RARE EARTH ELEMENTS (REE) DEPOSITS IN NEW MEXICO

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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
Elements in Computer Chips
(National Research Council, 2007)

- Green: elements needed in 1980s
- Yellow: additional elements needed today

Periodic Table of Elements
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!
Applications For Rare Earth Elements

**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

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

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

**Ceramics**
- Capacitors
- Sensors
- Colorants
- Scintillators

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

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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 (promethium) 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.
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

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.
Bastnäsite-(Ce), on dolomite, (x 14)
(Ce,La)(CO₃)F

MONAZITE

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

HTTP://UN2SG1.UNIGE.CH/ATHENA/...
• Bastnaesite CeFCO3
• Apatite > 5400 ppm total REE Ca5(PO4)3(OH,F,Cl)
• Monazite 500,000 ppm total REE (REE,Th)PO4
• Manganese nodules 99,000 ppm total REE
<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Cu</td>
<td>1,190,000</td>
<td>15,800,000</td>
<td>1,660,000</td>
<td>$2.3/lb</td>
<td>540,000,000</td>
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<td>Au</td>
<td>210</td>
<td>2,350</td>
<td>170</td>
<td>$950/oz</td>
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<td>REO</td>
<td>0</td>
<td>124,000</td>
<td>7,410</td>
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<td>As</td>
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<td>14</td>
<td>5</td>
<td>$950/kg</td>
<td>450+</td>
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<tr>
<td>Te</td>
<td>W</td>
<td>W</td>
<td>W</td>
<td>$145/kg</td>
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<td>cement</td>
<td>71,800,000</td>
<td>2,800,000,000</td>
<td>73,800,000</td>
<td>$100/mton</td>
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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
<table>
<thead>
<tr>
<th>DISTRICT NAME</th>
<th>PRODUCTION</th>
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<tbody>
<tr>
<td>Gallinas</td>
<td>Mountains 146,000 lbs of bastnasite concentrate</td>
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<tr>
<td>Petaca</td>
<td>112 lbs of samarskite, few hundred lbs of monazite, 12,000 lbs of Ta-Nb-REE ore</td>
</tr>
<tr>
<td>Elk</td>
<td>Mountain 500 lbs of Ta-U-REE concentrate</td>
</tr>
<tr>
<td>Rociada</td>
<td>Several thousand tons of REE-Ta ore</td>
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<tr>
<td>Tecolote</td>
<td>$10,000 worth of beryl, tantalite-columbite and monazite</td>
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<tr>
<td>Gold Hill</td>
<td>REE production in the 1950s</td>
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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 \( \text{Na}_2\text{O} + \text{K}_2\text{O} > 0.3718(\text{SiO}_2) - 14.5 \)
- Igneous rocks with mol \( \text{Na}_2\text{O} + \text{mol K}_2\text{O} > \text{mol Al}_2\text{O}_3 \)

Gallinas Mountains

Capitan pluton
In 1990, Molycorp, Inc. reported historic resources of 2.7 million short tons grading 0.18% $\text{Y}_2\text{O}_3$ and 1.2% $\text{ZrO}_2$ as disseminated eudialyte.
PROTEROZOIC TO CAMBRIAN-ORDOVICIAN
SYENITES, ALKALI GRANITES, EPI SYENITES
Episyenites in Longbottom Canyon, Caballo Mountains
Carbonatites are carbonate-rich rocks containing more than 50% magmatic carbonate minerals, less than 20% SiO$_2$, and are of apparent magmatic derivation.
Lemitar carbonatites (McLemore, 1983)

Chuadera carbonatites (van Allen et al., 1986)

Lemitar carbonatites (McLemore, 1983)
Lemitar carbonatite
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
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)
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
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
Heavy Mineral Sand Deposits
Small quantities of monazite-(Ce) are sometimes recovered as a by-product

USGS
Sanostee deposit, San Juan County
SANOSTEE

Q  basalt/diatreme
Kmu  Upper Mancos Shale
Kg  Gallup Sandstone
Kml  Lower Mancos Shale

beach-placer sandstone deposit
DEPOSITS FORM ALONG BEACHES

- SWAMP
- DUNES
- BACK BEACH
- UPPER FORESHORE
- LOWER FORESHORE
- MARINE BASIN

- High-grade black sand concentrations
- Low-grade black sand concentrations
REE CHEMISTRY
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
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

91% Gangue:
- Barite
- Carbonates
- Silicates

9% RE Oxide Basis
- La
- Nd
- Pr
- Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Y

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
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
BOTTLENECKS

- Risk and timing of investment
  - Unpredictable
  - Rapid change in demand
  - Engineering/design/production of these products is faster than the exploration/mining/processing

- Extraction
  - Supplies
  - Economically feasible in a timely manner

- Refining
  - Technically feasible
  - Economical
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.