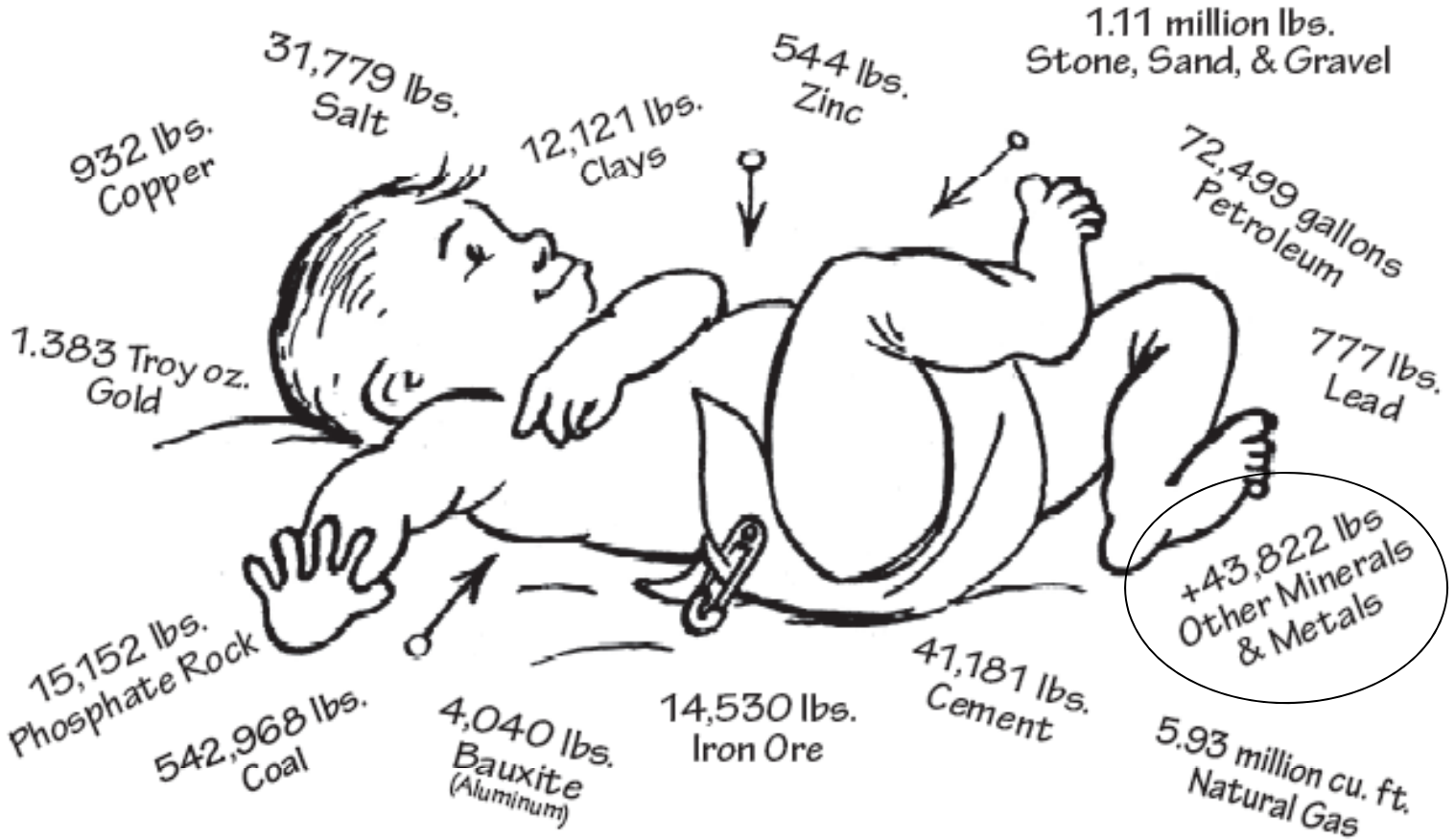
RARE EARTH ELEMENTS (REE) DEPOSITS IN NEW MEXICO

Virginia T. McLemore, New Mexico Bureau of Geology and Mineral Resources, New Mexico Institute of Mining and Technology, Socorro, NM 87801 ginger@gis.nmt.edu

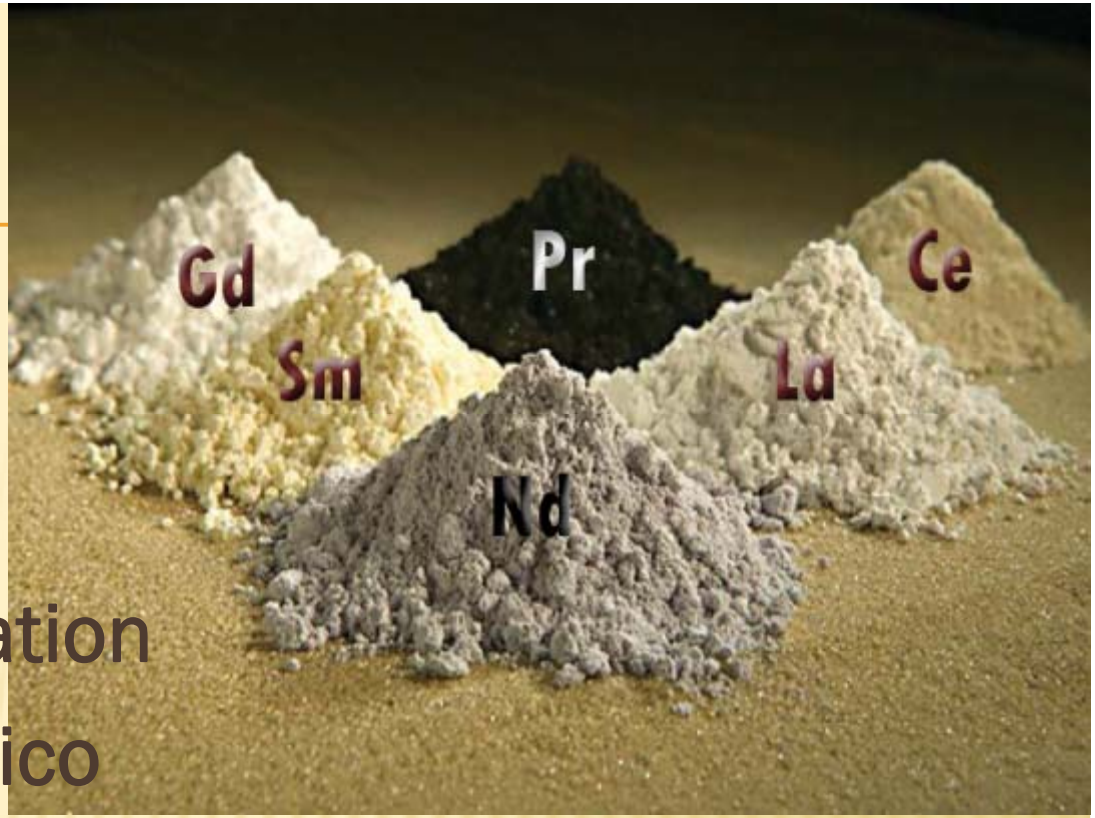
Every American Born Will Need...



2.9 million pounds of minerals, metals, and fuels in their lifetime

Learn more at www.mii.org

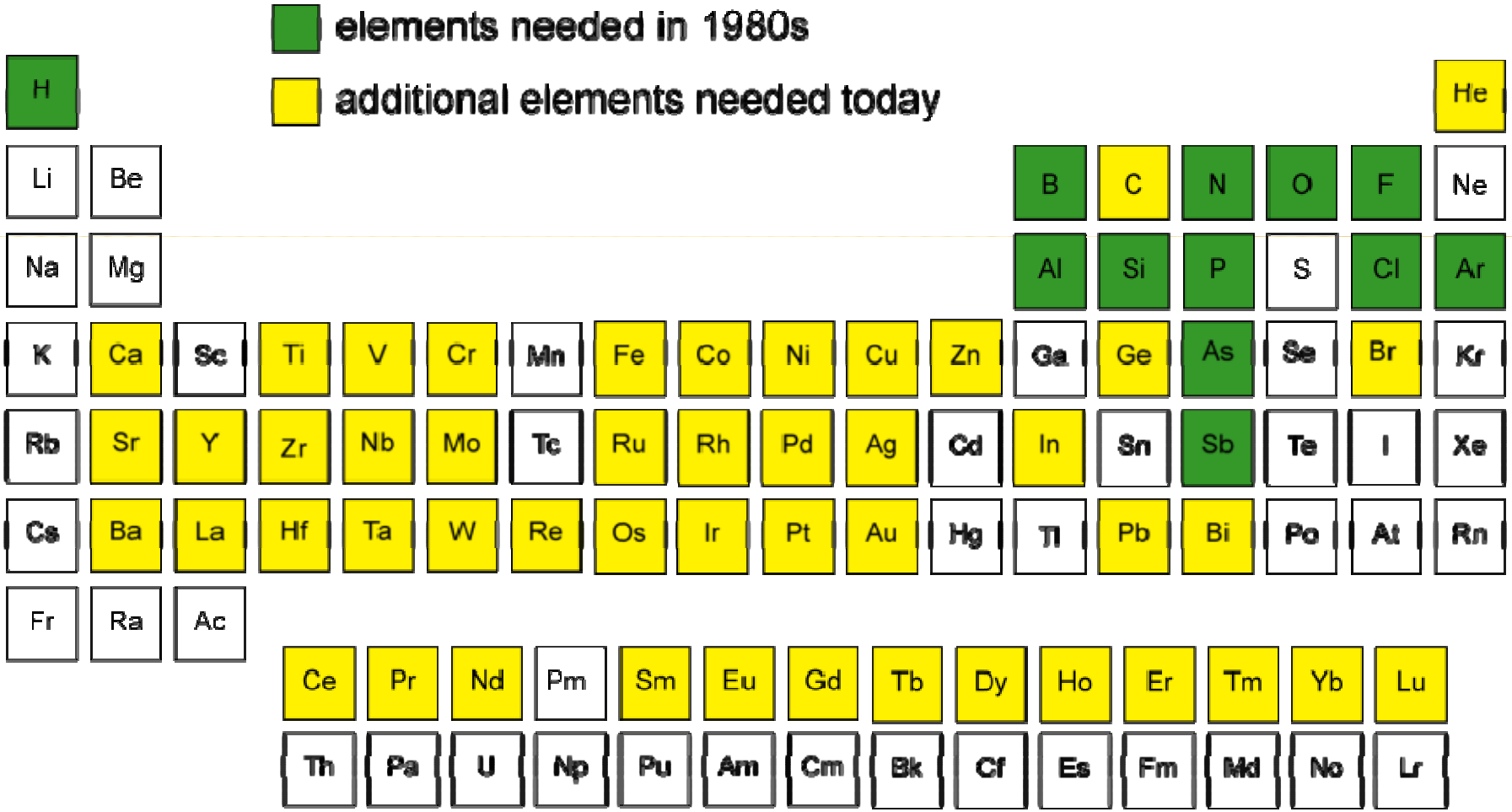
OUTLINE



- Introduction
- Methods
- Mining and Exploration of REE in New Mexico
- Types of REE Deposits in New Mexico
- Potential For New Mexico REE Deposits
- Challenges
- Conclusions

INTRODUCTION

Elements in Computer Chips
(National Research Council, 2007)



REE ORES

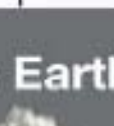
- REE ores contain all rare earth elements except Pm
- There is no shortage of REE ores

  Most rare earths are not rare
- Most ores are rich in Ce, La, Nd and Pr
- The rare earths are chemically very similar
- Producers try to balance supply and demand

  And are *rarely* successful!

Molycorp Minerals — Applications For Rare Earth Elements

Rare Earths



Catalysts

-Petroleum refining
-Chemical processing
-Catalytic converter
-Diesel additives
-Industrial pollution scrubber

Electronics

-Display phosphors (CRT, PDP, LCD)
-Medical imaging phosphors
-Lasers
-Fiber Optics
-Optical temperature sensors

Glass

-Polishing compounds
-Optical glass
-UV resistant glass
-Thermal control mirrors
-Colorizers/ Decolorizers

Ceramics

-Capacitors
-Sensors
-Colorants
-Scintillators

Metal Alloys

-Hydrogen storage (NiMH batteries, Fuel cells)
-Steel
-Lighter flints
-Aluminum/ Magnesium
-Cast iron
-Superalloys

Magnets

-Motors
-Disc drives & disk drive motors
-Power generation
-Actuators
-Microphones & speakers
-MRI

-Anti-lock brake system
-Automotive parts
-Communication systems
-Electric drive & propulsion
-Frictionless bearings
-Magnetic storage disk
-Microwave power tubes
-Magnetic refrigeration
-Magnetostrictive alloys

Other

-Water Treatment
-Fluorescent lighting
-Pigments
-Fertilizer
-Medical Tracers
-Coatings

RARE EARTH ELEMENTS—USES

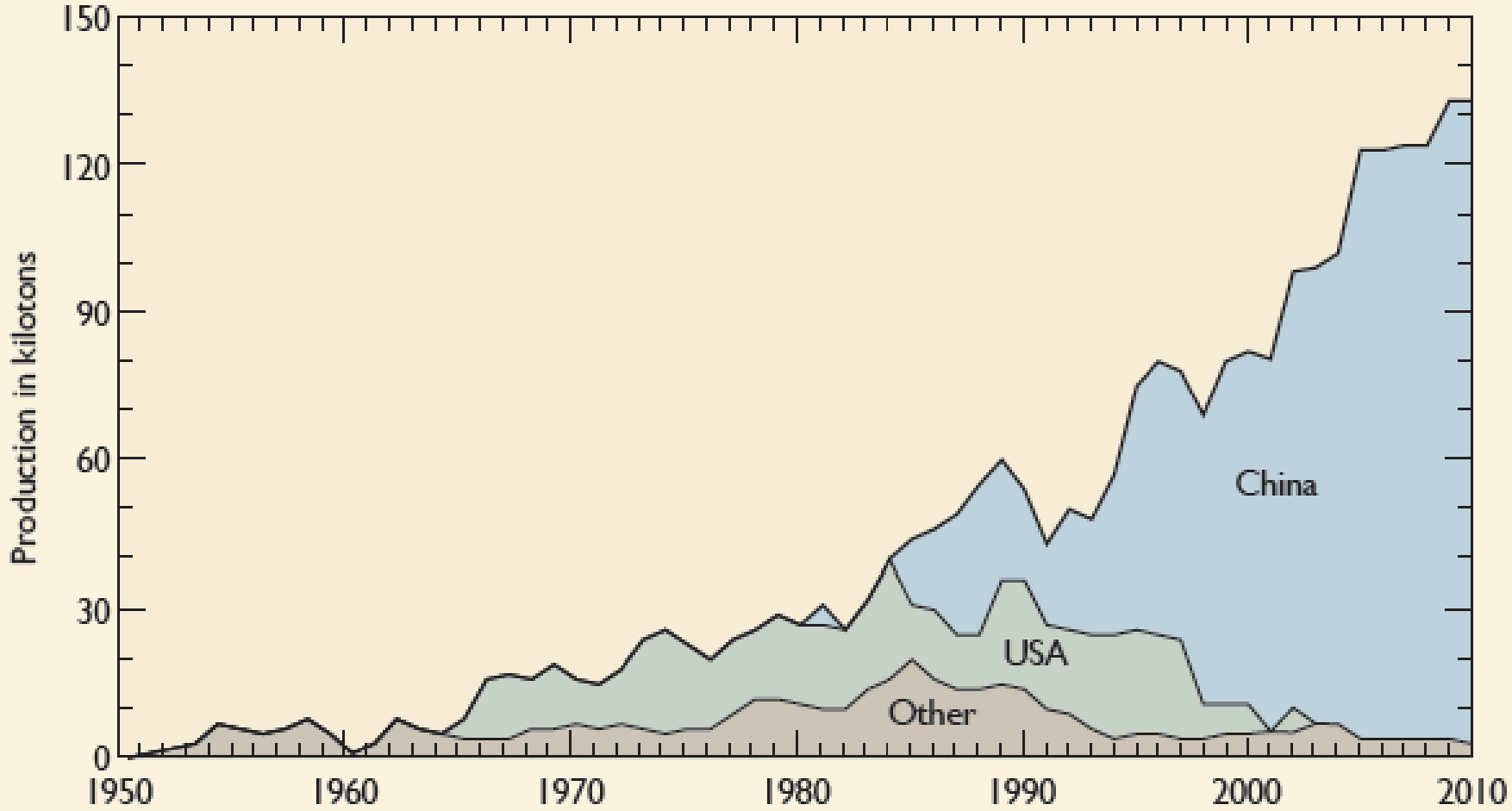
- permanent magnets, 16%
- automotive catalytic converters, 22%
- glass polishing and ceramics, 39%
- petroleum refining catalysts, 12%
- metallurgical additives and alloys, 9%
- rare-earth phosphors for lighting, televisions, computer monitors, radar, and x-ray-intensifying film, 1%
- miscellaneous, 1%
  - NiMH batteries
  - flints for lighters

Toyota Prius

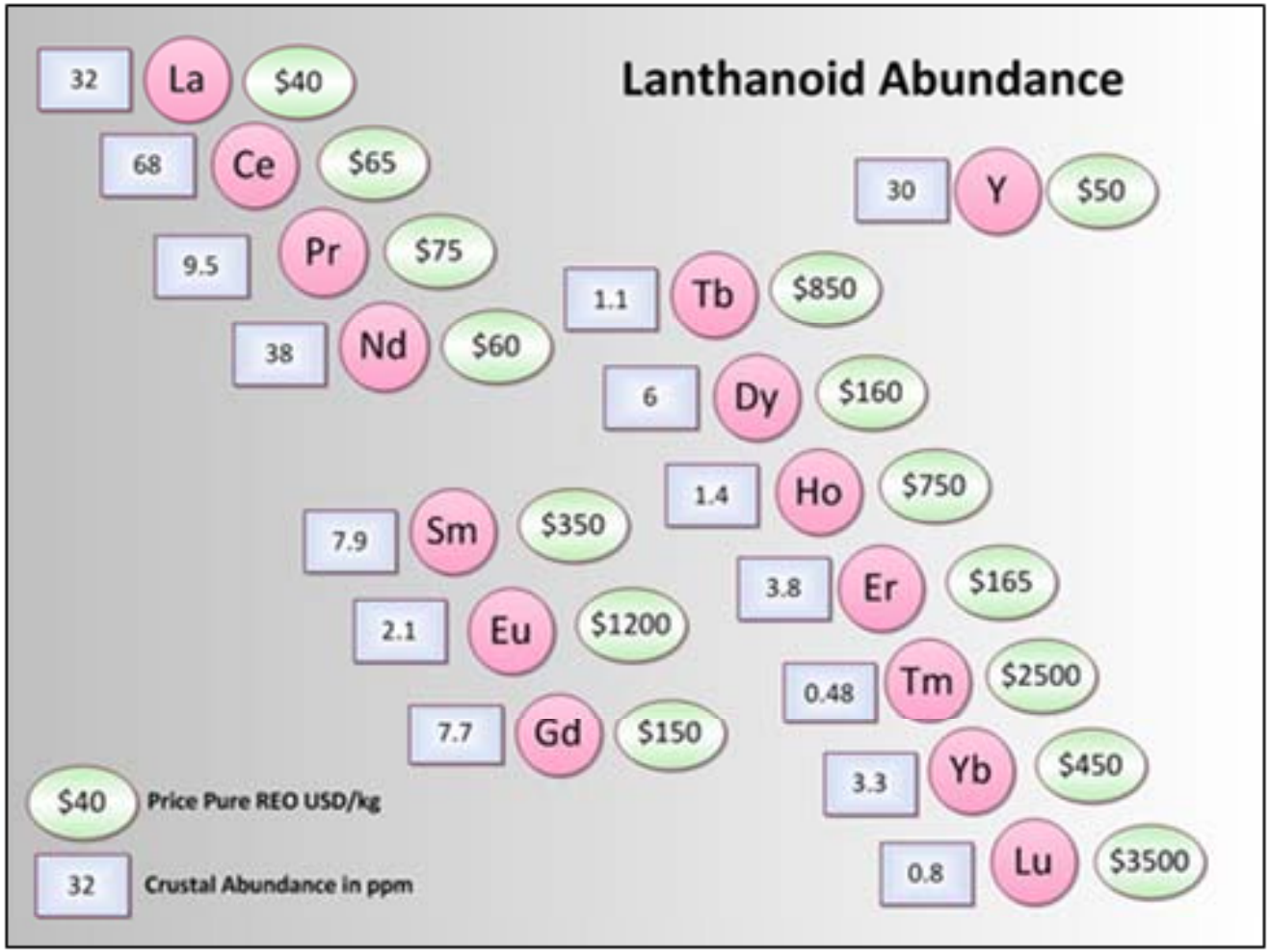
2.2 lbs Nd in magnets

22-33 lbs La in batteries

HTTP://WWW.MOLYCORP.COM/HYBRID_EV.ASP



Global production of rare earth elements, in kilotons, from 1950 through 2010.
Data from the U.S. Geological Survey.



Prices are for pure oxides from a leading rare earth elements chemical producer in 2009. Pm (prometheum) is not shown because it does not occur in nature and is not commercially available.

REO: rare earth oxide.

USD/kg: United States Dollars per kilogram.

USGS
OF2011-1189

Operating REE Mines

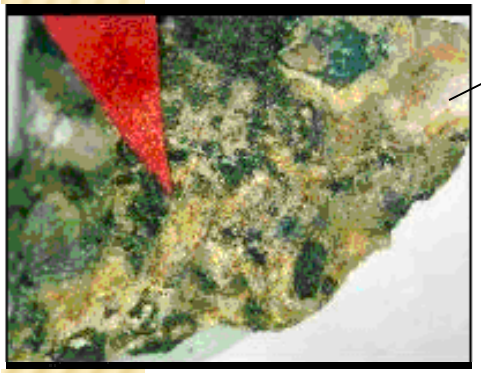
USGS

USGS OF2011-1189

RARE EARTH ELEMENTS—IMPORT SOURCES

- Bastnaesite (Ce, La, Y)CO3F
  - China, California
- Monazite (Ce, La, Th, Nd, Y)PO4
  - Australia, 67%
  - France, 33%
- Rare-earth metals, compounds, etc.
  - China, 74%
  - France, 21%
  - Japan, 3%
  - United Kingdom, 1%

Rare Earth Elements



1 Mountain Pass, USA
2 Pajarito Mountain, USA
3 Gallinas Mountains, USA
4 Iron Hill, USA
5 Bald Mountain, USA
6 Bear Lodge, USA
7 Pea Ridge, USA
8 Green Cove Springs, USA
9 Carolina placers, USA
10 Lemhi Pass, USA
11 Snowbird, USA
12 Rock Canyon Creek, Canada
13 Hoidas Lake, Canada
14 Thor Lake, Canada
15 Elliot Lake, Canada
16 Strange Lake, Canada
17 Ilimaussaq complex, Greenland
18 Araxa, Brazil
19 Barro do Itapirapua, Brazil
20 Lovozero and Khibina complexes, Russia
21 Tamazeight complex, Morocco
22 Bou Naga, Mauritania
23 Nile Delta and Rosetta, Egypt
24 Etaneo, Namibia
25 Okorusu, Namibia
26 Steenkampskraal, South Africa
27 Zandkopsdrift, South Africa
28 Pilnesberg Complex, South Africa
29 Naboomspruit, South Africa
30 Palabora, South Africa
31 Richards Bay, South Africa
32 Kangankunde, Malawi
33 Congolone, Mozambique
34 Karonge, Burundi
35 Chavara, India
36 Amba Dongar, India
37 Orissa, India
38 Perak, Malaysia
39 Maoniuping/Daluxao, China
40 Bayan Obo, China
41 Weishan, China,
42 Xunwu/Longnan, China
43 Dong Pao, Vietnam
44 Emeabba, Australia
45 Jangardup, Australia
46 Mount Weld, Australia
47 Brockman, Australia
48 Nolans Bore, Australia
49 Mary Kathleen, Australia
50 Olympic Dam, Australia
51 WIM 150, Australia
52 Dubbo Zirconia, Australia
53 Fraser Island, Australia

Figure 1 Map showing the global distribution of REE deposits.

Bayan Obo mine,
near Baotou, China
Photo from Google Earth

Mountain Pass, CA
Photo from Molycorp, Inc.

USGS SIR10-5220

Bastnäsite-(Ce), on dolomite, (x 14)
$(Ce,La)(CO_3)F$

HTTP://UN2SG1.UNIGE.CH/ATHENA/...

MONAZITE

HTTP://MINERAL.GALLERIES.COM/M...

- Bastnaesite $CeFCO_3$
- Apatite > 5400 ppm total REE $Ca_5(PO_4)_3(OH,F,Cl)$
- monazite 500,000 ppm total REE $(REE,Th)PO_4$
- manganese nodules 99,000ppm total REE

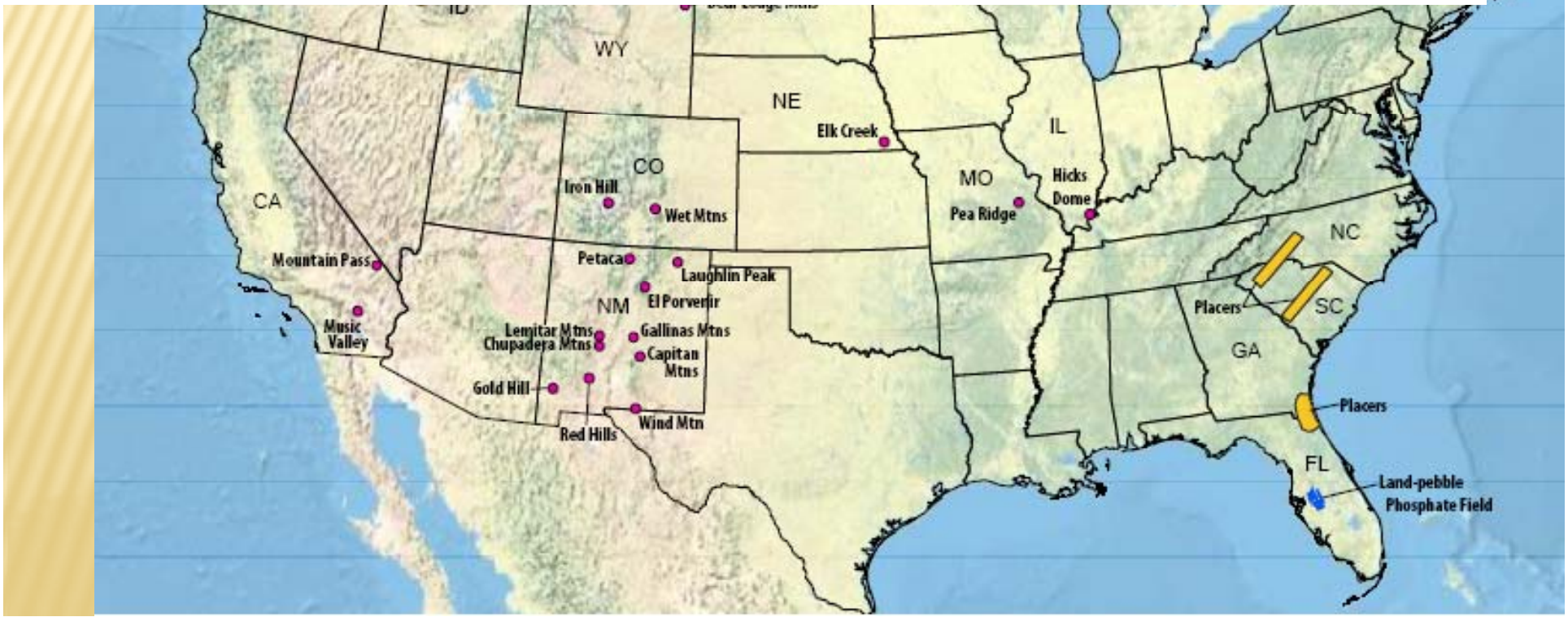
APATITE

HTTP://MINERAL.GALLERIES.COM/M...

Commodity	US production 2009 mt	World production 2009 mt	consumption 2009 mt	Price 2009	World reserves 2009 mt
Cu	1,190,000	15,800,000	1,660,000	$2.3/lb	540,000,000
Au	210	2,350	170	$950/oz	47,000
REO	0	124,000	7,410	varies	99,000,000
Be	120	140	140	$120/lb	15900+
Sb	0	187,000	22,400	$2.3/lb	2,100,000
As	385	52,500	3,600	$0.92/lb	1,070,000
Bi	100	7,300	1,020	$7.4/lb	320,000
Ga	0	78	20	$480/kg	1,000,000
Ge	5	14	5	$950/kg	450+
Te	W		W	$145/kg	22,000
cement	71,800,000	2,800,000,000	73,800,000	$100/mton	

MOUNTAIN PASS CARBONATITE, CALIFORNIA

- 1.3 Mt in reserves with a grade of 7.98%
  - Bastnaesite (light REEs)

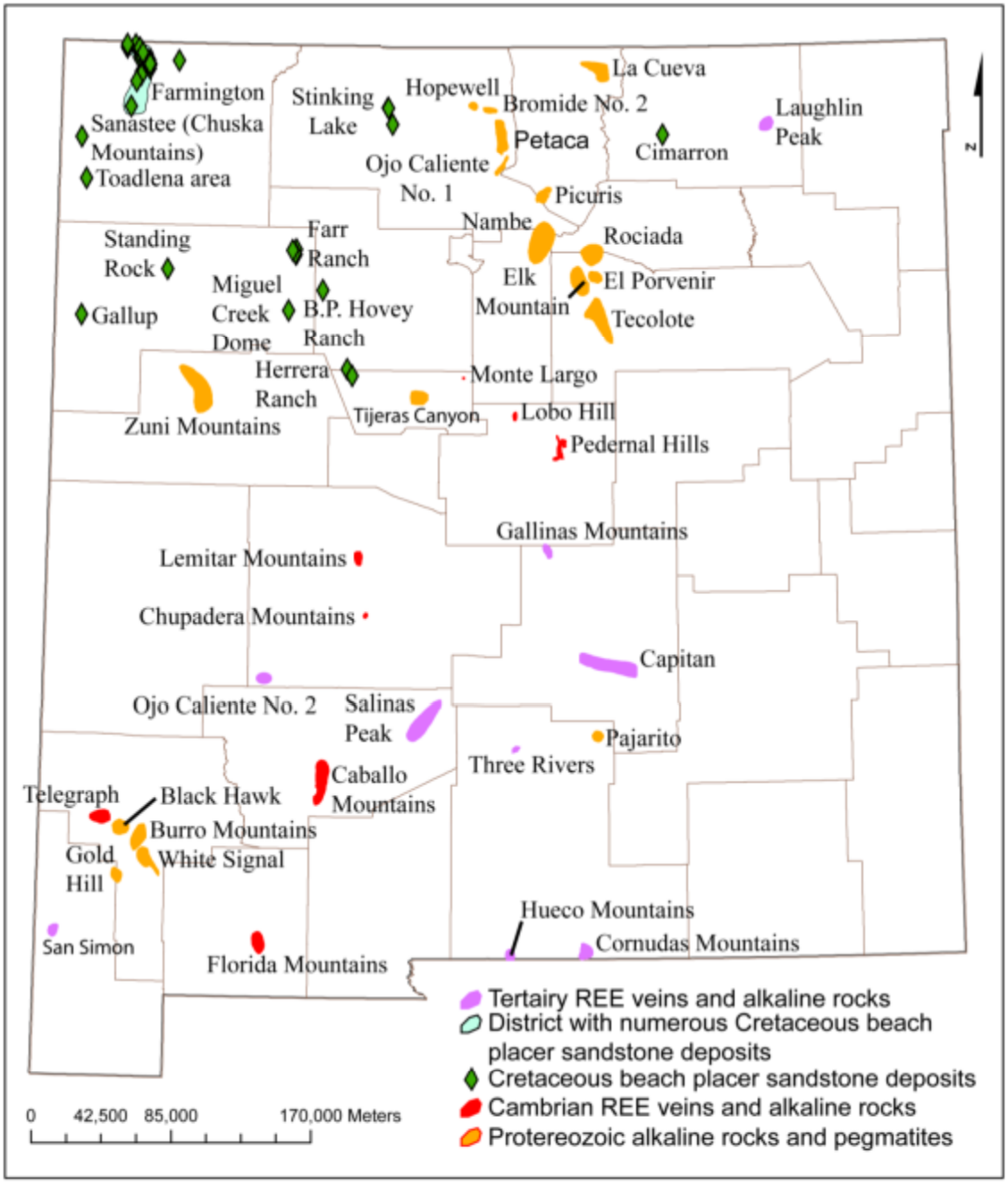


METHODS OF STUDY

METHODS

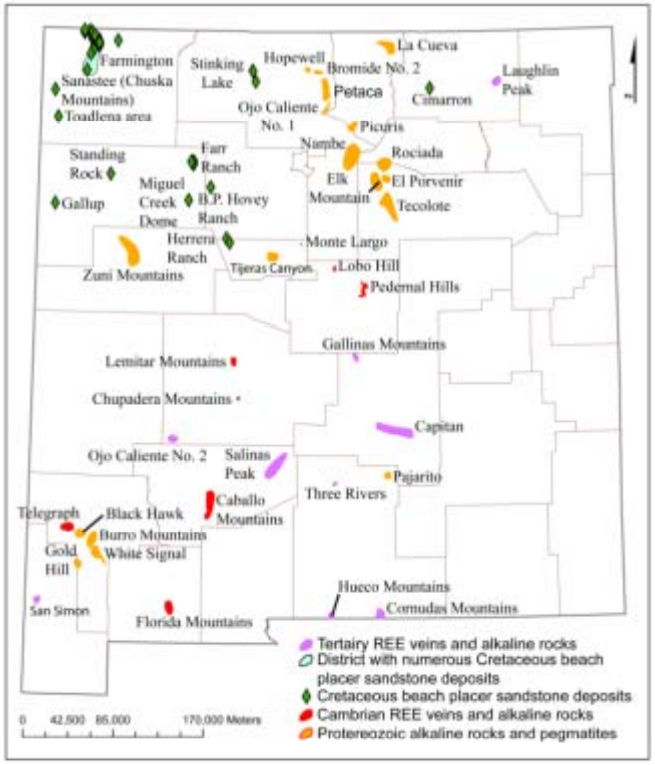
- Published and unpublished data were inventoried and compiled on existing mines and prospects within NM
- Evaluated the NURE data
- Entered data into GIS
- Field examination
- Mineralogy and chemical studies

MINING AND EXPLORATION HISTORY OF REE IN NEW MEXICO



Mining districts and areas in New Mexico that contain REE deposits

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.

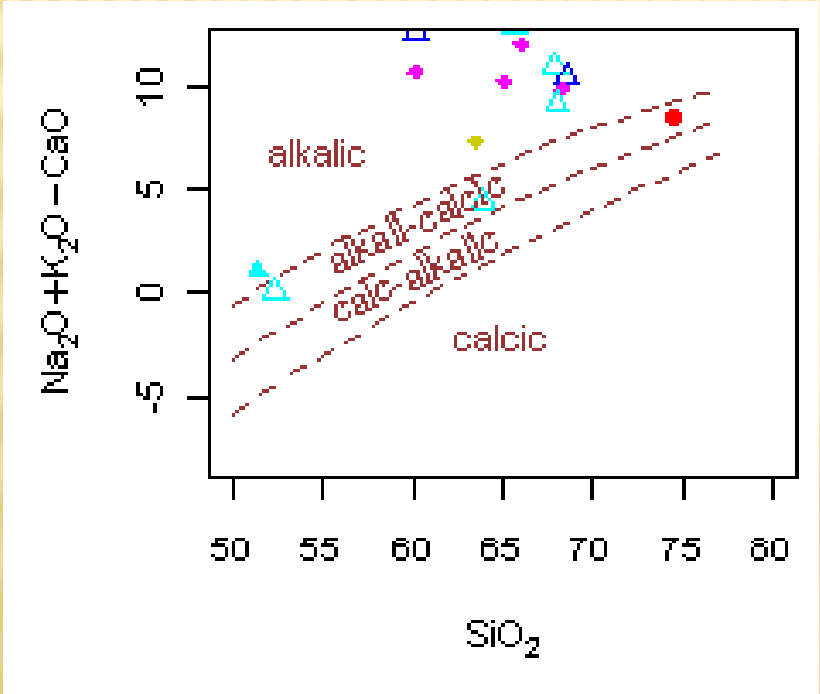
TYPES OF REE DEPOSITS IN NM

TYPES OF REE DEPOSITS IN NM

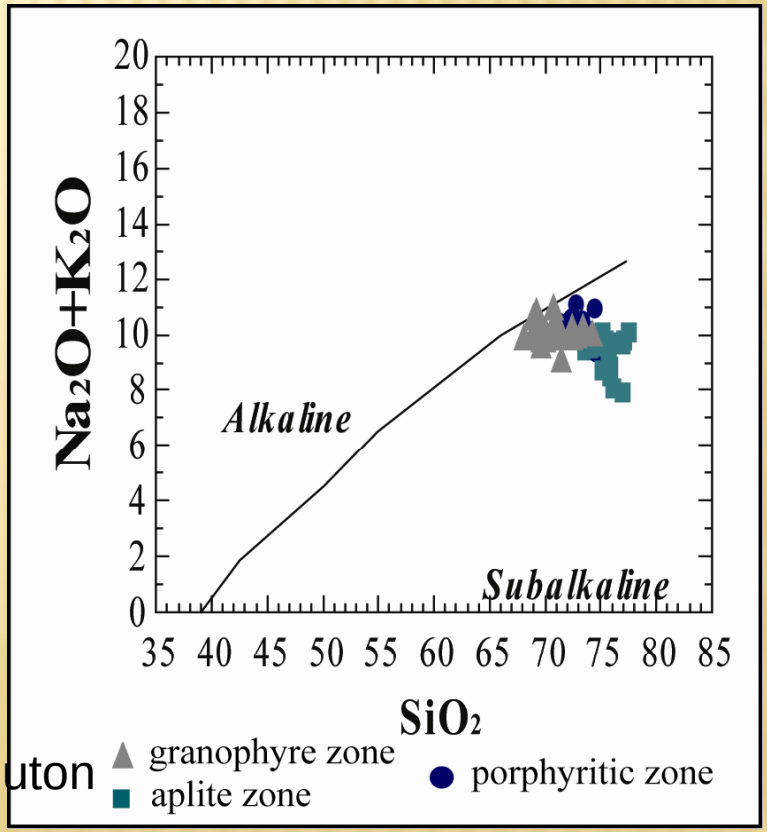
- Alkaline Igneous Rocks
- Carbonatites
- REE-Th-U Hydrothermal Veins
- Pegmatites
- Placer
- Other REE-Bearing Deposits

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



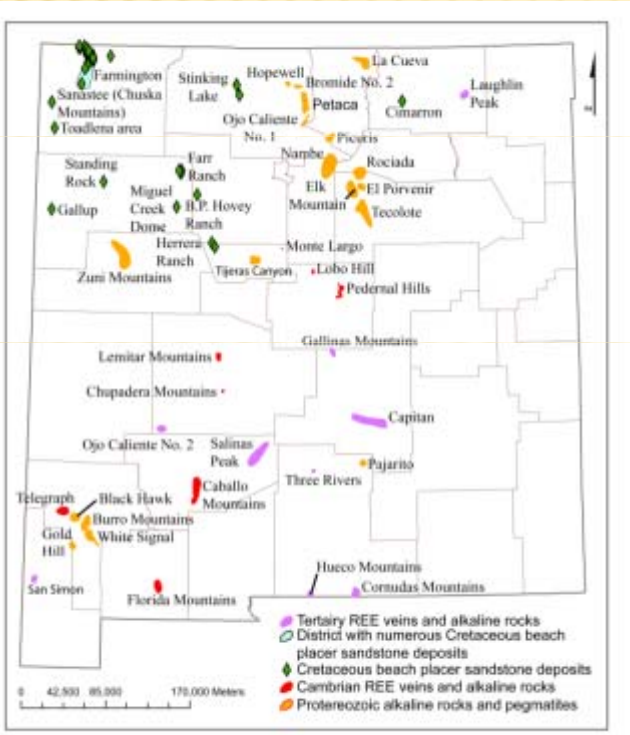
Gallinas Mountains

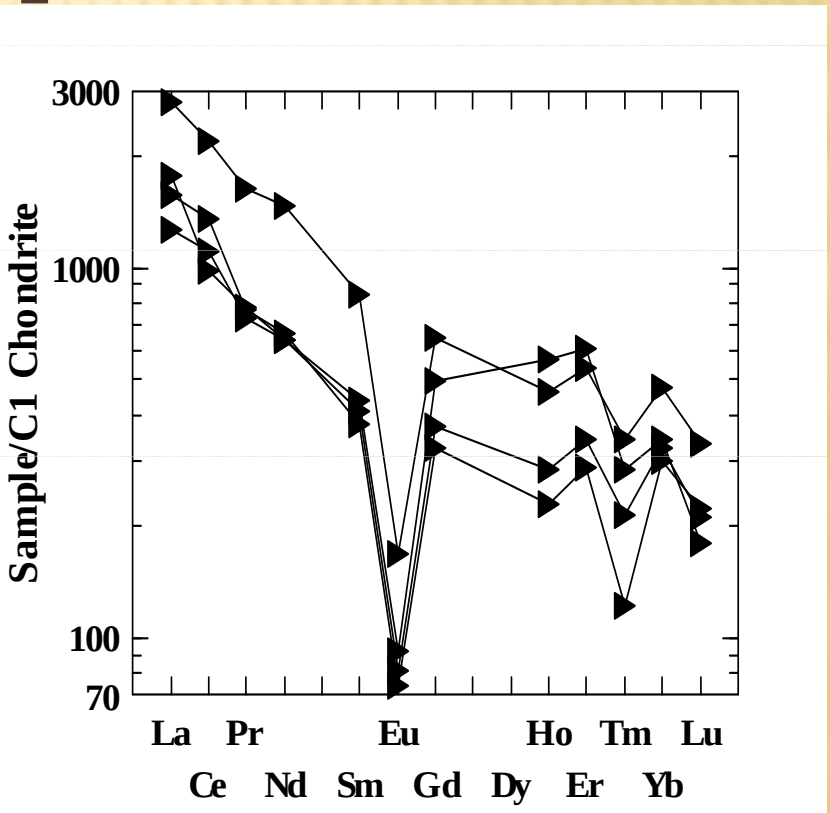


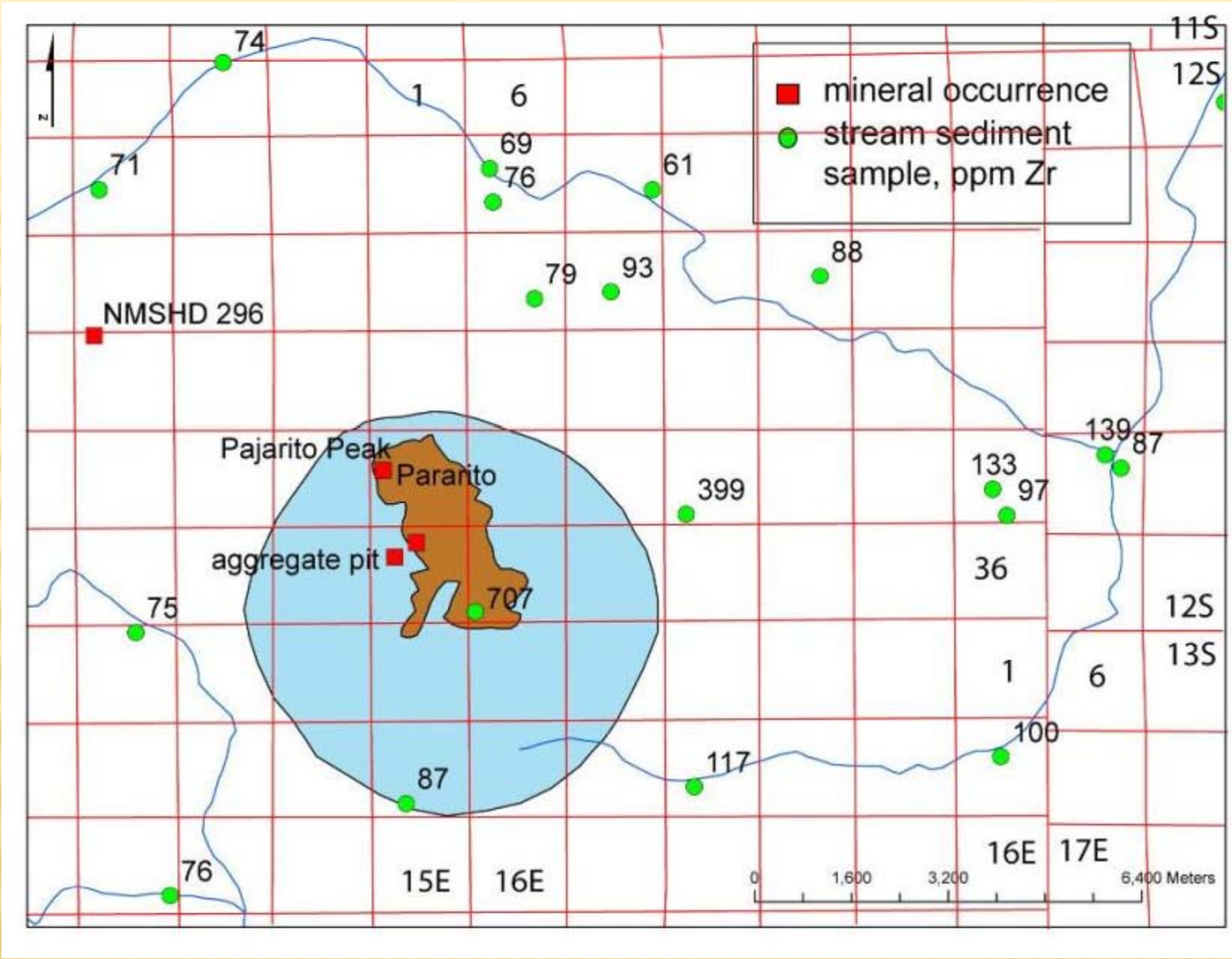
Capitan pluton

PAJARITO MOUNTAIN, MESCALERO APACHE INDIAN RESERVATION NEAR RUIDOSO

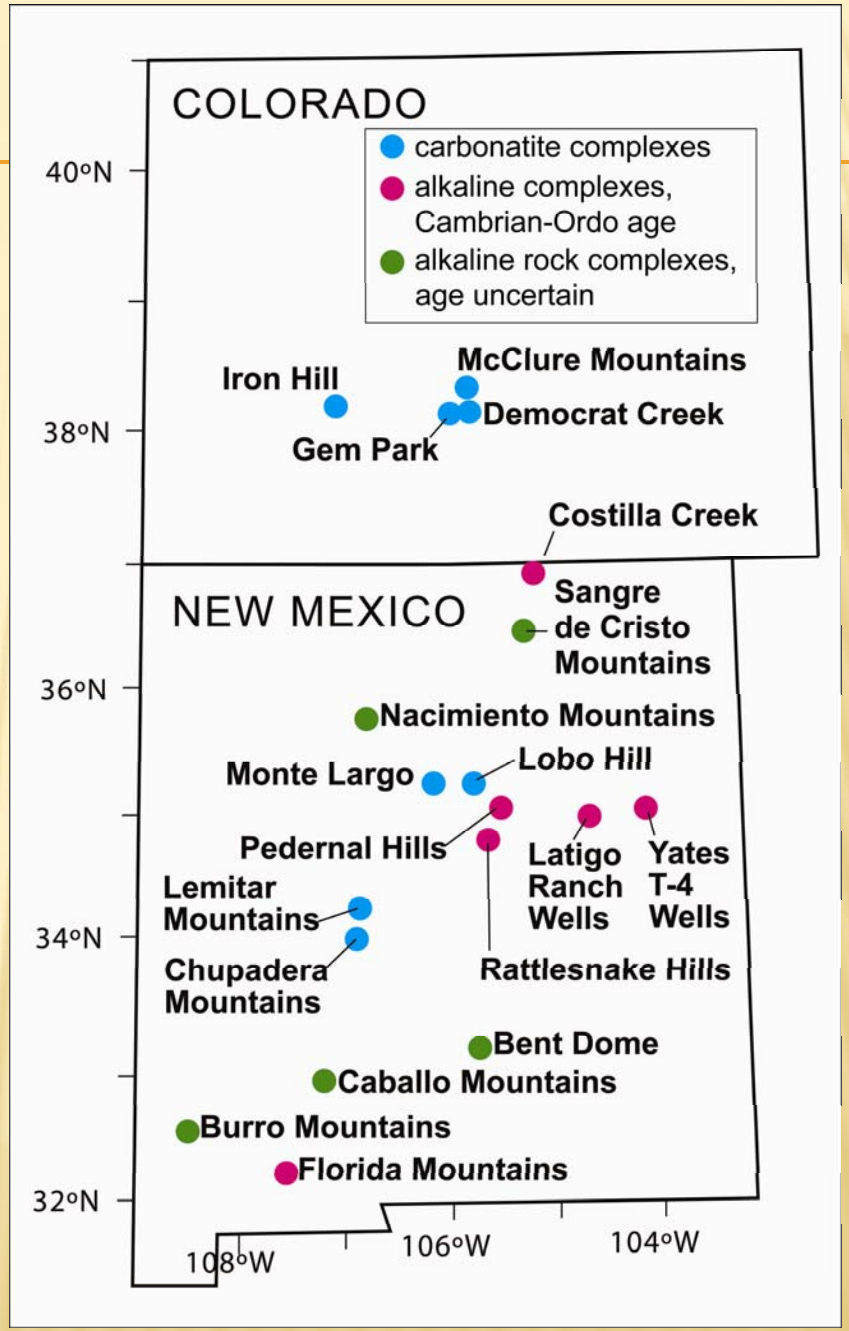
- In 1990, Molycorp, Inc. reported historic resources of 2.7 million short tons grading 0.18% Y_2O_3 and 1.2% ZrO_2 as disseminated eudialyte






mineral occurrence
stream sediment sample, ppm Zr
N
11S
12S
13S
74
71
1
6
69
76
61
79
93
88
NMSHD 296
Pajarito Peak
Parantito
aggregate pit
707
399
139
87
133
97
36
75
1
6
100
117
87
76
15E
16E
16E
17E
0
1,600
3,200
6,400 Meters

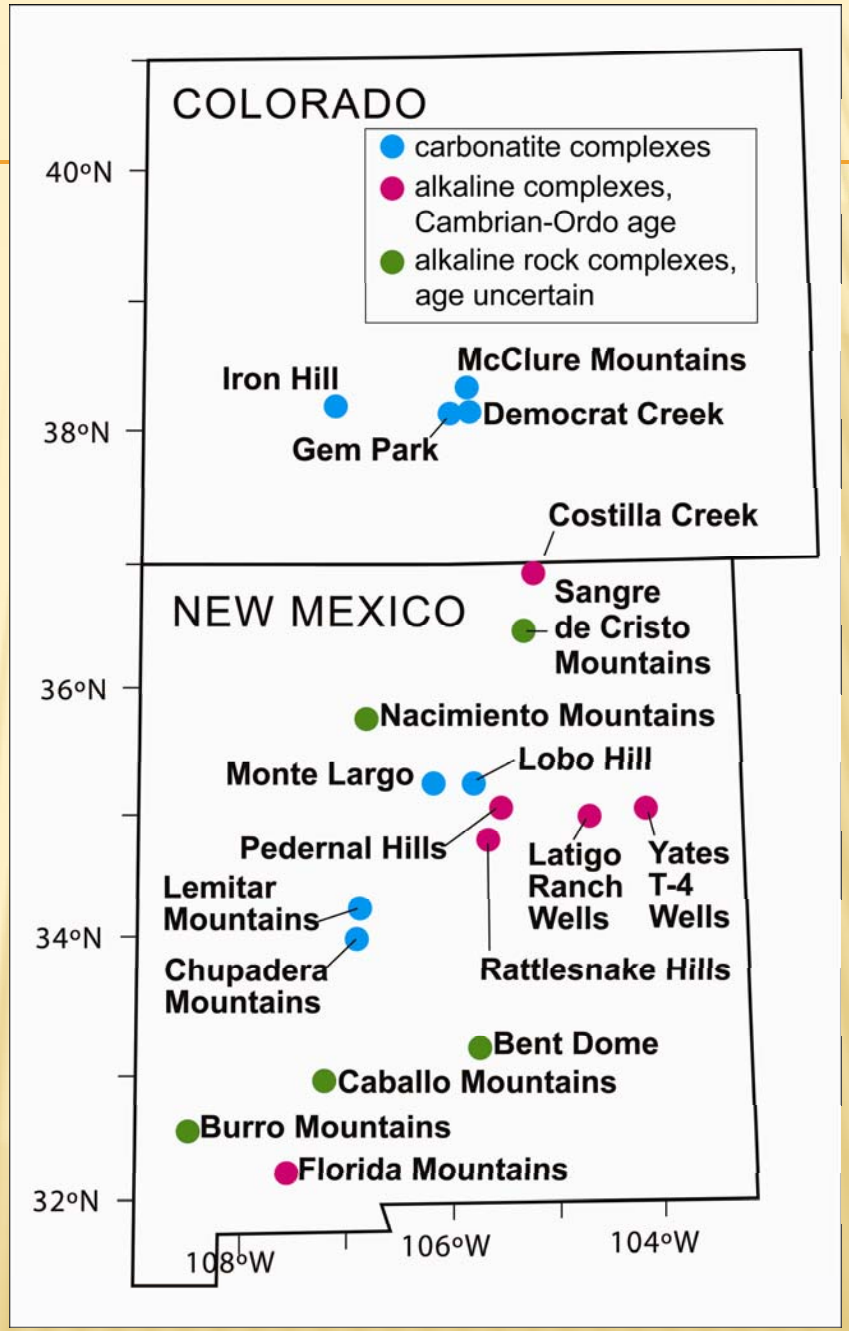
PROTEROZOIC TO CAMBRIAN-ORDOVICIAN SYENITES, ALKALI GRANITES, EPISYENITES

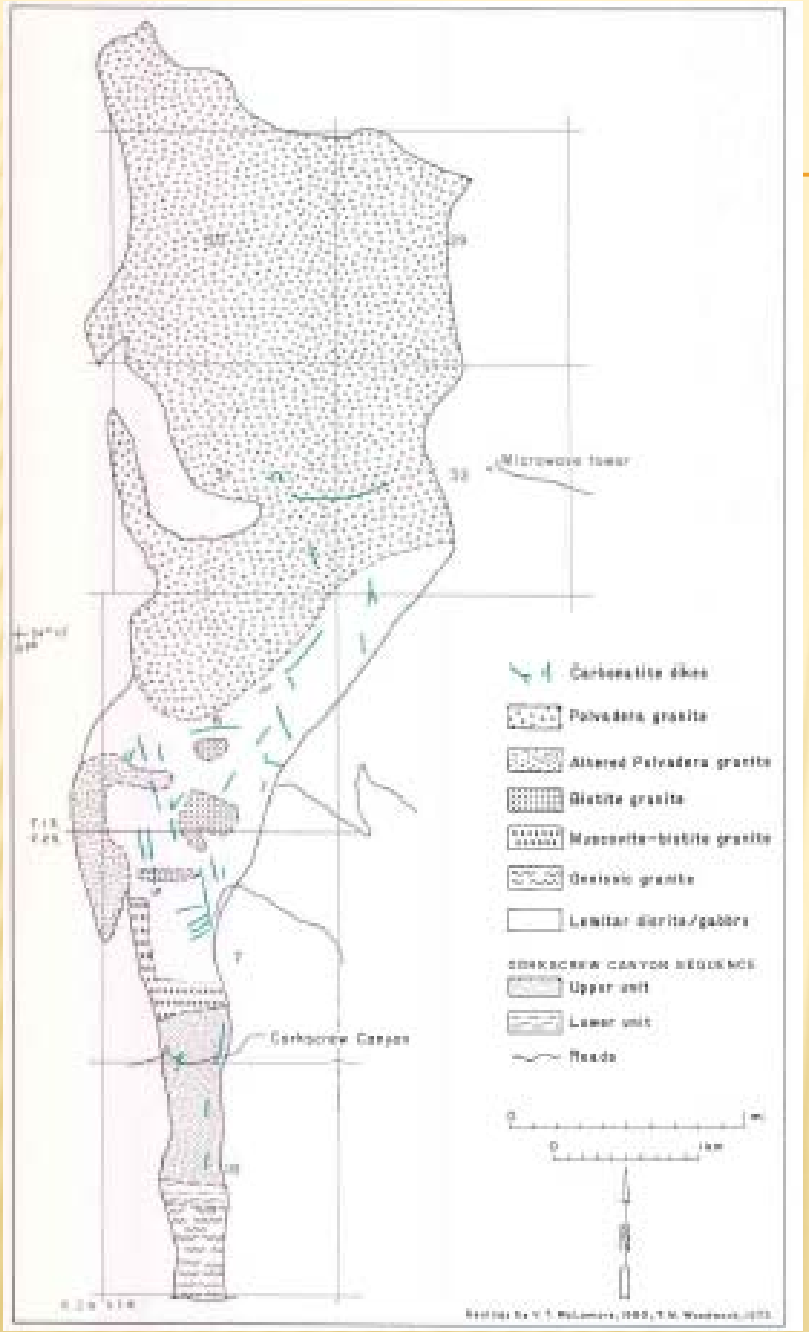


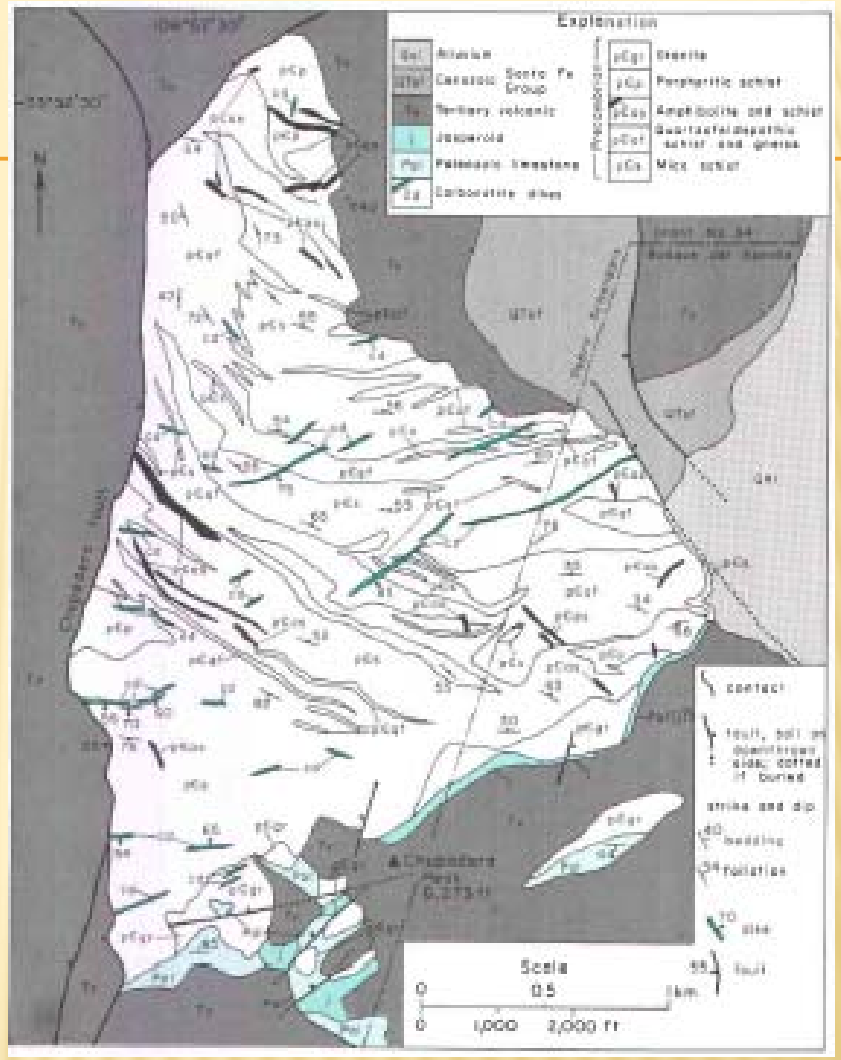
Episyenites in Longbottom Canyon, Caballo Mountains

CARBONATITES

- carbonate-rich rocks containing more than 50% magmatic carbonate minerals, less than 20% SiO_2, are of apparent magmatic derivation

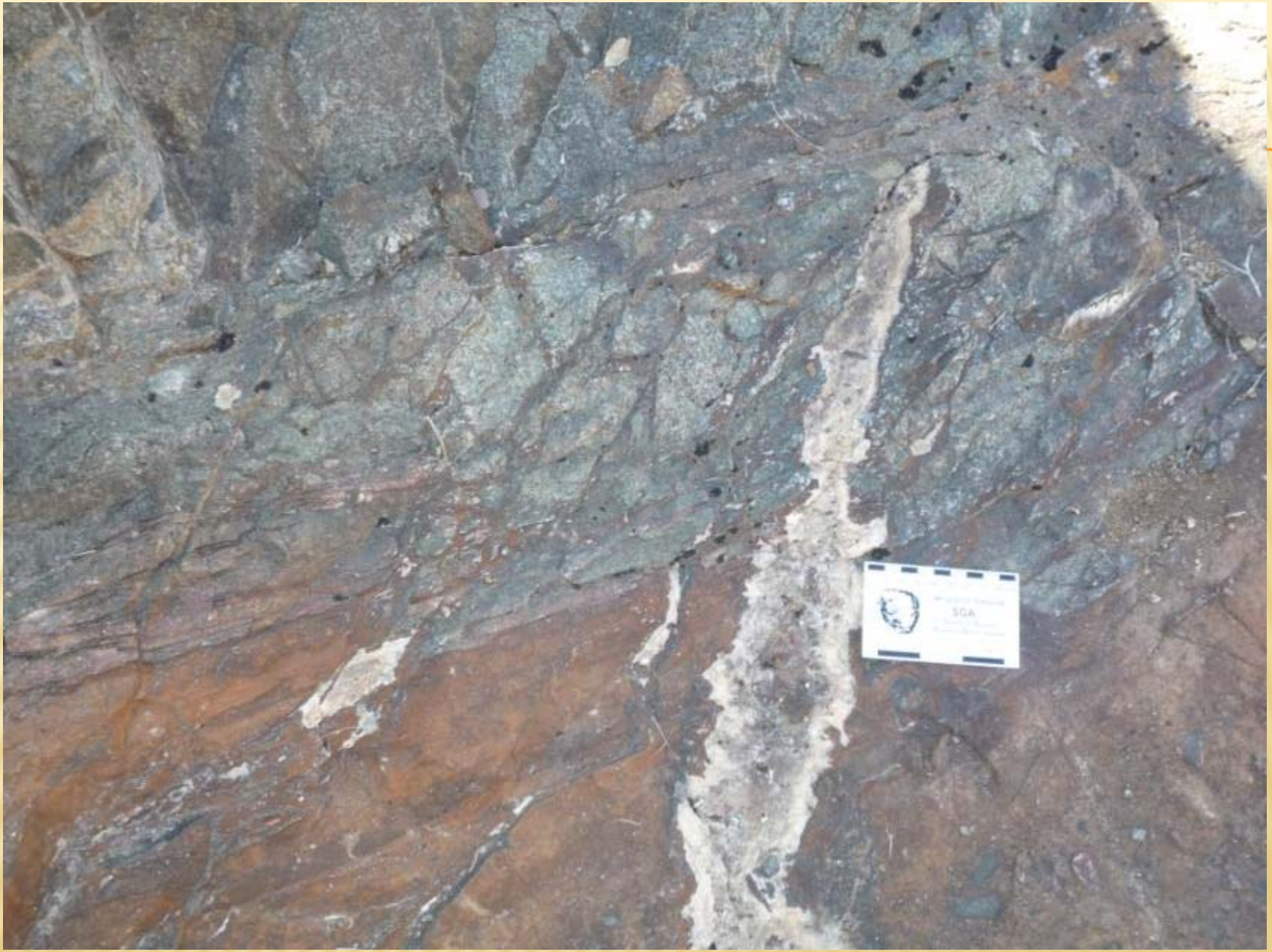




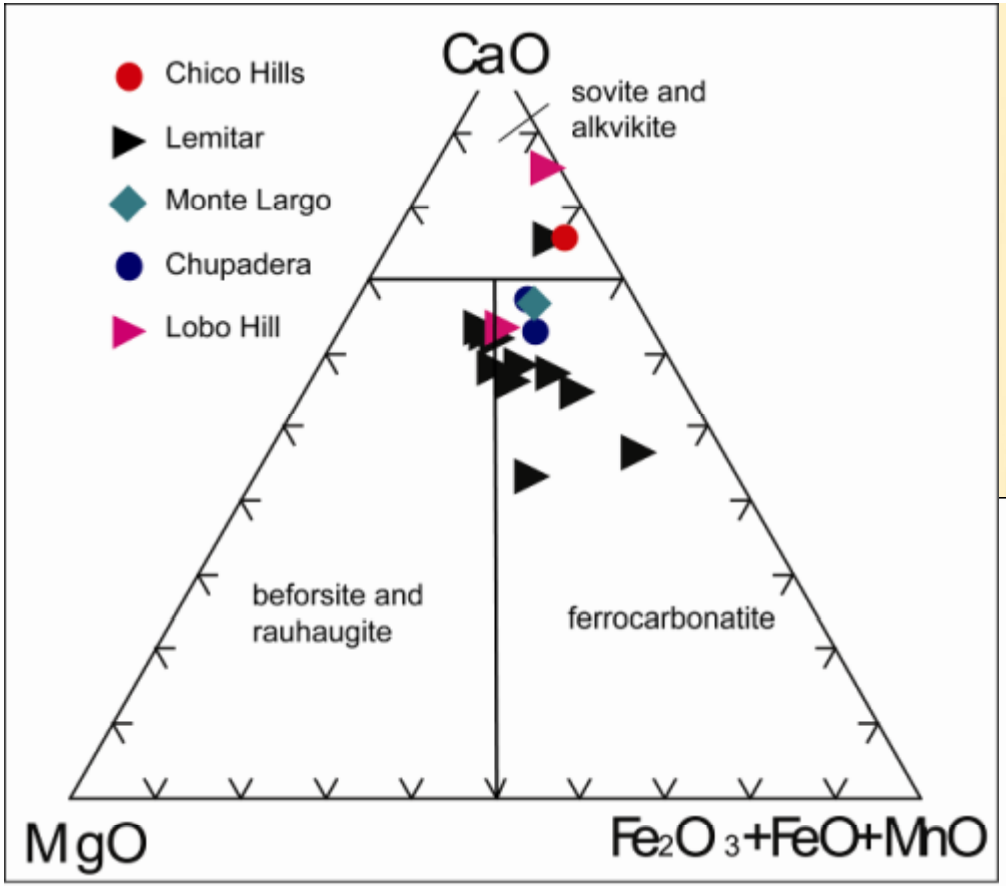


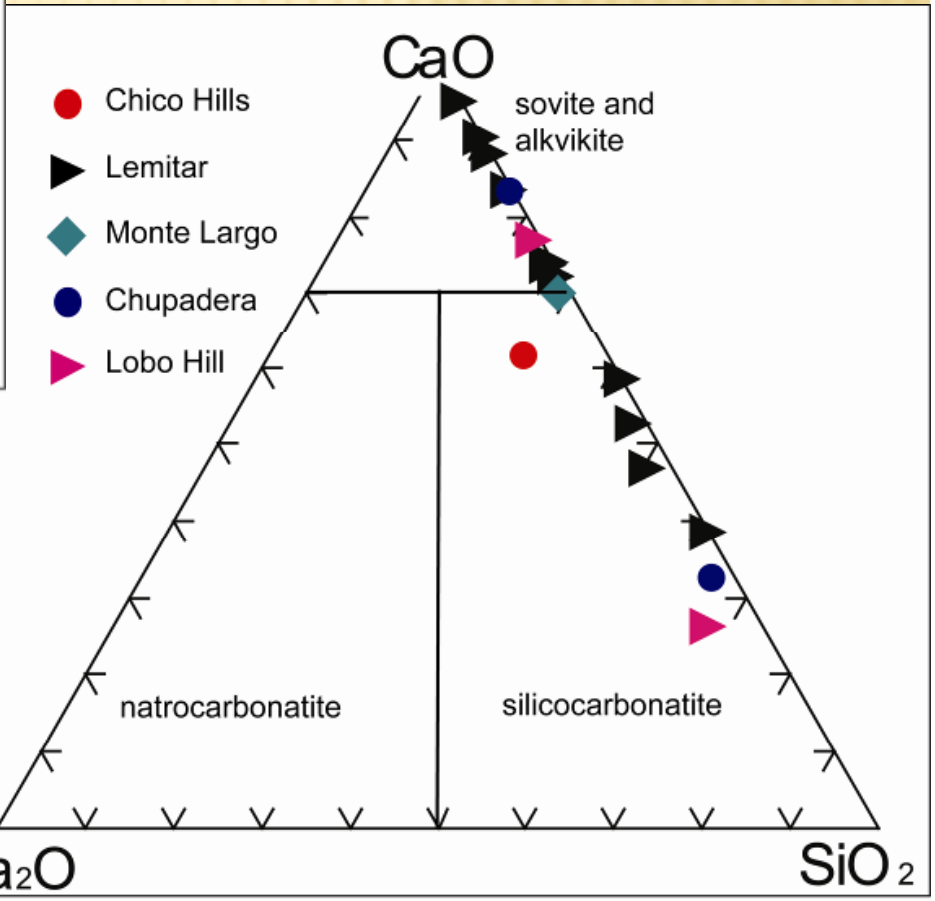
Chupadera carbonatites (van Allen et al., 1986)

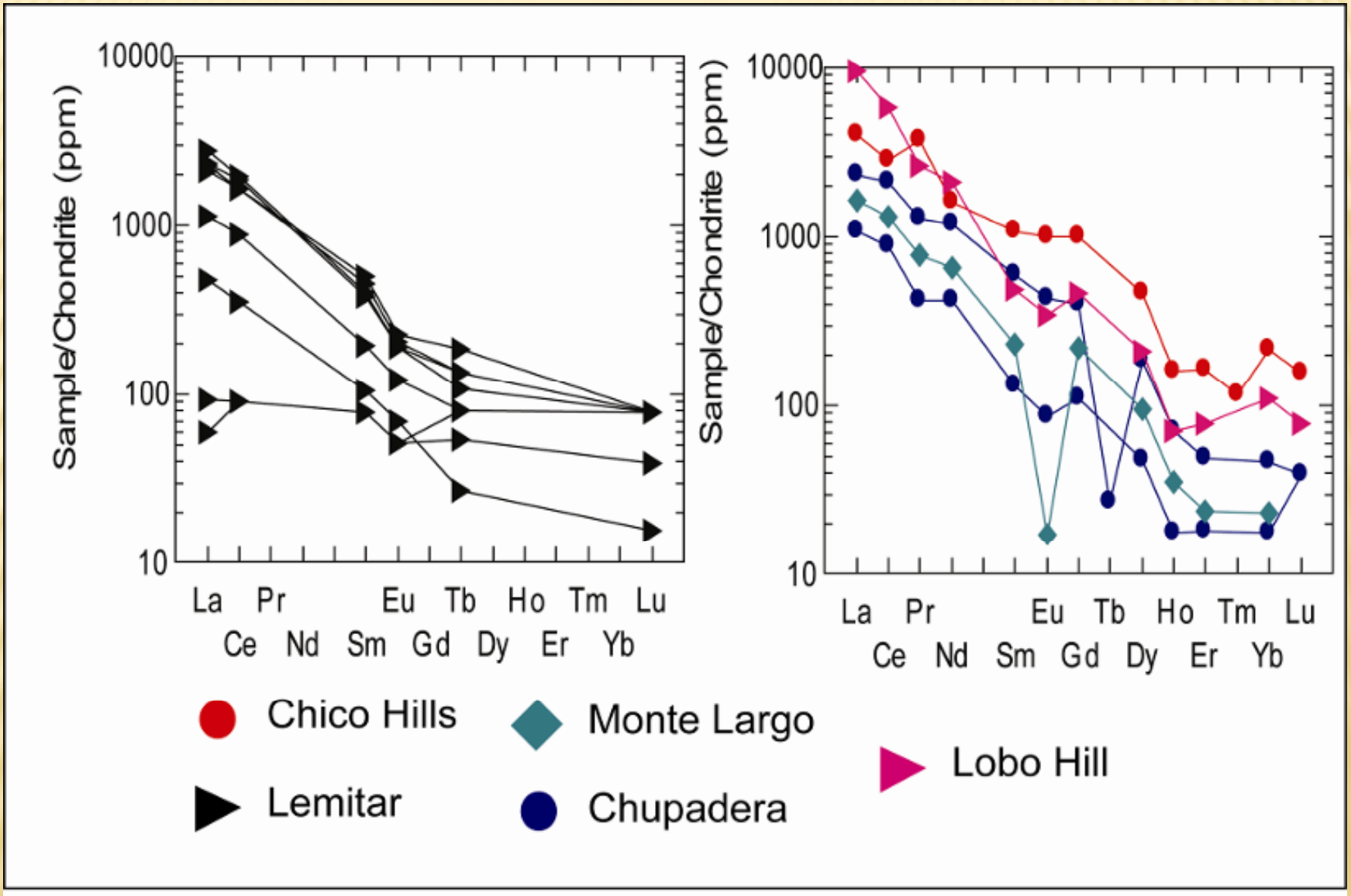
Lemitar carbonatites (McLemore, 1983)



Lemitar carbonatite

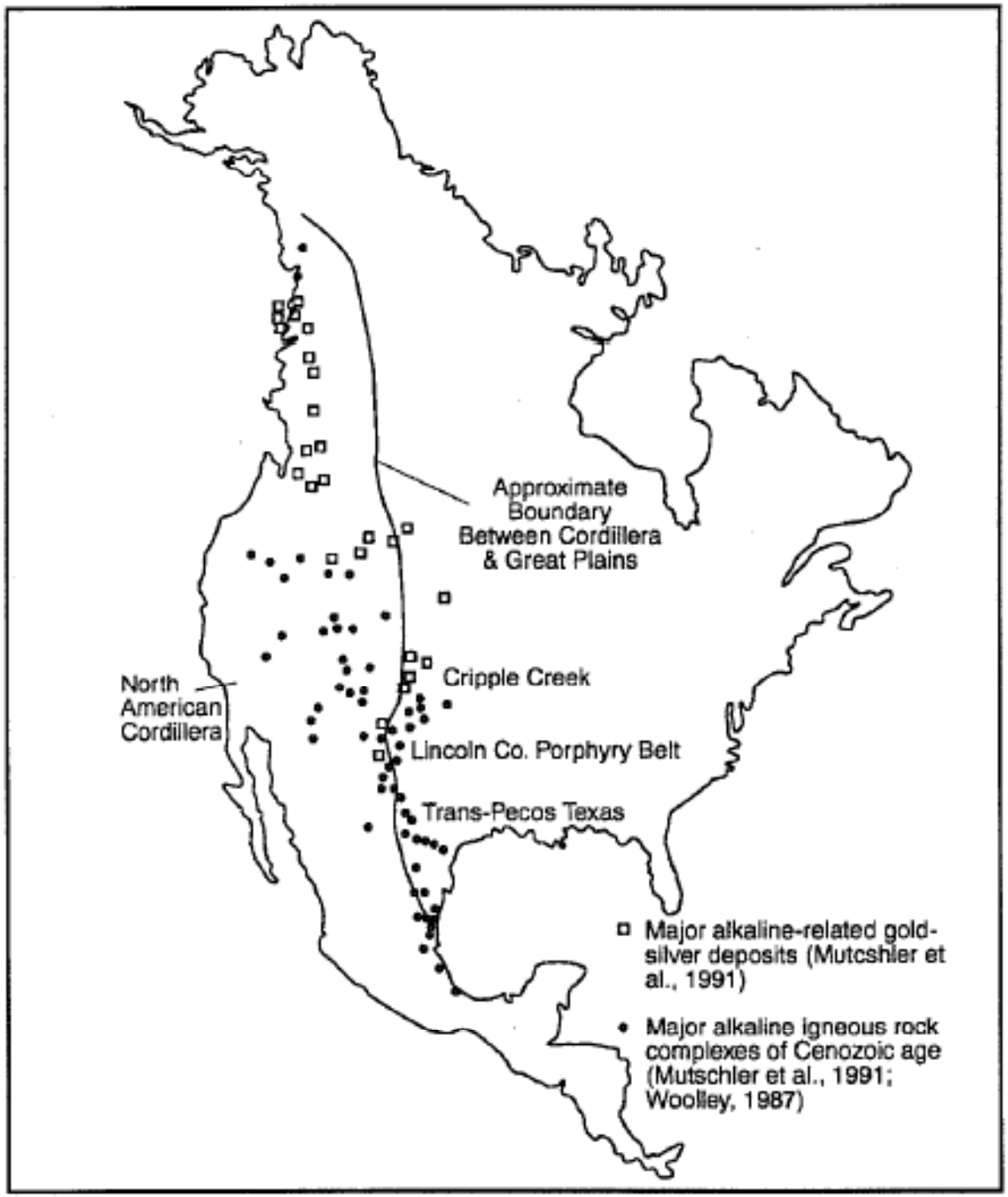

CaO
Chico Hills
Lemitar
Monte Largo
Chupadera
Lobo Hill
sovite and
alkvikite
beforsite and
rauhaugite
ferrocarbonatite
MgO
Fe2O3+FeO+MnO


CaO
Chico Hills
Lemitar
Monte Largo
Chupadera
Lobo Hill
sovite and
alkvikite
natrocarbonatite
silicocarbonatite
Na2O
SiO2

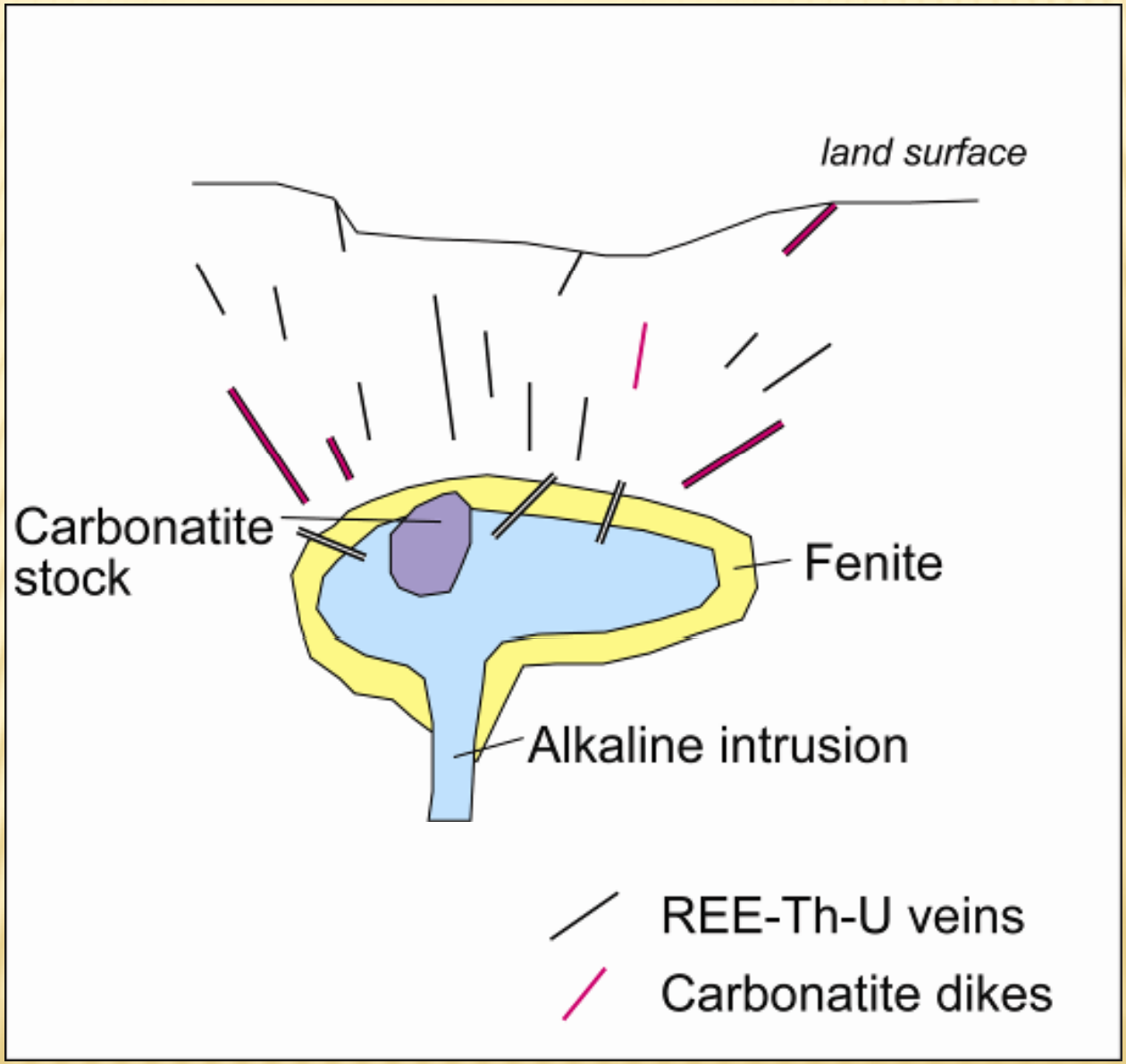

Sample/Chondrite (ppm)
10000
1000
100
10
La Pr Eu Tb Ho Tm Lu
Ce Nd Sm Gd Dy Er Yb
Chico Hills
Monte Largo
Lobo Hill
Lemitar
Chupadera

REE-TH-U HYDROTHERMAL VEINS

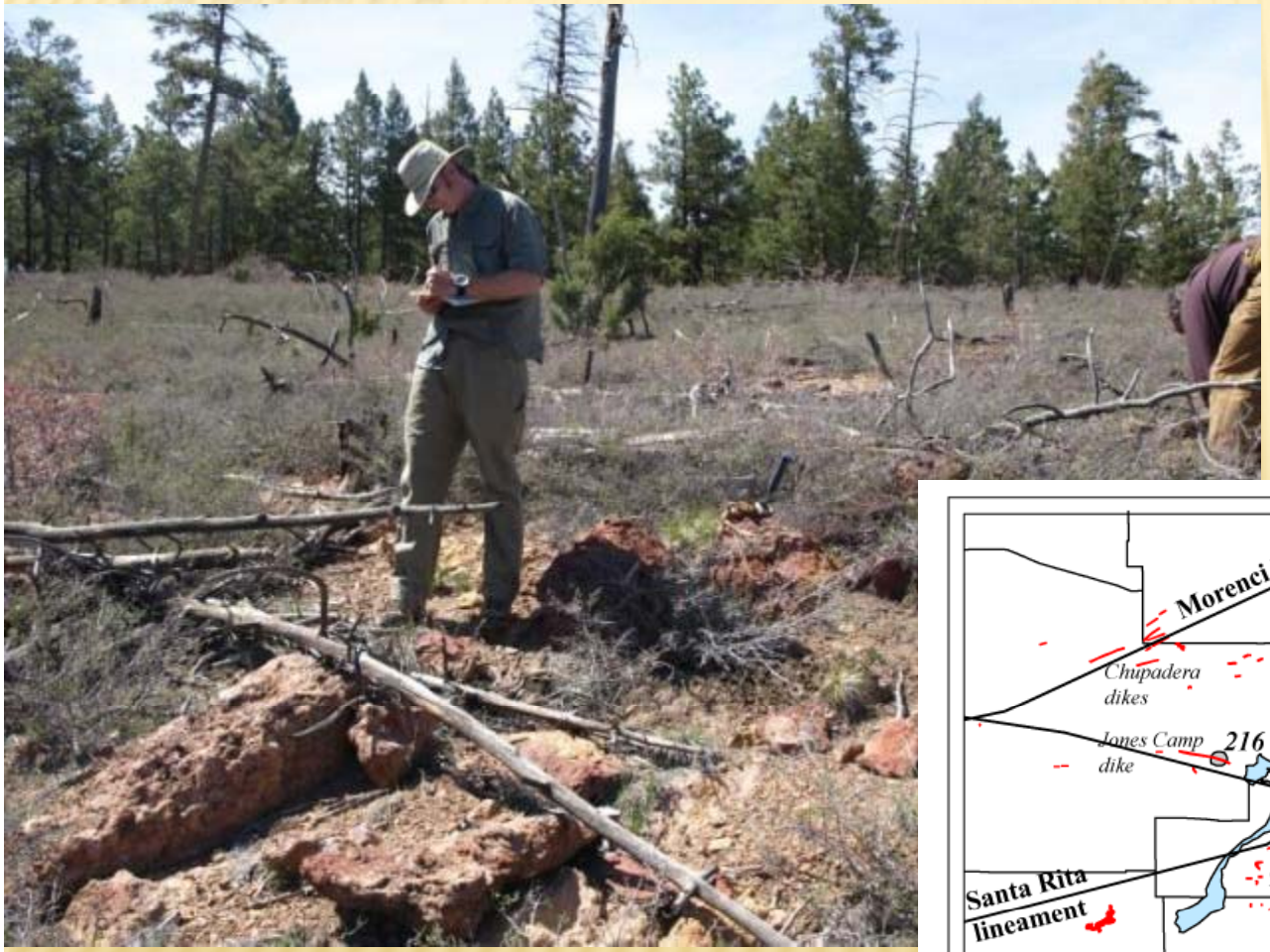
- various Th and REE minerals found in hydrothermal veins and are commonly associated with alkaline igneous rocks and carbonatites
- tabular bodies, narrow lenses, and breccia zones along faults, fractures and shear zones

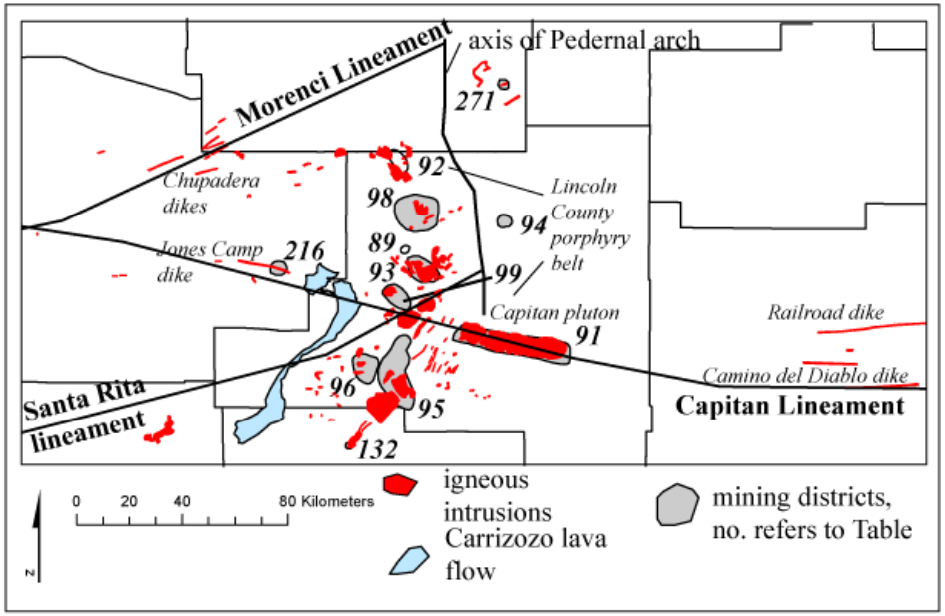


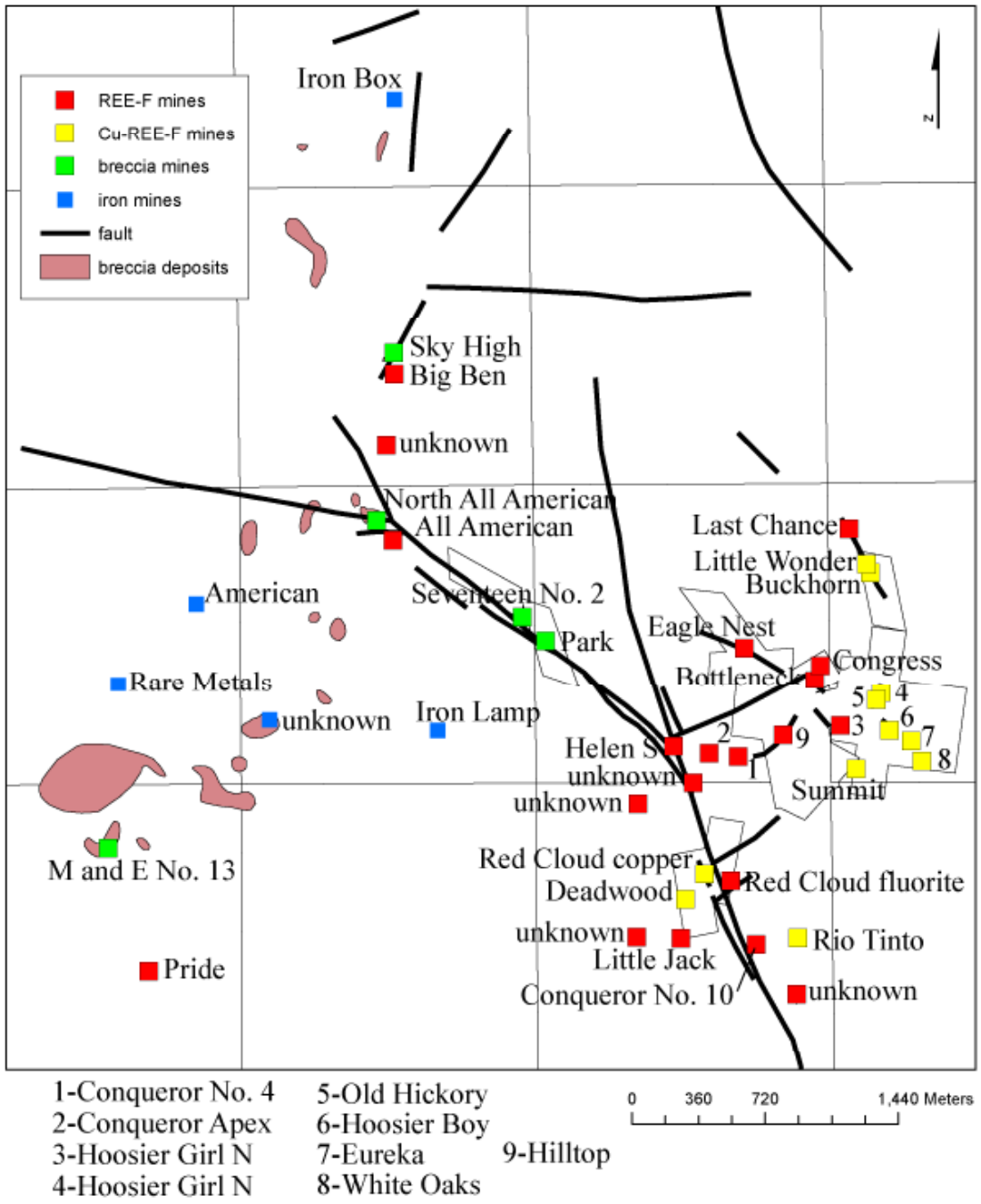
North American Cordilleran Belt of Alkaline Igneous Rocks

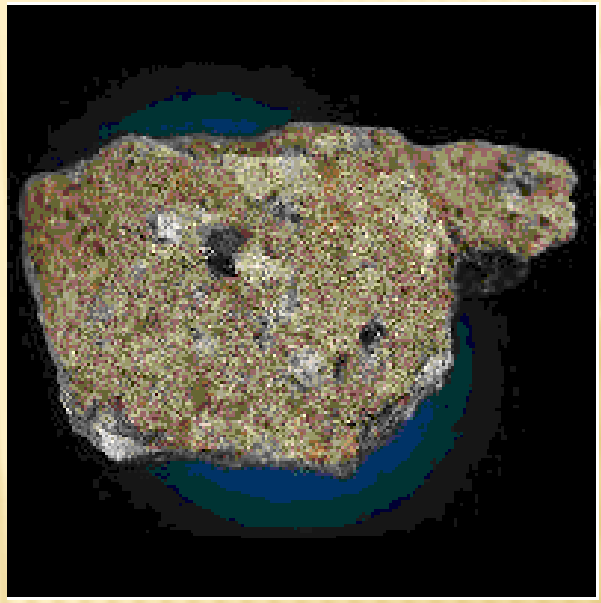

land surface
Carbonatite stock
Fenite
Alkaline intrusion
REE-Th-U veins
Carbonatite dikes

GALLINAS MOUNTAINS, LINCOLN COUNTY

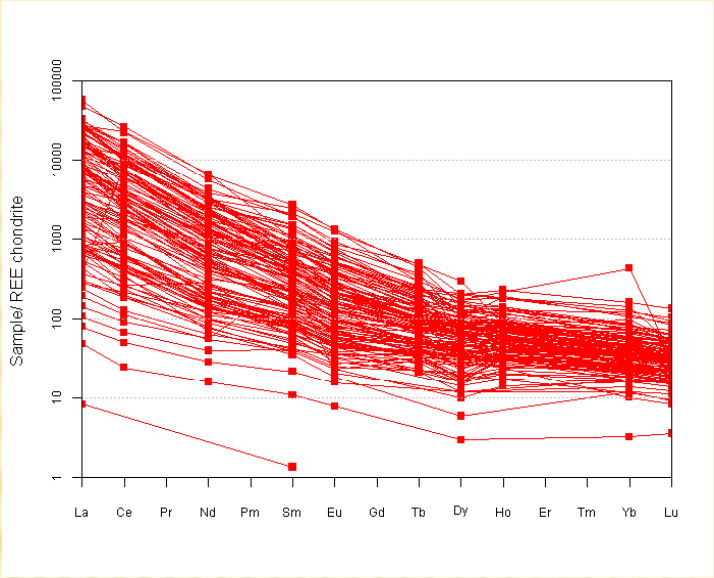




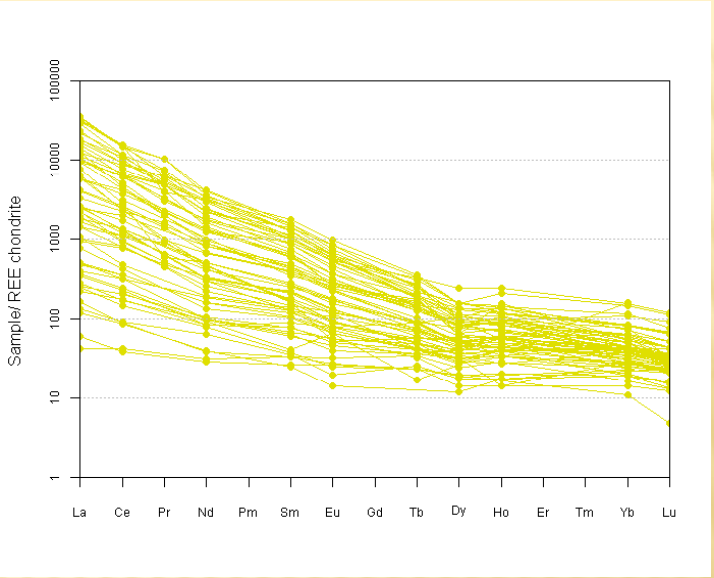




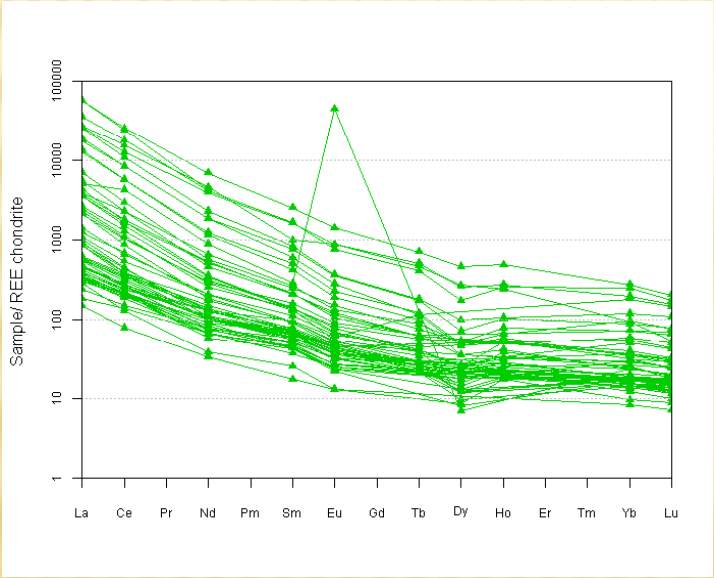
Mines and prospects in the Gallinas Mountains, Lincoln County



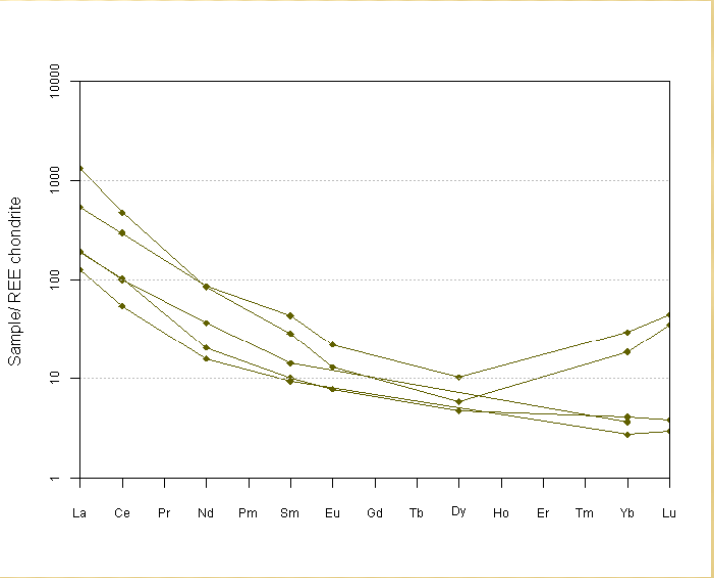
REE-F veins (131 samples)



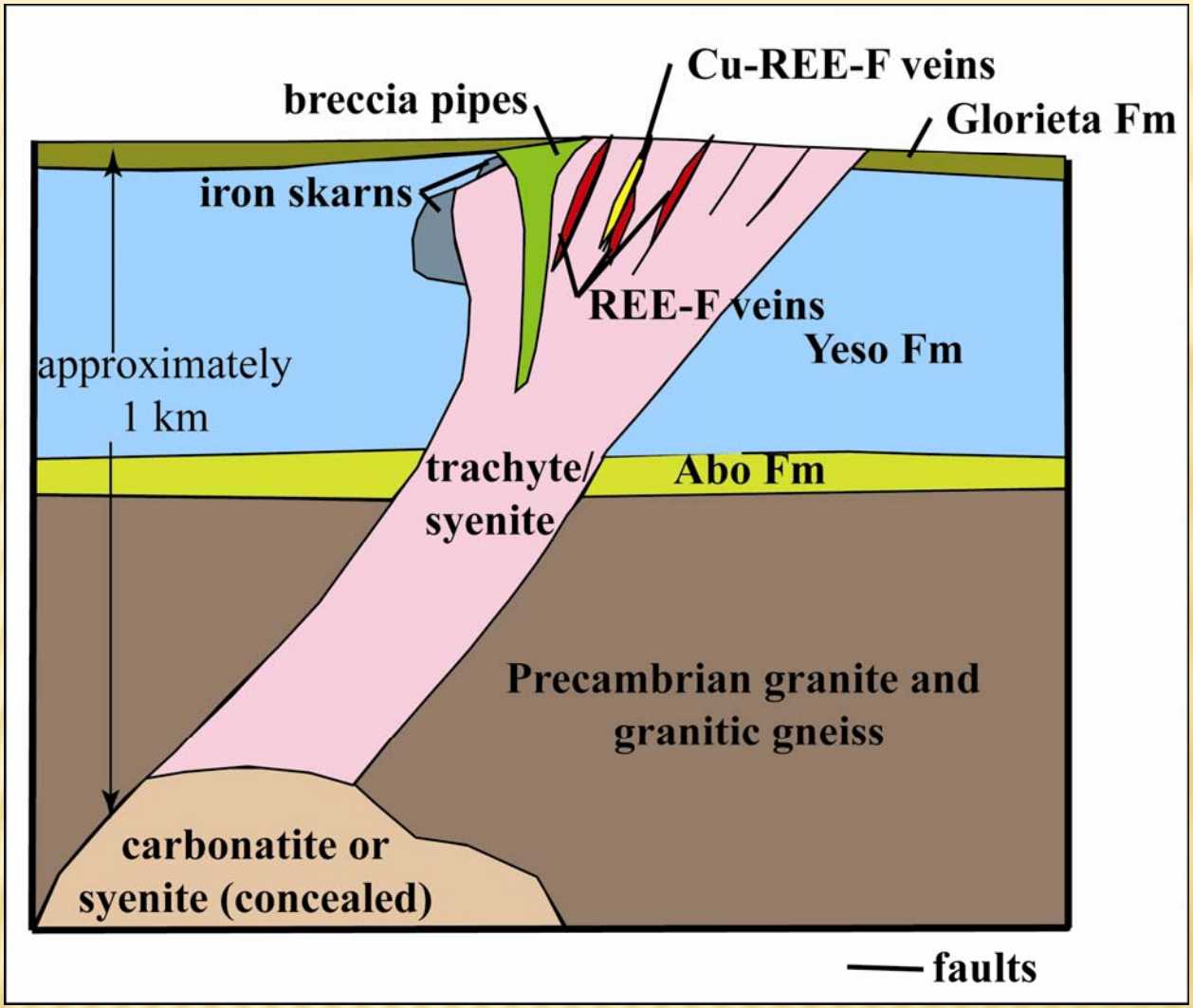
Cu-REE-F veins (65 samples)



Breccia pipe deposits (58 samples)



Iron skarns (6 samples)

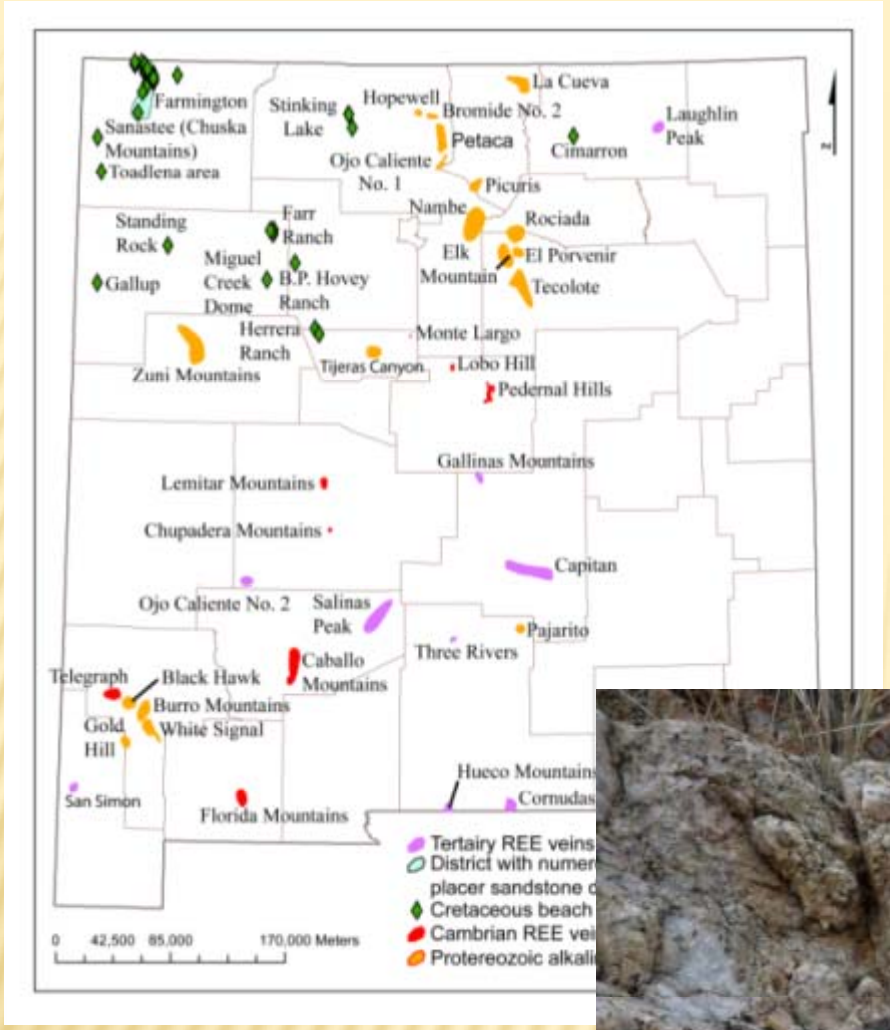


SCHEMATIC MODEL OF FORMATION OF THE MINERAL DEPOSITS IN THE GALLINAS MOUNTAINS, LINCOLN COUNTY, NEW MEXICO (MODIFIED IN PART FROM SCHREINER 1993; RICHARDS, 1995; WILLIAMS-JONES ET AL., 2000).

PEGMATITES

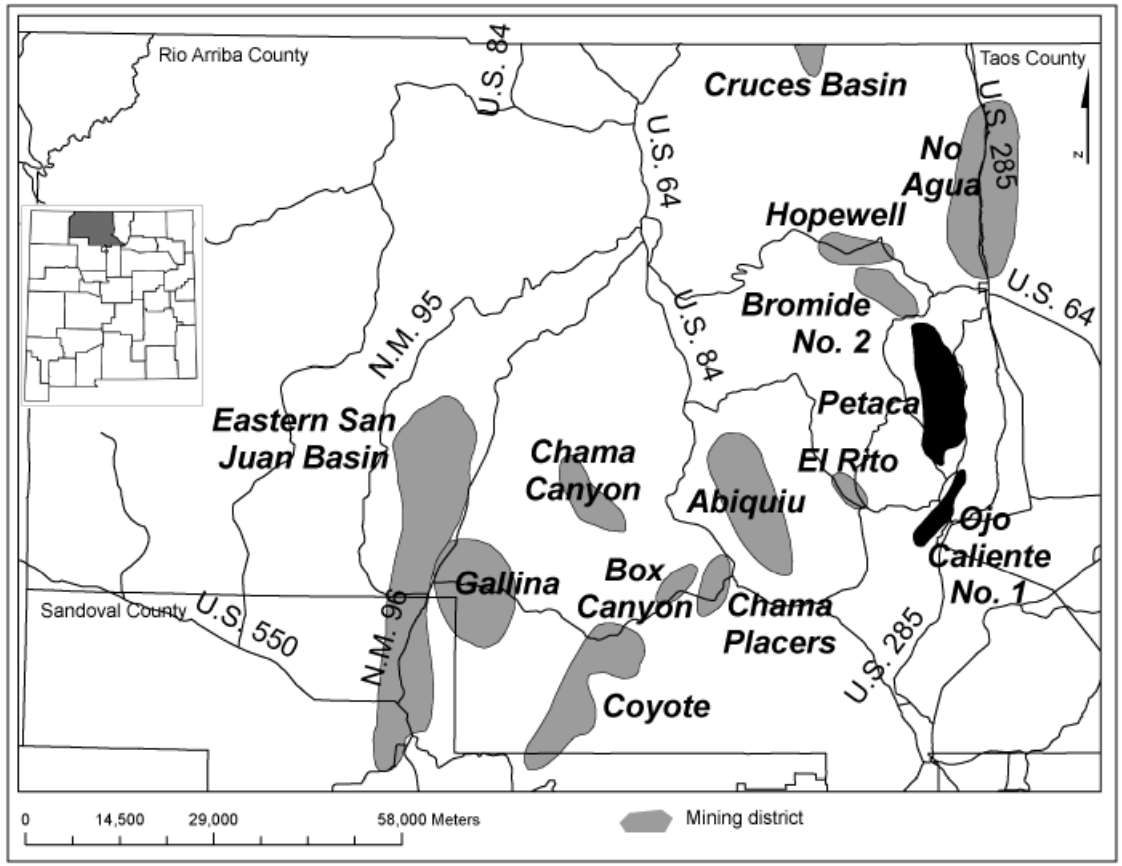
coarse-grained igneous rocks, lenses, or veins with granitic composition, contains essential quartz and feldspar, and represent the last and most hydrous phase of crystallizing magmas

PEGMATITES



PETACA

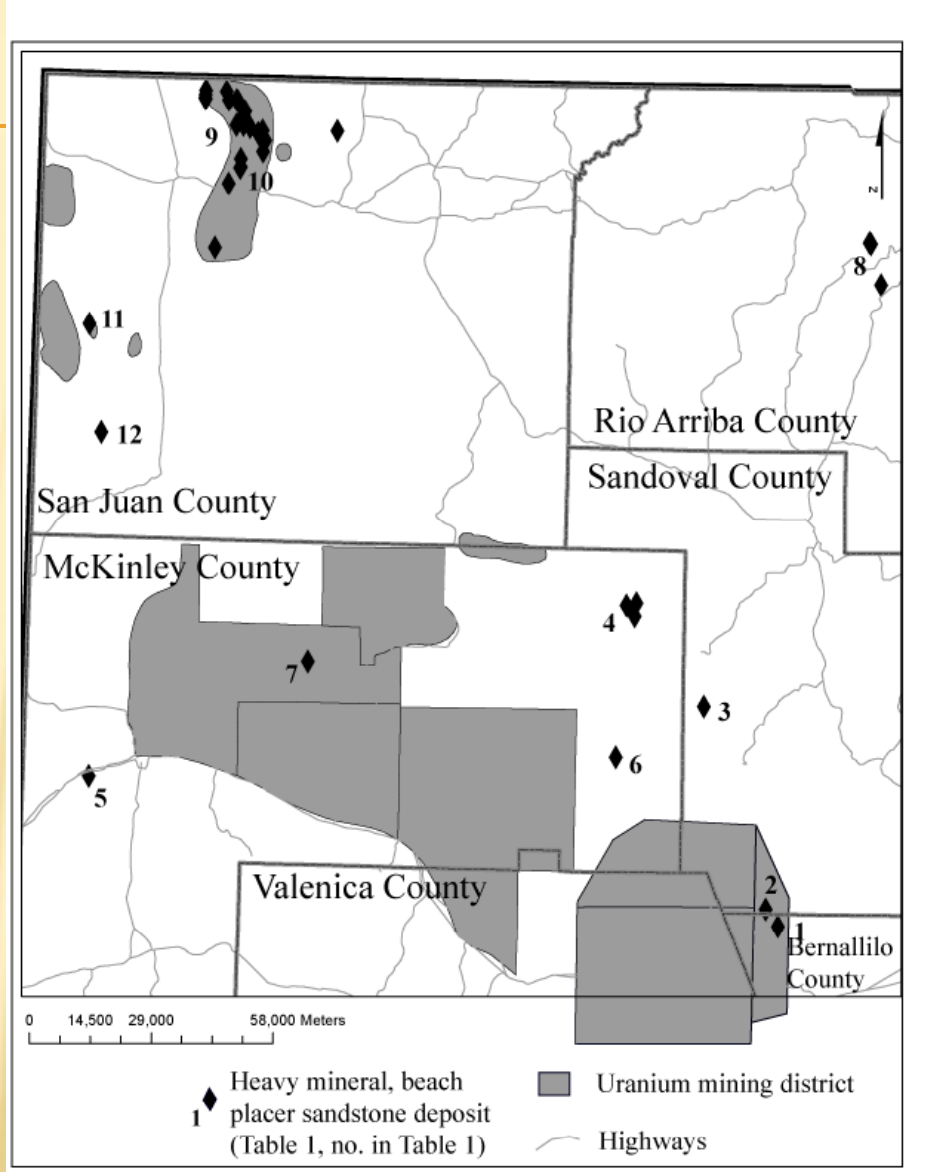
BURRO MOUNTAINS


Rio Arriba County
Taos County
Sandoval County
U.S. 84
U.S. 64
U.S. 285
N.M. 95
U.S. 550
N.M. 96
Cruces Basin
No Agua
Hopewell
Bromide No. 2
Petaca
El Rito
Ojo Caliente No. 1
Abiquiu
Chama Canyon
Eastern San Juan Basin
Gallina
Box Canyon
Chama Placers
Coyote
0
14,500
29,000
58,000 Meters
Mining district

PETACA

PLACERS

- accumulations of heavy, resistant minerals (i.e. high specific gravity) that form on upper regions of beaches or in long-shore bars in a marginal-marine environment
- In NM these are Cretaceous in age

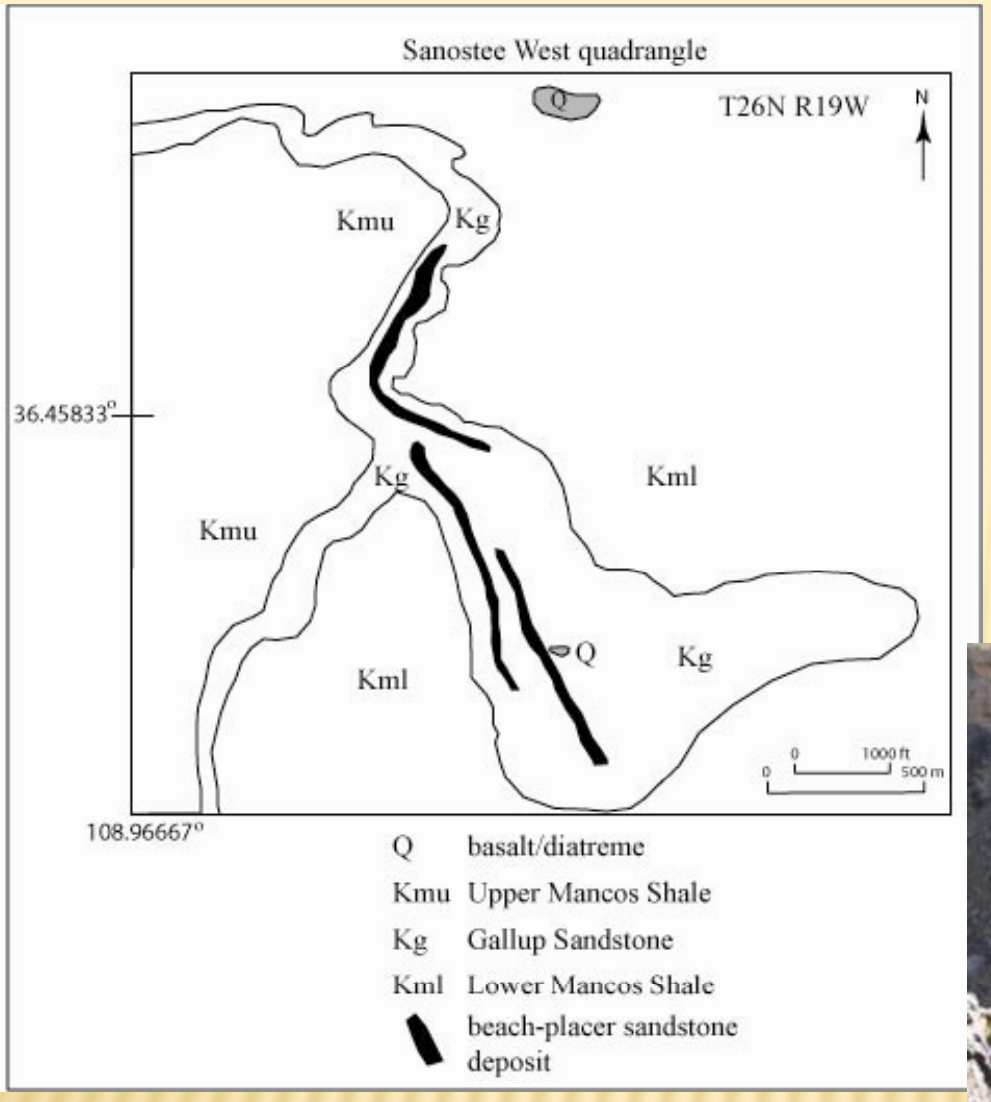


Australia

Heavy Mineral Sand Deposits
Small quantities of monazite-(Ce) are sometimes recovered as a by-product

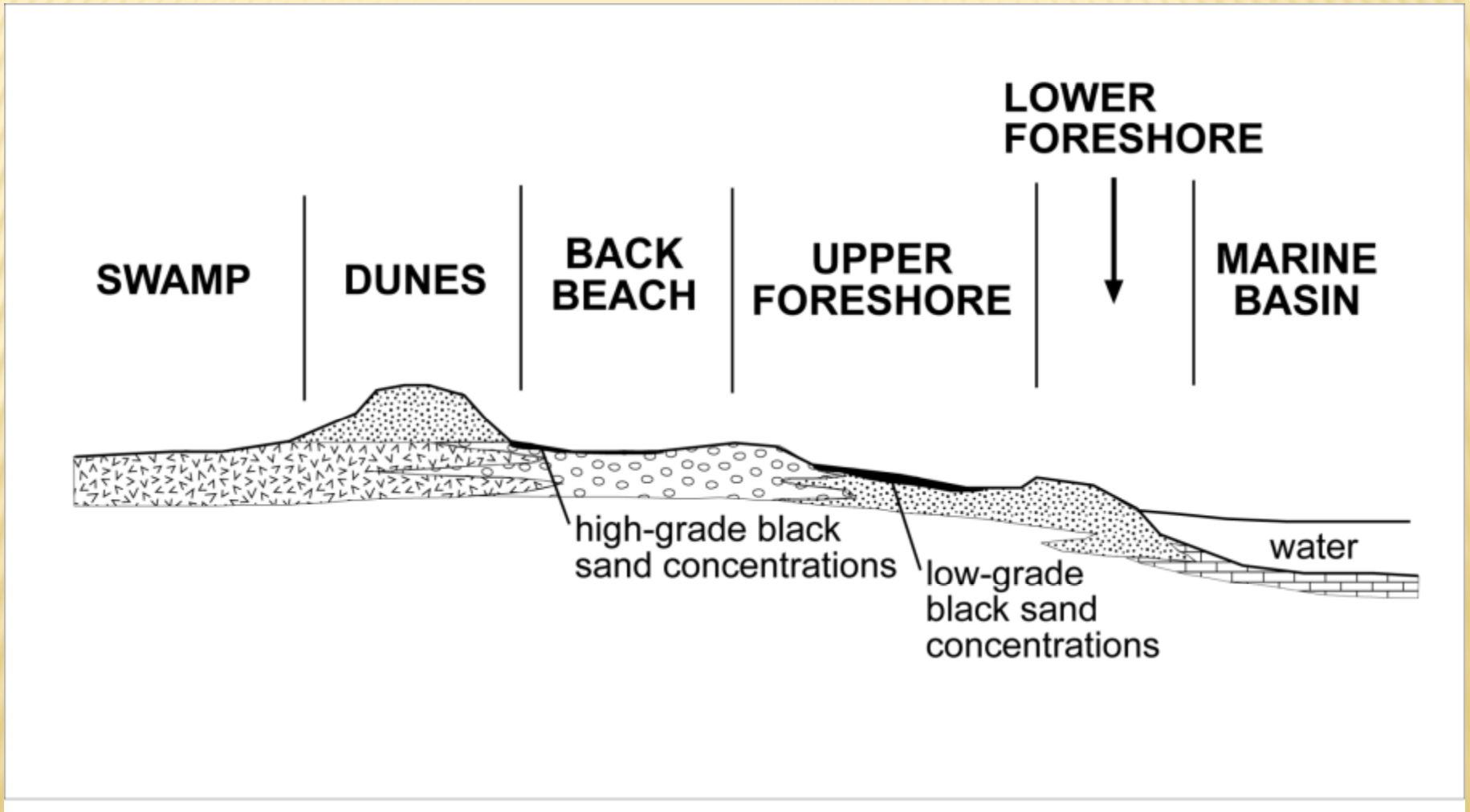
USGS

Sanostee deposit, San Juan County

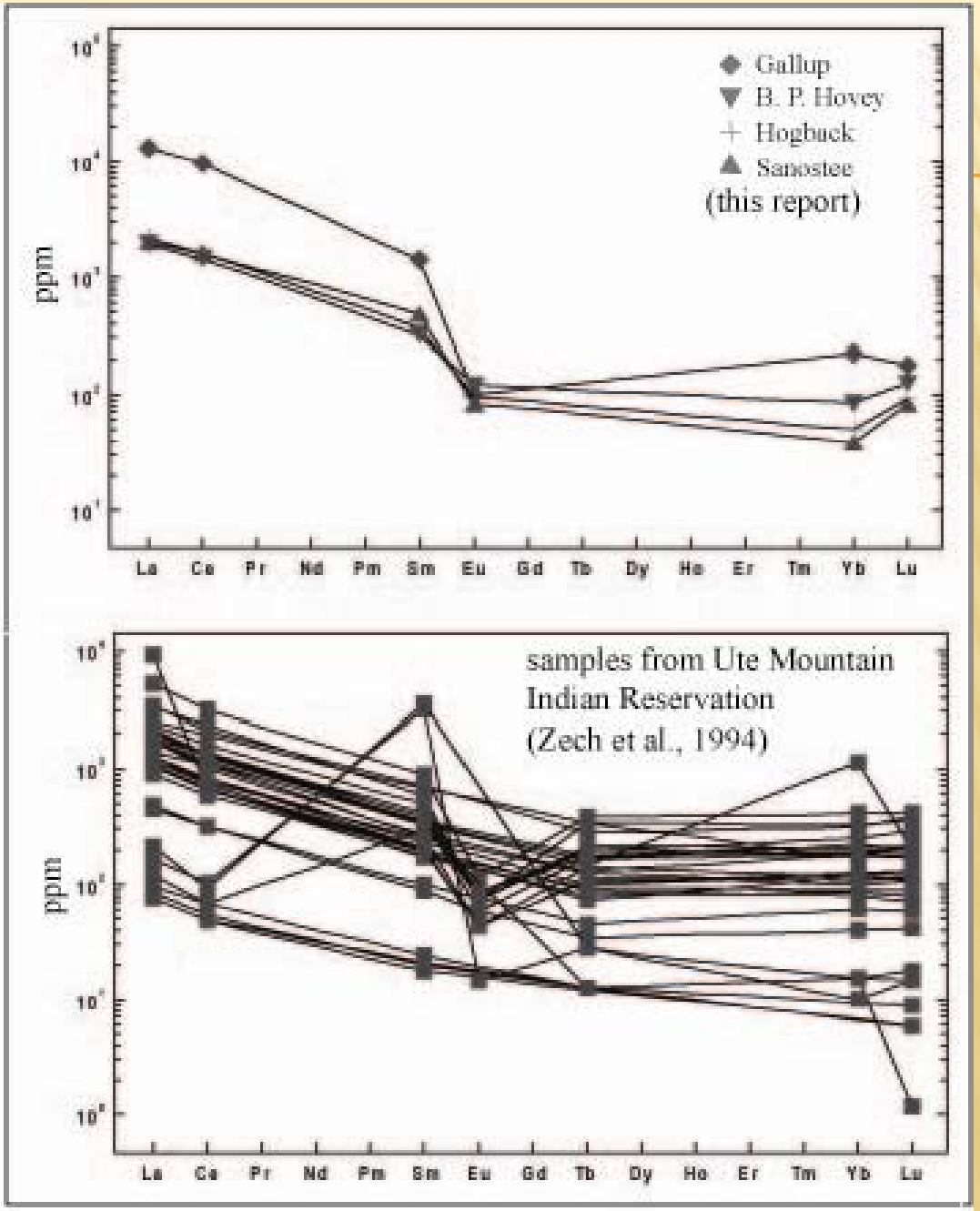

Sanostee West quadrangle
T26N R19W
N
Q
Kmu
Kg
Kml
36.45833°
108.96667°
0 1000 ft
0 500 m
Q basalt/diatreme
Kmu Upper Mancos Shale
Kg Gallup Sandstone
Kml Lower Mancos Shale
beach-placer sandstone deposit

SANOSTEE

DEPOSITS FORM ALONG BEACHES



REE CHEMISTRY

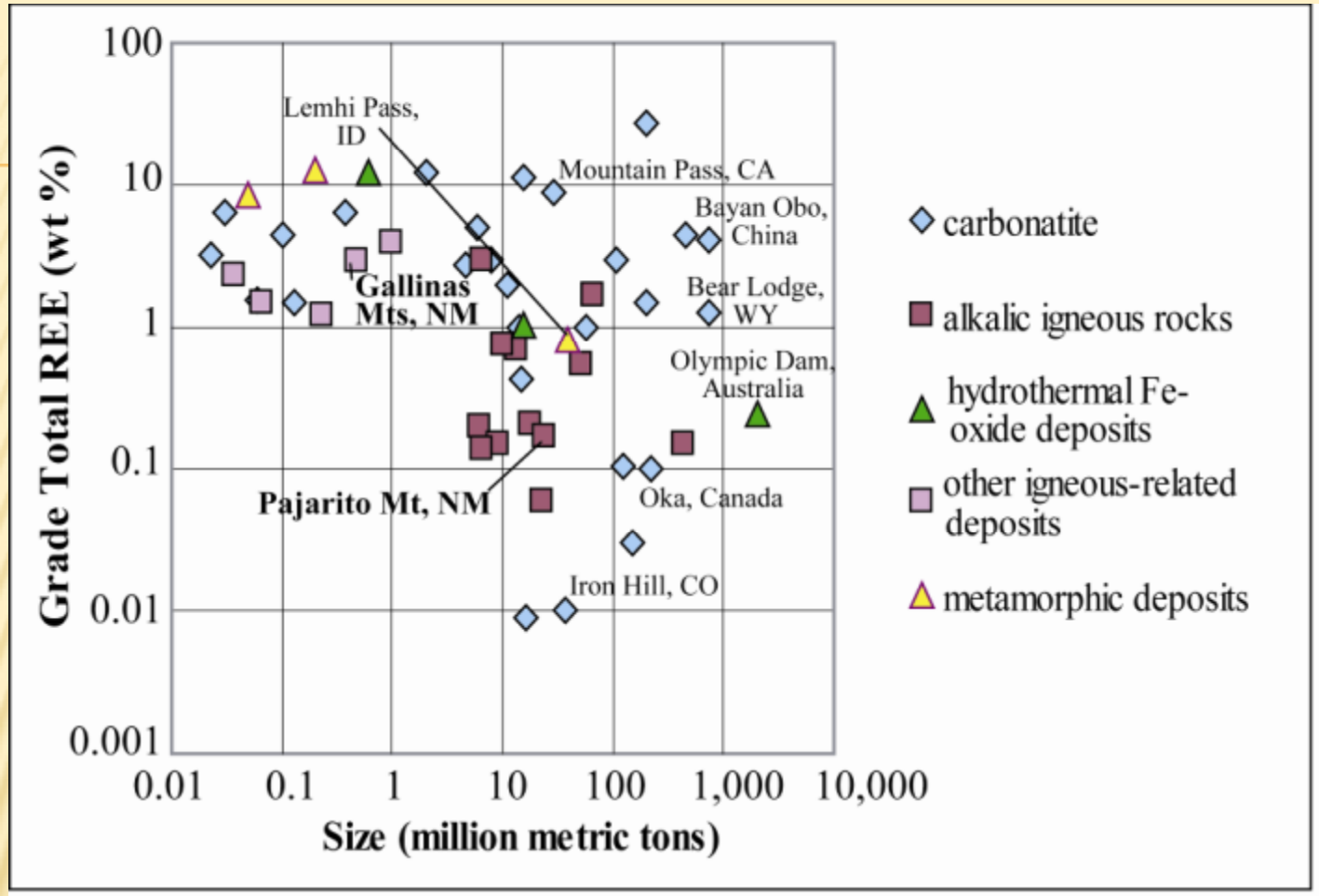


OTHER REE-BEARING DEPOSITS

- Uranium, thorium, and phosphate deposits and REE could be recovered as a by-product.
  - 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.

POTENTIAL FOR NEW MEXICO REE DEPOSITS

- Pajarito Mountain
- Carbonatites
- REE-Th-U hydrothermal vein and breccia deposits
  - Gallinas Mountains
  - Episyenites in Caballo, Burro Mts, Lobo Hill



GRADE AND SIZE (TONNAGE) OF SELECTED REE DEPOSITS, USING DATA FROM ORIS AND GRAUCH (2002) AND RESOURCES DATA FROM SCHREINER (1993) AND JACKSON AND CHRISTIANSEN (1993) FOR THE GALLINAS MOUNTAINS. DEPOSITS IN BOLD ARE LOCATED IN NEW MEXICO.

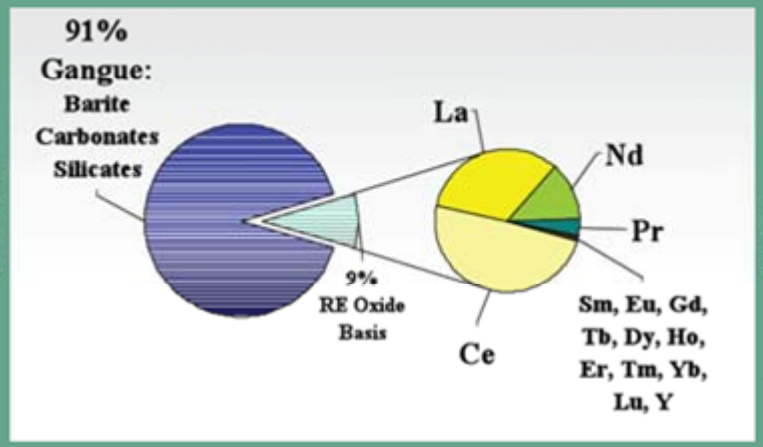
CHALLENGES

The main challenge is provide society with its needs, protect future resources, limit alteration of the landscape, and affect local communities as little as possible (i.e. sustainable development).

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

Mineral Processing



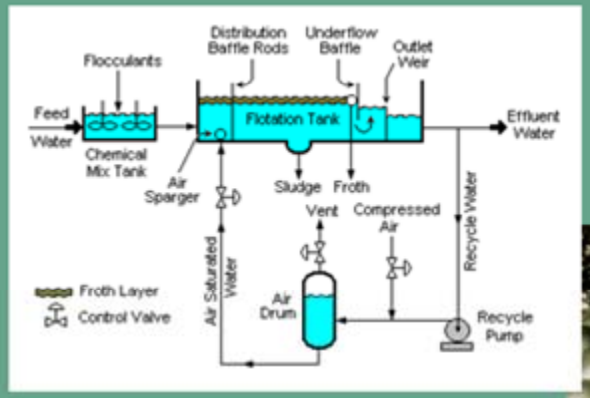
Source: Molycorp, Inc.

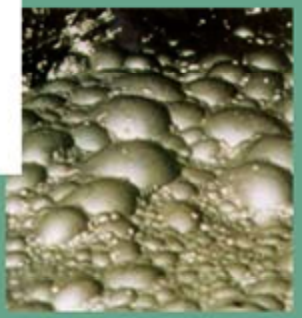
Mountain Pass, CA

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

USGS

Separating Rare Earth Minerals

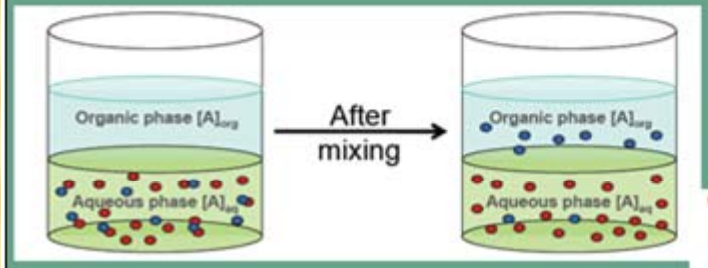


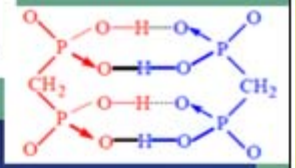


Froth flotation is the most common method for separation of rare earth minerals from other minerals in ore.

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

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

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
- Some of the REE required for these green technologies are found in New Mexico
- Need for understanding the mineralogy and distribution of these minerals in known ore deposits

THANK YOU!

QUESTIONS?