elements: Surface Water Guidelines

| | | Yellow River, Baotou, China Bayan Obo Industrial Complex | | | Valzinco, VA | | Thor Lake, NWT, Canada |
|---|---|---|---|---|---|---|---|
| | MPC* µg/L | Main Channel | Site F | Site G | VLZN-10 | VLZN-3 | Tailings HCT |
| pH | | 7.6 - 8.2 | | 3.7 - 6.9 | 1.1 | 3.3 | 7.5 |
| Y µg/L | 6.4 | | | | 370 | 2.0 | 0.183 |
| La µg/L | 10.1 | 0.103 | 140 | 988 | 340 | 4.6 | |
| Ce µg/L | 22.1 | 0.22 | 152 | 1149 | 870 | 9.5 | |
| Pr µg/L | 9.1 | 0.0304 | 16.08 | 294 | 150 | 1.2 | |
| Nd µg/L | 1.8 | 0.095 | 52.01 | 1193 | 650 | 4.7 | |
| Sm µg/L | 8.2 | 0.023 | 6.91 | 62.35 | 180 | 0.9 | |
| Gd µg/L | 7.1 | 0.028 | 7.22 | 67.33 | 140 | 0.7 | |
| Dy µg/L | 9.3 | 0.082 | 3.8 | 9.08 | 93 | 0.4 | |

*From: Maximum Permissible Concerntration; Sneller et al. (2000)

Thor Lake data: http://www.reviewboard.ca/registry/project.php?project_id=87

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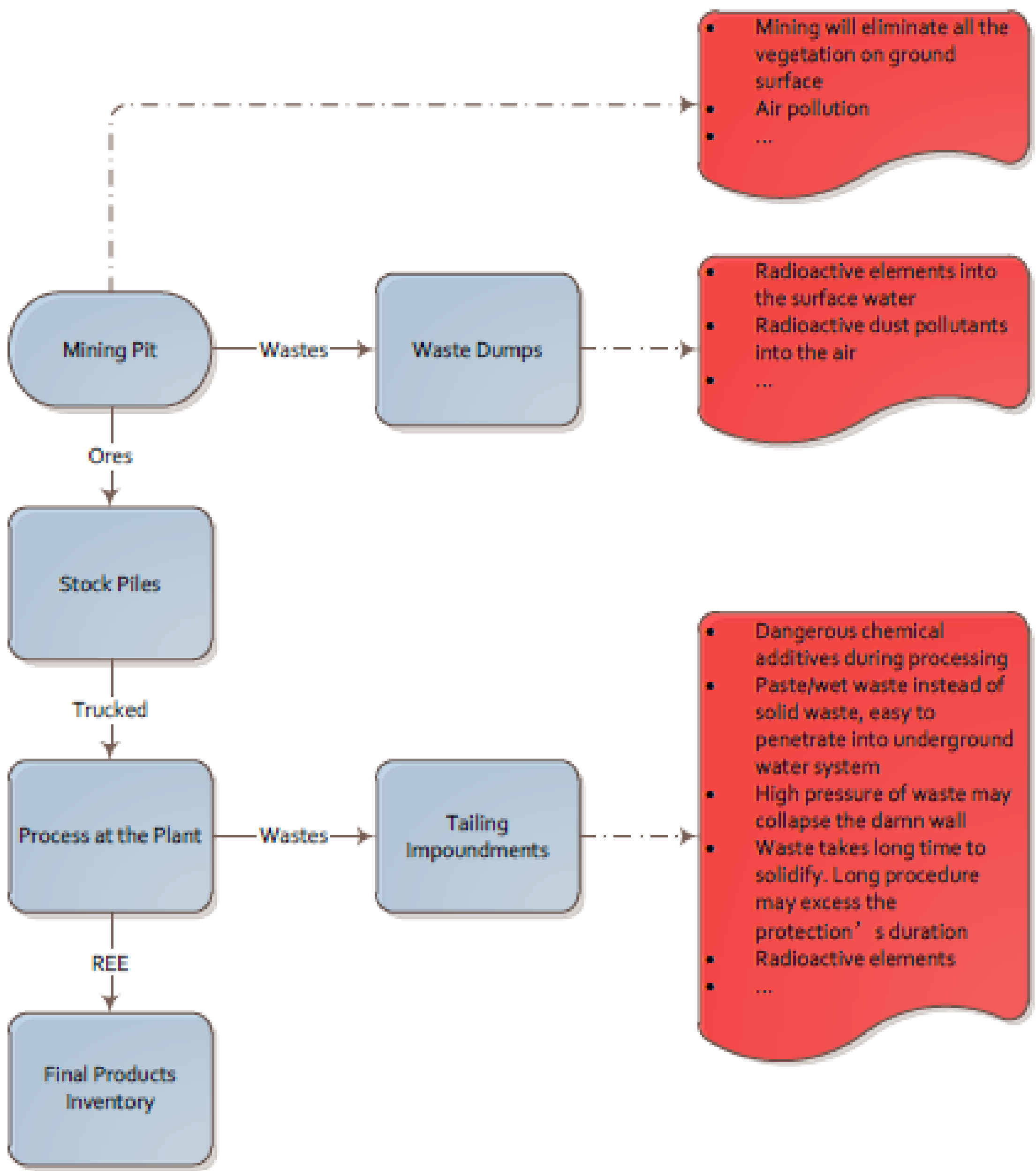
# Appendix 15: Environmental Risks from REE Production





**Politics & Economics of Rare Earths**

Citigroup – Global Commodities Research

Columbia University

School of International and Public Affairs

# RECYCLING

# Ce IN AUTOMOTIVE CATALYTIC CONVERTERS

- Recovering PGMs
- 19,000 metric tons Ce
- No technologies at the present time

http://pubs.usgs.gov/of/2013/1037/OFR2013-1037.pdf

**Figure 1.** Stockpiled catalytic converters (CATCONs) that have been removed from vehicles before the CATCONs were dismantled and recycled for platinum-group metals. Photograph courtesy of Ashok Kumar, Director, A–1 Specialized Services & Supplies, Inc. Used with permission.

# ECONOMIC RISKS

- Less than 1 in 10,000 deposits become mines
- Estimated 1 in 2,000 or 3,000 prospects become mines
- Ore processing is very deposit specific because of the mineralogy

**Table 2 Current producers out of China**

| No. | Company | Location | Country | Current capacity (tpy REO) | Target capacity after 2015 (tpy REO) |
|---|---|---|---|---|---|
| 1 | Molycorp Minerals | Mountain Pass, CA | USA | 3 000 | 40 000 |
| 2 | Lovozersky Mining Company | Kamasurt Mine, Kola Peninsula | Russia | 3 000–4 400 | 15 000 |
| 3 | Solikamsk Magnesium Works | Solikamsk Processing Plant,Urals | Russia | | |
| 4 | Indian Rare Earths | Orissa,Tamil Nadu and Kerala | India | 100 | 10 000 |
| 5 | Toyota/Sojitz/Gov.of Vietnam | | Vietnam | 1 800–2 000 | >2 000 |
| 6 | Neo | | Thailand | | |
| 7 | Lynas/Malaysia | Gebeng, Malaysia | Malaysia | | |
| 8 | Indústrias Nucleares do Brasil S/A (INB) | Buena Norte | Brazil | 1 500 | >1 500 |
| Total | | | | 9 500–11 000 | >68 500 |

**Table 3 Under preparation producers**

| No. | Company | Location | Countries | 2011-2013 Capacity (tpy REO) | Target capacity after 2010 (tpy REO) |
|---|---|---|---|---|---|
| 1 | Lynas Corp | Mount Weld, Western Australia, and a processing plant in Gebeng, Malaysia | Australia | 10 500 | 21 000 |
| 2 | Rareco/Great Western Minerals Group | Steenkramskaal, South Africa | South Africa/Canada | 3 000 | 5 000 |
| 3 | Sumitomo/Kazatomprom/ SARECO JV | Kazakhstan | Kazakhstan/ Japan | 3 000 | 15 000 |
| 4 | Toyota/Sojitz/Govt. of Vietnam | Dong Pao,Vietnam | Vietnam/Japan | 300 | 5 000 |
| 5 | Toyota/Indian Rare Earths jv | Orissa, India | India/Japan | 5 000 | 10 000 |
| 6 | Mitsubishi/Neo Material Technologies | Pitinga, Brazil | Japan/USA/Canada/Brazil | 500 | 1 000 |
| 7 | Alkane Resources | Dubbo, NSW, Australia | Australia | 2 600 | 6 000 |
| Total | | | | 24 900 | 63 000 |

**Table 4 Exploration-candidate supplier**

| No. | Company | Location | Countries | 2011-2013 Capacity (tpy REO) | Target capacity (tpy REO) in 2015 |
|---|---|---|---|---|---|
| 16 | Avalon Rare Metals Inc | Nechalacho deposit rich in HREEs in NWT, Canada | Canada | 0 | 5 000 |
| 17 | Quest Rare Metals | Strange Lake and others in Quebec/ Labrador, Canada | Canada | 0 | 0 |
| 18 | Ucore | Bokan-Dotson Ridge project, Alaska | USA | 0 | 0 |
| 19 | Matamec | Kipawa deposit in Quebec, Canada | Canada | 0 | 0 |
| 20 | Arafura | Nolan's project, Australia | Australia | 10 000 | 20 000 |
| 21 | Great Western Minerals Group | Hoidas Lake, Canada | Canada | 3 000 | 5 000 |
| 22 | Rare Element Resources | Bear Lodge, Wyoming, USA | USA | 0 | 0 |
| 23 | Stans Energy Corp | Kutessay ll Mine, Orlovka Kyrgyz Republic | Kyrgyz Republic | 0 | 0 |
| 24 | Greenland Minerals and Energy | Kvanefjeld-Greenland | GreenLand | 0 | 10 000 |
| 25 | Japan-Mongolia JV | Mongolia | Mongolia | 0 | 0 |
| Total | | | | 13 000 | 40 000 |

| Property | Proven & Probable Reserves | Measured & Indicated Resources | Inferred Resources | Total |
| --- | --- | --- | --- | --- |
| Mountain Pass | 48,375 | | | 48,375 |
| Mount Weld | 2,040 | 12,200 | 5,294 | 19,534 |
| Steenkampskraal | | | 250 | 250 |
| Dubbo Zirconia | | 37,500 | 35,700 | 73,200 |
| Nolan's Bore | | 17,400 | 12,800 | 30,200 |
| Bear Lodge | | | 15,876 | 15,876 |
| Montviel | | | 133,636 | 133,636 |
| Nechalacho | 12,001 | 88,130 | 226,880 | 327,011 |
| Kvanefjeld | | 365,000 | 92,000 | 457,000 |
| Strange Lake | | | 114,823 | 114,823 |

| Project | Tonnage (000) | Grade (%) | Mineral Type | HREE (%) | Stage | Start Up? |
|---|---|---|---|---|---|---|
| Mountain Pass | 48,375 | 7.0 | Carbonatite | 0.4 | Construction | 2012 |
| Mount Weld | 19,534 | 8.8 | Carbonatite | 3.0 | Construction | 2012 |
| Steenkampskraal | 250 | 11.7 | Monazite | 7.7 | Feasibility | 2013 |
| Dubbo Zirconia | 73,200 | 0.9 | Peralkaline syenite | 23.0 | Feasibility | 2014 |
| Nolan's Bore | 30,200 | 2.8 | Pegmatite | 4.0 | Feasibility | 2014 |
| Bear Lodge | 15,876 | 3.5 | Carbonatite | 3.3 | Pre-feasibility | 2015 |
| Montviel | 133,636 | 1.3 | Carbonatite | 2.0 | Scoping | 2015 |
| Nechalacho | 327,011 | 1.3 | Peralkaline syenite | 26.0 | Feasibiity | 2016 |
| Kvanefjeld | 457,000 | 1.0 | Peralkaline syenite | 14.0 | Pre-feasibility | 2016 |
| Strange Lake | 114,823 | 1.0 | Peralkaline syenite | 47.0 | Pre-feasibility | 2016 |

| Project | TREO Basket Value (mid 2011) | Annual TREO Production | Infra-structure | Necessary Capital Expenditure (US$ million) |
|---|---|---|---|---|
| Mountain Pass | 127 | 40,000 | | 781 |
| Mount Weld | 150 | 22,000 | | 512 |
| Steenkampskraal | 161 | 5,000 | Good | 70 |
| Dubbo Zirconia | 207 | 6,500 | Good | 178 |
| Nolan's Bore | 161 | 20,000 | Poor | 1,014 |
| Bear Lodge | 222 | 10,000 | Good | 88 |
| Montviel | 208 | | Good | 300 (?) |
| Nechalacho | 301 | 10,000 | Poor | 863 |
| Kvanefjeld | 218 | 43,729 | Poor | 2,310 |
| Strange Lake | 313 | 12,100 | Poor | 563 |

# RE-oxide prices, FOB China (US$/kg)

| Oxide 99% min purity | 2007 | 2008 | 2009 | 2010 | 31 March 2011 | 30 June 2011 | 18 Oct 2011 |
|---|---|---|---|---|---|---|---|
| Cerium | 3.65 | 4.25 | 4.15 | 61.00 | 121.00 | 149.00 | 71.00 |
| Dysprosium | 93.00 | 94.50 | 116.50 | 295.00 | 640.00 | 1510.00 | 2240.00 |
| Europium | 350.00 | 480.00 | 480.00 | 630.00 | 940.00 | 3190.00 | 3790.00 |
| Gadolinium | 10.45 | 7.75 | 6.75 | 44.50 | 147.50 | 202.50 | 142.50 |
| Lanthanum | 4.70 | 7.75 | 5.55 | 60.00 | 120.50 | 148.00 | 64.00 |
| Neodymium | 29.25 | 14.24 | 22.75 | 87.00 | 201.50 | 317.50 | 154.69 |
| Praseodymium | 29.75 | 14.25 | 22.25 | 86.50 | 196.00 | 238.50 | 218.50 |
| Samarium | 4.05 | 4.50 | 4.50 | 34.50 | 106.50 | 128.50 | 101.50 |
| Terbium | 610.00 | 410.00 | 350.00 | 605.00 | 990.00 | 2910.00 | 3010.00 |
| Yttrium | 11.40 | 15.25 | 10.25 | 72.50 | 142.50 | 169.50 | 142.50 |

Source: metal-pages.com

# POLITICS

# POLITICS

- Government reports are abundant
- China's policy is unknown and ever changing
- Afghanistan has potential REE deposits
- Some countries will subsidize the development of their deposits

# CHALLENGES

# KEY ISSUES FOR REE

- Finite resources
- Chinese market dominance
- Long lead times for mine development
- Resource nationalism/country risk
- High project development cost
- Relentless demand for high tech consumer products
- Ongoing material use research
- Low substitutability
- Environmental issues
- Low recycling rates
- Lack of intellectual knowledge and operational expertise in the west

**Table 12.** Time required to obtain permits, construct, and commission recently opened metal mines in the United States.

[NYA, not yet achieved, production not yet begun or commercial operations not achieved; PGE, platinum group elements. Yes, long permitting and development delays because of litigation by government agencies and nongovernmental organizations]

| Mine | | Commodity | Permitting began | Permitting completed | Production began | Commercial operations began | Litigation reported |
|---|---|---|---|---|---|---|---|
| Alta Mesa, | Texas | U | 1999 | 2004 | 10/2005 | 1/2006 | |
| Arizona 1, | Arizona | U | mid-2007 | 2009 | NYA | NYA | Yes. |
| Ashdown, | Nevada | Mo Au | 2/2004 | 11/2006 | 12/2006 | NYA | |
| Buckhorn, | Washington | Au | 1992 | 9/2006 | 10/2008 | 11/2008 | Yes. |
| Carlota, | Arizona | Cu | 2/1992 | 6/2007 | 12/2008 | 1/2009 | Yes. |
| Eagle, | Michigan | Ni Cu Co PGE | 4/2004 | 1/2010 | NYA | NYA | Yes. |
| East Boulder, | Montana | PGE | 1995 | 1998 | 6/2001 | 1/2002 | |
| Kensington, | Alaska | Au | 3/1988 | 6/2005 | 9/2010 | NYA | Yes. |
| Leeville, | Nevada | Au | 7/1997 | 8/2002 | 10/2006 | 4th quarter 2006 | |
| Lisbon Valley, | Utah | Cu | 2/1996 | 7/2004 | 1st quarter 2006 | NYA | Yes. |
| Pend Oreille, | Washington | Zn | 1992 | 9/2000 | 1/2004 | 8/2004 | |
| Phoenix, | Nevada | Au | 1/1999 | 1/2004 | 10/2006 | 4th quarter 2006 | |
| Pogo, | Alaska | Au | 12/1997 | 4/2004 | 2/2006 | 4/2007 | |
| Rock Creek, | Alaska | Au | 2003 | 8/2006 | 9/2008 | NYA | Yes. |
| Rossi (Storm), | Nevada | Au | 1990 | 3Q/2006 | 3/2007 | 12/2007 | |
| Safford, | Arizona | Cu | 4/1998 | 7/2006 | 4th quarter 2007 | 2nd half 2008 | Yes. |
| Turquoise Ridge, | Nevada | Au | 9/1995 | 5/2003 | 2004 | NYA | |

(Long et al., 2010)

# ADDITIONAL CHALLENGES

- How much REE do we need?
- Are there enough REE in the pipeline to meet the demand for these technologies and other uses?
- Can REE be recycled?
- Are there substitutions that can be used?
- What are the reclamation challenges?
  - REE are nearly always associated with U and Th and the wastes from mining REE will have to accommodate radioactivity and radon

# ADDITIONAL CHALLENGES

- Will there be enough scientists engineers to develop the mine?
- Substitutions

# CONCLUSIONS

- REE are important for green technologies as well as our entire lifestyle and new uses will be found because of their unique properties
- REE are found in specific locations based on favorable geology and there is sufficient supply for the near future
- Need for understanding the mineralogy and distribution of these minerals in known ore deposits