Critical Minerals in New Mexico

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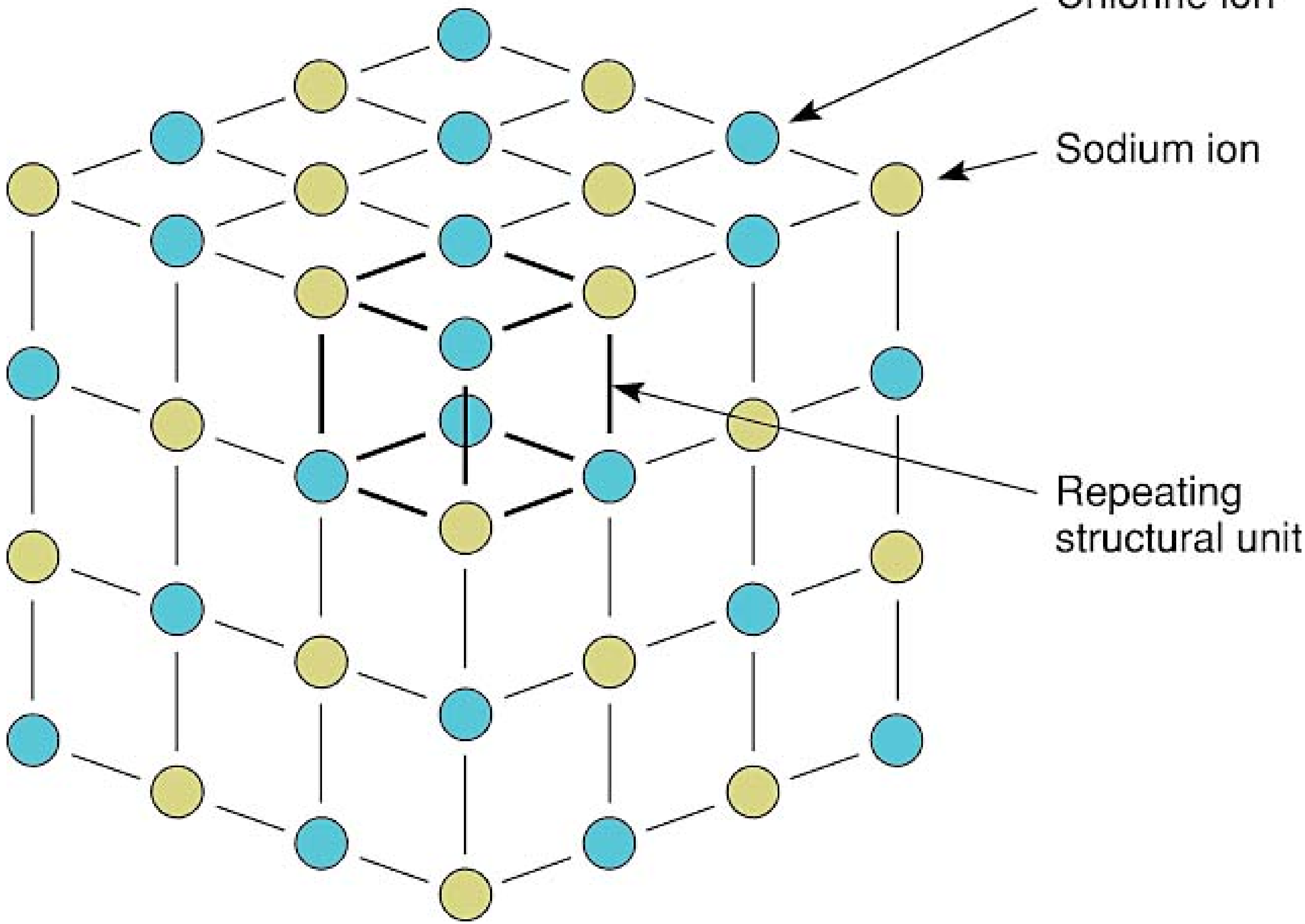
What is a mineral?

What is a mineral?

- Naturally occurring
- Inorganic
- Solid
- Homogeneous
- Crystalline material
- With a unique chemical element or compound with a set chemical formula
- Usually obtained from the ground

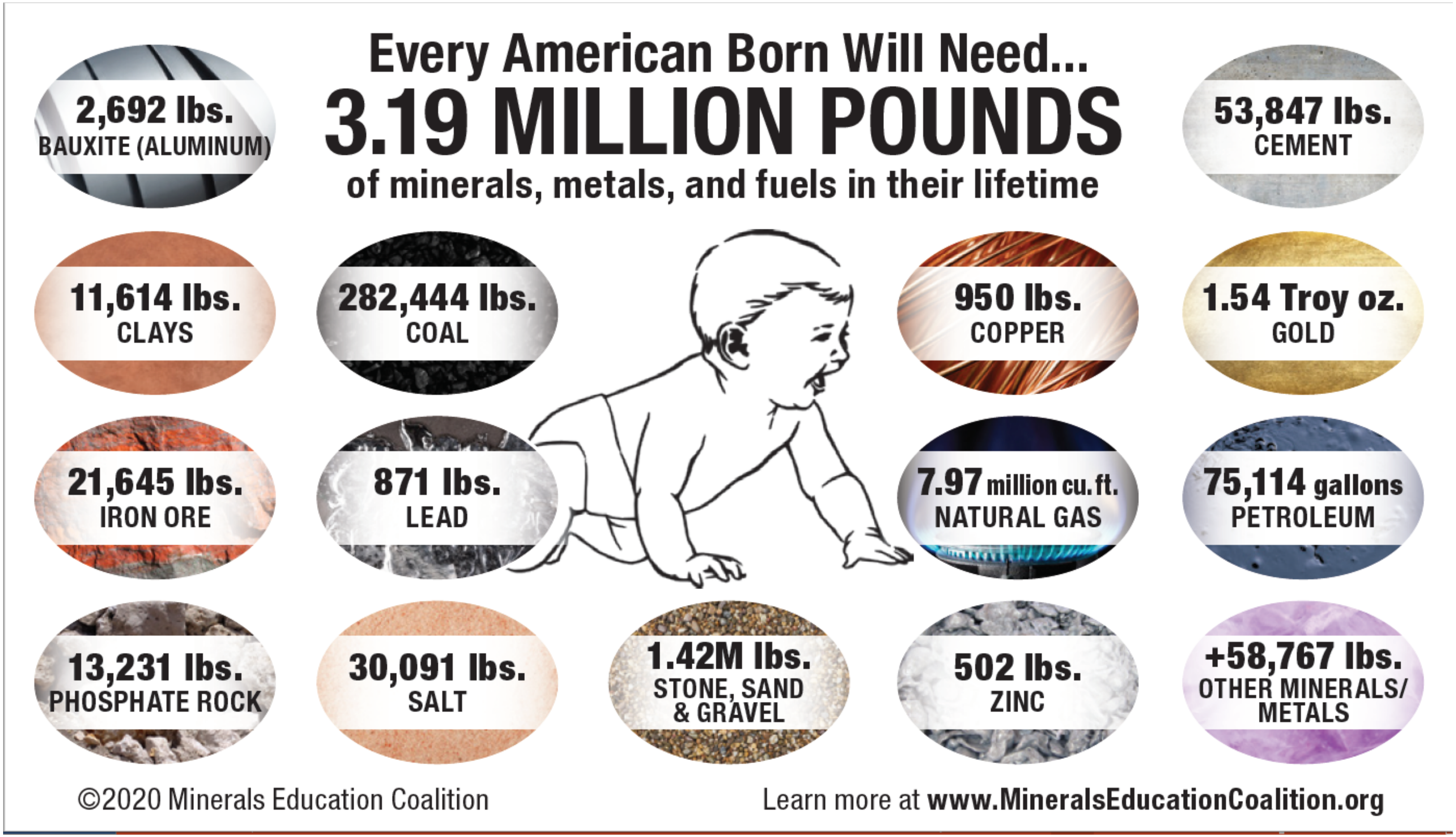


A crystal is composed of a structural unit that is repeated in three dimensions. This is the basic structural unit of a crystal of sodium chloride, the mineral halite.

Another definition

Definition of Minerals

In industry, *minerals* refer to any rock, mineral, or other naturally occurring material of economic value, including metals, industrial minerals, energy minerals, gemstones, aggregates, and synthetic materials sold as commodities.



https://mineralseducationcoalition.org/mining-mineral-statistics/

Every Year— 38,052 pounds of new minerals must be provided for every person in the United States to make the things we use every day

8,509 lbs. **Stone** used to make roads, buildings, bridges, landscaping, and for numerous chemical and construction uses

5,599 lbs. **Sand & Gravel** used to make concrete, asphalt, roads, blocks and bricks

496 lbs. **Cement** used to make roads, sidewalks, bridges, buildings, schools and houses

357 lbs. **Iron Ore** used to make steel— buildings; cars, trucks, planes, trains; other construction; containers

421 lbs. **Salt** used in various chemicals; highway deicing; food & agriculture

217 lbs. **Phosphate Rock** used to make fertilizers to grow food; and as animal feed supplements

164 lbs. **Clays** used to make floor & wall tile; dinnerware; kitty litter; bricks and cement; paper

65 lbs. **Aluminum (Bauxite)** used to make buildings, beverage containers, autos, and airplanes

12 lbs. **Copper** used in buildings; electrical and electronic parts; plumbing; transportation

11 lbs. **Lead** 87% used for batteries for transportation; also used in electrical, communications and TV screens

6 lbs. **Zinc** used to make metals rust resistant, various metals and alloys, paint, rubber, skin creams, health care and nutrition

36 lbs. **Soda Ash** used to make all kinds of glass; in powdered detergents; medicines; as a food additive; photography; water treatment

5 lbs. **Manganese** used to make almost all steels for construction, machinery and transportation

332 lbs. **Other Nonmetals** have numerous uses: glass, chemicals, soaps, paper, computers, cell phones

24 lbs. **Other Metals** have the same uses as nonmetals but also electronics, TV and video equipment, recreation equipment, and more

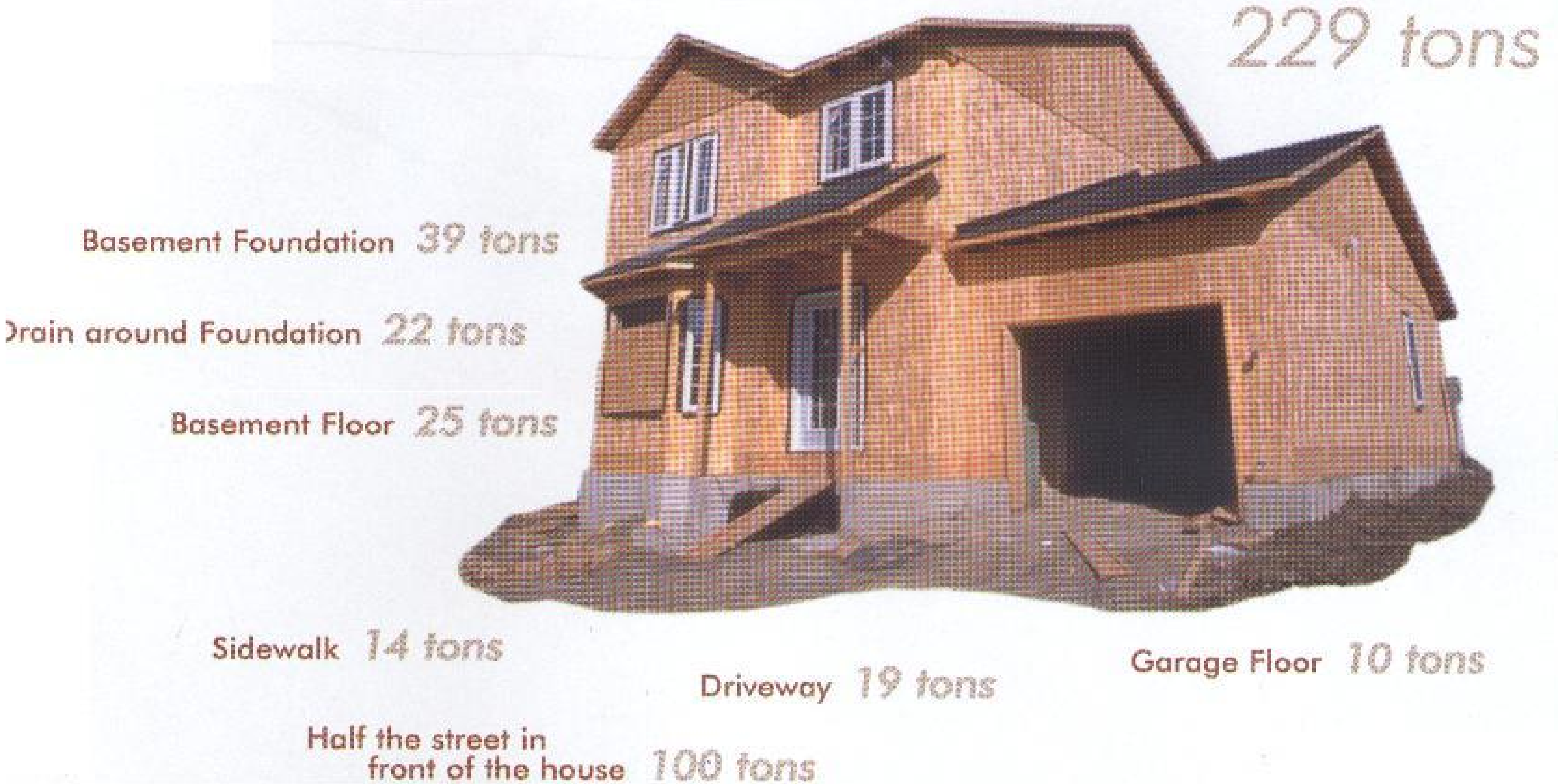
Including These Energy Fuels

- 951 gallons of **Petroleum**
- 6,792 lbs. of **Coal**
- 80,905 cu. ft. of **Natural Gas**
- 1/4 lb. of **Uranium**

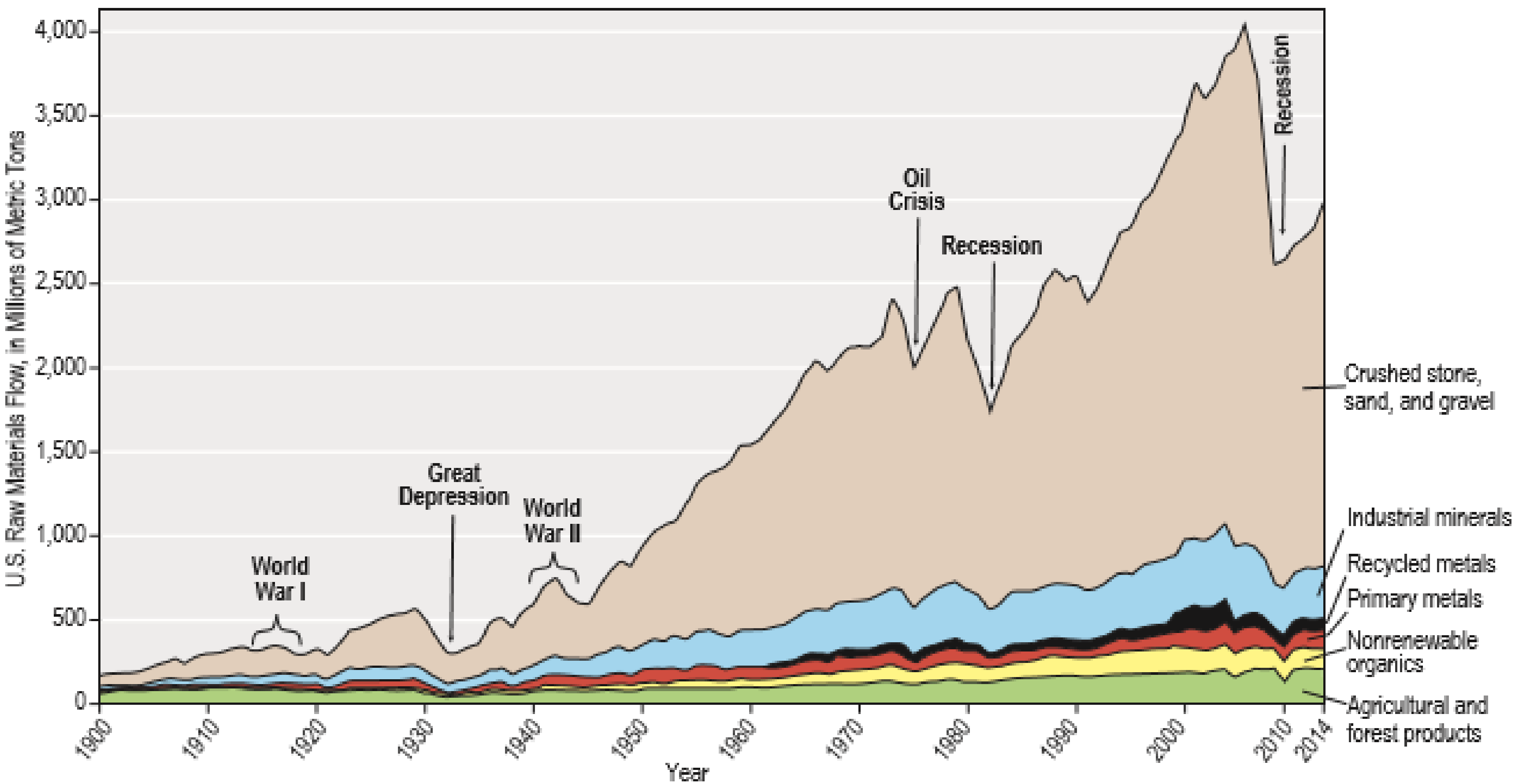
To generate the energy each person uses in one year—

http://www.mii.org/pdfs/2011PerCapita.pdf

AGGREGATE USED IN ONE HOUSE

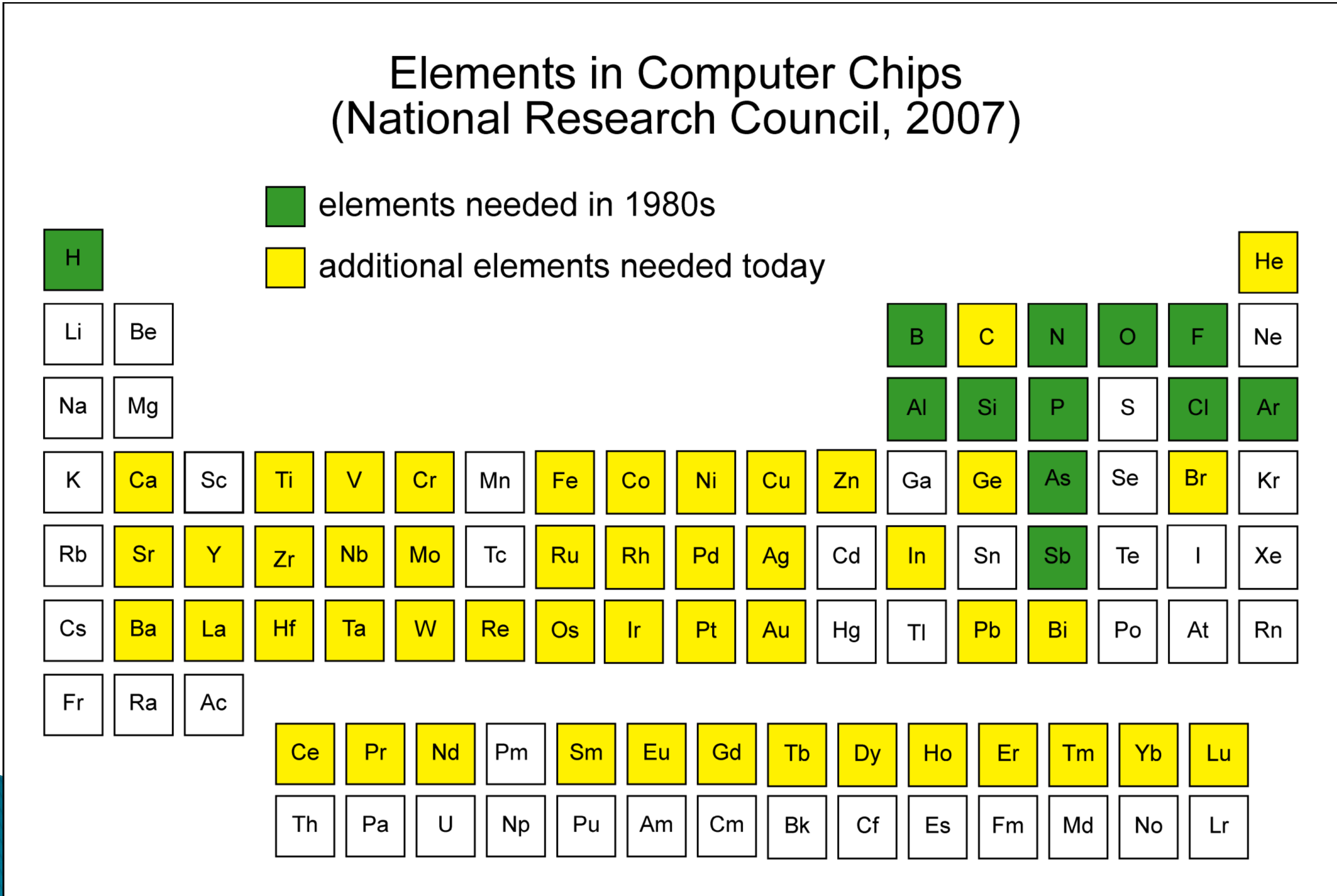


U.S. flow of raw materials by weight 1900-2014. The use of raw materials in the U.S. increased dramatically during the last 100 years (modified from Wagner, 2002).



https://www.usgs.gov/centers/nmic/mineral-commodity-summaries

For example, computer chips…



Definition of Critical Minerals

is a mineral

(1) identified to be a nonfuel mineral or mineral material essential to the economic and national security of the United States

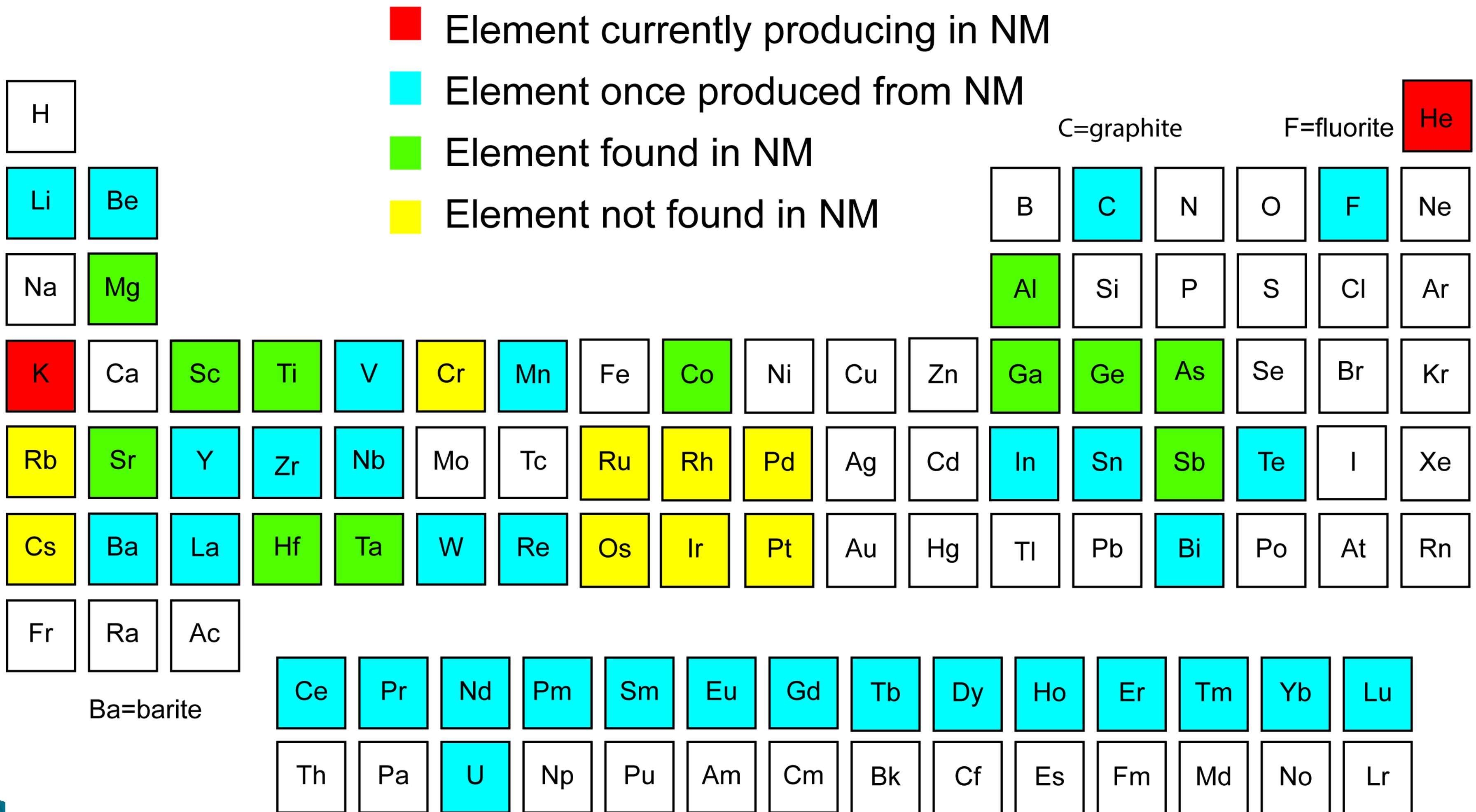
(2) from a supply chain that is vulnerable to disruption

(3) that serves an essential function in the manufacturing of a product, the absence of which would have substantial consequences for the U.S. economy or national security

Critical Minerals

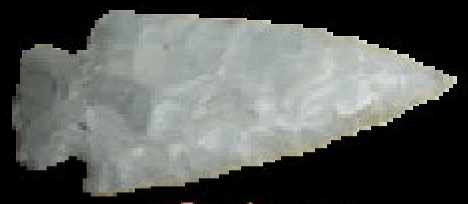
- 35 critical minerals were identified
- New Mexico has many of these critical minerals
  - Potash is currently being produced in Carlsbad
  - Porphyry copper deposits in Grant County contain rhenium, indium, and germanium
  - Uranium deposits in the Grants district, also contain vanadium
  - Exploration for other critical minerals include REE, tellurium, lithium, beryllium, cobalt
  - Other critical minerals were once produced from New Mexico (tin, vanadium, manganese, fluorspar, barite, graphite, REE, tellurium, beryllium)

Critical Minerals in New Mexico



Note that any element or commodity can be considered critical in the future depending upon use and availability. Coal contains several of these critical elements.

Arrowhead clipart from www.firstpeople.us



Critical and strategic minerals will change with time.

Avatar

Critical Minerals 2018 in the US

- Aluminum (bauxite), metal used in almost all sectors of the economy
- Antimony, used in batteries and flame retardants
- Arsenic, used in lumber preservatives, pesticides, and semi-conductors
- Barite, used in cement and petroleum industries (drilling muds)
- Beryllium, used as an alloying agent in aerospace/defense industries, shielding
- Bismuth, used in medical and atomic research
- Cesium, used in research and development, Clock for G5 technology
- Chromium, used primarily in stainless steel and other alloys
- Cobalt, used in rechargeable batteries and superalloys
- Fluorspar, used in the manufacture of aluminum, gasoline, and uranium fuel
- Gallium, used for integrated circuits and optical devices like LEDs
- Germanium, used for fiber optics and night vision applications
- Graphite (natural), used for lubricants, batteries, and fuel cells
- Hafnium, used for nuclear control rods, alloys, and high-temperature ceramics
- Helium, used for MRIs, lifting agent, and research
- Indium, mostly used in LCD screens
- Lithium, used primarily for batteries

Critical Minerals 2018 in the US—cont

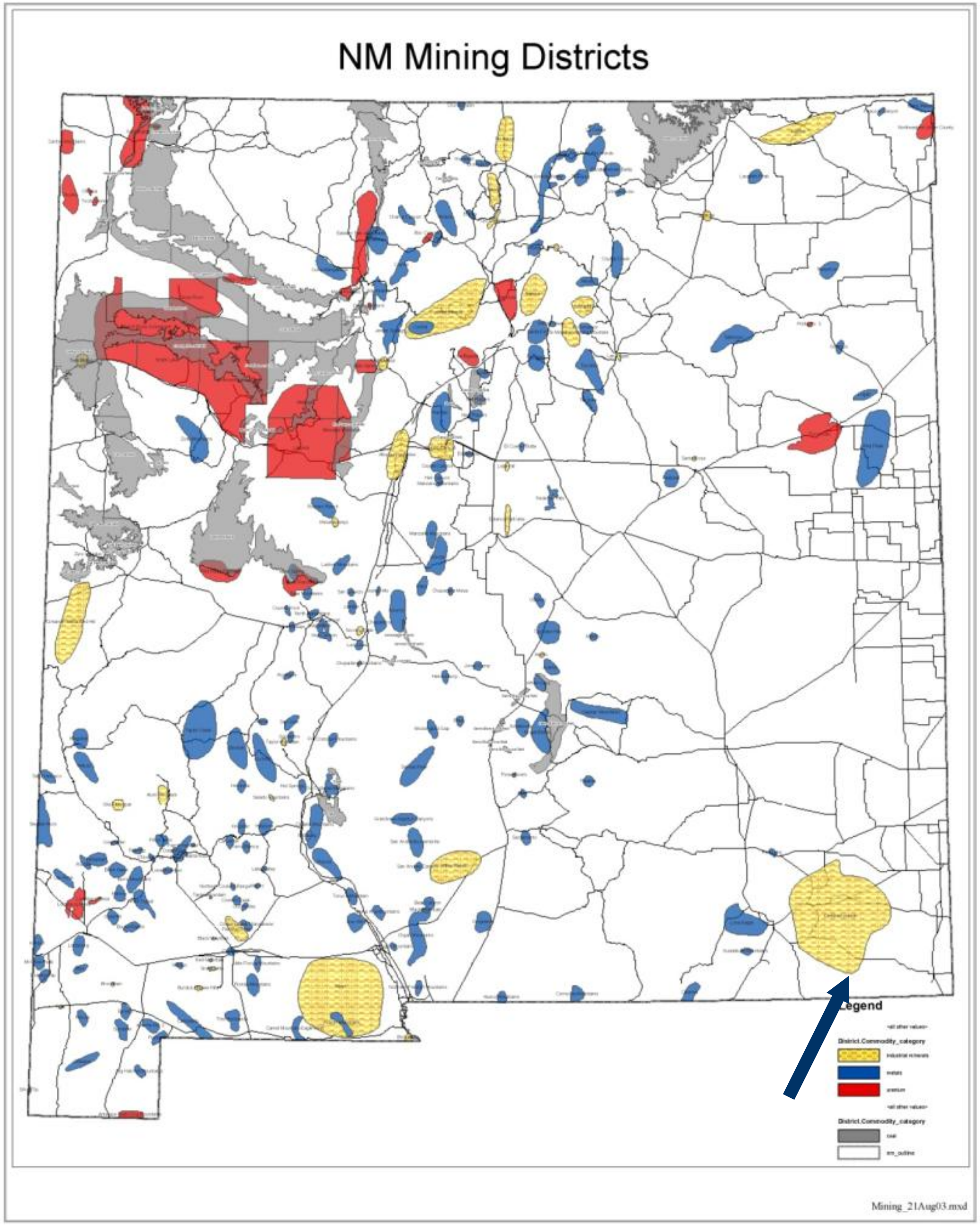
- Magnesium, used in furnace linings for manufacturing steel and ceramics, batteries
- Manganese, used in steelmaking
- Niobium, used mostly in steel alloys
- Platinum group metals, used for catalytic agents
- Potash, primarily used as a fertilizer
- Rare earth elements group, primarily used in batteries, electronics, magnets
- Rhenium, used for lead-free gasoline and superalloys
- Rubidium, used for research and development in electronics
- Scandium, used for alloys and fuel cells
- Strontium, used for pyrotechnics and ceramic magnets
- Tantalum, used in electronic components, mostly capacitors
- Tellurium, used in steelmaking and solar cells
- Tin, used as protective coatings and alloys for steel
- Titanium, overwhelmingly used as a white pigment or metal alloys
- Tungsten, primarily used to make wear-resistant metals
- Uranium, mostly used for nuclear fuel
- Vanadium, primarily used for titanium alloys
- Zirconium, used in the high-temperature ceramics industries

Some of the challenges in producing minerals

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

Potash

- Uses—fertilizers, chemical industry
- New Mexico is the leading state in the U.S. for potash production and reserves (Utah produces potash, resources found in Arizona)
- U.S. imports 90% of potash used, 85% from Canada



POTASH PRODUCTION

1951-2017 >114 million tons worth >$16 billion

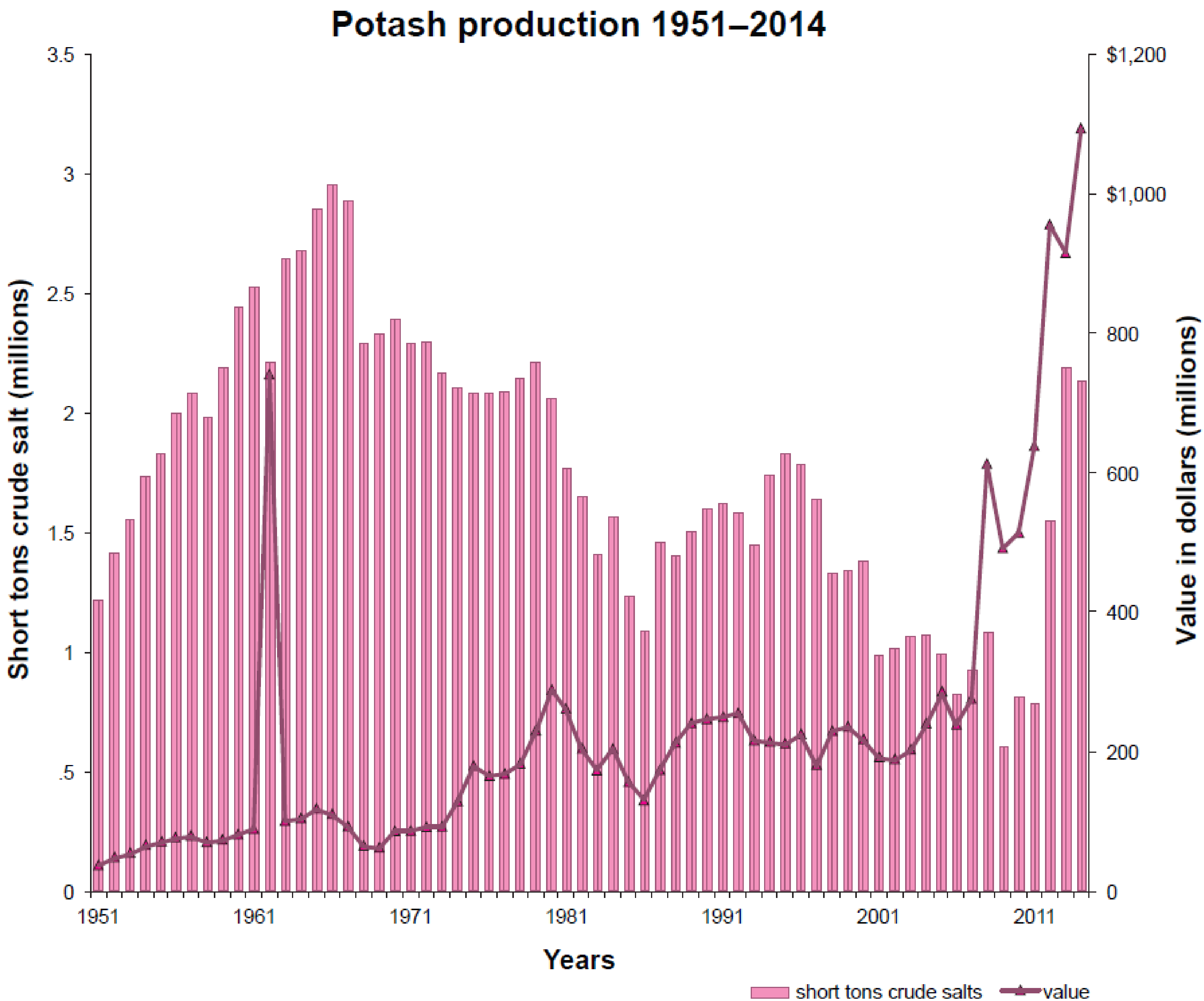
Reserves in Carlsbad District

Potash (>553 million tons)

Potash is used in fertilizers among other uses

Intrepid closed one mine

Competition from Canadian deposits, low prices, over supply

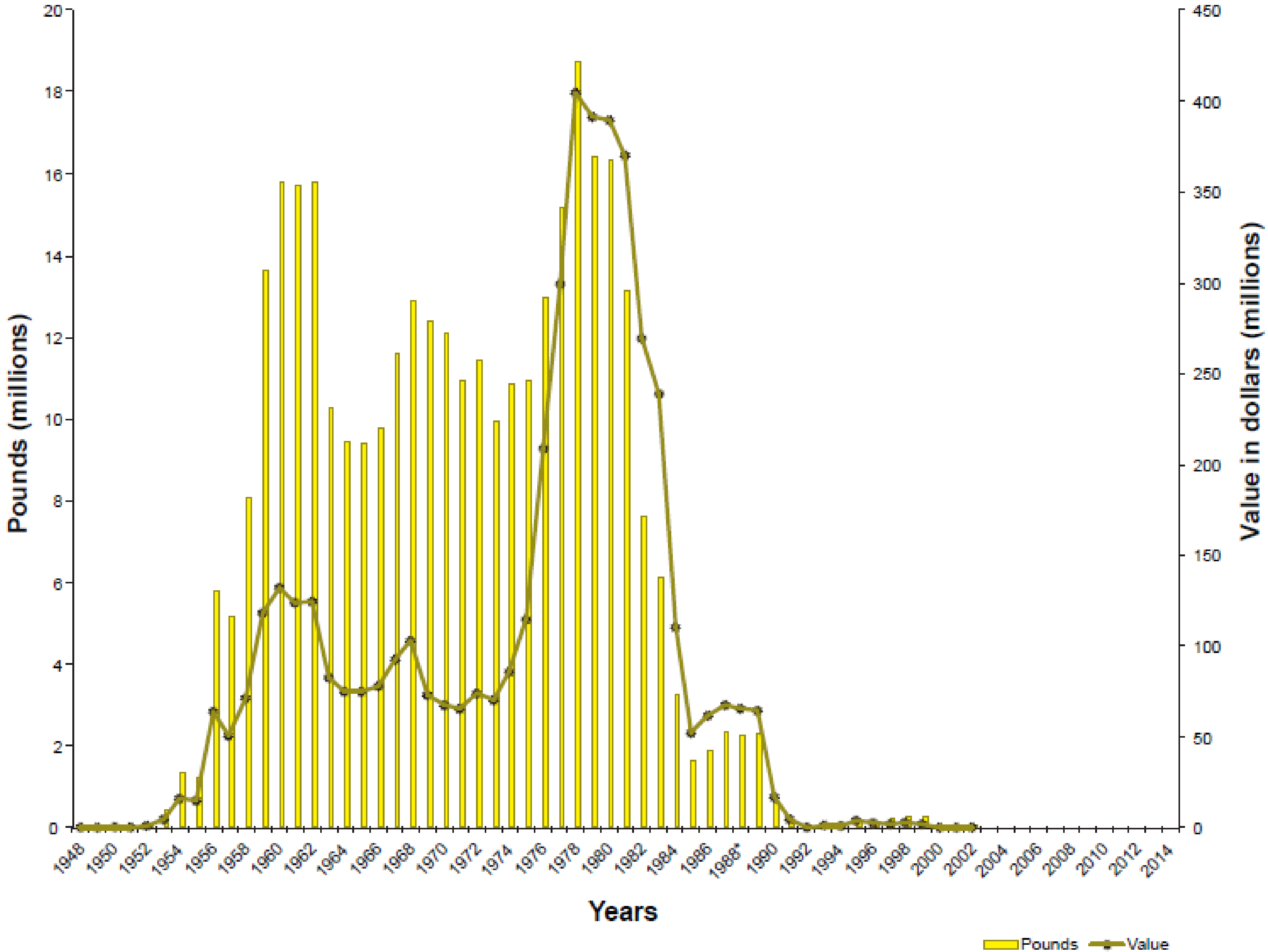


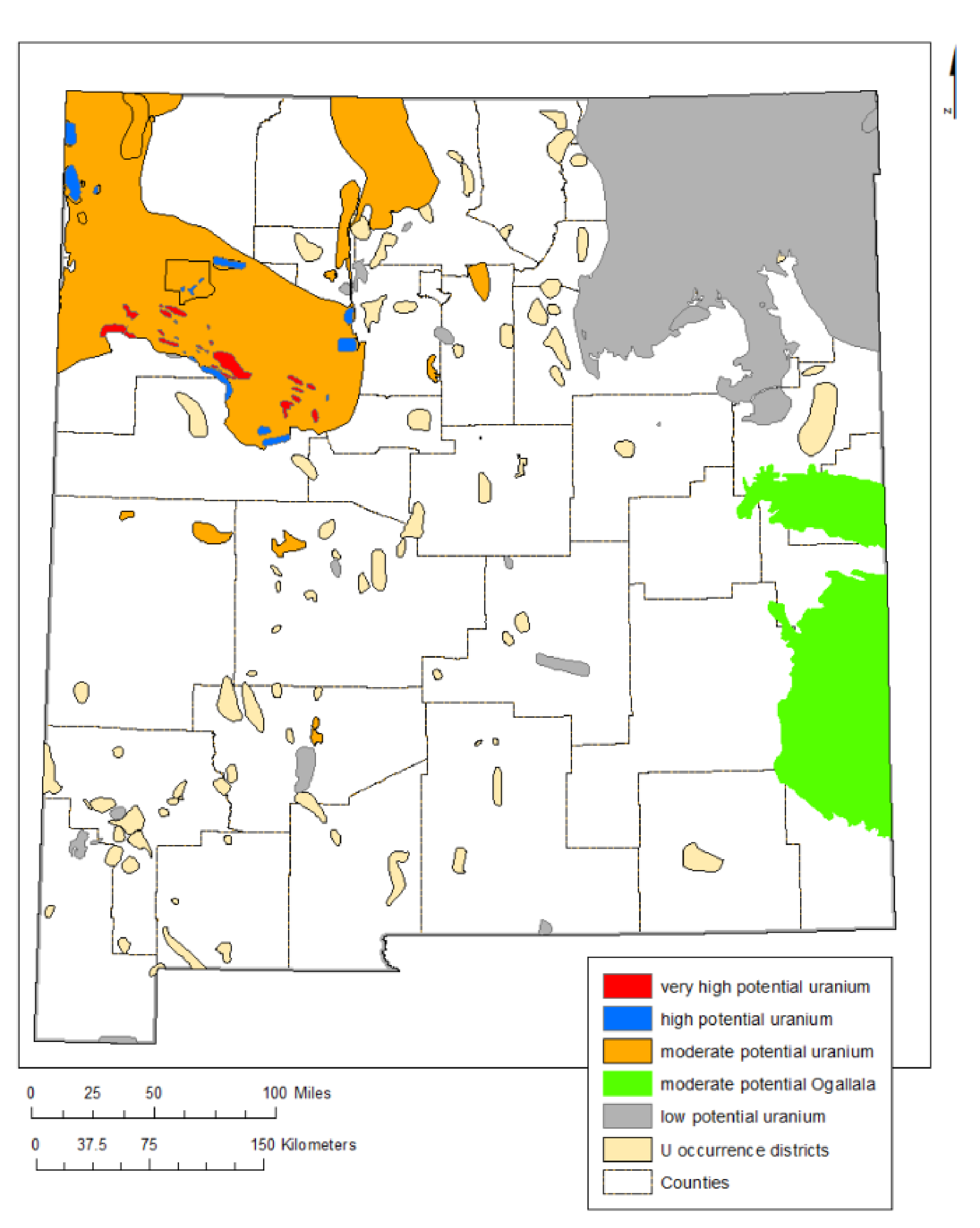
Potash production 1951–2014
Short tons crude salt (millions)
3.5
3
2.5
2
1.5
1
.5
0
Value in dollars (millions)
$1,200
$1,000
800
600
400
200
0
1951
1961
1971
1981
1991
2001
2011
Years
short tons crude salts
value

Uranium

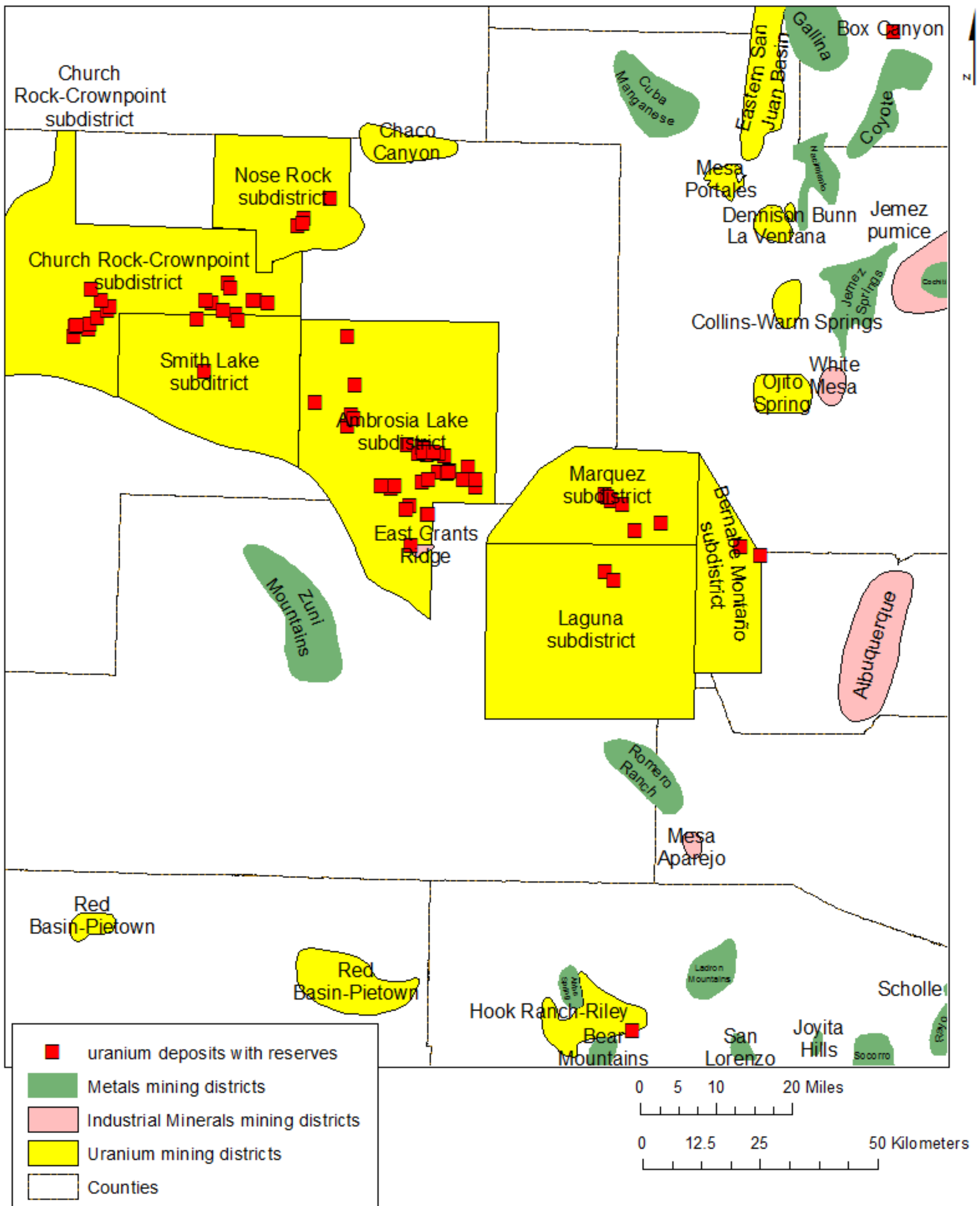
- Uses—99 nuclear energy power reactors (20% electricity in U.S.), fuel for space missions, defense, armor shielding in tanks, anti-tank systems
- NM is 2nd in uranium resources 15 million tons ore at 0.277% U_3O_8 (84 million lbs U_3O_8) at $30/lb (DOE estimates in 2002)
- Numerous companies have acquired properties in NM (Energy Fuels Inc., Laramide Resources, Rio Grande Resources among others)

Uranium production 1948–2014



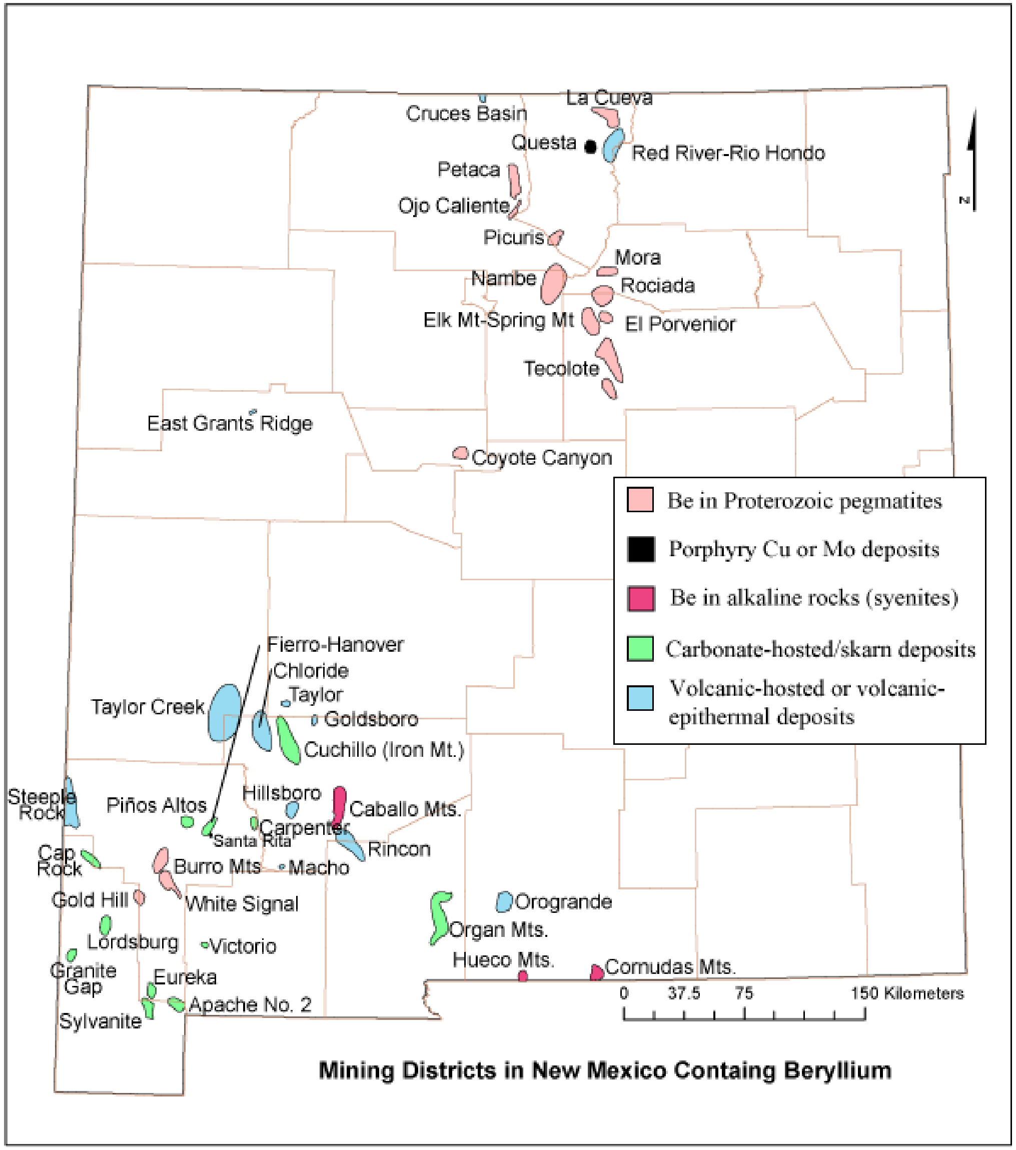


Uranium potential in New Mexico (most U-sandstone deposits also contain vanadium)



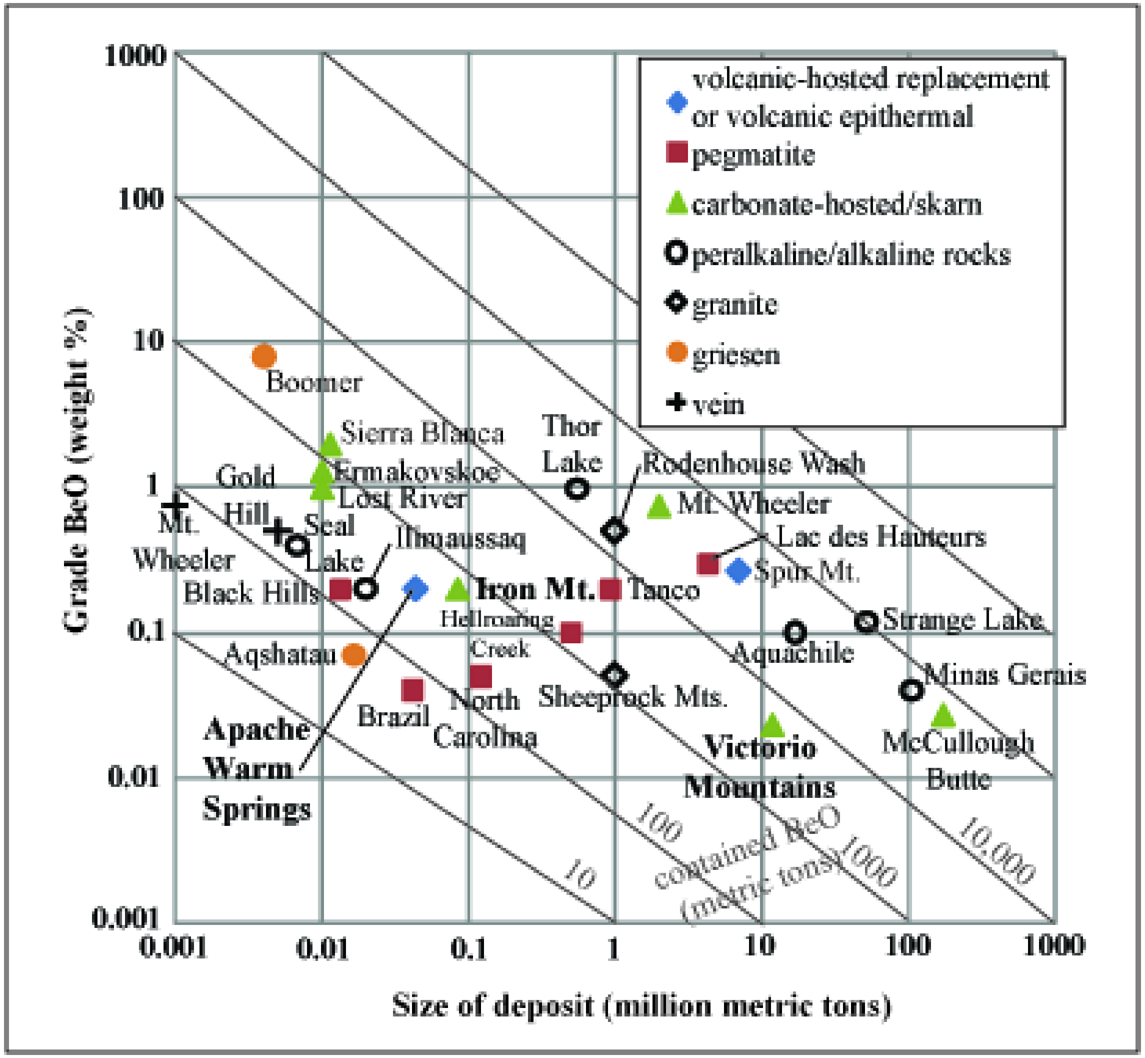
Deposits with uranium resources in New Mexico (McLemore and Chenoweth, 2017). Only major mines and deposits are included here.

Beryllium in New Mexico



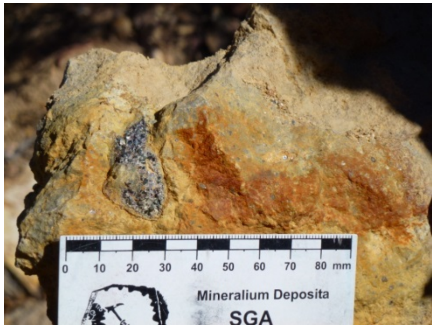
- Defense
- Telecommunications
- Nuclear energy industries
- Shielding in some of our nuclear, medical, and other equipment
- Many of our electronic devices

Apache Warm Springs beryllium deposit (Be), as determined from trenching and drilling, looking northeast (N section 6, T9S, R7W).



Grade-tonnage of beryllium deposits (modified from Barton and Young, 2002). Deposits in bold are located in New Mexico.

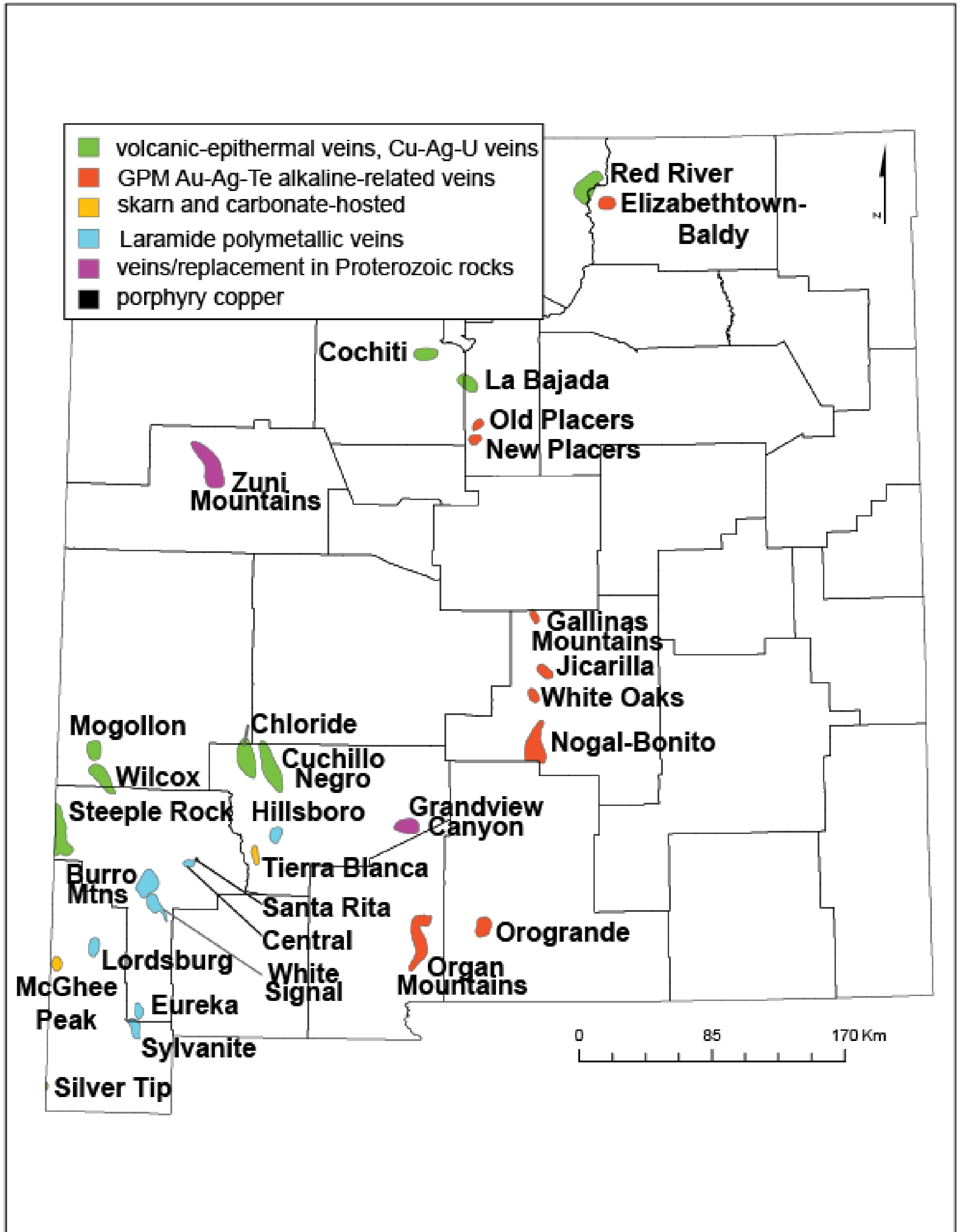
Uses of Tellurium



- Alloying additive in steel to improve machining characteristics
- Processing of rubber
- As a component of catalysts for synthetic fiber production
- As pigments to produce various colors in glass and ceramics
- **Thermal imaging devices**
- Thermoelectric cooling devices, such as summertime beverage coolers
- Thermoelectronics
- **Solar panels/cells**

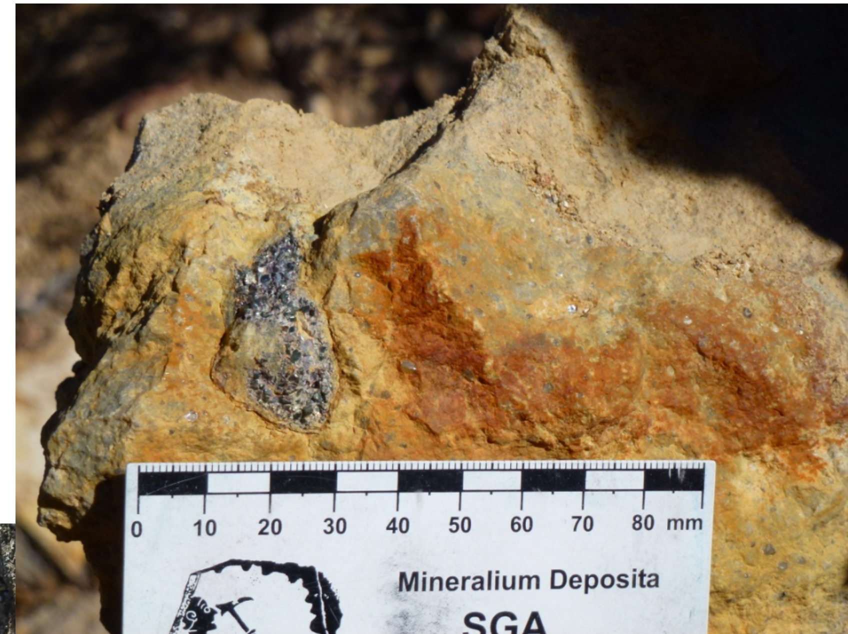
Tellurium

- Production—byproduct of copper refining (refinery in Texas)
- Lone Pine, Catron County produced 5 tons of Te from Au-Te volcanic-epithermal veins

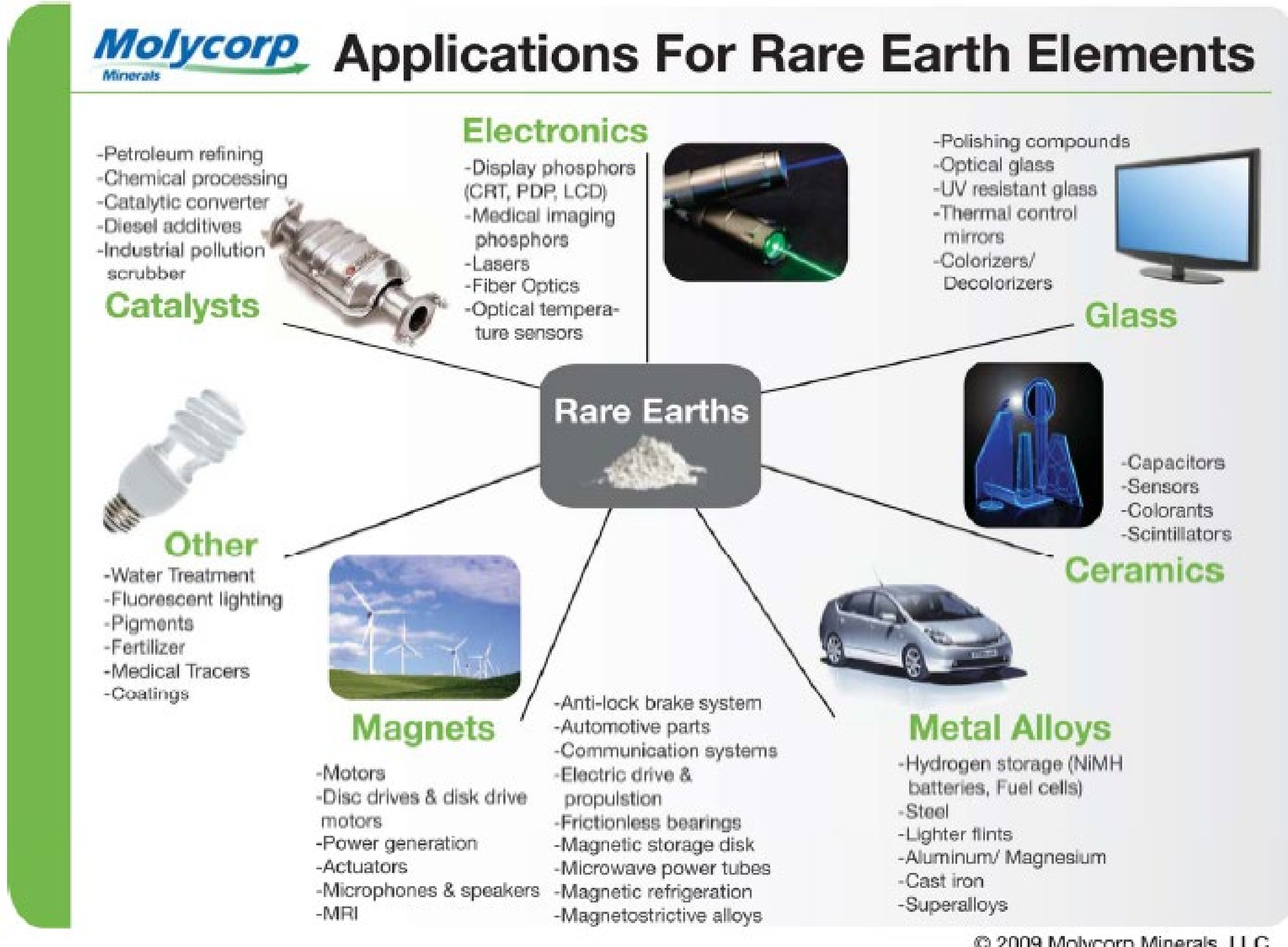


Mining districts in New Mexico with tellurium minerals or chemical assays >20 ppm Te

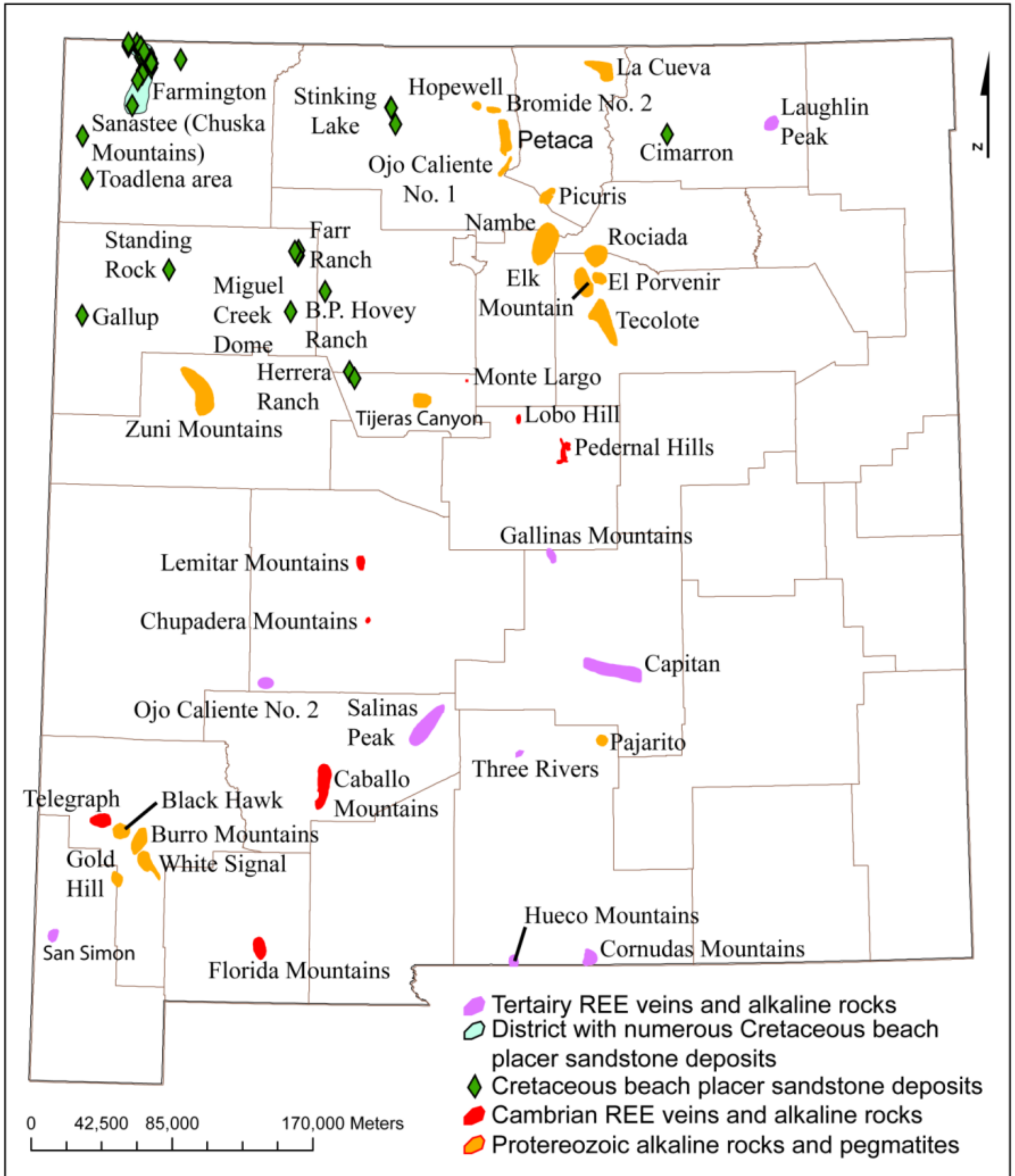
Lone Pine, Wilcox district, Catron County—volcanic epithermal vein



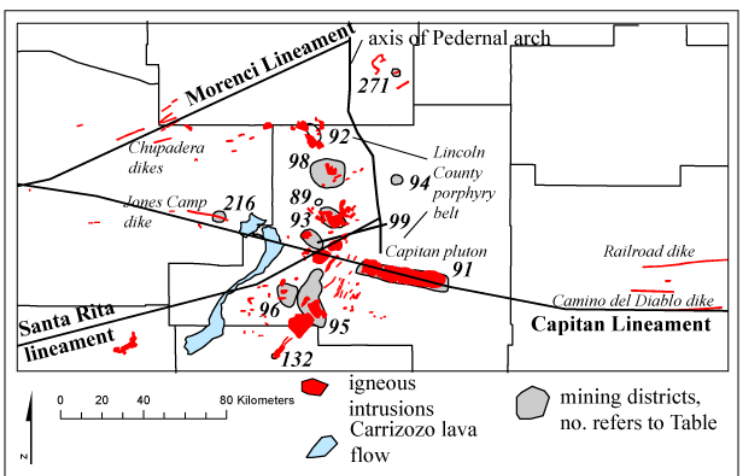
Rare Earth Elements

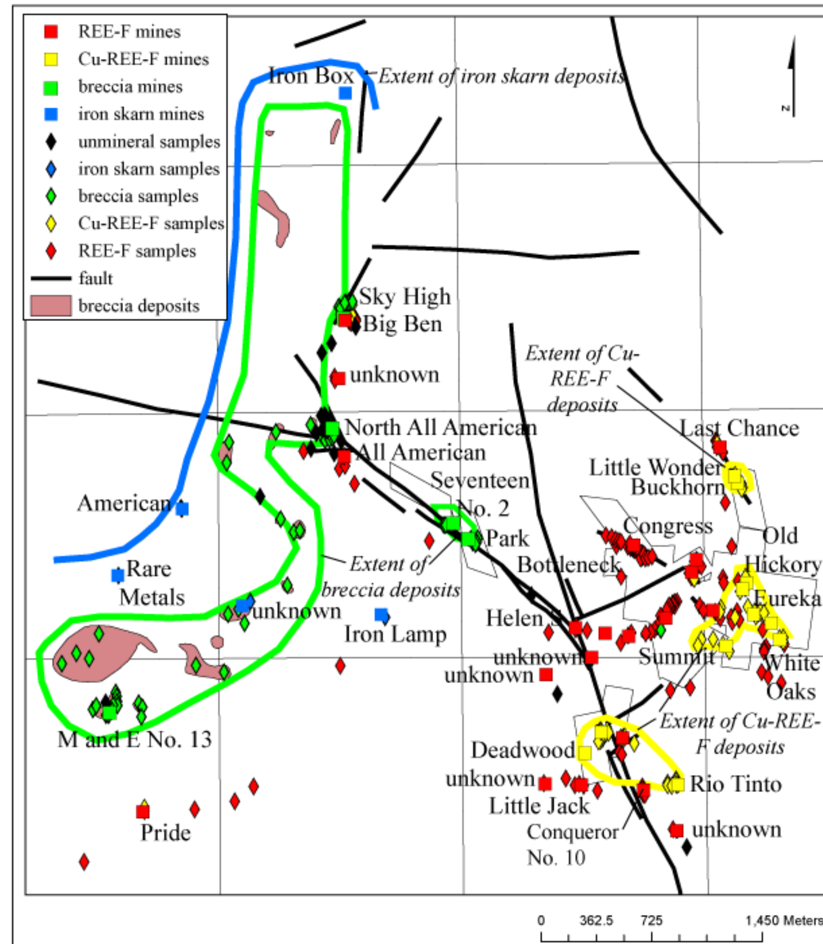


Occurrences of Rare Earth Elements (REE) in New Mexico

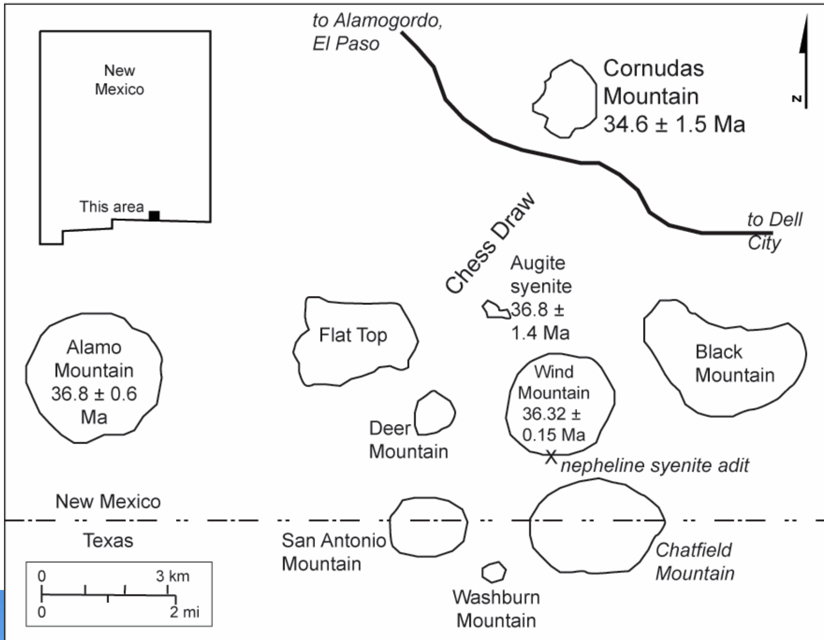


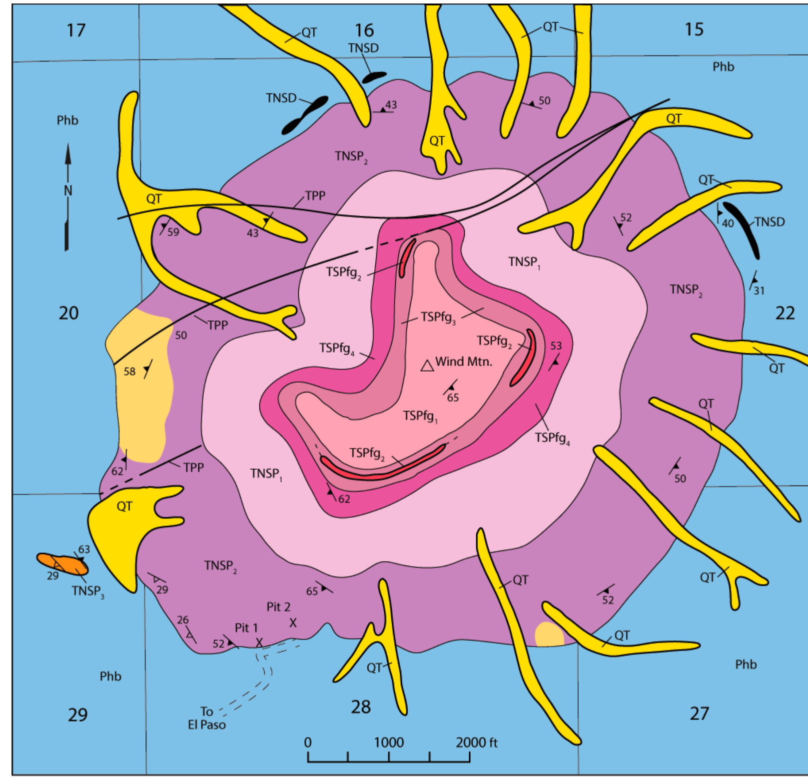
REE in Gallinas Mountains, Lincoln County





REE in Cornudas Mountains, Otero County





QUAT.

QT	Talus and fan deposits

TERTIARY

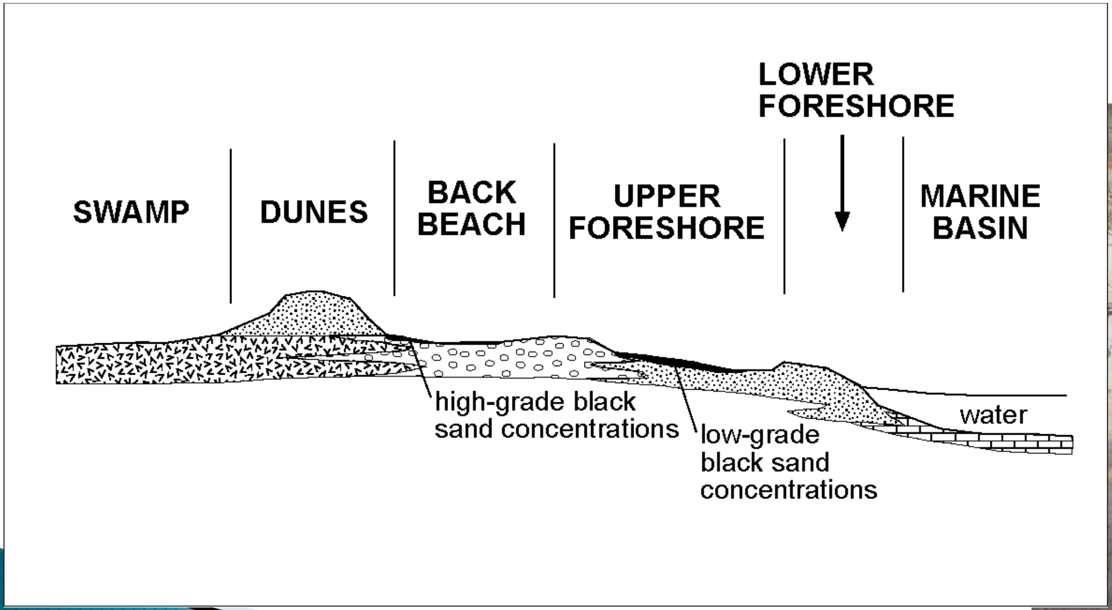
(dashed line)	Phonolite Dike—Porphyritic
TNSP1	Syenite Porphyry—fine-grained, contains minor interstitial analcite plus accessory aegirine-soda amphibole-biotite and magnetite in a feldspar rich groundmass
TPfg2	Syenite Porphyry—fine-grained, contains dominant feldspar enclosing aegitine-soda amphibole-biotite.
TSPfg2	Syenite Porphyry—fine-grained, contains dominant feldspar enclosing aegitine-soda amphibole-biotite. The zone is more mafic than $TSPfg_1$
TSPfg3	Syenite Porphyry—fine-grained, contains moderate interstial analcite plus accessory aegirine-soda amphibole-biotite and magnetite in a feldspar richground-mass
TNP1	Nepheline-Syenite Porphyry—course-grained alkali-feldspar phenocrysts in a matrix of dominant feldspar with moderate interstitial nepheline and analcime plus accessory argirine-soda-amphibole and minor magnetite
TNSP2	Nepheline-Syenite Porphyry—medium-grained alkali-feldspar phenocrysts in a matrix of dominant feldspar with moderate interstitial nepheline and minor analcime plus accessory argirine-soda-amphibole-biotite and minor
(pale yellow)	Mafic—zonation/lamination
TNSP3	Nepheline-Syenite Porphyry—medium-grained alkali-feldspar is present as subhedral blocky prisms. Intersitial nepheline plus accessory arfedsonite-aegirine and minor magnetite are present in a feldspar rich groundmass. The orientation of the feldspar crystals are vertical rather than flat (as in the main intrusive mass), suggesting a different intrusive limestone
(black)	Nepheline-Syenite Dikes—fine-grained massive crystalline dike-like bodies outcrop around the stock in the hornfels facies of the limestone

PERMIAN

Phb	Limestone—Hueco Fm. and Bone Spring Fm. limestone undifferentiated. Near the contact with the stock, the limestone is altered to a hornfels facies by contract metamorphism.
X	Nephaline-syenite pits

Beach-placer sandstone deposits

- 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
- Known in the industry as mineral sands



Modern beach-placer sandstone deposits in Virginia

Beach-placer sandstone deposits

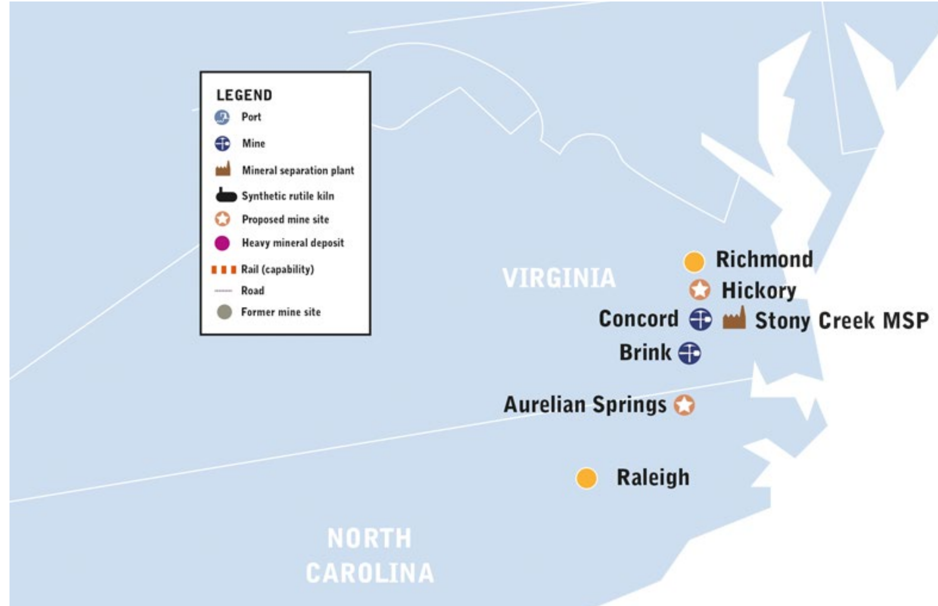
- Formed by mechanical concentration (i.e. settling) of heavy minerals by the action of waves, currents, and winds
- Composed of rutile, titanite, ilmenite, zircon, magnetite, monazite, apatite, xenotime, garnet, and allanite, among other minerals
- Ti, Zr, Fe are important economically
- Nb, Th, U, Sc, Y, and REE also can be important

Modern beach-placer sandstone deposits in Virginia

Modern examples

- Atlantic Coast, USA
- southeastern Australia
- Andhra Pradesh, India

- Mined for titanium, zircon, and monazite (a Ce-bearing REE mineral)



Stony Creek beach-placer sandstone deposit, Virginia

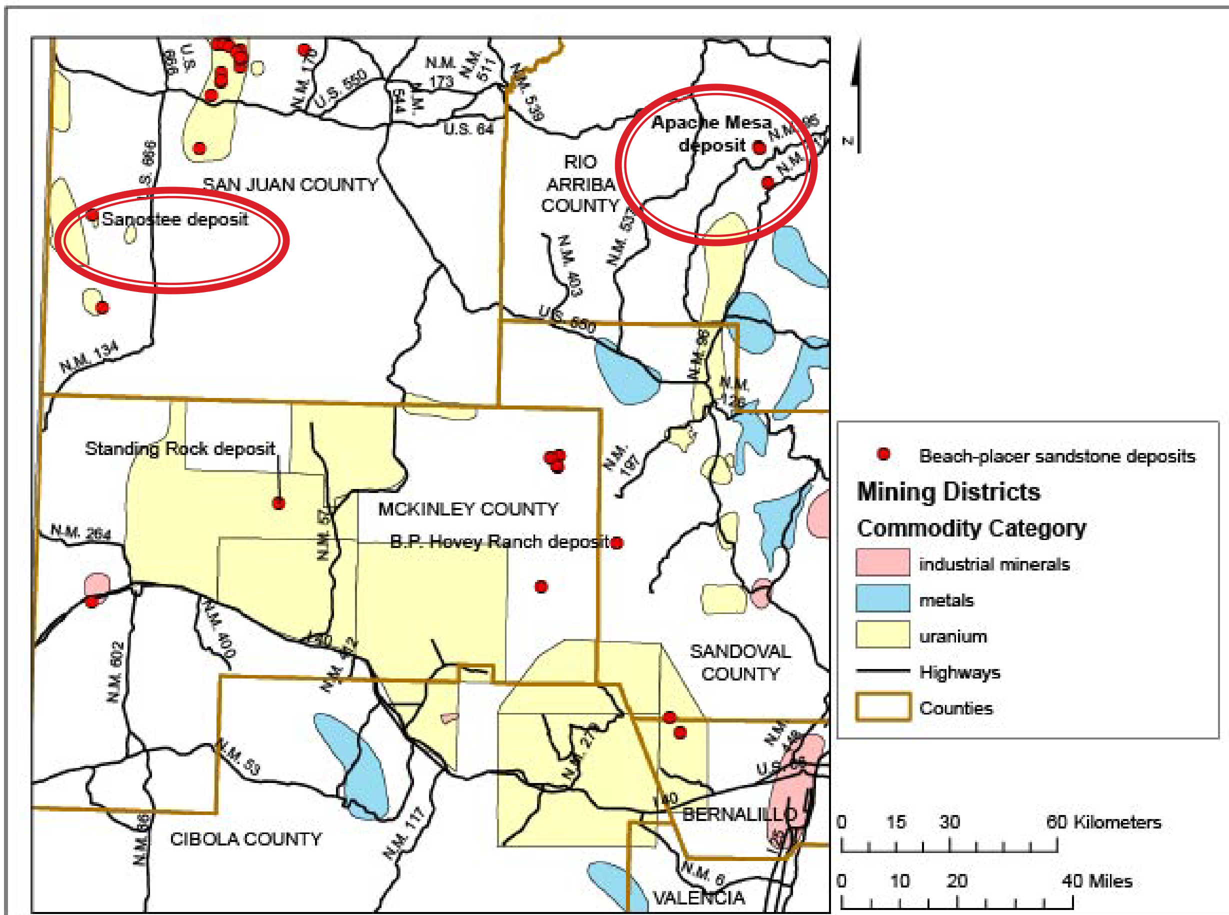
Economics of modern mineral sands

- Economic deposits are 10 million tons of >2% heavy minerals

- Zirconium as zircon (1-50%)
  - Ceramic tiles, bricks used to line steel making furnaces, alloying agent in steel, laboratory crucibles
- Titanium as ilmenite (10-60%), rutile, leucoxene (titanium, 5-25%)
  - alloys in aircraft, white pigment found in toothpaste, paint, paper, glazes, and some plastics, heat exchangers in desalination plants, welding rods
- REE as monazite $(Ce,La,Y,Th)PO_4$) (<15%)
  - Catalyst, glass, polishing, re-chargeable batteries, magnets, lasers, glass, TV color phosphors, wind turbines
- Other minerals
  - Garnet, starolite, kyanite trace-50%

New Mexico

Beach-placer sandstone deposits in the San Juan Basin are restricted to Late Cretaceous rocks belonging to the Gallup, Dalton, Point Lookout, and Pictured Cliffs Sandstones



Resources are estimated by the USBM as 4,741,200 short tons of ore containing 12.8% TiO_2, 2.1% Zr, 15.5% Fe and less than 0.10 ThO_2 with some REE (USBM files)

Sanostee deposit, San Juan County

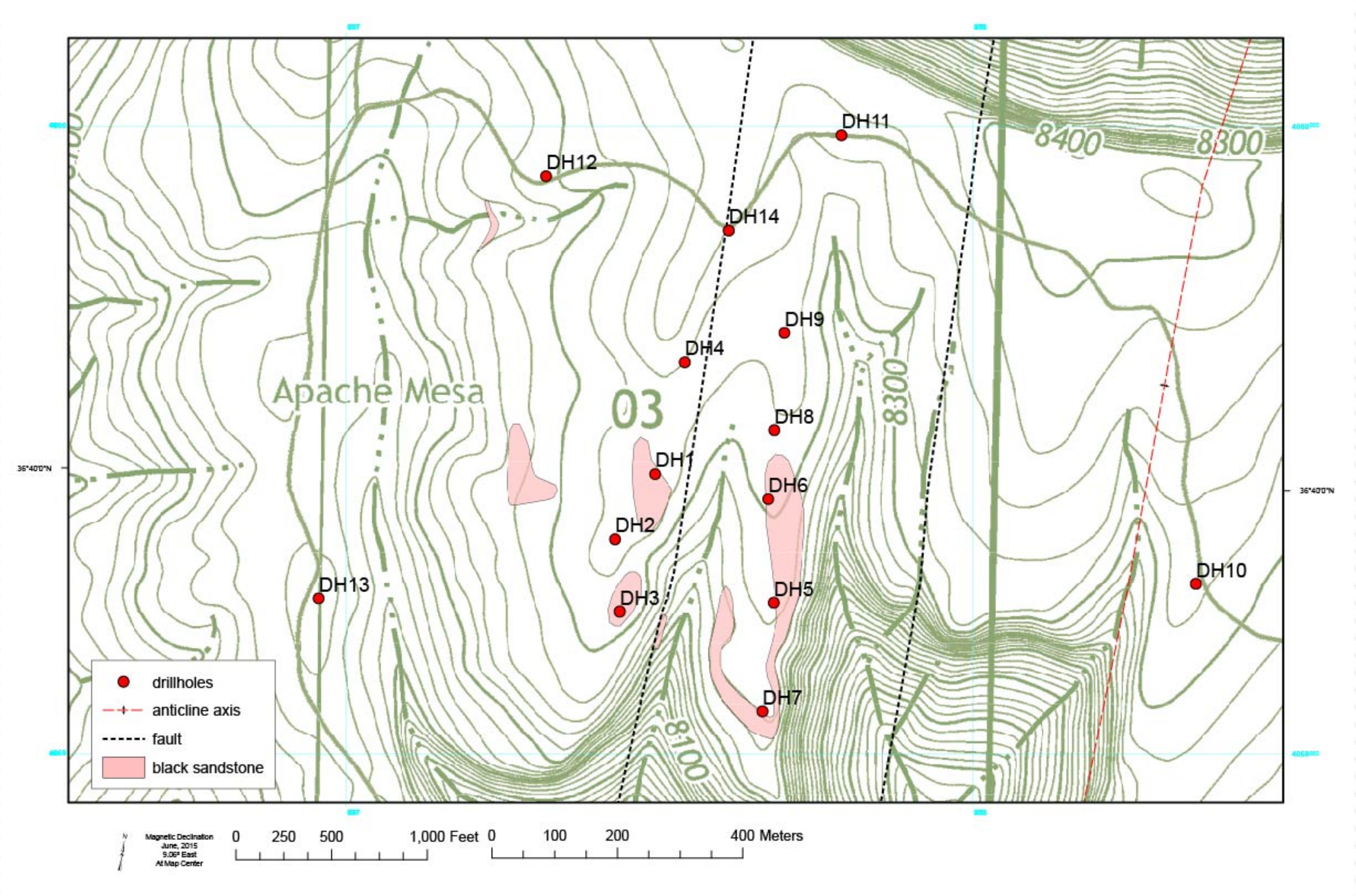
Apache Mesa, Jicarilla Indian Reservation

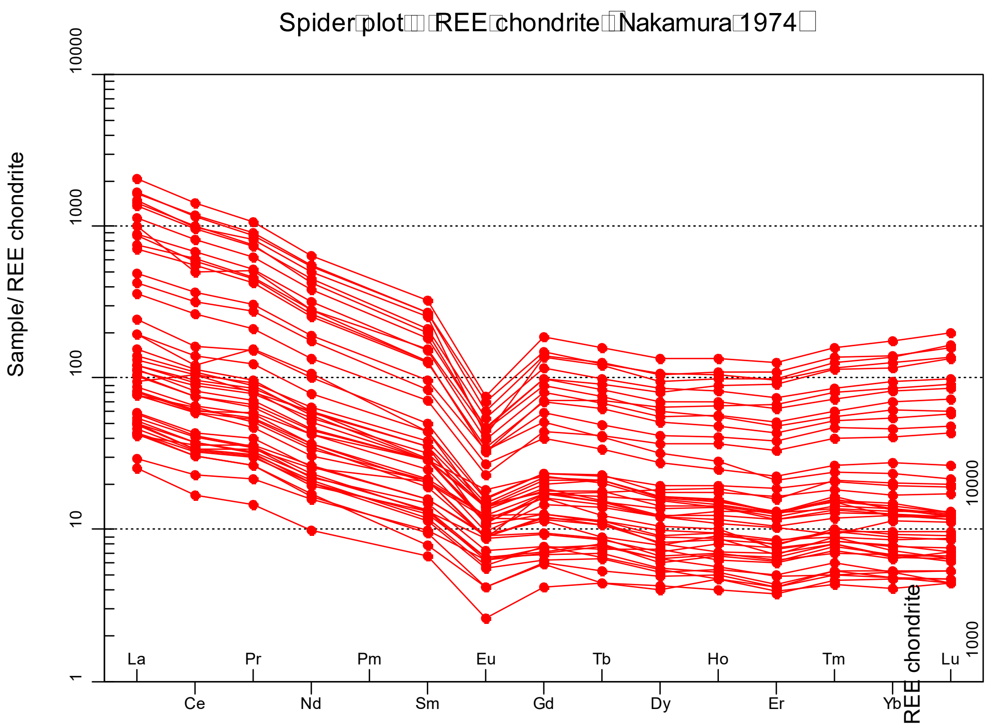
Drilled in August 2015

Small footprint with little land disturbance

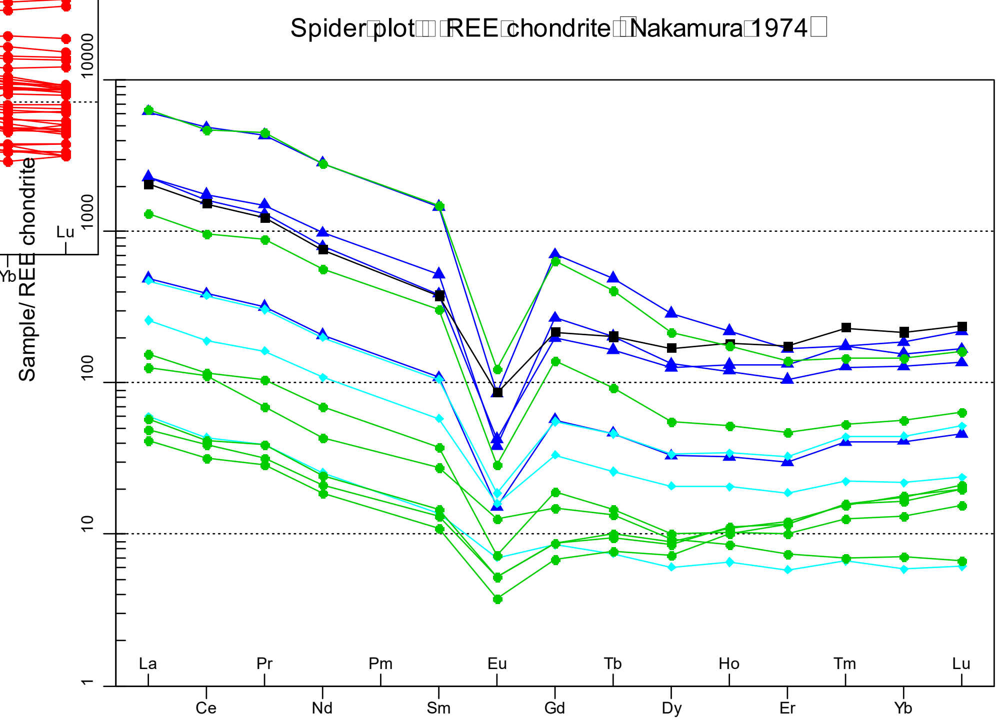
CS 14 track drill rig by Layne Drilling Co.

Apache Mesa drill holes





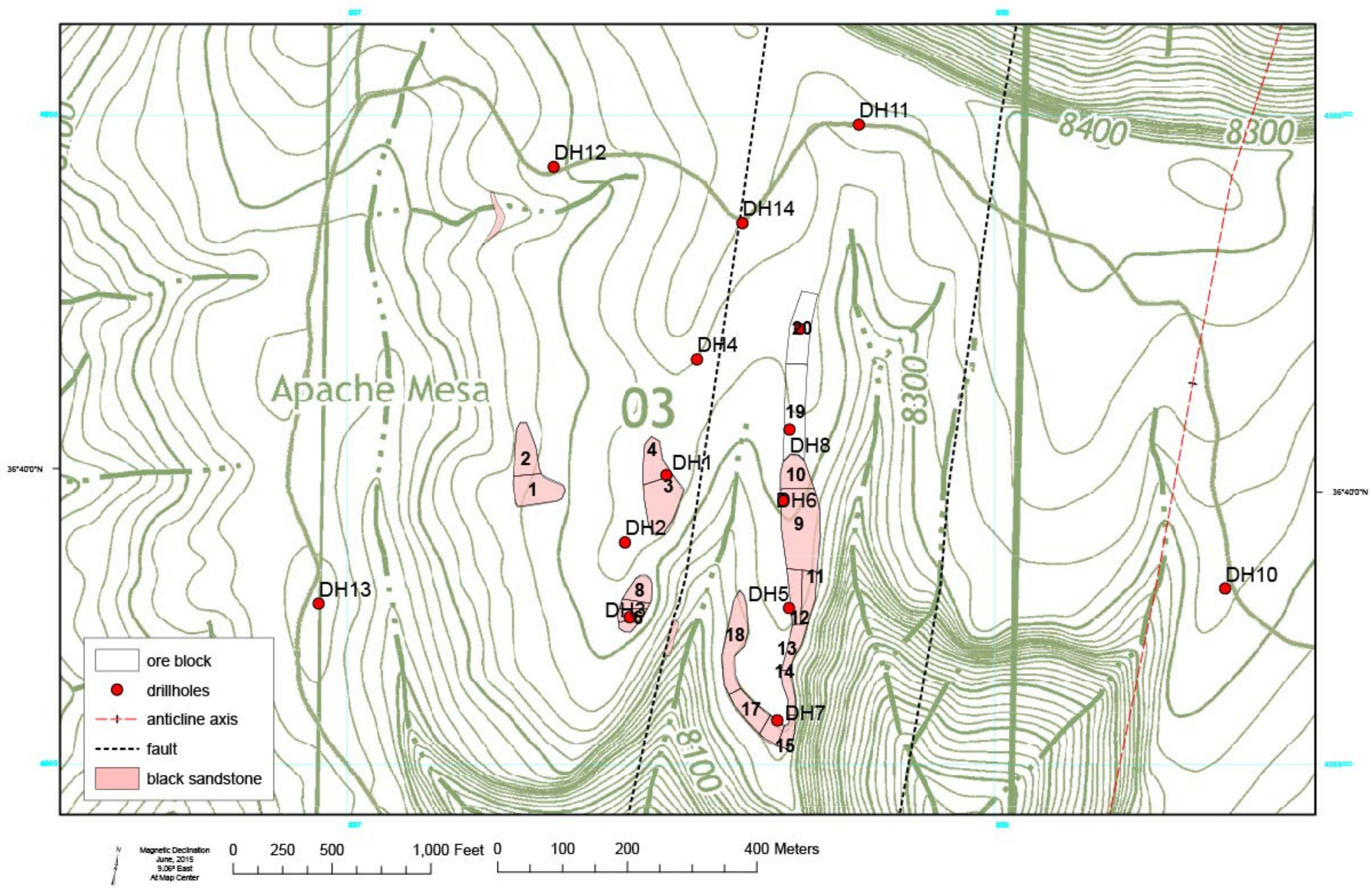
GEOCHEMISTRY

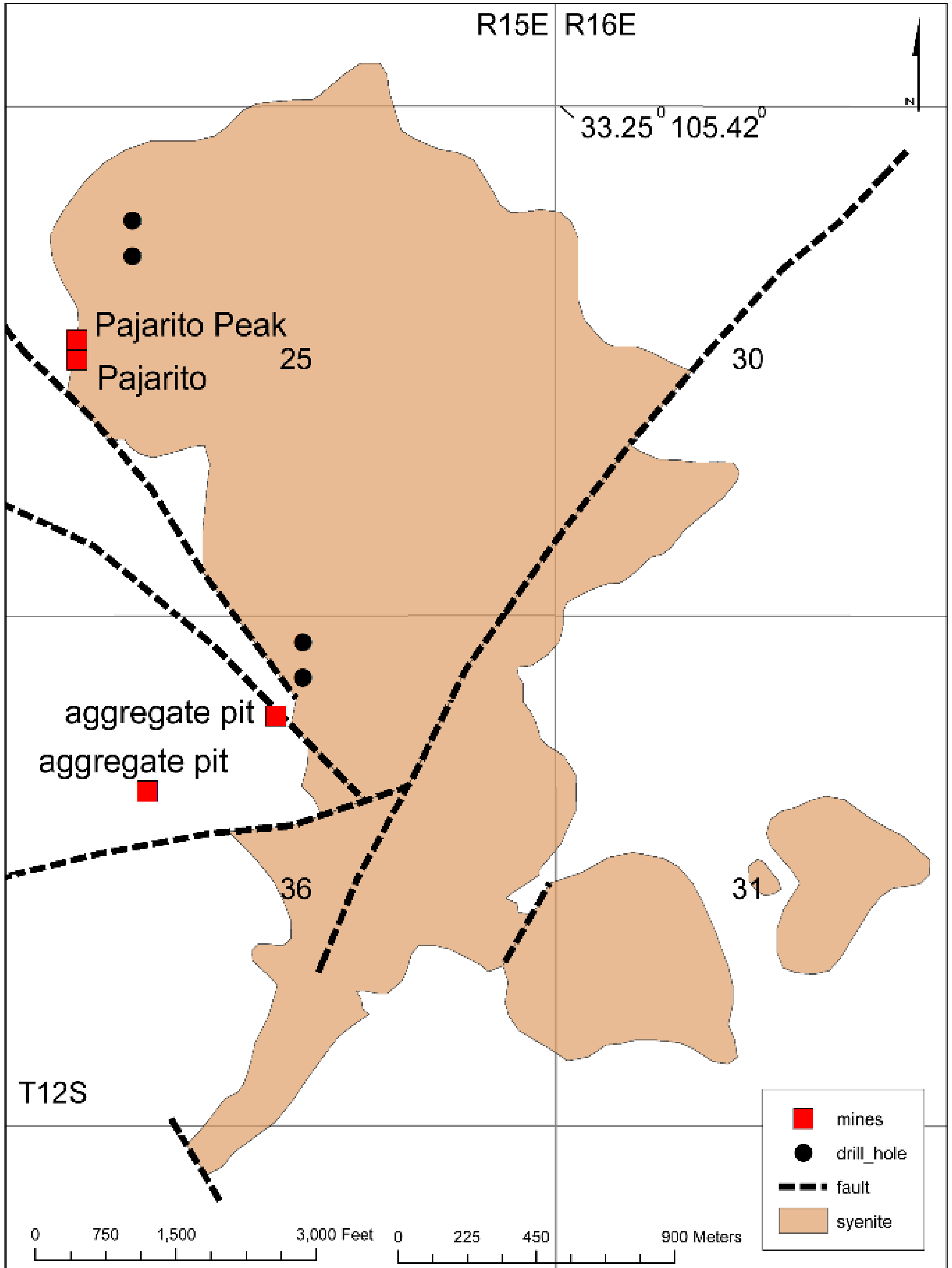


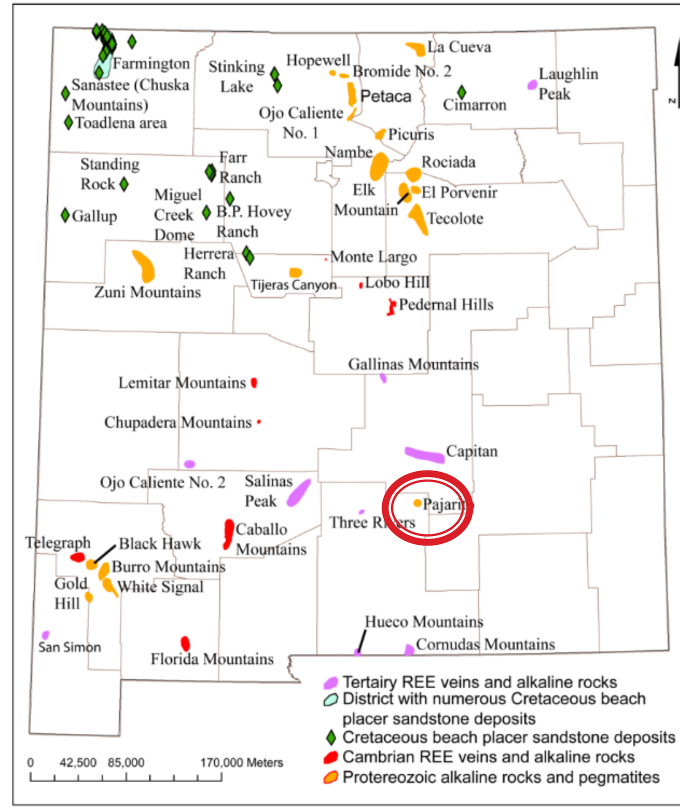
Chondrite-normalized REE plot of selected beach-placer deposits, Apache Mesa (red), Standing Rock (light blue), Sanostee (dark blue), and B.P. Hovey (black), San Juan Basin, New Mexico. Chondrite values are from Nakamura (1974).

Economics of Apache Mesa deposit

132,900 short tons (120,564 metric tons) of ore with grades of 3% TiO_2, 108 ppm Cr, 46 ppm Nb, 2,187 ppm Zr, 40 ppm Th, and 522 ppm TREE







Proterozoic Pajarito Mountain, Mescalero, NM

Proterozoic Pajarito Mountain

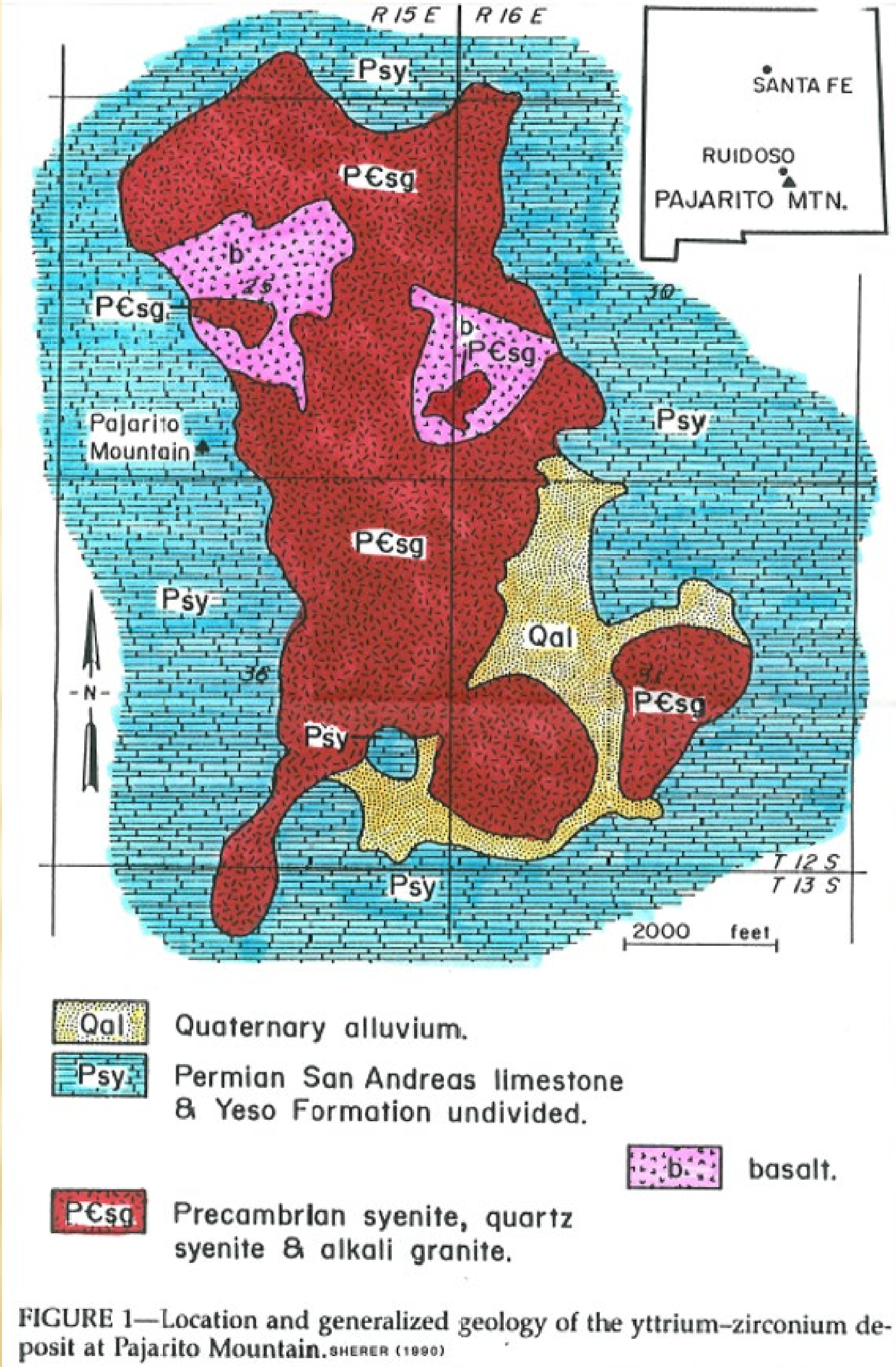
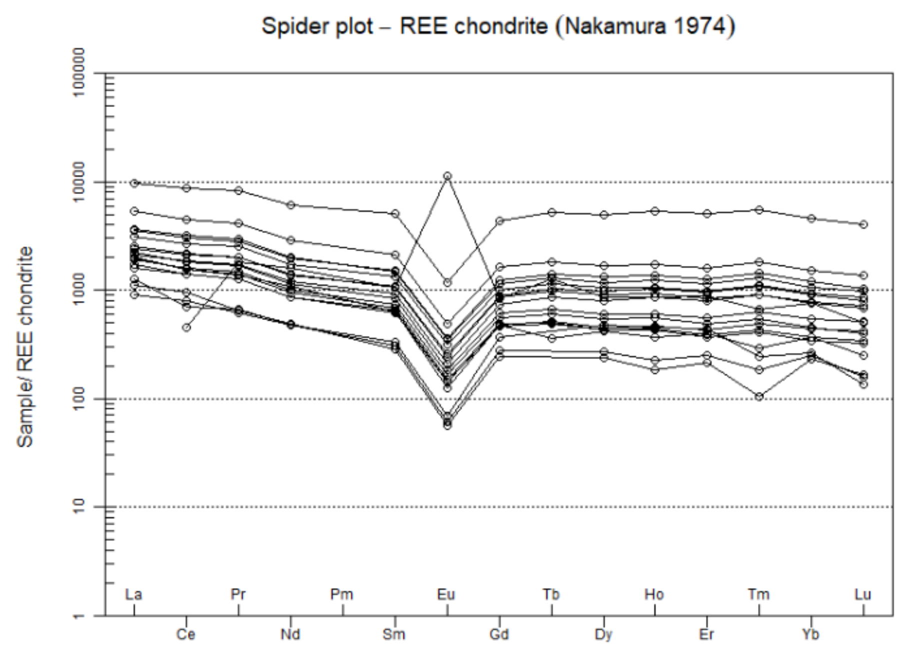


FIGURE 1—Location and generalized geology of the yttrium–zirconium deposit at Pajarito Mountain. SHERER (1990)

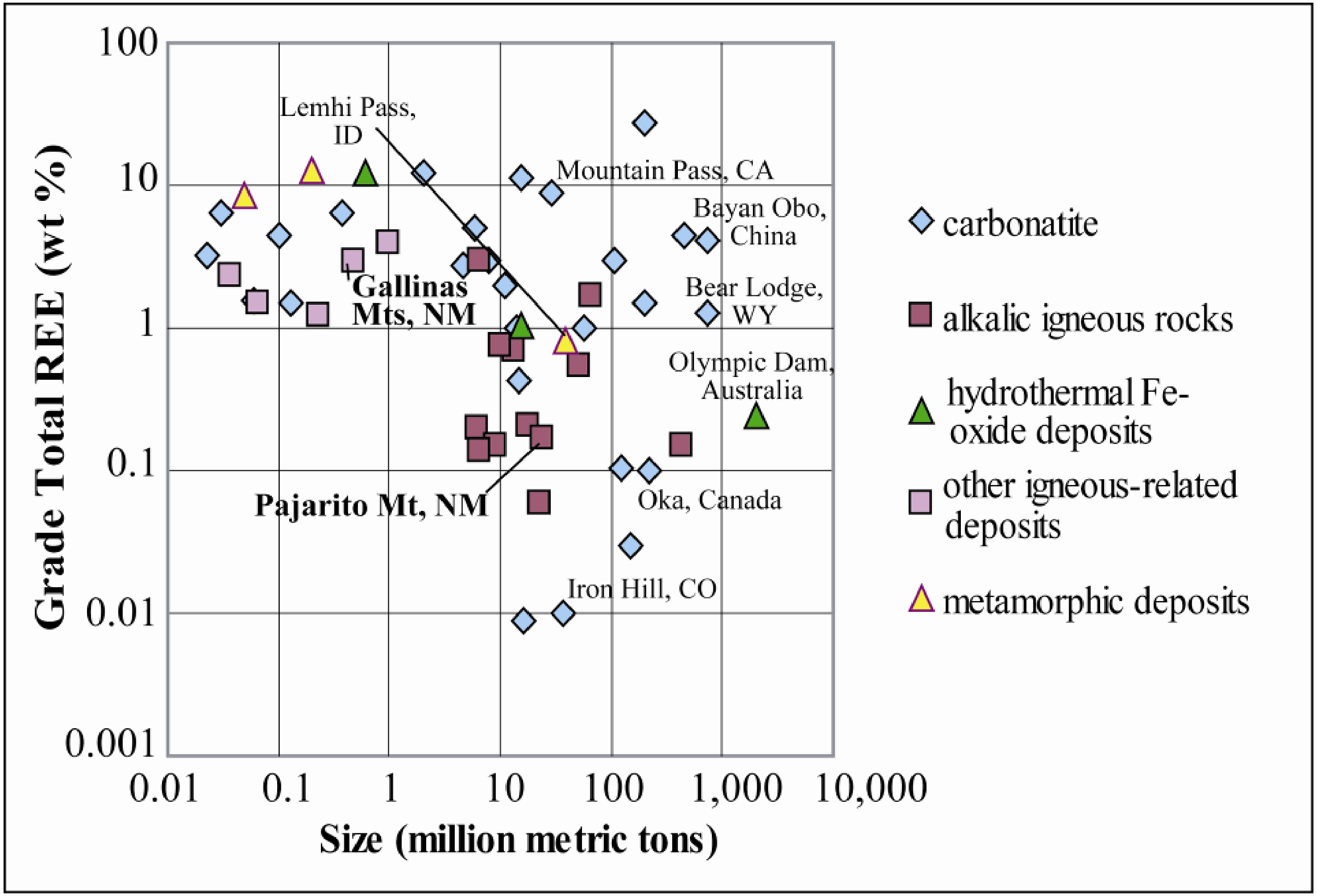


Mineralogy Proterozoic Pajarito Mountain (Berger, 2018)

- Eudialyte $Na_4(Ca,Ce)_2(Fe^{++},Mn,Y)ZrSi_8O_{22}(OH,Cl)_2$
- Fluorite CaF_2
- Apatite $Ca_5(PO_4)_3(OH,F,Cl)$ (with U, Th)
- Zircon ZrSiO4 (with U, REE)
- 2 REE-bearing silicates

Proterozoic Pajarito Mountain

- 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
- Historic REE resources—537,000 short tons of 2.95% total REE (Jackson and Christiansen, 1993)



Grade and size (tonnage) of selected REE deposits, using data from Oris and Grauch (2002) and resources data from Jackson and Christiansen (1993). Deposits in bold are located in New Mexico.

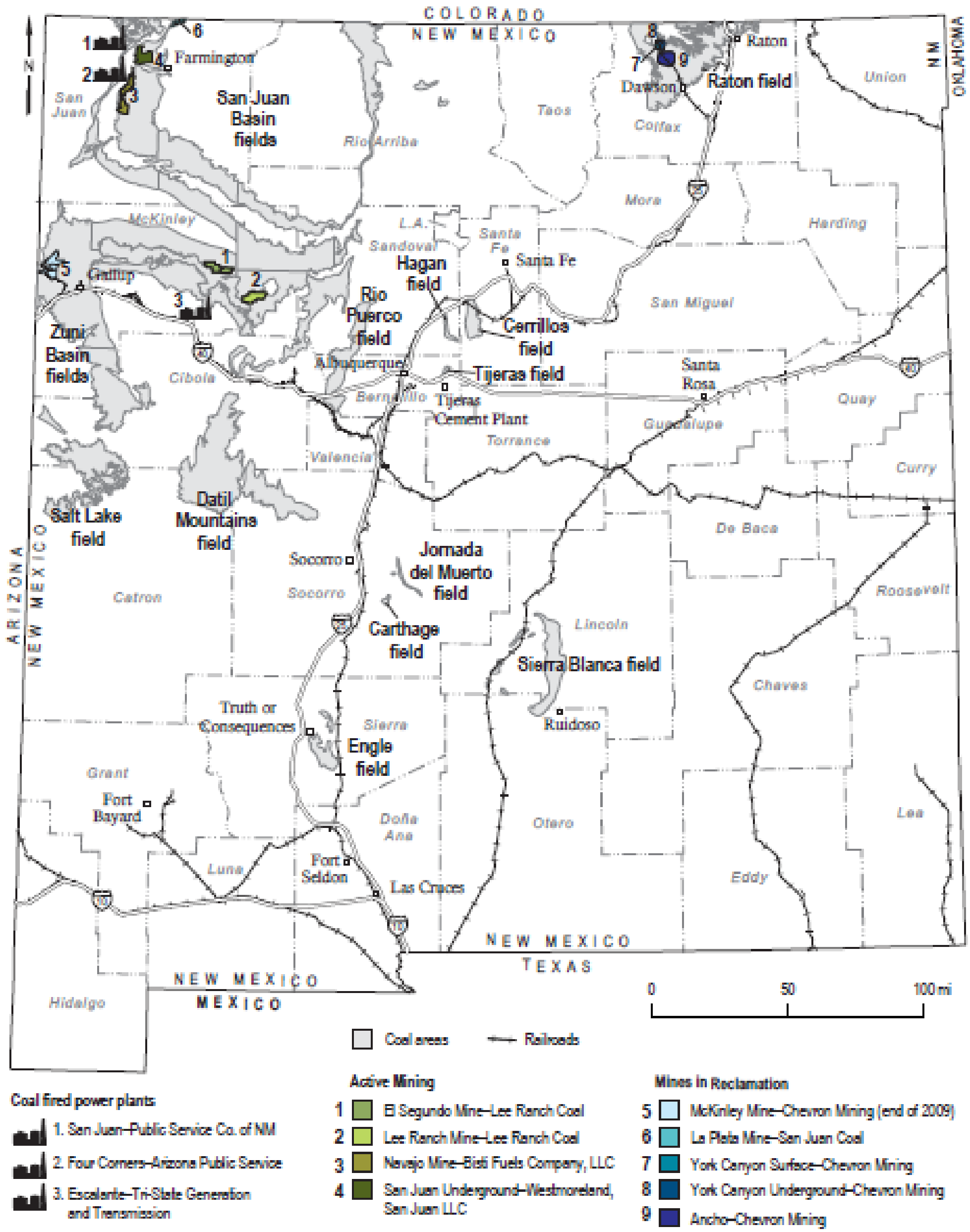
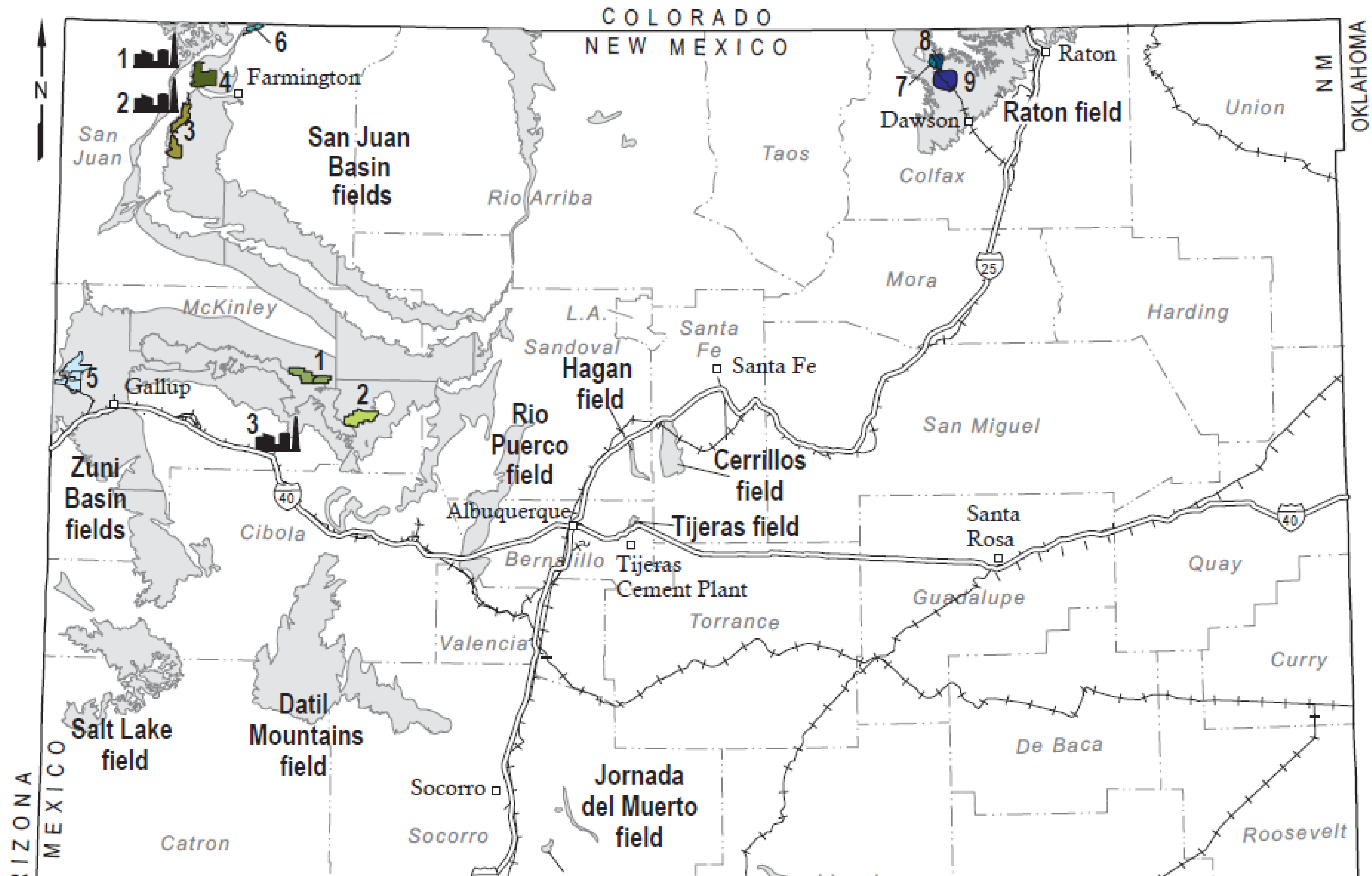


Figure 3. Coal fields of New Mexico, from Hoffman et al. (2009). Mines are surface operation unless specifically noted in legend. Lee Ranch Mining suspended in 2016.

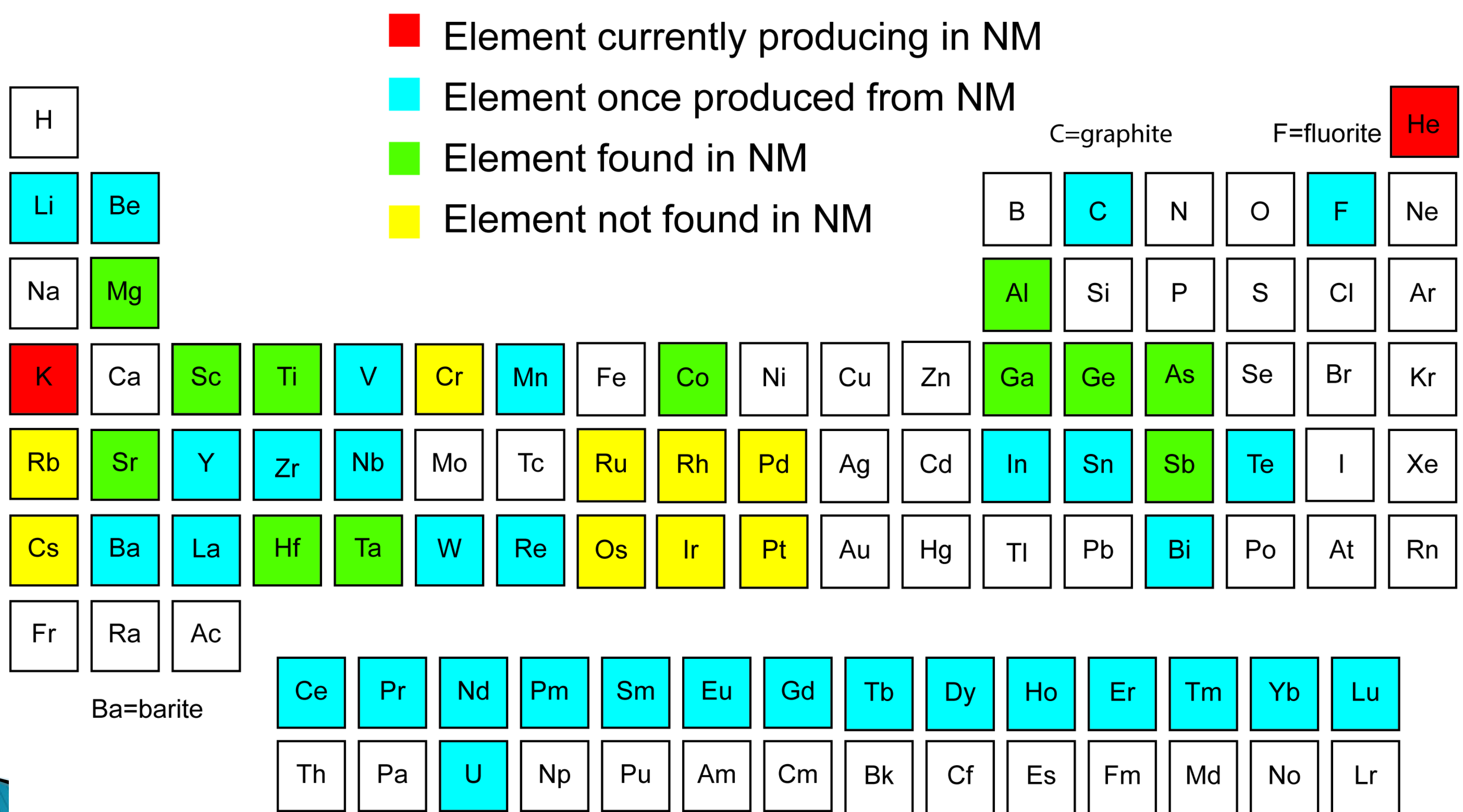
New project awarded by the DOE—REE and other critical minerals in coal deposits



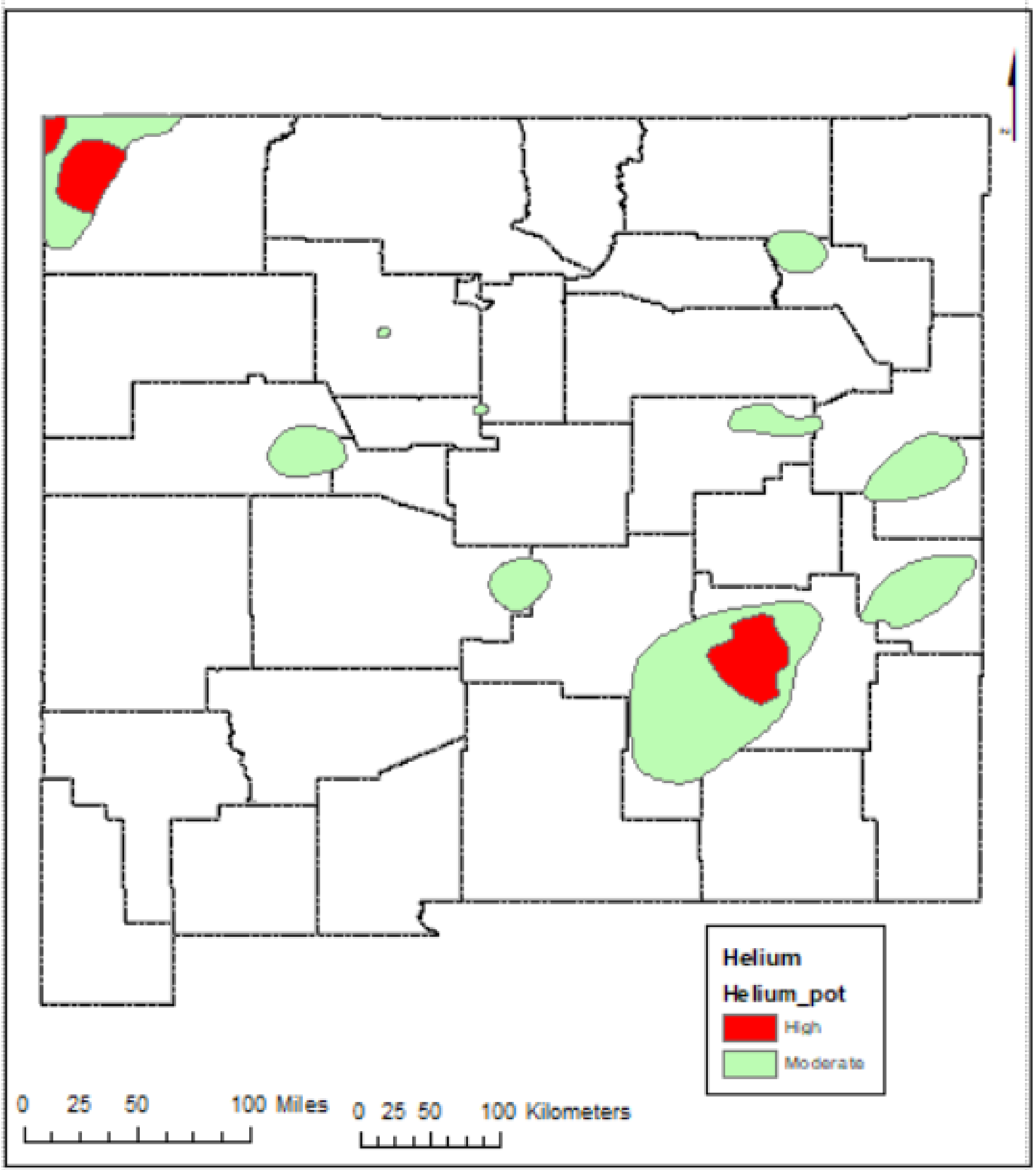
Coal has potential for REE, Co, Ga, Ge, and other CM

Potential for other critical minerals in San Juan Basin (helium, Li, graphite, etc.)

Critical Minerals in New Mexico

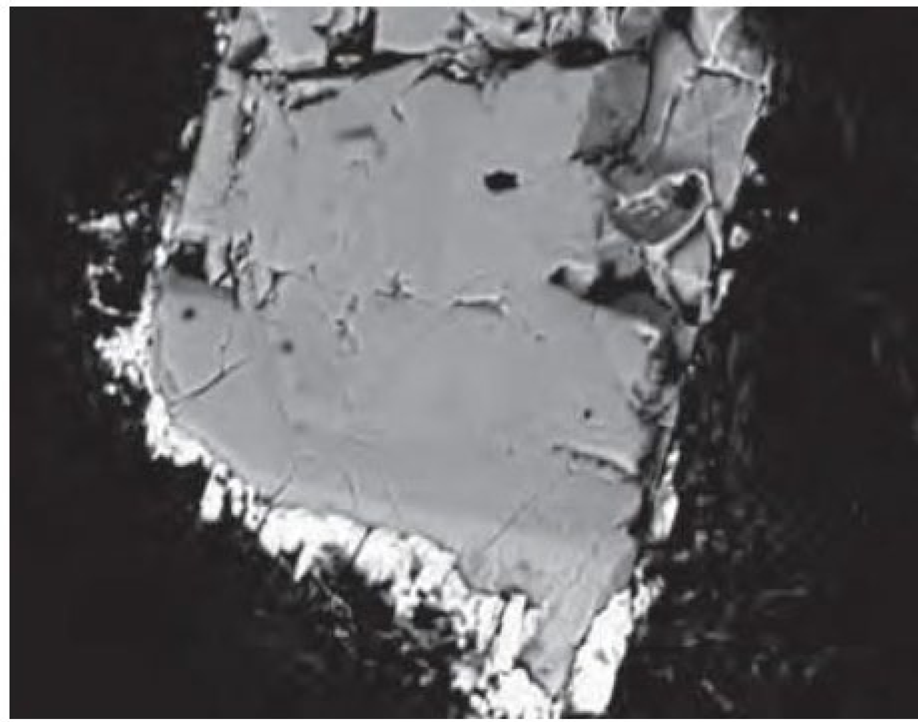


Note that any element or commodity can be considered critical in the future depending upon use and availability. Coal contains several of these critical elements.



Helium potential in New Mexico

Another potential source are mine wastes (mine rock piles, coal ash, tailings, acid mine drainage, etc.) at inactive mines and abandoned mine lands likely have potential for Critical Minerals, including REE, that could be recovered and pay for cleanup costs



Backscattered electron image of an REE-rich overgrowth (clearly visible here as a bright white band) on a zoned magmatic zircon. Field of view is 150 micrometers (0.15 mm).

What are the challenges in producing critical minerals?

- Meeting the demand (quick change in supply and demand difficult for mines to meet)
- Permitting
- Fear that producing a byproduct could jeopardize production of major commodity
- Environmental issues
  - Many are associated with U/Th (radioactivity)
- Financing for both exploration/mining and development of new products
- Social license to operate
- Local infrastructure 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).

What types of careers are needed?

- Geologists, engineers, mineralogists, hydrologists
- Drillers for exploration
- Mechanics to keep equipment running
- Business men and women to finance these ventures
- Inventors to improve the technology of exploration (drones)
- Inventors to find new uses of commodities to make our life better
- Reclamation specialists to reclaim the mine sites when mining is completed
- Government regulators

CONCLUSIONS

- Evaluation of CM and REE in NM is important to understand what is available in order to make appropriate land use decisions
- As the economics for some of these elements increases because of increased demand and short supplies, the dollar value per ton of ore may rise, enhancing deposit economics
- Ultimately, economic potential will most likely depend upon production of more than one commodity and more than one deposit in NM