# ME571/GEO571 Geology of Industrial Minerals Spring 2018

Commodities, Part 5

strontium, sodium sulfate, trona (soda ash), talc, lithium, summary comments

# Safety

# *Reminders*

- Commodity presentations—send me your powerpoints
- April 28 AIPG meeting and Field trip in afternoon (perlite mine or carbonatites)
- Research Projects presentation April 30
- Finals, written Project due May 4
- No class May 7

# Strontium

# Strontium—introduction

- Sr
- 15th abundant element
- does not occur naturally as an element, in compounds
- No production in the United States since 1959
- celestite or celestine $SrSO4$ (same structure as barite) 56.4% Sr
- strontianite $SrCO_3$, 70.1% Sr

# Celesitite

http://www.zeuter.com/~tburden

# Strontianite

http://www.zeuter.com/~tburden

Strontium and strontianite are named after Stronian, a village in Scotland near which the mineral was discovered in 1790 by Adair Crawford and William Cruickshank

A critical mineral

# Strontium—uses

- faceplate glass of color television picture tubes, 77%
- **ferrite ceramic magnets**, 8%
- pyrotechnics and signals, 9%
  - fireworks (red flame)
  - flares
- other applications, 6%
  - refining zinc
  - optical materials

# Strontium—production

| Salient Statistics—United States: | 2013 | 2014 | 2015 | 2016 | 2017[e] |
|---|---|---|---|---|---|
| Production | — | — | — | — | — |
| Imports for consumption: | | | | | |
| Celestite[1] | 21,900 | 24,200 | 24,500 | 4,420 | 10,800 |
| Strontium compounds[2] | 7,190 | 7,600 | 7,100 | 6,420 | 6,390 |
| Exports, strontium compounds | 37 | 104 | 86 | 91 | 49 |
| Consumption, apparent: | | | | | |
| Celestite | 21,900 | 24,200 | 24,500 | 4,420 | 10,800 |
| Strontium compounds | 7,160 | 7,500 | 7,020 | 6,330 | 6,340 |
| Total | 29,000 | 31,700 | 31,500 | 10,800 | 17,200 |
| Price, average value of celestite imports at port of exportation, dollars per ton | 50 | 50 | 51 | 78 | 73 |
| Net import reliance[3] as a percentage of apparent consumption | 100 | 100 | 100 | 100 | 100 |

**Recycling:** None.

USGS Mineral Yearbooks metric tons

| Salient Statistics—United States: | 2013 | 2014 | 2015 | 2016 | 2017[e] |
|---|---|---|---|---|---|
| Production | — | — | — | — | — |
| Imports for consumption: | | | | | |
| Celestite[1] | 21,900 | 24,200 | 24,500 | 4,420 | 10,800 |
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| Net import reliance[3] as a percentage of apparent consumption | 100 | 100 | 100 | 100 | 100 |

**Recycling:** None.

# Strontium—geology

- association with rocks deposited by the evaporation of sea water (evaporites)
- igneous rocks
- Brines

- Barite and calcite must be removed—costly

# Sodium sulfate

# Sodium sulfate—introduction

- disodium sulfate ($Na_2SO_4$),
- inorganic chemical
- Thenardite $Na_2SO_4$
- Hanksite $Na_22K(SO_4)_9(CO_3)2Cl$
- Glauberite $Na_2Ca(SO_4)_2$

# Sodium sulfate—uses

- soap and detergents, 46%
- textiles, 12%
- pulp and paper, 13%
- glass, 11%
- carpet fresheners, 7%
- miscellaneous, 11%

# Sodium sulfate—reserves

- Botswana
- China
- Egypt
- Italy
- Mongolia
- Romania
- South Africa

USGS Mineral Yearbooks

# Sodium sulfate—geology

- brines or crystalline evaporite deposits
- 10 ft thick deposit 1400 ft below the surface near Green River, Wyoming
- Searles and Owens Lakes in California
  - 450 million tons of sodium sulfate resource
- Great Salt Lake, Utah
  - 400 million tons of resource

# Sodium sulfate—byproduct

- byproduct from the production of ascorbic acid, boric acid, cellulose, chromium chemicals, lithium carbonate, rayon, resorcinol, and silica pigments

# Glauberite

http://mineral.galleries.com/m...

# Searles Lake

http://www.bovagems.com/eclectic/HTML/19971001_1097BOVA2.html

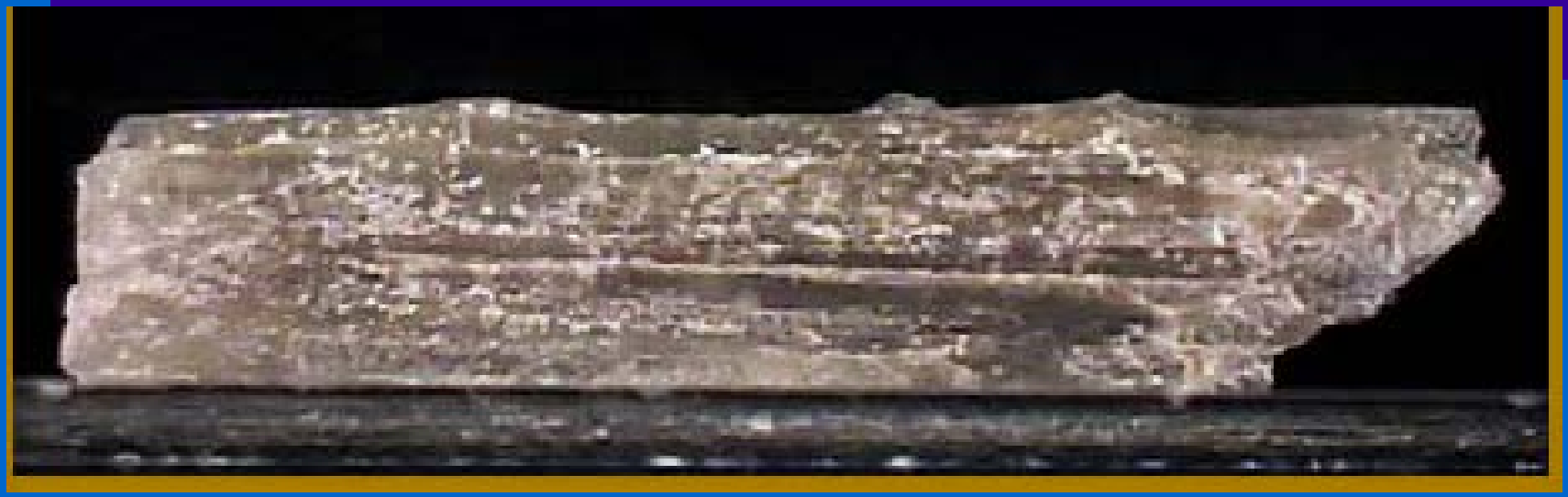
# Soda ash (Trona, Baking Soda)

# Soda ash—introduction

- sodium carbonate ($Na_2CO_3$)
- Trona ($Na_2CO_3 \cdot NaHCO_3 \cdot 2H_2O$)
- nahcolite ($NaHCO_3$)
- Gaylussite $Na_2Ca(CO_3)_2 - 5H_2O$
- mixture of various salts and other trace impurities (including sand, clay and metals such as potassium, silicon, magnesium, calcium, iron, aluminum and titanium)
- Nonflammable
- white, yellow, brown or gray
- no notable odor
- Decomposes beginning at 70oC

# Trona

http://mineral.galleries.com/minerals/carbonat/trona/trona.jpg



# Trona

http://www.trainweb.org/wyomingrails/wymining/trona.html

# Gaylussite

http://mineral.galleries.com/minerals/carbonat/gaylussi/gaylussi.jpg

- baking soda is produced from soda ash, or sodium carbonate
- Also sodium bicarbonate, bicarbonate of soda, bicarb and sodium bicarb
- used
  - leavening agent for baked products
  - fire retardant
  - cleansing agent
  - degreaser
  - medicine
  - removes moisture and has deodorizing properties

# Ancient uses

- Egyptians used it to make glass ornaments and vessels
- Romans also used soda ash for baking bread, making glass and for medicinal purposes
- extraction from the ashes of various plants continued until the middle of the 19th century and gave it the present-day name of "soda ash"

# Soda ash—uses

- glass, 50%
- chemicals, 27%
- soap and detergents, 11%
- distributors, 6%
- flue gas desulfurization and pulp and paper, 2% each
- water treatment, 1%
- other, 1%
  - baking soda

# Soda ash—production

| Salient Statistics—United States: | 2013 | 2014 | 2015 | 2016 | 2017[e] |
|---|---|---|---|---|---|
| Production[2] | 11,500 | 11,700 | 11,600 | 11,800 | 11,800 |
| Imports for consumption | 13 | 39 | 40 | 35 | 24 |
| Exports | 6,460 | 6,670 | 6,400 | 6,780 | 6,870 |
| Consumption: | | | | | |
| Apparent[3] | 5,000 | 5,100 | 5,200 | 5,010 | 4,950 |
| Reported | 5,120 | 5,170 | 4,990 | 5,120 | 4,900 |
| Price: | | | | | |
| Average sales value (natural source): | | | | | |
| f.o.b. mine or plant, dollars per metric ton | 145.18 | 148.67 | 155.30 | 149.83 | 152.00 |
| f.o.b. mine or plant, dollars per short ton | 131.71 | 134.87 | 140.88 | 135.92 | 138.00 |
| Stocks, producer, yearend | 348 | 271 | 285 | 336 | 296 |
| Employment, mine and plant, number[e] | 2,500 | 2,500 | 2,500 | 2,500 | 2,500 |
| Net import reliance[4] as a percentage of apparent consumption | E | E | E | E | E |

**Recycling:** No soda ash was recycled by producers; however, glass container producers are using cullet glass, thereby reducing soda ash consumption.

USGS Commodity Summaries metric tons

**World Production and Reserves:** Reserves for Turkey were revised based on new Government information.

| | Mine production | | Reserves[5, 6] |
|---|---|---|---|
| Natural: | 2016 | 2017[e] | |
| United States | 11,800 | 11,800 | [7]23,000,000 |
| Botswana | 250 | 250 | 400,000 |
| Kenya | 450 | 450 | 7,000 |
| Turkey | 1,900 | 2,100 | 840,000 |
| Other countries | — | 15,000 | 280,000 |
| World total, natural (rounded) | 14,400 | 15,000 | 25,000,000 |
| World total, synthetic (rounded) | 39,200 | 39,000 | XX |
| World total (rounded) | 53,600 | 54,000 | XX |

# Soda ash—geology

- Bedded lacustrine deposits
- bedded trona and disseminated shortite and locally abundant halite in the Wilkins Peak Member of the Green River Formation
  - 82 billion short tons of trona
  - 53 billion tons of mixed trona and halite
- nahcolite is found in the Parachute Creek Member of the Green River Formation
  - 32 billion short tons

# Wyoming

- 50-60 million years ago during the Eocene Age in the Wilkins Peak Member of the Green River Formation
- freshwater lake, Lake Gosiute, covered an estimated 15,000 square miles
- minerals and mud settled in the bottom of the lake and sodium, alkaline and bicarbonate, were transported to the lake by runoff water
- Green River formation with 42 beds that cover about 1,300 square miles

Trona is mined underground, using heavy equipment like the Continuous Miner pictured above. The ore is then carried to the surface and

https://www.wyomingmining.org/minerals/trona/

# Processing

- 3 grades—light, medium and dense
- differ in physical characteristics, such as bulk density and particle size and shape

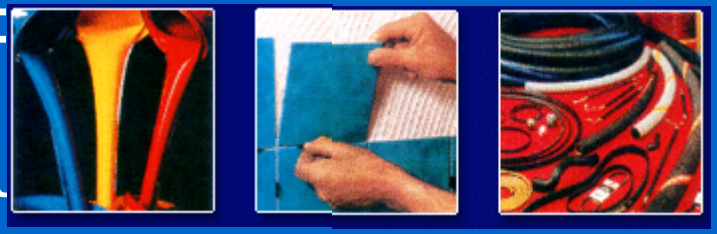
# Environmental issues

- volatile organic compounds and hazardous air pollutants
- nitrogen oxides
- methane

# Talc

# Introduction

Talc is an important industrial mineral, it is a vital part of everyday life. It can be found in:



- the magazines;
- the polymers in our cars and hou
- the paints
- the tiles we walk on

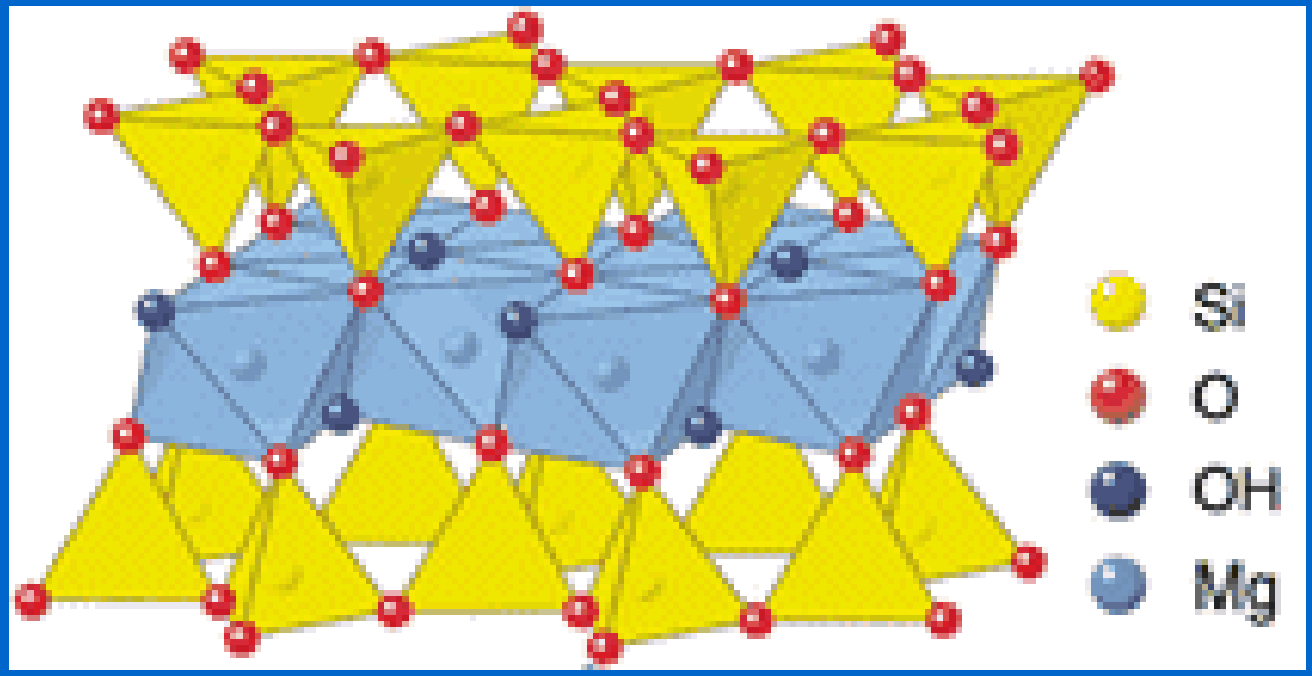
✓ Talc has high heat and chemical resistance, good electrical insulating properties, and improves stiffness and tensile strength, making it useful for use in the plastics and rubber industries.

✓ Low electrical conductivity and acids make it an ideal surface for lab counter tops and electrical switchboards.

It is also an important filler material for paints, rubber and insecticides. It is most known as the primary ingredient in talcum powder.

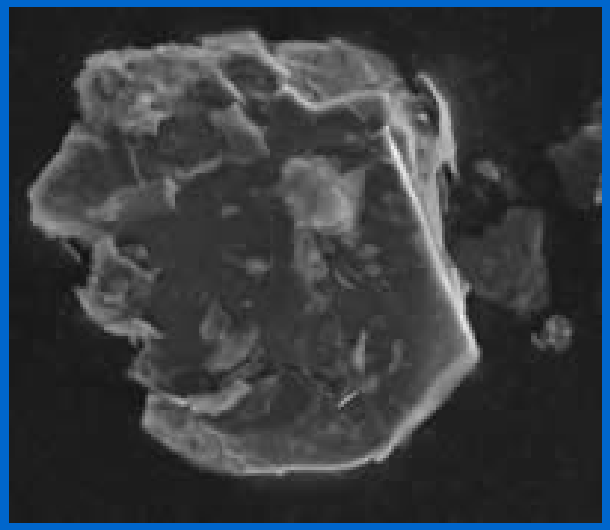
# Mineralogy

Talc is a hydrated magnesium sheet silicate, $Mg_3Si_4O_{10}(OH)_2$. Its elementary sheet is composed of a layer of magnesium-oxygen/hydroxyl octahedra, sandwiched between two layers of silicon-oxygen tetrahedra.

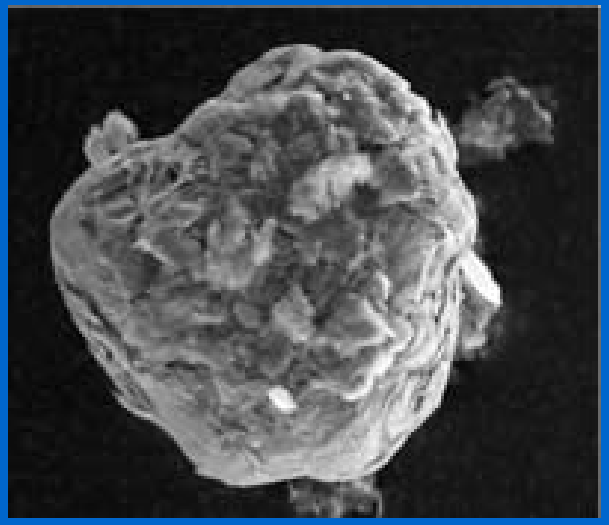


# MORPHOLOGY

The size of an individual talc platelet can vary from approximately 1 micron to over 100 microns depending on the deposit. It is this individual platelet size that determines a talc's lamellarity. The elementary sheets are stacked on top of one another, like flaky pastry, and, because the binding forces linking one elementary sheet to its neighbors are very weak, the platelets slide apart at the slightest touch, giving talc its characteristic softness.



Macro-crystalline talc



Micro-crystalline talc

- Mineral specimens are not very common as it does not form very large crystals
- It often replaces other minerals on an atom by atom basis and forms what are called **pseudomorphs** (false shape).

The talc takes the form of the mineral it replaces. A specimen of what looks like milky quartz is quite a surprise when it not only has a soapy feel but can be scratched by a fingernail.

# Geology

Talc is one of the common minerals in metamorphic rock. Although talc deposits can be found throughout the world in various geological contexts.

Economically viable concentrations of talc are not that common.

Best field indicators are softness, color, soapy feel, luster and cleavage.

Talc deposits result from the transformation of existing rocks under the effect of hydro-thermal fluids carrying one or several of the components needed to form the mineral ($MgO$, $SiO_2$, $CO_2$).

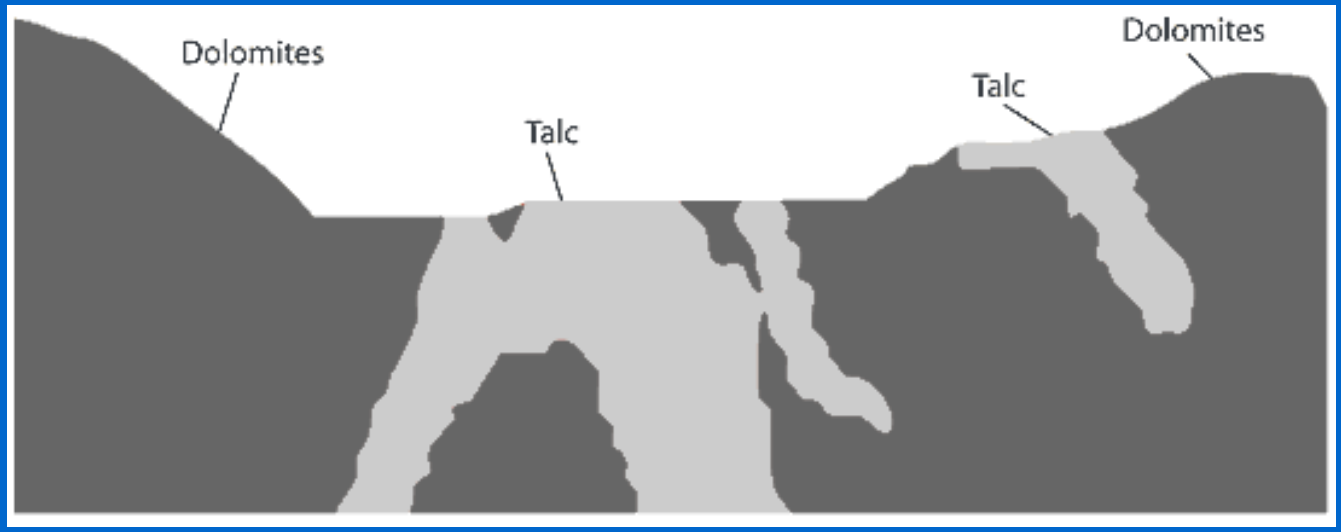
The size and shape of talc deposits depend upon:

- the intensity of the hydrothermal activity
- Pressure and deformations

# Types of talc deposit

**Magnesium carbonate derivative orebodies**

The talc results from the transformation of carbonates (dolomite and magnesite) in the presence of silica. Deposits of this kind represent some 60% of world production and provide some of the whitest and purest talc ores. The Yellowstone (Montana, USA) and Respina (North-West Spain) talc deposits are good examples.



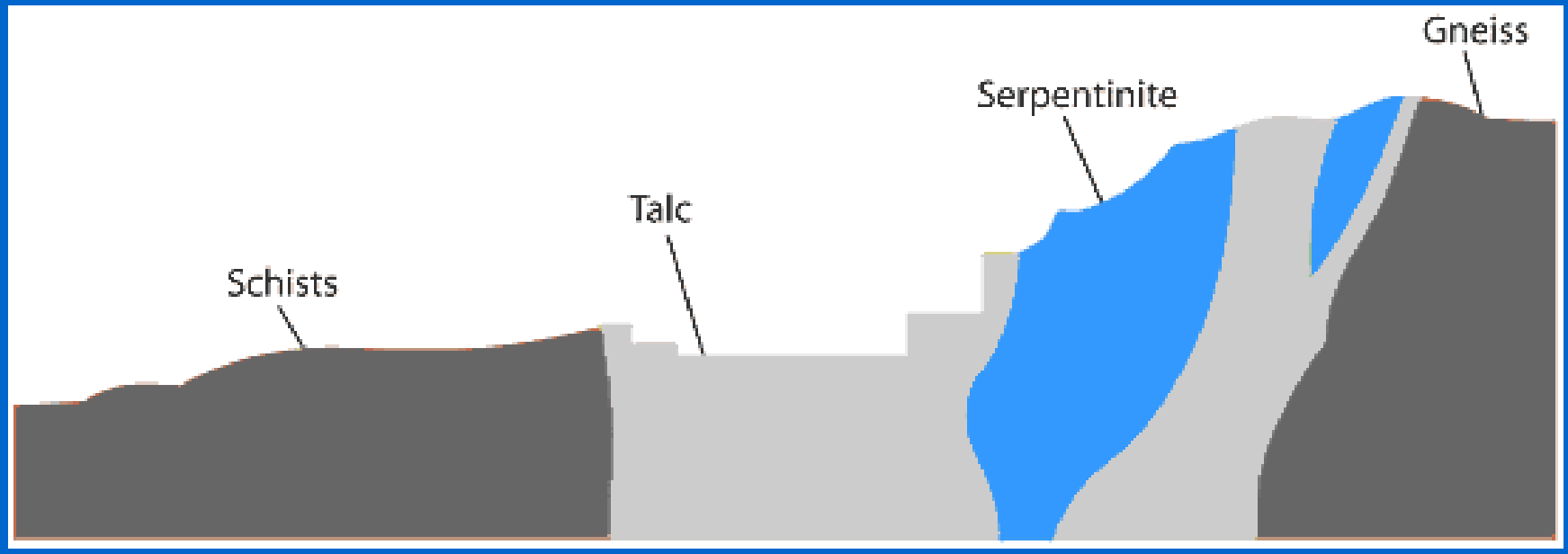

**Yellowstone mine in Montana - US**

# Types of talc deposit

**Serpentinite derivative orebodies**

About 20% of present world production comes from the transformation of serpentinite into a mixture of talc and reactional magnesium carbonates. This ore, commonly called "soapstone", is always grey and never pure. To be used as an industrial mineral, it is often upgraded by flotation to increase the talc content and whiteness.

This type of deposit is relatively common and widely distributed along ultra-mafic rock belts. In Vermont (USA), Quebec and Ontario (Canada) and Finland are deposits currently being worked.



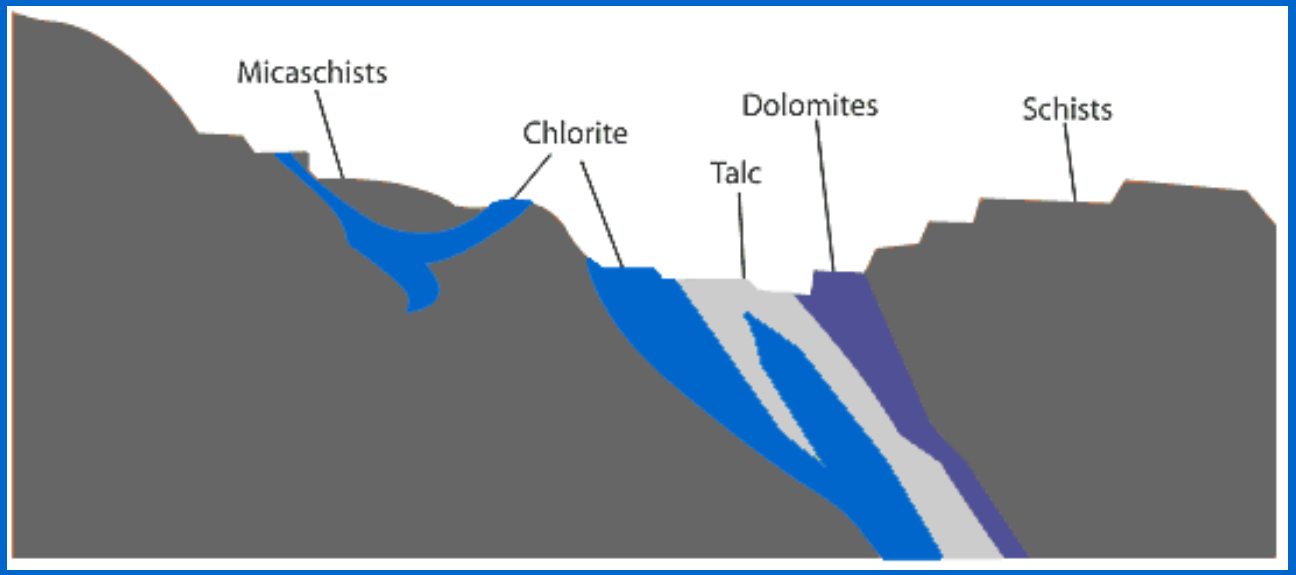

**Argonaut mine in Vermont - US**

# Types of talc deposit

**Siliceous or silico-aluminous rock derivative orebodies**

Results from the transformation of siliceous rocks. Magnesium is brought by the migration of hydro-thermal fluids.

If the parent rock has a silico-aluminous composition, e.g. pelitic schist or gneiss, and under the same conditions of formation, chlorite can be formed in addition to the talc, the resulting ore being a mixture of both talc and chlorite. This type of deposit can be found in association with the magnesium-carbonate derivative type, this kind of deposit represents about 10% of world production.




**Trimouns mine, French Pyrenees**

# PHYSICAL CHARACTERISTICS

- Color is green, gray and white to almost silver.
- Luster is dull to pearly or greasy.
- Transparency crystals are translucent and masses are opaque.
- Crystal System is monoclinic.
- Crystal Habits: flattened tabular crystals with a hexagonal cross-section, usually talc is found in compact or lamellar masses. Forms pseudomorphs (false shape) of other crystals such as quartz, pyroxenes, olivines and amphiboles.
- Cleavage is perfect in one direction, basal.
- Fracture is uneven to lamellar.
- Hardness is 1
- Specific Gravity is 2.7 - 2.8 (average)
- Streak is white.
- Associated Minerals include serpentine, dolomite, magnesite, quartz, pyroxenes, olivine, biotite and amphiboles.

# USES

- Agriculture and Food
- Ceramics
- Coatings
- Paper
- Personal Care
- Plastics
- Rubber
- Wastewater treatment


# Substitutes

The major substitutes for talc are:

- clays and pyrophyllite in ceramics
  - kaolin and mica in paint and rubber
    - kaolin in paper
      - clays and mica in plastics

- **Notable Occurances:** include many mines up and down the Appalachian Mountains and in California and Texas, USA; Germany; Florence, Italy; Tyrol, Austria; Transvaal, South Africa and Shetland, Scotland.

# Mining Methods

## Overburden removal

Most talc deposits are open-pit mines. The waste rock covering the talc vein is removed using shovels.

## Talc extraction

The exposed talc is then extracted using shovels. Even at this early stage, the different ore types are sorted as they are extracted from the seam.

"Pedra Preta“ Mine, in Brumado – Bahia state - Brazil

# Mineral Processing

Beneficiation

According to their talc content and brightness is a key phase of the production process. Techniques include hand sorting, state-of-the-art laser and image analysis technology or flotation.

- ✓First milling: to liberation size which can vary from 0.4 to 0.08 mm
- ✓Magnetic Separators: remove magnetic materials.
- ✓Froth Flotation: to improve product purity.
- ✓Thickening
- ✓Filtering
- ✓Drying

- ✓ Milling

  To obtain just the right particle size distribution curve and top cut for a given application, the techniques used include compressed air, steam and impact grinding. Median particle sizes can range from less than 1 micron to 15 microns, and top cuts from 6 microns to over 100 microns.

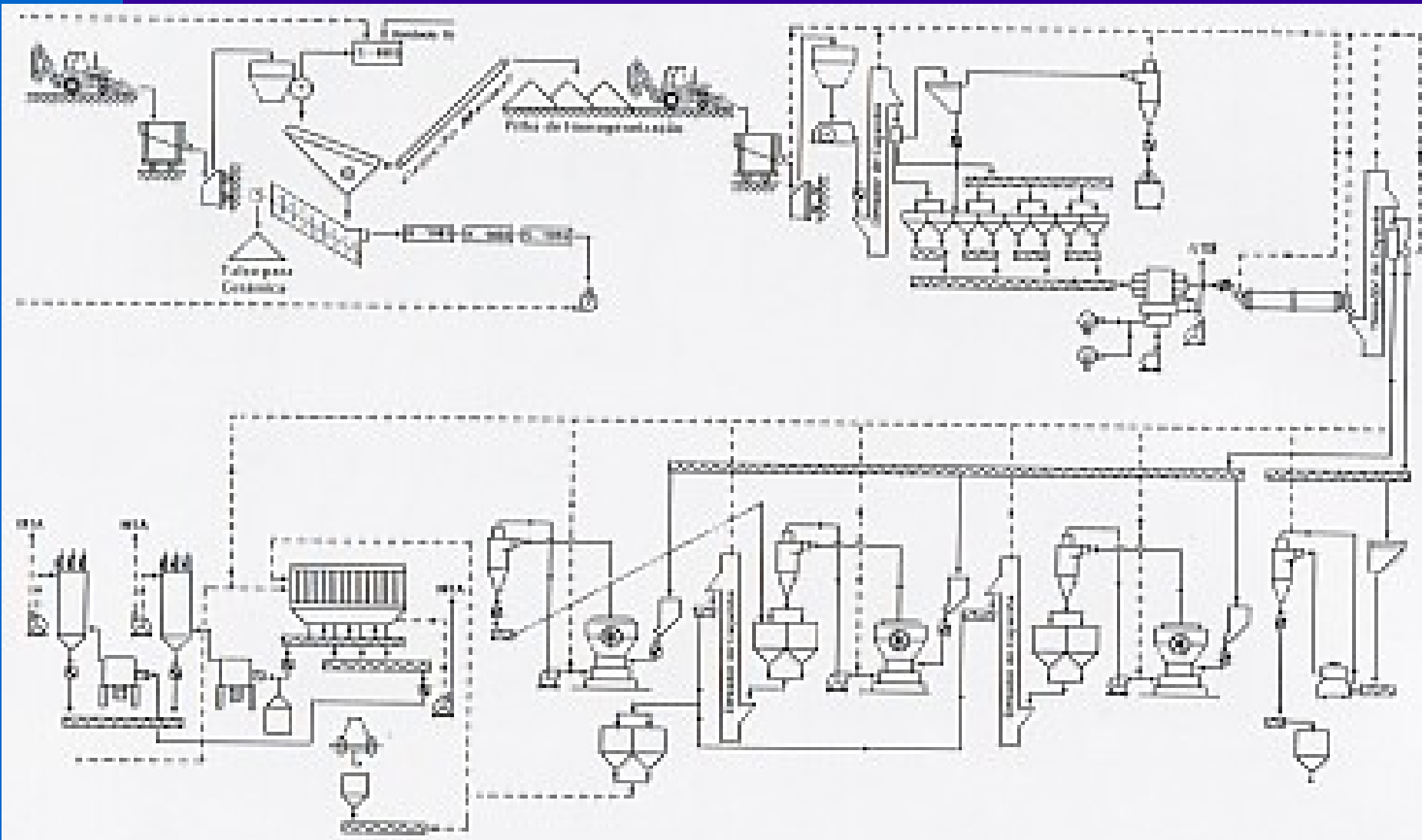
- ✓ Treated talcs

  Certain grades of talc are treated, e.g. amine-coated talcs for fertilizers, silane-coated talcs for the rubber industry and cationic talcs for pitch control in papermaking. For the cosmetics and pharmaceuticals industries, talcs are heat-treated to decontaminate them.

- ✓ Talc delivery forms and packaging

  Talc powder is delivered in bags, semi-bulk bags or in bulk. Increasingly, there is a demand for talc in pellet form or as a liquid (slurry).

# Mineral Processing Flow Sheet – Magnesita Inc.



# Mine Production and Reserve

| Salient Statistics—United States: | 2013 | 2014 | 2015 | 2016 | 2017[e] |
|---|---|---|---|---|---|
| Production, mine | 542 | 608 | 615 | 536 | 550 |
| Sold by producers | 560 | 551 | 535 | 527 | 540 |
| Imports for consumption | 275 | 308 | 322 | 378 | 380 |
| Exports | 196 | 190 | 206 | 169 | 210 |
| Consumption, apparent[2] | 621 | 726 | 731 | 745 | 710 |
| Price, average, milled, dollars per metric ton[3] | 163 | 171 | 186 | 193 | 200 |
| Employment, mine and mill, talc[4] | 250 | 230 | 239 | 223 | 210 |
| Employment, mine and mill, pyrophyllite[4] | 23 | 26 | 29 | 30 | 31 |
| Net import reliance[5] as a percentage of apparent consumption | 13 | 14 | 16 | 28 | 23 |

Recycling: Insignificant.

USGS Commodity Summaries  thousand metric tons

**World Mine Production and Reserves:**

| | Mine production | | Reserves[6] |
|---|---|---|---|
| | 2016 | 2017[e] | |
| United States (crude) | 536 | 550 | 140,000 |
| Brazil (crude and beneficiated)[7] | 850 | 850 | 52,000 |
| China (unspecified minerals) | 1,800 | 1,900 | Large |
| France (crude) | 450 | 470 | Large |
| India[7] | 1,000 | 1,000 | 110,000 |
| Japan[7] | 365 | 370 | 100,000 |
| Korea, Republic of[7] | 600 | 610 | 11,000 |
| Mexico | 700 | 650 | Large |
| Other countries | [7]1,680 | [7]1,700 | Large |
| World total (rounded) | [7]7,900 | [7]8,100 | Large |

**World Resources:** The United States is self-sufficient in most grades of talc and related minerals. Domestic and world resources are estimated to be approximately five times the quantity of reserves.

# Lithium

# Lithium—introduction

- Lightest of all metals
- Critical mineral
- lithium rich brines (lithium salt) and hard rock ore (lithium minerals)
  - mineable brines is about 0.023 to 0.15%
  - ore is about 1 - 4%

# Lithium—properties

- silvery
- highest specific heat of any solid element, it has found use in heat transfer applications
- corrosive

# Lithium—uses

- special glasses and ceramics
- synthesis of organic compounds
- alloying agent
- **battery anode material**
- Lithium stearate high-temperature lubricant
- greases
- Cosmetics and skin preparations
- primary aluminum production

# Lithium—substitutions

- sodic and potassic fluxes in ceramics and glass manufacture
- calcium and aluminum soaps as substitutes for stearates in greases
- zinc, magnesium, calcium, and mercury as anode material in primary batteries

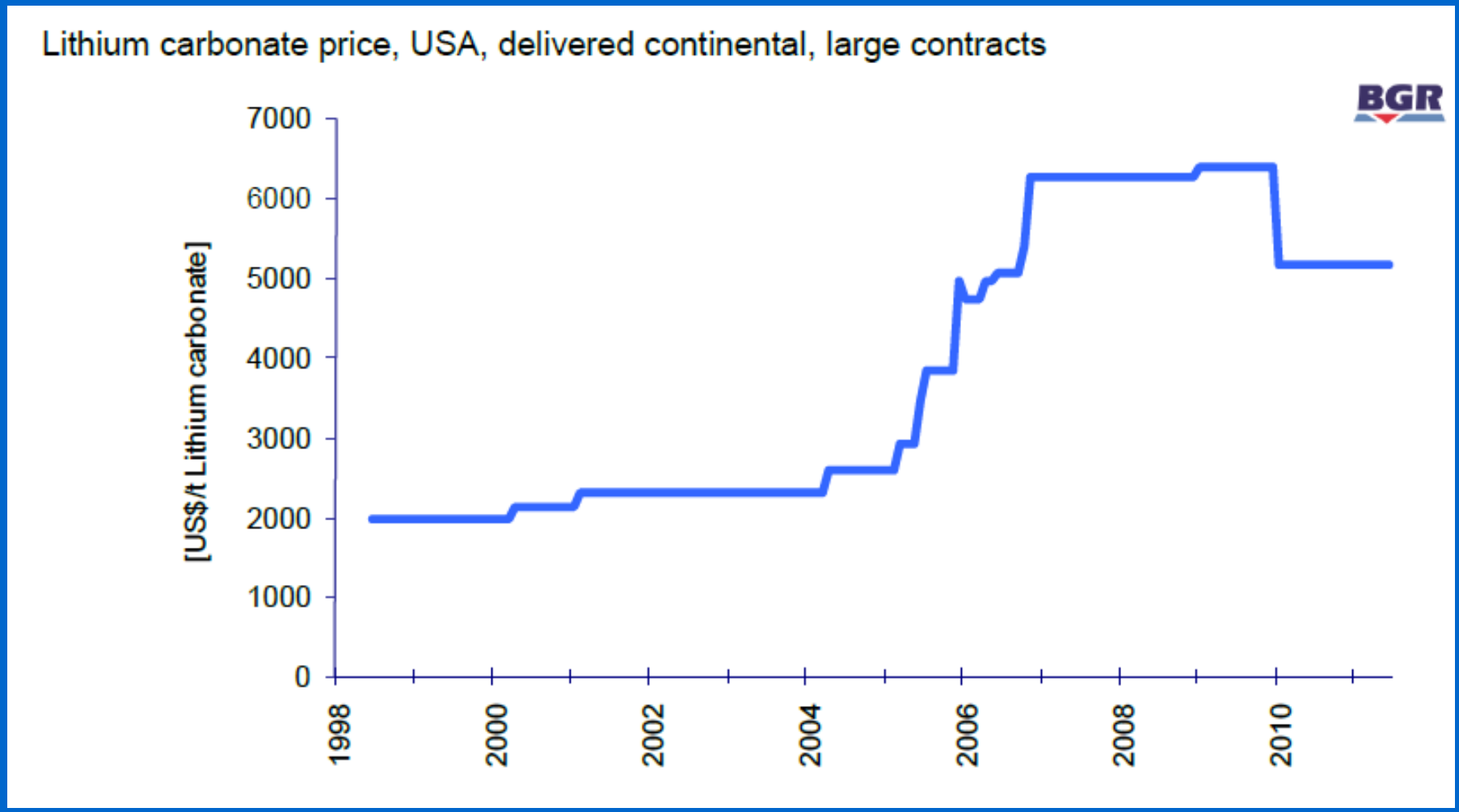
# Lithium—production

| Salient Statistics—United States: | 2013 | 2014 | 2015 | 2016 | 2017e |
|---|---|---|---|---|---|
| Production | [1]870 | W | W | W | W |
| Imports for consumption | 2,210 | 2,130 | 2,750 | 3,140 | 3,430 |
| Exports | 1,230 | 1,420 | 1,790 | 1,520 | 1,850 |
| Consumption, estimated | 2,000 | [2]2,000 | [2]2,000 | [2]3,000 | [2]3,000 |
| Price, annual average, battery-grade lithium carbonate, dollars per metric ton[3] | 6,800 | 6,690 | 6,500 | 8,650 | 13,900 |
| Employment, mine and mill, number | 70 | 70 | 70 | 70 | 70 |
| Net import reliance[4] as a percentage of estimated consumption | >50 | >25 | >25 | >50 | >50 |

**World Mine Production and Reserves:** Reserves for Australia and the United States were revised based on new information from Government and industry sources.

| | Mine production | | Reserves[6] |
|---|---|---|---|
| | 2016 | 2017e | |
| United States | W | W | 35,000 |
| Argentina | 5,800 | 5,500 | 2,000,000 |
| Australia | 14,000 | 18,700 | [7]2,700,000 |
| Brazil | 200 | 200 | 48,000 |
| Chile | 14,300 | 14,100 | 7,500,000 |
| China | 2,300 | 3,000 | 3,200,000 |
| Portugal | 400 | 400 | 60,000 |
| Zimbabwe | 1,000 | 1,000 | 23,000 |
| World total (rounded) | [8]38,000 | [8]43,000 | 16,000,000 |

# Price


Lithium carbonate price, USA, delivered continental, large contracts
BGR
[US$/t Lithium carbonate]
7000
6000
5000
4000
3000
2000
1000
0
1998
2000
2002
2004
2006
2008
2010

## PRICES

The prices (*Industrial Minerals* 2004) of various lithium ores (in dollars per short ton) are

| | | |
|---|---|---|
| Ceramic spodumene: | 7.25% $Li_2O$ | $330 to $350 (free on board [f.o.b.] West Virginia) |
| Glass-grade spodumene: | 5% $Li_2O$ | $195 to $200 (f.o.b. Amsterdam) |
| Petalite: | 4.2% $Li_2O$ | $165 to $260 (f.o.b. Durban) |

# Market

**Table 2.** World market shares for various lithium end-uses from 2007 through 2009.

[World market share is expressed as a percentage (%) of the total global sales of lithium; production is in metric tons of contained lithium. Data are from Jaskula (2008–2010)]

| End-use | 2007 | 2008 | 2009 |
|---|---|---|---|
| World market share: | | | |
| Ceramics and glass | 18% | 31% | 30% |
| Batteries | 25% | 23% | 21% |
| Lubricating greases | 12% | 10% | 10% |
| Pharmaceuticals and polymers | 7% | 7% | 7% |
| Air conditioning | 6% | 5% | 5% |
| Primary aluminum (alloying) | 4% | 3% | 3% |
| Other | 28% | 21% | 24% |
| World production, in metric tons of contained lithium | 25,400 | 25,400 | 18,000 |

http://pubs.usgs.gov/circ/1371/pdf/circ1371_508.pdf

# Uses

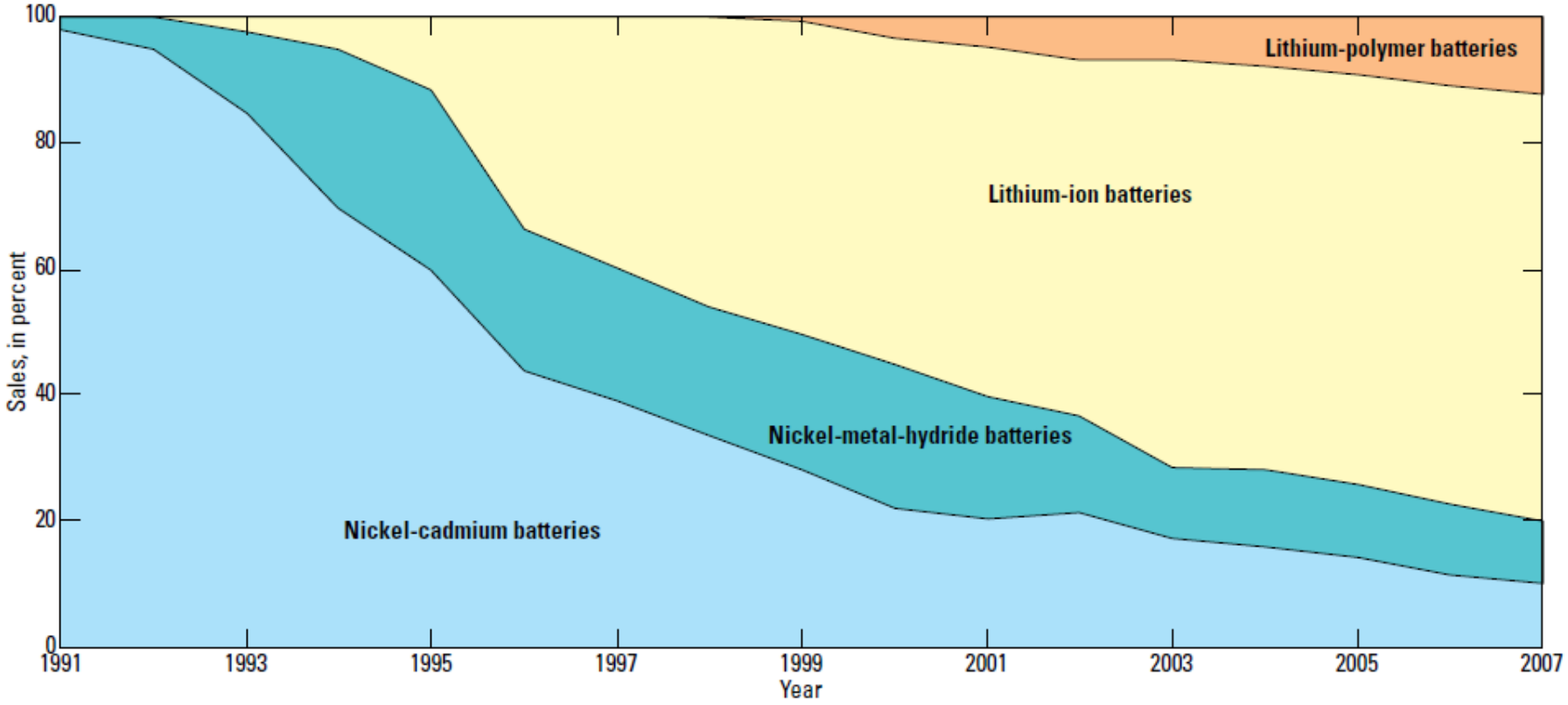



**Figure 2.** Chart showing sales of rechargeable batteries worldwide from 1991 through 2007. Values are expressed as percentage of total global sales of rechargeable batteries. Data are from Wilburn (2007) and Takashita (2008).

http://pubs.usgs.gov/circ/1371/pdf/circ1371_508.pdf

# Lithium—geology

- Lepidolite, spodumeme, petalite, and amblygonite
- brines of Searles Lake, California and Nevada
- pegmatites
- clay mineral hectorite (smectite), bentonite
- lacustrine/playa deposits

**Table 3.** World production of lithium from minerals and brine in 2008, by country.

[Values are in metric tons of contained lithium. Production data are estimated and rounded to no more than three significant digits. Table includes data available through April 1, 2009. Data are from Jaskula (2008) and Tahil (2008). LiCl, lithium chloride; $Li_2CO_3$, lithium carbonate; NA, not available]

| Country[1] | Deposit type | Lithium product | Production |
|---|---|---|---|
| Production from minerals: | | | |
| Australia | Spodumene | Concentrate | 6,280 |
| Brazil | Various | Concentrate | 160 |
| Canada[2] | Spodumene | Concentrate | 690 |
| China | Various | $Li_2CO_3$ | 880 |
| Portugal | Lepidolite | Concentrate | 700 |
| Zimbabwe | Various | Concentrate | 500 |
| Total | | | 9,210 |
| Production from brine: | | | |
| Argentina[3] | NA | $Li_2CO_3$ | 1,880 |
| | NA | LiCl | 1,290 |
| Chile[3] | NA | $Li_2CO_3$ | 9,870 |
| | NA | LiCl | 720 |
| China | NA | $Li_2CO_3$ | 2,410 |
| United States[4] | NA | $Li_2CO_3$ | 1,710 |
| Total | | | 17,900 |

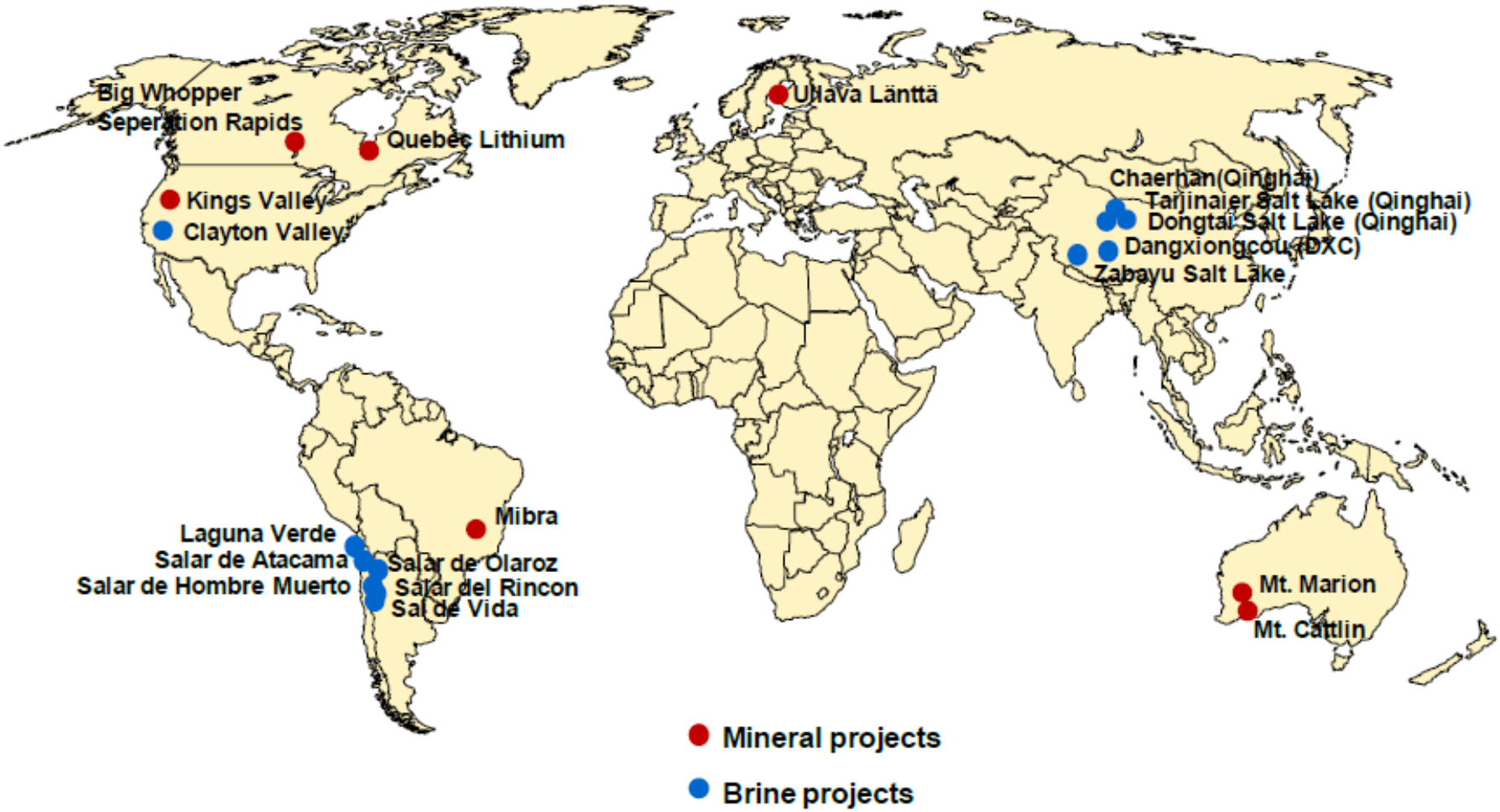
[1]Other countries produce small amounts of lithium but are not included here.

[2]Based on all Canada's spodumene concentrates (Tantalum Mining Corp. of Canada Ltd., Tanco property).

[3]New information was available from Argentine and Chilean sources, prompting major revisions in how lithium production was reported.

[4]The estimate for the United States is taken as the suggested production of Chemetall's Clayton Valley mine at Silver Peak, Nevada, as reported by Tahil (2008, p. 20).

# Selected lithium projects 2010

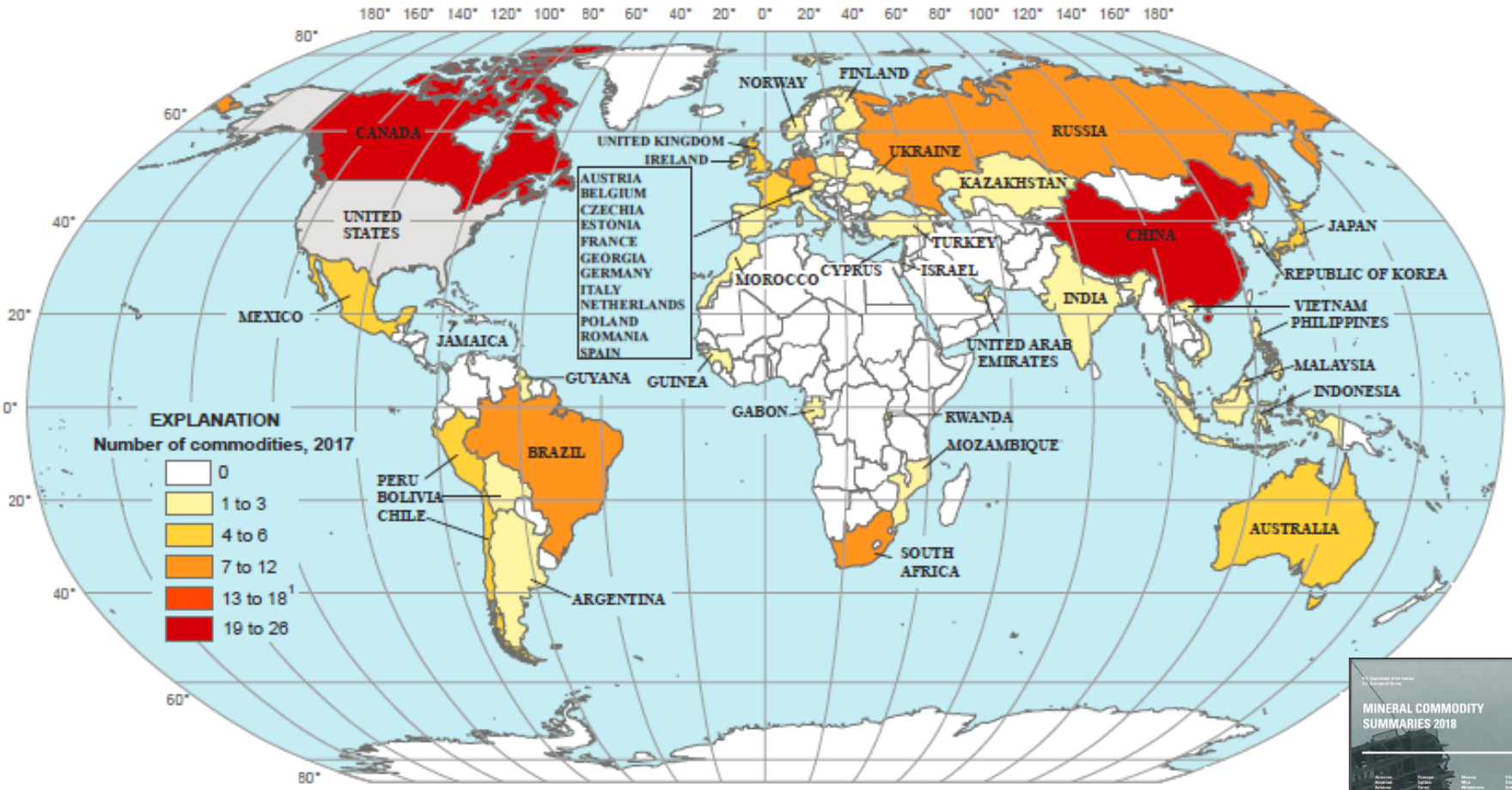


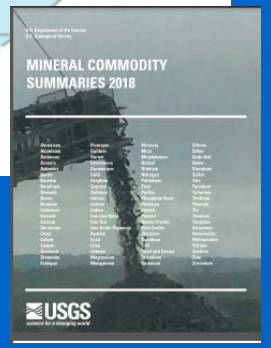
# SUMMARY COMMENTS

# 2017 U.S. NET IMPORT RELIANCE[1]

| Commodity | Percent | Major import sources (2013–16)[2] |
|---|---|---|
| ARSENIC (trioxide) | 100 | Morocco, China, Belgium |
| ASBESTOS | 100 | Brazil, Russia |
| CESIUM | 100 | Canada |
| FLUORSPAR | 100 | Mexico, China, South Africa, Vietnam |
| GALLIUM | 100 | China, Germany, United Kingdom, Ukraine |
| GRAPHITE (natural) | 100 | China, Mexico, Canada, Brazil |
| INDIUM | 100 | Canada, China, France, Republic of Korea |
| MANGANESE | 100 | South Africa, Gabon, Australia, Georgia |
| MICA, sheet (natural) | 100 | China, Brazil, Belgium, Austria |
| NEPHELINE SYENITE | 100 | Canada |
| NIOBIUM (columbium) | 100 | Brazil, Canada, Russia |
| QUARTZ CRYSTAL (industrial) | 100 | China, Japan, Romania, United Kingdom |
| RARE EARTHS | 100 | China, Estonia, France, Japan |
| RUBIDIUM | 100 | Canada |
| SCANDIUM | 100 | China |
| STRONTIUM | 100 | Mexico, Germany, China |
| TANTALUM | 100 | Brazil, Rwanda, Australia, Canada |
| THALLIUM | 100 | Russia, Germany |
| THORIUM | 100 | India, United Kingdom |
| VANADIUM | 100 | Czechia, Austria, Canada, Republic of Korea |
| YTTRIUM | 100 | China, Estonia, Japan, Germany |
| GEMSTONES | 99 | Israel, India, Belgium, South Africa |
| BISMUTH | 96 | China, Belgium, Peru |
| POTASH | 92 | Canada, Russia, Israel, Chile |
| TITANIUM MINERAL CONCENTRATES | 91 | South Africa, Australia, Canada, Mozambique |
| ANTIMONY (oxide) | 85 | China, Belgium, Bolivia |
| ZINC | 85 | Canada, Mexico, Peru, Australia |
| STONE, dimension | 83 | China, Brazil, Italy, Turkey |
| RHENIUM | 80 | Chile, Belgium, Germany, Poland |
| ABRASIVES, fused aluminum oxide (crude) | >75 | China, Canada, France |
| ABRASIVES, silicon carbide (crude) | >75 | China, Netherlands, South Africa, Romania |
| BARITE | >75 | China, India, Mexico, Morocco |
| BAUXITE | >75 | Jamaica, Brazil, Guinea, Guyana |
| TELLURIUM | >75 | Canada, China, Belgium, Philippines |
| TIN | 75 | Peru, Indonesia, Malaysia, Bolivia |
| COBALT | 72 | Norway, China, Japan, Finland |
| PEAT | 71 | Canada |
| DIAMOND (dust, grit, and powder) | 70 | China, Ireland, Russia, Romania |
| CHROMIUM | 69 | South Africa, Kazakhstan, Russia |
| PLATINUM | 68 | South Africa, Germany, United Kingdom, Russia |
| SILVER | 62 | Mexico, Canada, Peru, Poland |
| ALUMINUM | 61 | Canada, Russia, United Arab Emirates, China |

# MAJOR IMPORT SOURCES OF NONFUEL MINERAL COMMODITIES FOR WHICH THE UNITED STATES WAS GREATER THAN 50% NET IMPORT RELIANT IN 2017



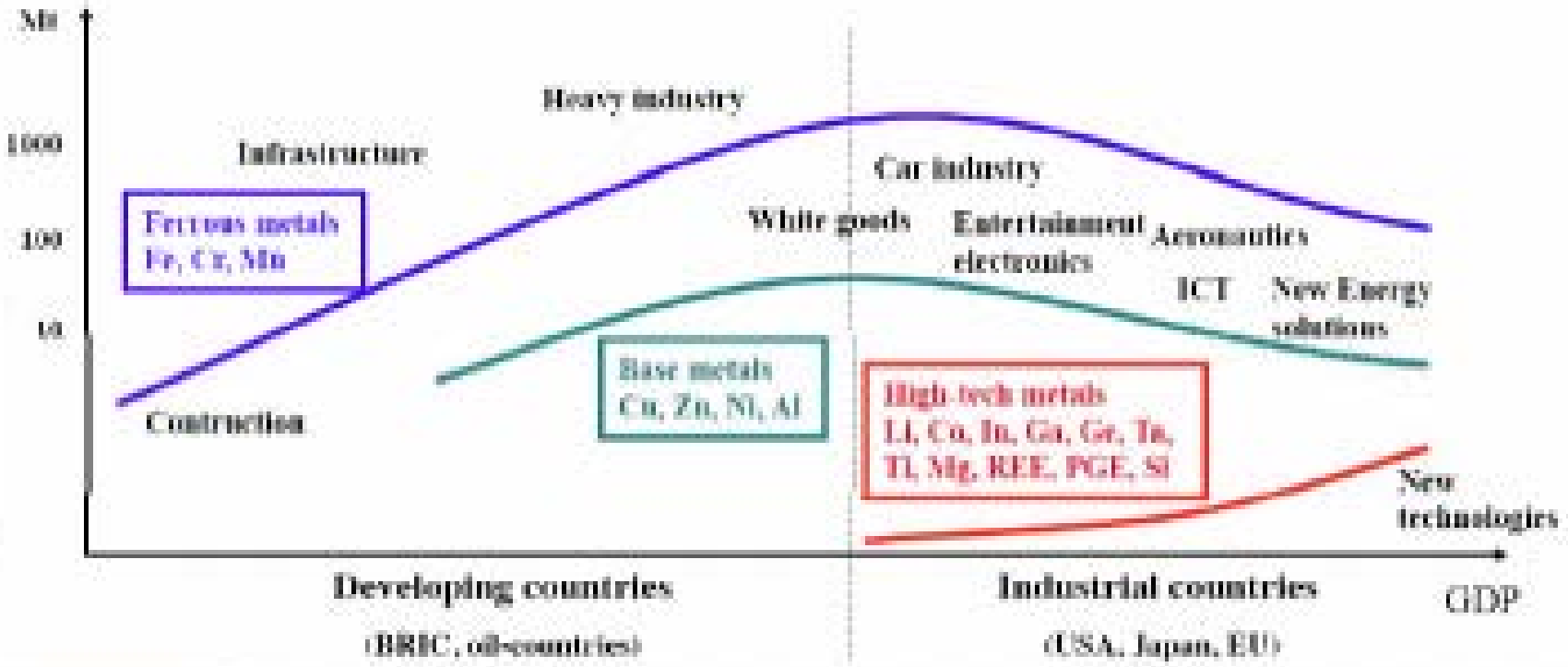
## TABLE 1.—U.S. MINERAL INDUSTRY TRENDS

| | 2013 | 2014 | 2015 | 2016 | 2017[e] |
|---|---|---|---|---|---|
| Total mine production (million dollars): | | | | | |
| Metals | 29,900 | 28,900 | 24,400 | 23,500 | 26,300 |
| Industrial minerals | 43,100 | 49,600 | 48,200 | 47,300 | 48,900 |
| Coal | 36,700 | 34,800 | 28,500 | 22,300 | 24,500 |
| Employment (thousands of production workers): | | | | | |
| Coal mining | 67 | 62 | 54 | 42 | 42 |
| Nonfuel mineral mining | 100 | 100 | 99 | 95 | 97 |
| Chemicals and allied products | 491 | 497 | 507 | 516 | 523 |
| Stone, clay, and glass products | 275 | 280 | 296 | 307 | 310 |
| Primary metal industries | 306 | 310 | 307 | 296 | 301 |
| Average weekly earnings of production workers (dollars): | | | | | |
| Coal mining | 1,362 | 1,435 | 1,387 | 1,336 | 1,430 |
| Chemicals and allied products | 918 | 917 | 928 | 951 | 1,010 |
| Stone, clay, and glass products | 782 | 828 | 842 | 850 | 870 |
| Primary metal industries | 959 | 991 | 987 | 1,003 | 997 |

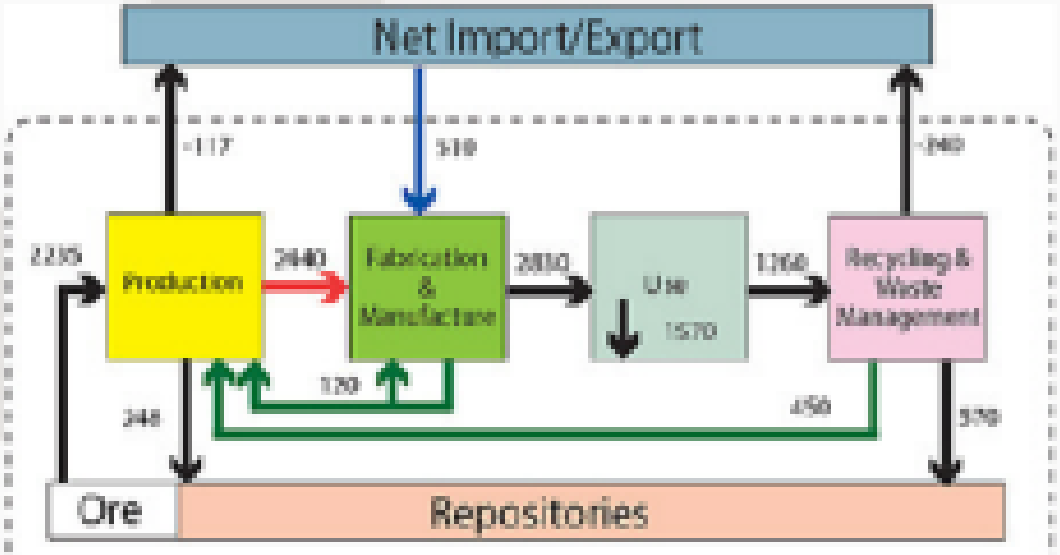
*Estimated.

Sources: U.S. Geological Survey, U.S. Department of Energy, and U.S. Department of Labor.

# Growing Demand for Earth Resources



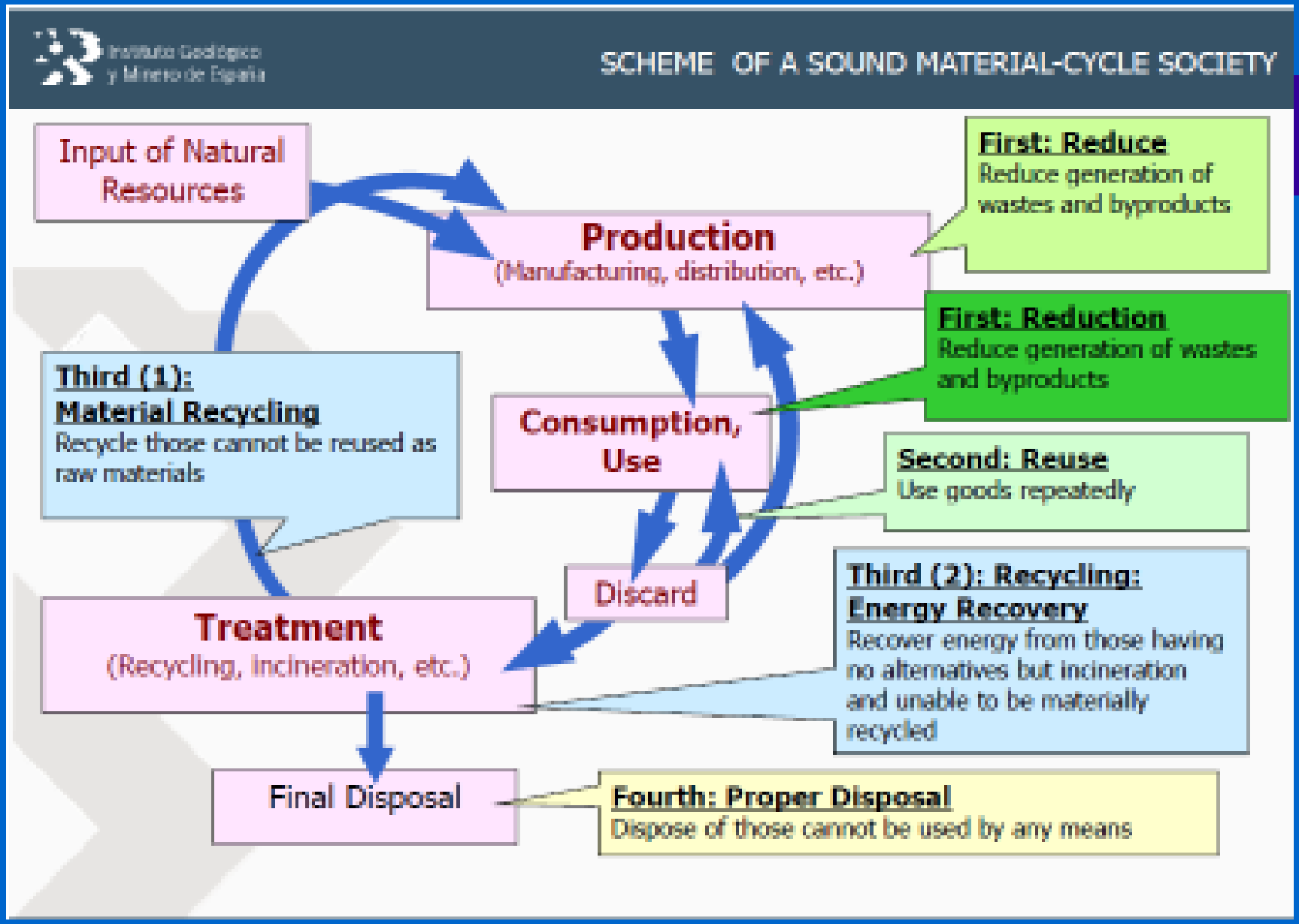
- **Material Flow Analysis:** systematic accounting of the flows and stocks of materials within a system defined in space and time.
- **Fossil fuels:** consumed when burned to generate usable energy
- **Nonfuel minerals:** can be recycled after initial use
  - **primary resources:** extracted from Earth's crust
  - **secondary resources:** recovered from scrap
  - **"tertiary" resources**: imports of metals or metal-containing products




U.S. copper cycle in 1994. Thousand metric tons of copper

Red: processing of domestic copper ore
Green : recycled material
Blue: imported material in semifinished or finished products
2,8 Mt used:

- 70% primary
- 16% secondary
- 13% tertiary




http://www.kotu.oulu.fi/projektit/oms/map3/Manuel_Regueiro.pdf

- Long term **mineral availability** (> 10 y) function of five factors:
  - **Geologic**: does the mineral resource exist
  - **Technical**: can we extract and process it
  - **Environmental and social**: can we produce it in environmentally and socially accepted ways
  - **Political**: how do governments influence availability through their policies and actions
  - **Economic**: can we produce it at a cost users are willing and able to pay
- Short- and medium-term availability (< 10 y) :
  - Significant restrictions to supply may occur: physical unavailability or higher prices.

Economics will prevail, which means metallurgists won’t risk lowering major commodity (for example, Cu) recovery to improve byproduct recovery (for example, Te, In, Ge, Ga).

# *Reminders*

- Commodity presentations—send me your powerpoints
- April 28 AIPG meeting and Field trip in afternoon (perlite mine or carbonatites)
- **Research Projects presentation April 30**
- Finals, written Project due May 4
- No class May 7