ME571/Geol571 Advanced Topics

Geology and Economics of Strategic and Critical Minerals

Commodities—other

Virginia T. McLemore

ASSIGNMENT

- Lemitar field trip April 9 (Thurs, 1 PM)
- Cripple Creek April 10-11
- April 13—each will lead discussion on a paper, final given out
- April 20—no class
- April 24—NMGS Spring Meeting, Macy Center
- April 27, project presentations (written and oral)
- May 7, final exam, field trip reports, and written presentation due

Midterms

- An **ore deposit** is a well-defined mineral deposit that has been tested and found to be of sufficient size, grade, and accessibility to be extracted (i.e. mined) and processed at a profit at a specific **time**.
- Be is critical to national defense

Complexities of the stock market—Au

- Price of Au in April 2012 $1642, April 2015 $1202 (drop of 27%)
- Mining companies on the Toronto Venture and Toronto Stock Exchange 1716 in April 2012 to 1471 Feb 2015 (drop of 13%)
- 589 junior companies have negative working capital (40%)
- 7 major gold miners were not profitable from 2003-2013 despite a gold price that escalated over 250% (Cipher Research)

Germanium

Germanium

- German chemist Clemens Winkler in 1886 in the silver sulfide mineral argyrodite from Freiberg, Saxony, Germany
- greyish-white, metallic in appearance, and metallic
- Atomic number 32
- Main source is sphalerite

Germanium

Table 1
Germanium distribution on Earth and in major rock types

Material	Ge [ppm] (mean)	Reference
Earth	13.8	Dasch (1996)
Earth's core	37	Dasch (1996)
Primitive mantle	1.1	Dasch (1996)
Oceanic crust	1.5	Taylor and McLennan (1985)
Continental crust	1.6	Taylor and McLennan (1985)
Ultramafic rocks	1.3	Faure (1998)
Mafic rocks	1.4	Faure (1998)
Granite	1.3	Faure (1998)
Shale	1.6	Faure (1998)
Sandstone	0.8	Faure (1998)
Carbonate rocks	0.2	Faure (1998)
Deep-sea clay	2.0	Faure (1998)

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Germanium—uses

- 35%: Polymerisation catalysts (plastics)
- 25%: Infrared optics
- 20%: Fiber-optic systems
- 12%: Electronics/solar electrical applications
- 8%: Other uses (e.g., phosphors (in fluorescent lamps), metallurgy and chemotherapy (toxic effects against certain microorganisms)

Germanium—production

Salient Statistics—United States:	2010	2011	2012	2013	2014[e]
Production, refinery[e]	3,000	3,000	W	W	W
Total imports[1]	44,700	38,500	48,500	45,700	45,000
Total exports[1]	8,000	5,900	15,300	12,500	11,000
Shipments from Government stockpile excesses	—	—	—	—	—
Consumption, estimated	40,000	36,000	38,000	38,000	35,000
Price, producer, yearend, dollars per kilogram:					
Zone refined	1,200	1,450	1,640	1,900	1,900
Dioxide, electronic grade	720	1,250	1,360	1,230	1,300
Stocks, producer, yearend	NA	NA	NA	NA	NA
Net import reliance[2] as a percentage of estimated consumption	90	90	85	85	95

World Refinery Production and Reserves:

	Refinery production[e] 2013	Refinery production[e] 2014	Reserves[5]
United States	W	W	Data on the recoverable content of zinc ores are not available.
China	110,000	120,000	
Russia	5,000	5,000	
Other countries	40,000	40,000	
World total	[6]155,000	[6]165,000	

http://minerals.usgs.gov/minerals/pubs/mcs/2015/mcs2015.pdf

Germanium—growth

- thin-film application for solar panels
- digital video discs
- SiGe chips
- Ge-based semiconductors
- other electronic devices

Germanium

Summary Of Germanium Processing Facilities

Facility Name	Location	Type of Operations
Atomergic Chem	Plainview, NY	Refining
Cabot	Revere, PA	Refining
Eagle-Picher	Quapaw, OK	Refining
Jersey Miniere	Clarksville, TN	Mining
Musto Exploration	St. George, UT	Mining and Refining

http://www.epa.gov/osw/nonhaz/industrial/special/mining/minedock/id/id4-ger.pdf

Germanium

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Table 4
Germanium concentrations in minerals from pegmatites, greisens and skarns

Host mineral	Rock types	Ge [ppm]	*n*	Ref.
Topaz	Pegmatite, greisen	29–700	32	Oftedal (1963), Schrön (1968), Seim and Schweder (1969)
Quartz	Pegmatite, greisen	0.85–7.1	9	Bernstein (1985)
Alkali feldspar	Pegmatite, greisen	2.4–7.8	26	Novokhatskiy et al. (1967)
Orthoclase	Pegmatite	2.2–6.0	3	Schrön (1968)
Plagioclase	Pegmatite	7.0–9.5	2	Bernstein (1985)
Muscovite	Pegmatite	16.5–62.7	4	Bernstein (1985)
Spodumene	Pegmatite	5–28	4	Novokhatskiy et al. (1967), Higazy (1953)
Lepidolite	Pegmatite	7.7–25	11	Novokhatskiy et al. (1967)
Pollucite	Pegmatite	15–18	2	Novokhatskiy et al. (1967)
Epidote	Skarn	1.1–10	21	Bernstein (1985)
Garnet	Skarn	0.9–180	271	Bernstein (1985)
Clinopyroxene	Skarn	1.1–80	67	Novokhatskiy et al. (1967)

n = number of analyses.

Germanium

Table 5
Exceptional germanium concentrations in oxide and hydroxide minerals

Host mineral	Ge [ppm]	Type of mineralization	Reference
Hydrocassiterite	10,000	Porphyry and vein–stockwork Sn–Ag	Moh (1977)
Hematite	7000	Apex mine: oxidation zone	Bernstein (1985)
Goethite	5310	Apex mine: oxidation zone	Bernstein (1985)
Cassiterite	3000	Porphyry and vein–stockwork Sn–Ag	Bernstein (1985)
Magnetite	100	BIF and Lahn–Dill-type deposits	Lange (1957), Sarykin (1977)
Mn oxides and hydroxides	10	hydrothermal veins, oxidation zone	Voskresenskaya et al. (1975)

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Minerals

Table 2. Selected germanium minerals
[Modified from Weeks (1973)]

Mineral	Composition	Germanium content (weight percent)
Renierite[1]	(Cu,Fe,Ge,As,Zn)S	4.6-9.2
Germanite[2]	$Cu_{11}Ge(Cu,Ge,Fe,Zn,W,Mo,As,V)_{4\text{-}6}S_{16}$	6.2-10.9
Argyrodite	Ag_8GeS_6	6.4
Fleischerite	$Pb_3Ge(SO_4)_2(OH)_6 \cdot 3H_2O$	7
Itoite	$Pb_3Ge(SO_4)_2O_2(OH)_2$	7.6
Schaurteite	$Ca_3Ge(SO_4)_2(OH)_6 \cdot 3H_2O$	13.4
Briartite	$Cu_2(Fe,Zn)GeS_4$	18.5-18.9
Stottite	$FeGe(OH)_6$	31.5

[1]Bernstein, 1986b, p. 213

[2]Palache, Berman, and Frondel, 1944, p. 386; Bernstein, 1986a, p. 1686.

Germanium

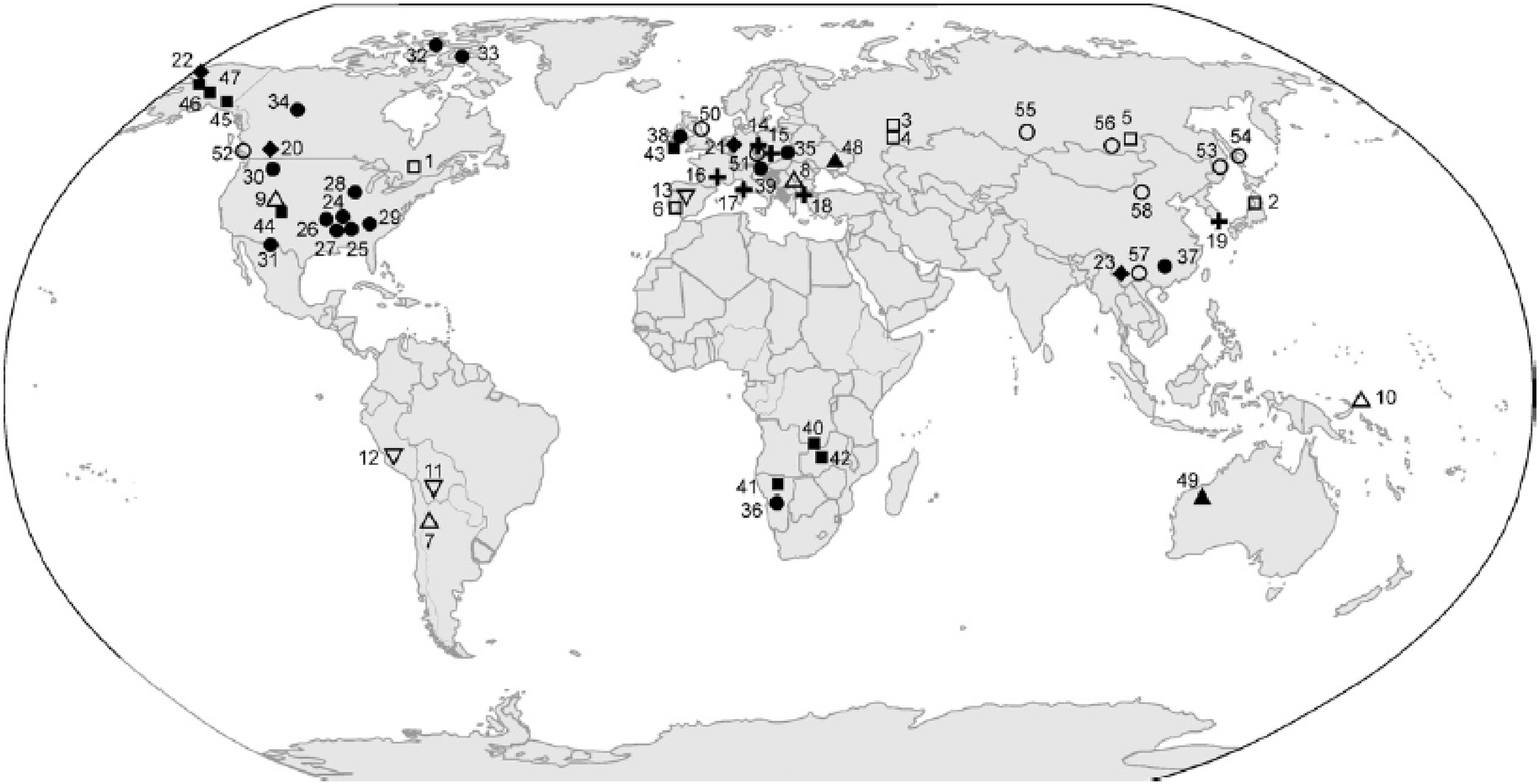

Fig. 1. Germanium-bearing ore deposits. □ Volcanic-hosted massive sulphide (VHMS) Cu–Zn(–Pb)(–Ba) deposits: 1 Abitibi–Belt: Kidd Creek, Noranda, Bousquet 2 Mine, Canada; 2 Kuroko-type (and Besshi-type) deposits, Japan; 3 Gaiskoje, Russia; 4 Bakr Tau, Russia; 5 Gorevskoe and Ozernoe, Russia; 6 Iberian Pyrite Belt: Neves Corvo, Portugal; △ Porphyry and vein–stockwork Cu–Mo–Au deposits: 7 Capillitas, Argentina; 8 Bor,

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Germanium—types of deposits

- Volcanic-hosted massive sulfide (VHMS) Cu–Zn(–Pb)(–Ba) deposits
- Porphyry and vein–stockwork Cu–Mo–Au deposits
- Porphyry and vein–stockwork Sn–Ag deposits
- Vein-type Ag–Pb–Zn(–Cu) deposits
- Sediment-hosted massive sulfide (SHMS) Zn–Pb–Cu(–Ba) deposits
- Carbonate-hosted base metal deposits
- Mississippi Valley-type (MVT) Zn–Pb–Fe(–Cu)(–Ba)(–F) deposits
- Coal and lignite
- Fe oxide deposits

Germanium

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High-grade Ge concentrations in ores

Type of mineralization	Ge-bearing mineral phases	Ge [ppm] $1<x<10$
Sulphide ores		
VHMS Cu–Zn(–Pb)(–Ba)	Sphalerite, (bornite, renierite, germanite)	100
(Thereof Kuroko-type)	Sphalerite, bornite, renierite	300
Porphyry and vein–stockw. Cu–Mo–Au	CuAs-sulphides, bornite, sphalerite, (renierite, germanite)	$x*10$
Porphyry and vein–stockw. Sn–Ag	Argyrodite, (Sn–minerals, sphalerite)	$x*10$
Vein-type Ag–Pb–Zn(–Cu)	Argyrodite, sphalerite	$x*100$
SHMS Zn–Pb–Cu(–Ba)	Sphalerite, wurtzite	$x*10$
MVT, IRT, APT Zn–Pb	Sphalerite, wurtzite	$x*100$
KPT Cu–Pb–Zn–Ge	Ge-sulphides, CuAs-sulphides, bornite, (sphalerite)	1000
Oxide ores		
KPT oxidation zones	Iron oxides, iron hydroxides, sulphates, arsenates	1000
Oxidation zones of Sn-sulphides	Secondary tin hydroxide, tin oxide	$x*10$
Non-sulphide Zn–Pb	Iron hydroxides; willemite–hemimorphite	$x*10$

Graphite

Graphite

- Greek (graphein): to draw/write
- for its use in pencils
- Graphite, plumbago, black lead

Graphite—introduction

- C
- Iron-black to steel-gray, soft (1-2 hardness)
- Confused with molybdenite, which is denser and has a silver blue streak
- Gray streak
- Luster is metallic to dull
- Cleavage is perfect in one direction

History

- First use of graphite: primitive man to make drawings, and by Egyptians to decorate pottery.
- Graphite processing: 1400 AD in the Haffnerzell District of Bavaria.
- Through the Middle Ages graphite was confused with galena and Molybdenite.
- First names: Plumbago (lead -silver) & black lead
- Discovered: 1565 by Gessner (recognized as a mineral), but its composition was determined in 1779 by Scheele.

Graphite—properties

- Milled, drilled and turned in a lathe to a desired shape
- Making brushes
- Conductive
- Chemically stable
- High strength
- Hardness 1-2
- Specific gravity 2.2
- Good conductor of electricity
- Lubricant

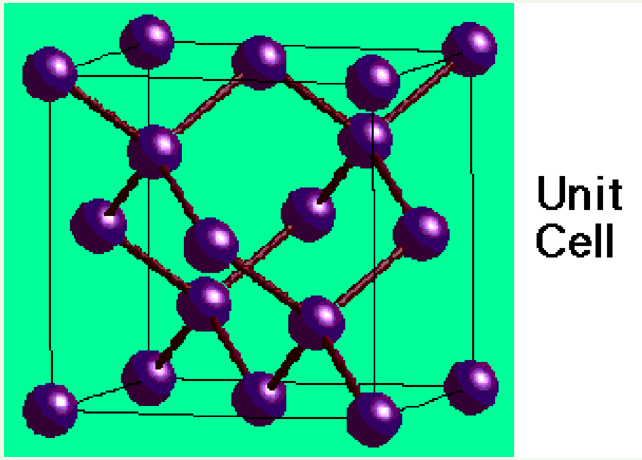
Physical Characteristics

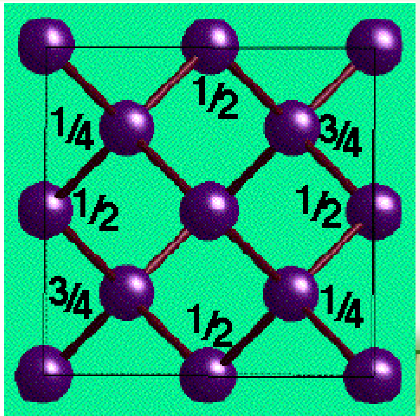
- **Color** is dark gray, black, or black silver.
- **Luster** is metallic to dull.
- **Transparency** crystals are opaque
- **Crystal System** is hexagonal
- **Hardness** is 1 - 2
- **Specific Gravity** 2.2
- **Cleavage** is perfect in one direction.
- **Fracture** is flaky.
- **Streak** is black gray to brownish gray.
- **Melting Point** of 3,500ºC.
- **Graphite** is an excellent conductor of heat and electricity.
- **Other Characteristics:** thin flakes are flexible but inelastic, mineral can leave black marks on hands and paper.
- **Best Field Indicators are** softness, luster, density and streak.

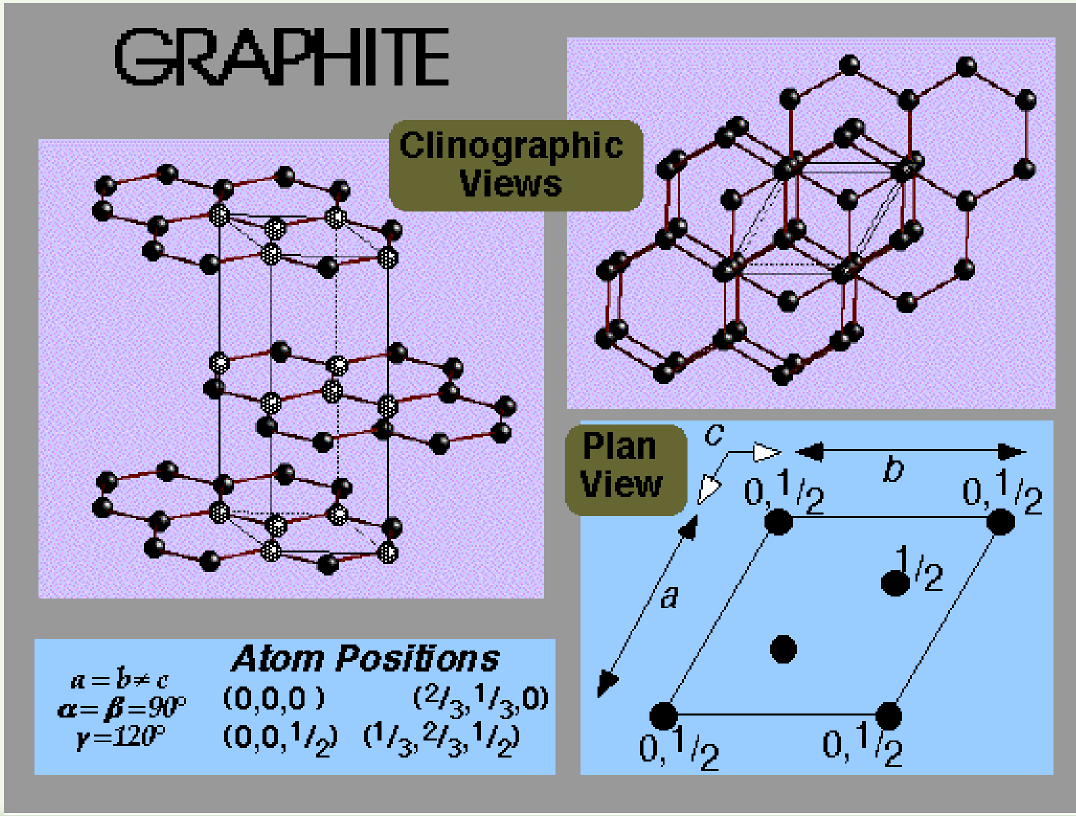
Mineralogy

Graphite is a native element composed only of carbon. It has the same composition as diamond, however it has very different structures.

- Diamond crystallizes in the Isometric system X graphite crystallizes in the hexagonal system.







Source- http://www.chem.ox.ac.uk/icl/heyes/structure_of_solids/Lecture1/Lec1.html

Graphite

Graphite (5 cm across) from the famous Plumbago mine, Seathwaite, Borrowdale, England.
John A. Jaszczak collection 15461 and photo 36-12.

http://www.phy.mtu.edu/faculty/info/jaszczak/borrowdale.html

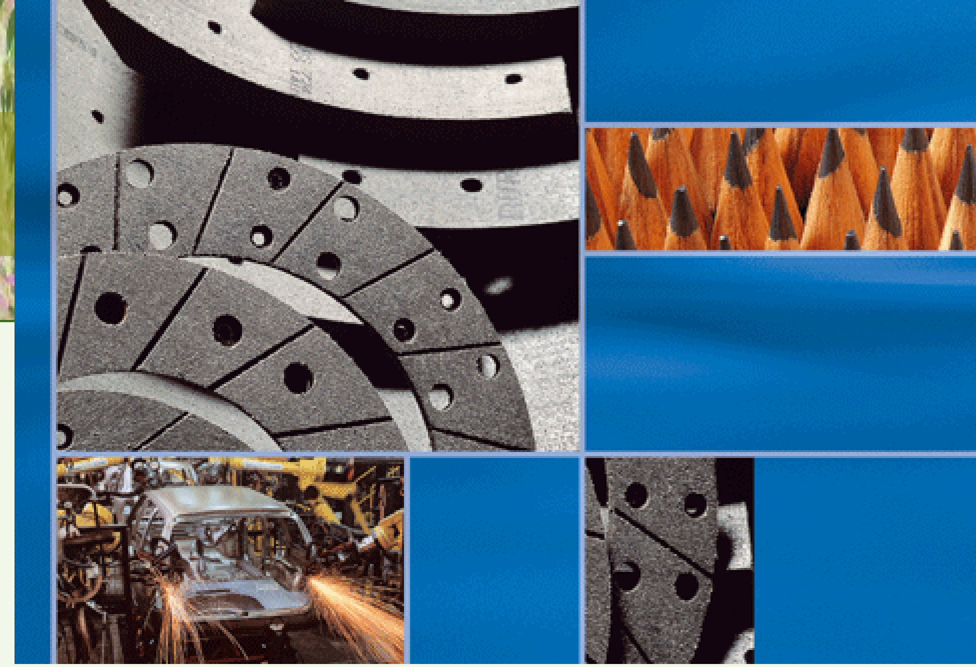
Graphite—uses

- Refractory applications 45% (brick and linings)
- Brake linings 20%
- Lubricants, 5%
- Dressings and molds in foundry operations, 5%
- Other uses 25% (batteries)

Graphite—uses

- Pebble-bed nuclear reactors
- Lithium-ion batteries
- Graphene
- Fuel cells
- Solar panels

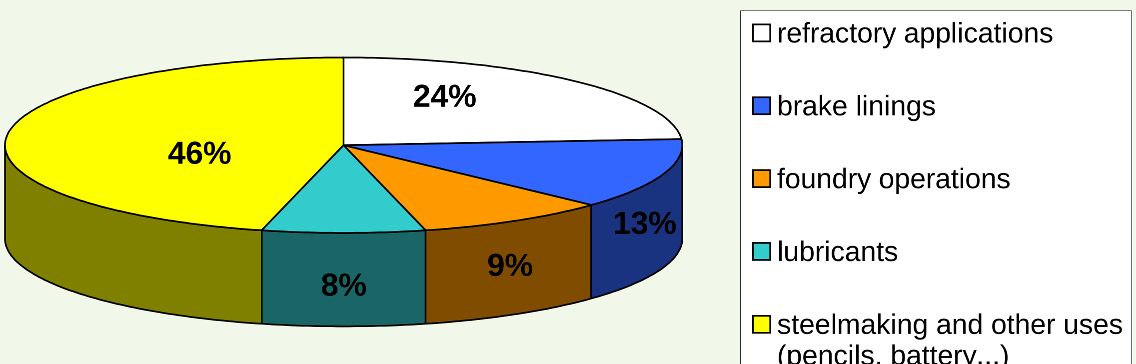
END-USES

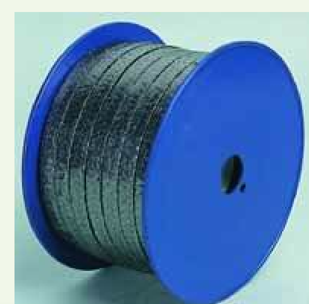


Main uses are in refractors, lubricants, brake linings, foundry molds, and electrodes (batteries). Non-traditional applications include expanded graphite and graphite foils (a thin graphite cloth).

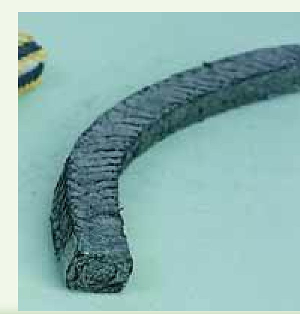
Graphite Foils

Uses of natural graphite in 2004





Graphite Packing

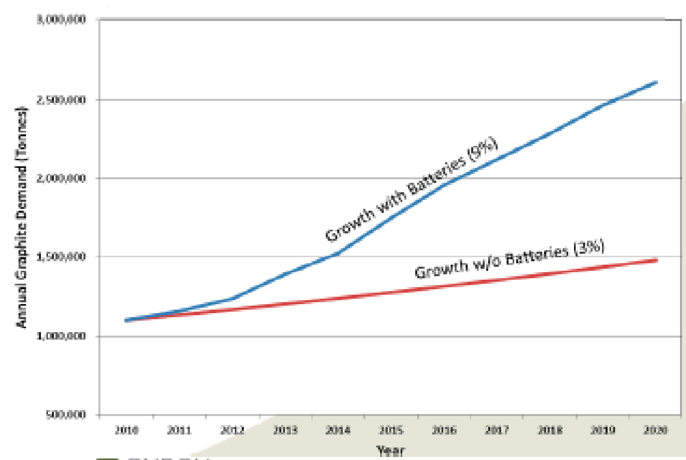


Expanded Graphite

	Flake	Amorphous	Vein/Lump	Synthetic
Steel Manufacturing				
Crucibles	■	■		
Electrodes				■
Foundry Additive	■	■	■	
Ladles	■	■		
Carbon Risers - steel	■	■		
Refractories	■	■		
Retorts	■			
Carbon Brushes, Batteries & Expanded Graphite				
Batteries	■		■	■
Carbon Brushes	■	■		■
Expanded Graphite	■			
Foil	■			
Flame Retardants	■			
Fuel Cells	■			■
Carbon Pans	■			
Castings				
Coatings	■	■		
Foundry Core & Mold Washes	■	■		
Molds	■	■		
Powder Metallurgy	■		■	
Friction Material				
Brake Linings and clutch facings	■	■		■
Lubricants	■	■	■	■
Pencils	■	■		
Other				
Carbon Additives		■		■
Catalysts	■			
Cloth & Fibers				■
Nuclear Reactors	■			
Paint		■		
Plastics & Resins	■			

Flake Graphite

- **Widest range of end uses**
- **Increasing demand for high purity flake graphite**
- **No substitute:**
  Synthetic graphite has high purity but is 4x the cost
  Synthetic graphite ($7,000-20,000/t)*
  Natural flake ($2,000-3,000/t)*
- **Flake graphite used in batteries - not amorphous**



BYRON

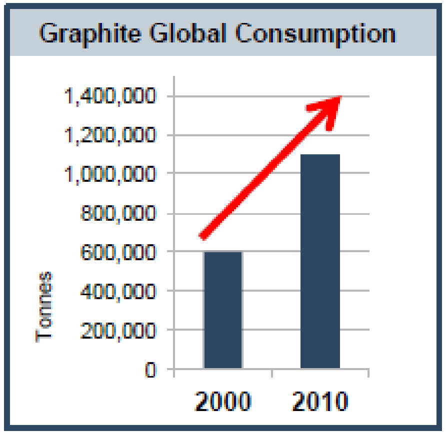
Source: Cormark Securities

Restricted and Unstable Supply in China = Opportunity

- China (+70% of world production) is losing dominance over graphite market due to export tariffs and environmental regulations that reduce supply and increase prices
- China also faced with a reduction of large and medium flake production

Flake graphite production outside of China:

Brazil Canada India Madagascar Norway Zimbabwe Germany



- Global consumption of natural graphite has doubled from 2000 to 2010
- Urbanization of China and India is driving the demand of graphite
- For the graphite used in the battery application alone, demand is expected to increase from 125,000 tons in 2010 to 320,000-640,000 tons in 2020; **a growth rate of 10-18%***
- European Union declared graphite as one of 14 critical raw materials

Graphite Mine

Inventory of different sizes for different uses and end users

End-Users

Typical one-year supply contracts establishing prices, specifications, volume, timing and delivery

- Graphite is not an openly traded mineral
- Prices are negotiated between end users and producers for annual and, sometimes, multi-year contracts
- Prices for graphite vary according to different parameters such as carbon content (purity), size, impurities and shape
- Continuous contact with customers is necessary
- There is a market for 100% of mined graphite material (from large to fine flakes)
- Market Study is underway to identify all end users in all market segments

Graphite—substitutions

- Graphite powder
- Scrap from discarded machined shapes
- Calcined petroleum coke
- Molybdenum disulfide
- Finely ground coke with olivine

Graphite—production

Salient Statistics—United States:	2010	2011	2012	2013	2014[e]
Production, mine	—	—	—	—	—
Imports for consumption	65	72	57	61	62
Exports	6	6	6	9	9
Consumption, apparent[1]	60	66	50	52	53
Price, imports (average dollars per ton at foreign ports):					
Flake	720	1,180	1,370	1,330	1,540
Lump and chip (Sri Lankan)	1,700	1,820	1,960	1,720	1,890
Amorphous	257	301	339	375	364
Net import reliance[1] as a percentage of apparent consumption	100	100	100	100	100

USGS Commodities Summary

Graphite—production

World Mine Production and Reserves: The reserves data for Brazil were revised based on information reported by the Government of Brazil.

	Mine production 2013	Mine production 2014[e]	Reserves[2]
United States	—	—	—
Brazil	95	80	40,000
Canada	20	30	([3])
China	750	780	55,000
India	170	170	11,000
Korea, North	30	30	([3])
Madagascar	4	5	940
Mexico	7	8	3,100
Norway	2	2	([3])
Russia	14	14	([3])
Sri Lanka	4	4	([3])
Turkey	5	30	([3])
Ukraine	6	6	([3])
Zimbabwe	4	6	([3])
Other countries	1	1	([3])
World total (rounded)	1,110	1,170	110,000

USGS Commodities Summary

Graphite

- graphite comes in three forms: amorphous, flake and vein/lump. Amorphous graphite contains 70-75% carbon and is the most common. Flake graphite is 85-90% carbon and is used for higher value applications like batteries. Vein/lump graphite is 90-96% carbon and is most valuable because it requires the least processing.
- graphite is used in refractories – used to line high-temperature equipment; pencils; lithium-ion batteries – used in consumer electronics and electric vehicles; fuel cells; and Pebble Bed nuclear reactors. It is used in foundries, lubricants and brake linings. Graphite is also used to produce graphene, a tightly packed single layer of carbon atoms that can be used to make inexpensive solar panels, powerful transistors, and even a wafer-thin tablet that could be the next-generation iPad. Graphene, extremely light and strong, has been called "the world's next wonder material."
- the closure of graphite mines in China, which produces 75% of the world's graphite, has resulted in a fall in global graphite production to 1.3 million tonnes per annum in 2011. Like rare earths, China is restricting the export of graphite to protect its own domestic industries. The second largest producer is India, followed by Brazil, North Korea, Austria and Canada.
- Graphite exploration is focused in Canada, with eight companies exploring properties in Quebec and Ontario. Europe has a number of mothballed mines that could return to production.

- The United States, Europe and China have included graphite among a short list of critical metals.
- the US Geological Service estimates the graphite market to be 10 times the size of the market for rare earth elements. The graphite market is about the same size as the market for nickel. 60% of the market is amorphous graphite and 40% is flake graphite. Most of the growth is in flake graphite (see bullet point below)
- natural graphite can be processed to make synthetic graphite useful for high-value applications like lithium-ion batteries, but the process is expensive – $10,000 to $20,000/ton versus $3-4,000/t for flake graphite. The result is a race to find the best flake graphite deposits.
- graphite is different from gold, silver, copper, etc because users require a specific carbon purity level. "It's security of supply that keeps you up at night," says Berry.
- 33% of the graphite market produces refractories and crucibles (used in foundries); only 5% is for batteries. But the lithium-ion battery market is expected to grow by 25% a year.
- Three of the largest lithium-ion battery makers in the world, GS Yuasa Corp, LG Chem and Liotech, a consortium between Russia and China, are building the largest lithium-ion battery plant in the world, in Russia. "Just these three heavy hitters in the battery space are making multi-million dollar bets on the future of lithium-ion technology, which cannot push forward without graphite," says Berry.
- future uses of graphite could include vanadium-redox batteries and hydrogen fuel cells. Graphite could also potentially replace silicon in microchips and silver used in solar panels.
- by 2020 world consumption of graphite will be 1.9m tonnes, which does not include graphite needed for batteries, fuel cells and Pebble Bed nuclear reactors.

- China will require 400,000 tonnes of large flake graphite for Pebble Bed nuclear reactors and lithium-ion batteries will require 327,000 tonnes. The current supply of large flake graphite is 400,000t, so there will be a need to double the supply of large flake graphite used in batteries and nuclear reactors in the next eight years. "The takeaway is if you buy into the electrification thesis, and I'm halfway right, demand should easily outstrip supply," says Berry.

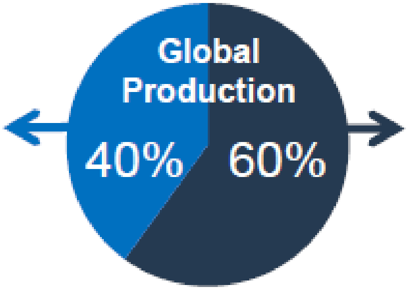
Graphite—geology

Types of Natural Graphite :

- Disseminated flake
- Crystalline vein (lump or high crystalline graphite)
- Amorphous

Associated Minerals include quartz, calcite, micas, iron meteorites, and tourmalines.

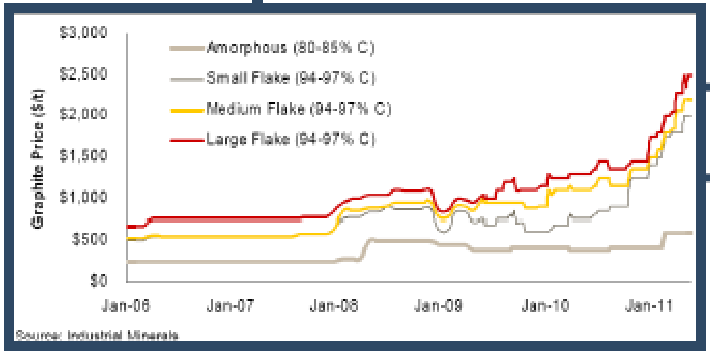
Graphite is not a homogenous commodity; it occurs naturally in 3 forms:



Flake
Highest Price, Lowest Supply
High Purity: 85%-98% carbon

Amorphous
Least graphitic of the three
Lower Purity: 60%-90% carbon

Vein/Lump
Uncommon & highly localized;
<1% of world production;
Marginal applications



- Flake size and purity directly affects the price
- Natural medium/large flake graphite forecasted between $1,750 and $2,000/t

As at Aug 9, 2012 - Amorphous: $600-800,
Medium Flake: $1,600-1,900, Large Flake: $1,800-2,200

Graphite—geology

- Disseminated in metamorphosed, silica-rich sedimentary rocks
- Flake graphite disseminated in marble
- Metamorphic coal or carbon-rich sediments
- Veins filling fractures, fissures, and cavities
- Contact metamorphic deposits in sedimentary rocks

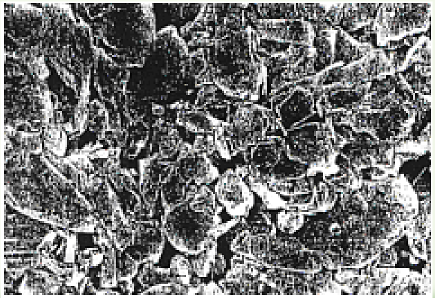
Geology

Flake graphite:

- is found in metamorphic rocks uniformly distributed through the ore body or in concentrated lens shaped pockets.
- Graphite flake occurs as a scaly or lamella form in certain metamorphic rocks such as limestone, gneisses and schists.
- Carbon concentrations vary between 5% and 40%.
- Flake graphite occurs in most parts of the world. Notable deposits are Canada, Brazil, Madagascar, Australia, USA(Texas-1980, Alabama &Pennsylvania-1960's), Germany
- **Flake**: marble, gneiss, and schist (most common rock types)

Table 4. Sample assay results

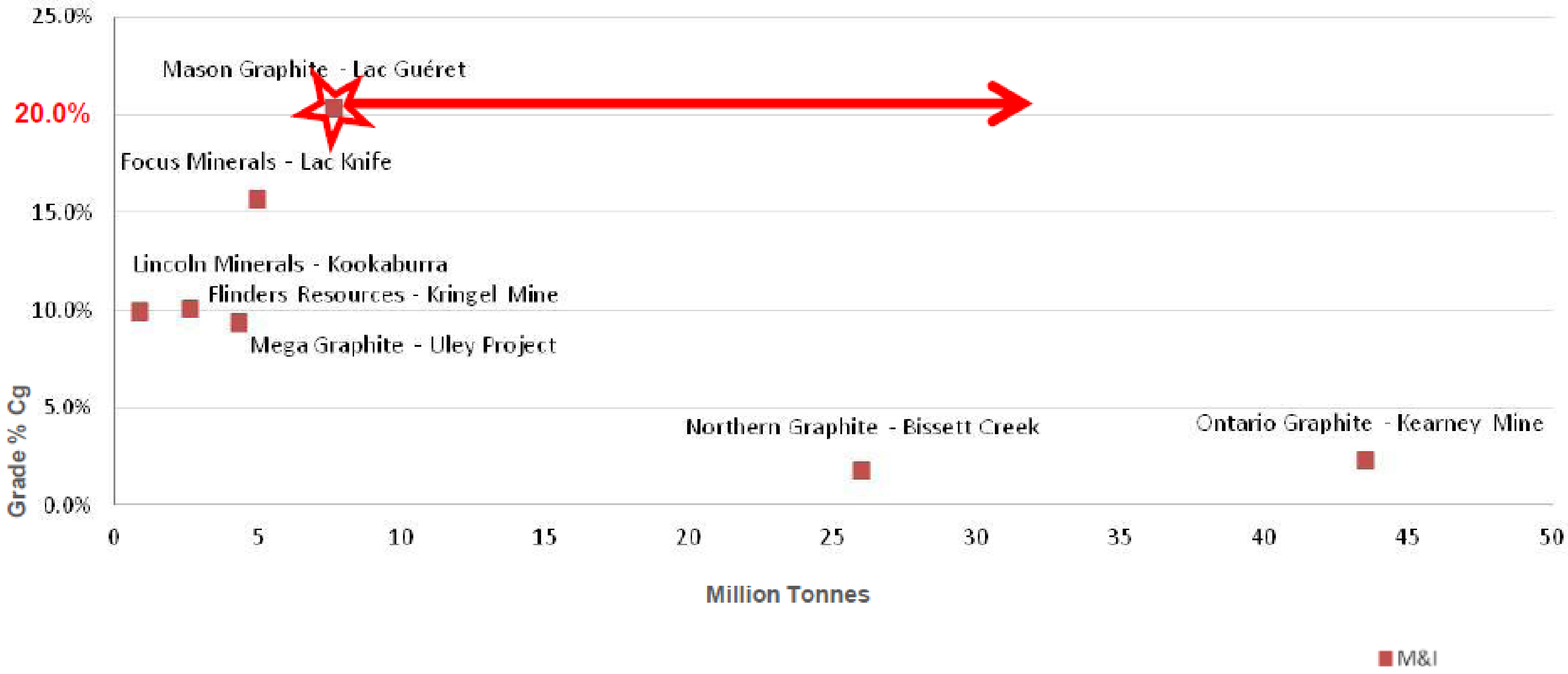
Size	Kilograms of Flake per Ton of Ore
+50 mesh	3.0–7.0
–50 +100 mesh	3.5–19.0
–100 mesh	4.0–35.0
Total flake	17.5–~65.0



Source -http://www.alibaba.com/catalog/10876290/Natural_Flake_Graphite.html

Graphite (@ $1,750) 20.4%	=	Gold (@ $1,250) 9.1 g/t	=	Silver (@ $14) 800 g/t	=	Copper (@ $2.75) 6%

Mason Graphite

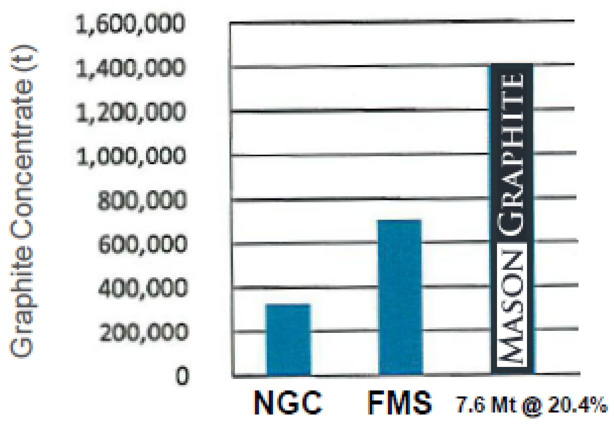


25.0%
20.0%
15.0%
10.0%
5.0%
0.0%
Grade % Cg
Mason Graphite - Lac Guéret
Focus Minerals - Lac Knife
Lincoln Minerals - Kookaburra
Flinders Resources - Kringel Mine
Mega Graphite - Uley Project
Northern Graphite - Bissett Creek
Ontario Graphite - Kearney Mine
0
5
10
15
20
25
30
35
40
45
50
Million Tonnes
M&I

MASON GRAPHITE

Company	Market Cap (Mar 1, 2013)	Flagship Project location	M&I (Mt)	M&I Grade (%Cg)	Inferred (Mt)	Inferred Grade (%Cg)
Northern Graphite Corp. (NGC)	$49.8M	Ont., CA	18.97	1.81%	55.04	1.57
Focus Graphite Inc. (FMS)	$73.7M	Qc., CA	4.94	15.76%	3.00	15.58
Flinders Resources Ltd. (FDR)	$30.7M	Sweden	2.6	10.5%	6.93	8.82
Mason Graphite (LLG)	**$43.6M**	**Qc., CA**	**7.59**	**20.40%**	**2.8**	**17.29**

Total Saleable Graphite Concentrate (M&I)



Definition drilling on Mason Graphite's Lac Guéret Project is expected to quickly and largely surpass the quantity and quality of comparable projects

Two Major Graphite Zones

MASON GRAPHITE

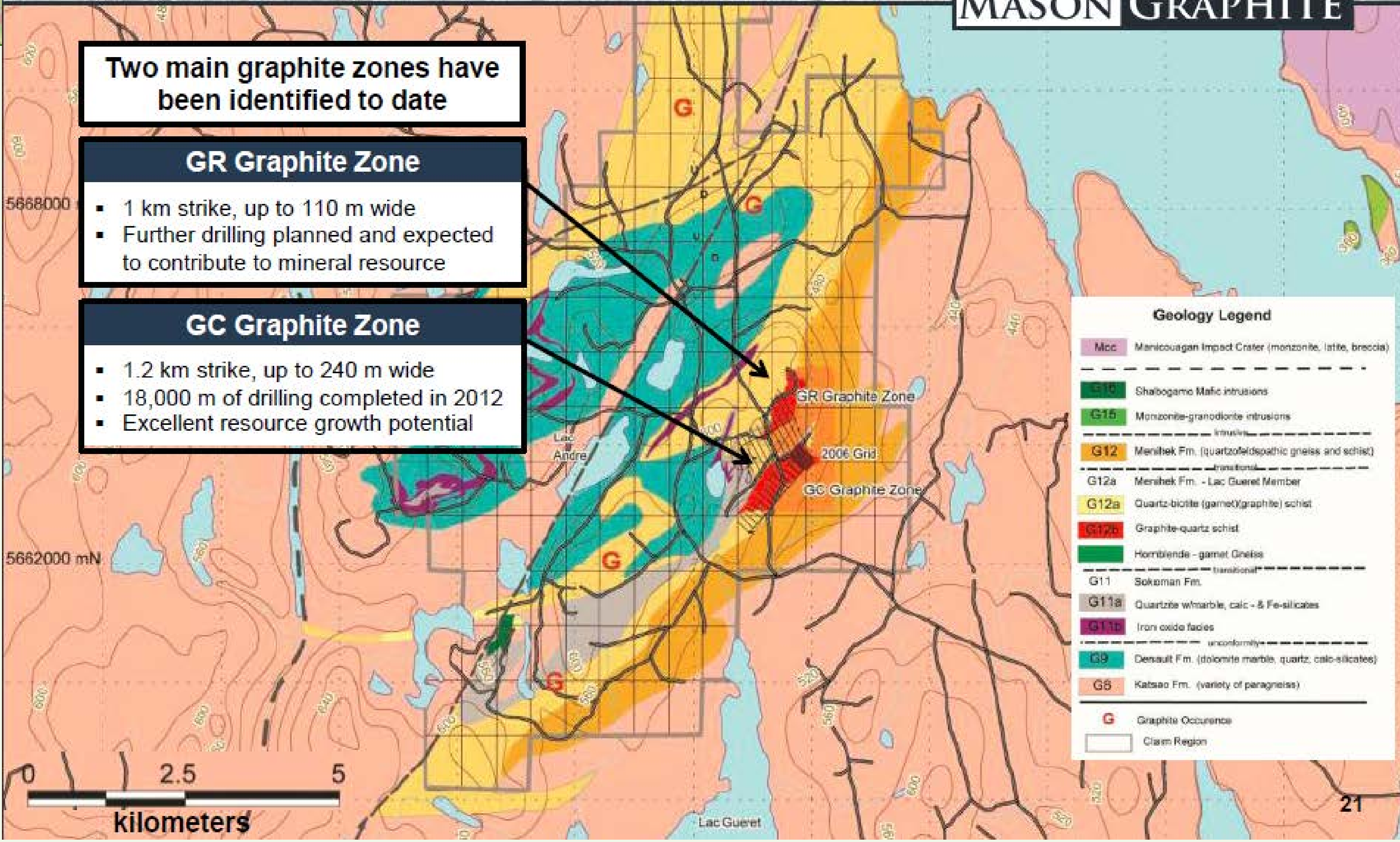
Two main graphite zones have been identified to date

GR Graphite Zone

- 1 km strike, up to 110 m wide
- Further drilling planned and expected to contribute to mineral resource

GC Graphite Zone

- 1.2 km strike, up to 240 m wide
- 18,000 m of drilling completed in 2012
- Excellent resource growth potential



Geology

Crystalline vein graphite:

- is believed to originate from crude oil deposits that through time, temperature and pressure have converted to graphite.
- Vein graphite is found along the intrusive contacts of pegmatites with limestone.
- The vein fissures are typically between 1cm and 1 m thick, and are normally > 90% pure.
- Although this form of graphite is found all over the world, it is only commercially mined in Sri Lanka (hand cobbing).

Source - http://www.asbury.com

Geology

Amorphous graphite:

- Amorphous graphite is found as minute particles in beds of mesomorphic rocks such as coal, slate or shale deposits.
- The graphite content ranges from 25% to 85% dependent on the geological conditions.
- Most of the amorphous deposits with economic importance are formed by metamorphism of coal or carbon rich sediments.
- Notable occurrences are in Mexico, North Korea, South Korea and Austria.

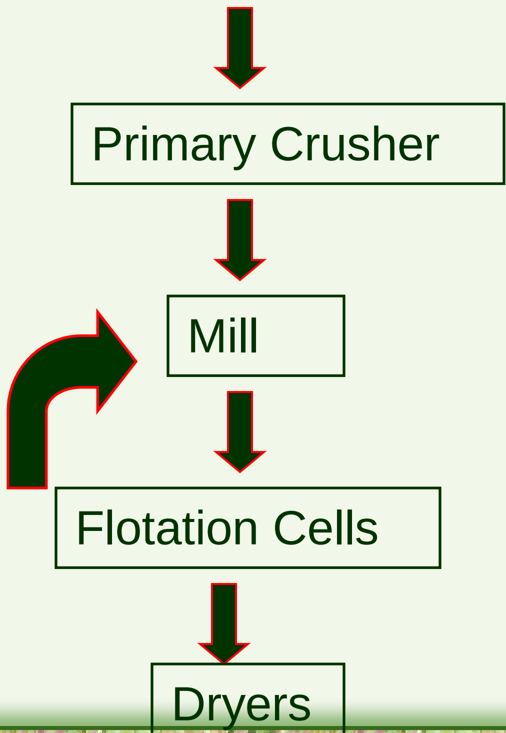
Source - http://kuroko.mus.akita-u.ac.jp/sampimag/11767e.htm

Artificial Graphite

- Synthetic graphite can be produced from coke and pitch.
- Synthetic Graphite consists mainly of graphitic carbon that has been obtained by graphitisation, heat treatment of non-graphitic carbon, or by chemical vapour deposition from hydrocarbons at temperatures above 2100K .
- Synthetic Graphite tends to be of higher purity though not as crystalline as natural graphite.
- On the whole, synthetic graphite tends to be of a lower density, higher porosity and higher electrical resistance.
- Its increased porosity makes it unsuitable for refractory applications.

Source - http://www.intertrade.com.

Mining Method



Graphite is commonly extracted through open-pit methods. In some cases, it has been extracted through underground mining (vein deposits in Sri Lanka).

Mining - Graphite ore is extracted with the use of shovels & bulldozers that load dump trucks with the crude ore.

Mechanical concentration - The ore is crushed by a primary crusher and then submitted to a series of roll crushers and classifiers to remove the oversizes and gangue. Flotation is used for the mechanical separation of the graphite from impurities present in the ore. The cycle mill-flotation is repeated until a grade between 87 - 96% of carbon is reached.

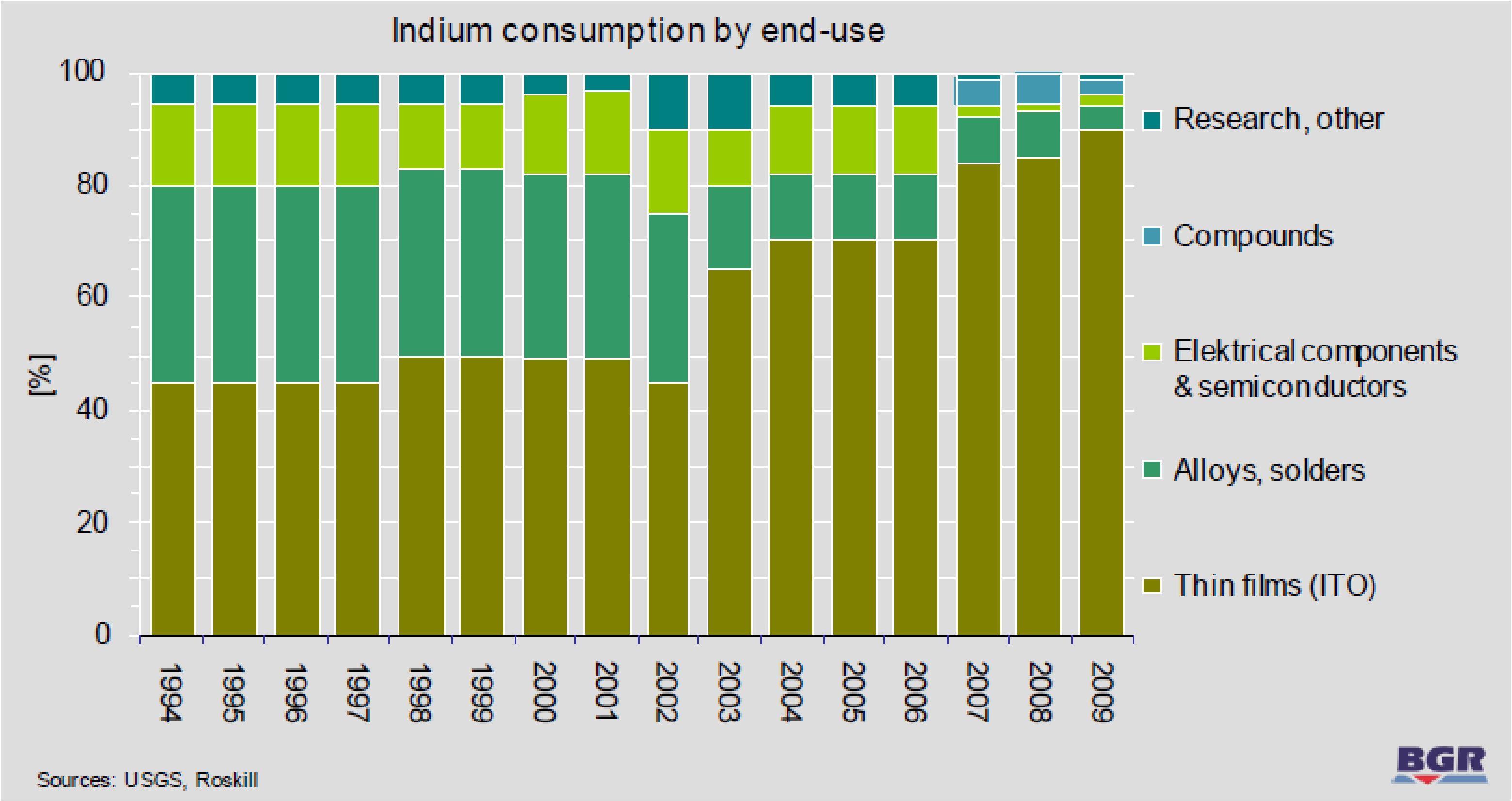
Chemical concentration - Concentration with the use of chemical agents is used to remove impurities that remain in the graphite after the mechanical concentration process. Some firms make high purity graphite (98% - 99%carbon) by leaching concentrate with strong acids or alkalis.

Indium

Indium

- In
- 0.05 ppm crust
- 0.072 ppm oceanic crust
- Silver-white, malleable, ductile metal
- High plastic properties even at freezing
- coat glass, forming a mirror surface with equally good reflective properties and more corrosion resistance than silver

Uses



Indium for photovoltaic application particularly in CIS (copper-indium-selenide) thin-film solar cells is a relatively new application with strong growth potential.

Indium

- Solar panels
- Flat screens (LCDs)
- Solders and alloys
- Semiconductors

Indium is used to make flat panel displays.

Appearance

silvery lustrous gray

Indium Wire

Indium in solar panels

- 50 metric tons required for enough solar panels to provide 1 gigawatt of energy
- $500/kg in 2009
- 2008—US used 800 megawatts of energy by solar panels connected to the grid (0.1% total US energy)
- 600,000 metric tons reserves in the world in 2009
  - Zinc sulfide deposits
  - Tin-tungsten veins
  - Porphyry copper deposits

Ingots of Indium.

Production

Country	Mine production zinc	Mine production ore concentrate	Estimated indium content in concentrate		Share
	million t Zn content	million t Sphalerit	[ppm]	[t]	[%]
China	2.8	4.2	50	210	45.0
Peru	1.5	2.2	20	44	9.4
Canada	0.7	1.1	37	40	8.6
Australia	1.3	1.9	15	29	6.2
USA	0.7	1.0	20	21	4.5
Mexico	0.5	0.8	20	16	3.4
other	3.6	5.4	20	107	23.0
total	**11.1**	**16.6**	**29**	**467**	

Estimated indium mine production from zinc deposits in 2009 (Roskill 2010).

Production

Salient Statistics—United States:	2010	2011	2012	2013	2014[e]
Production, refinery	—	—	—	—	—
Imports for consumption	117	146	109	97	120
Exports	NA	NA	NA	NA	NA
Price, annual average, dollars per kilogram:					
U.S. producer[1]	565	720	650	615	735
New York dealer[2]	552	685	540	570	695
99.99% c.i.f. Japan[3]	546	680	510	575	700
Net import reliance[4] as a percentage of estimated consumption	100	100	100	100	100

World Refinery Production and Reserves:

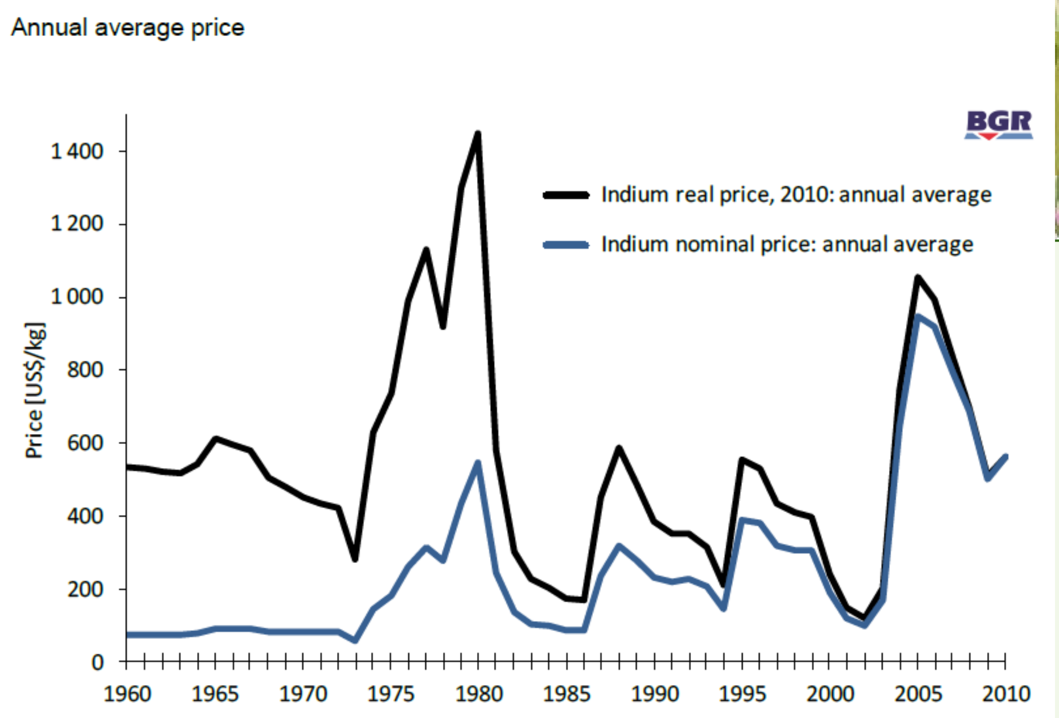
	Refinery production 2013	Refinery production 2014[e]	Reserves[5]
United States	—	—	Quantitative estimates of reserves are not available.
Belgium	30	30	
Canada	65	65	
China	415	420	
France	33	48	
Germany	10	10	
Japan	72	72	
Korea, Republic of	150	150	
Peru	11	11	
Russia	13	13	
World total (rounded)	799	820	

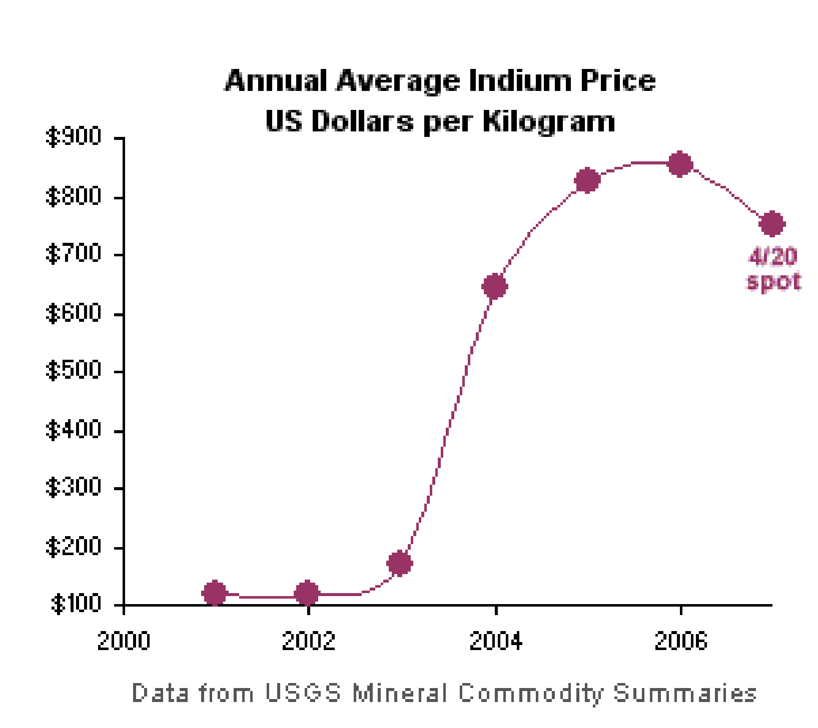
http://minerals.usgs.gov/minerals/pubs/mcs/2015/mcs2015.pdf

Companies

Companies	Plant location	Refinery capacity [t]	Secondary capacity [t]
Nanjaing Germanium Factory	China	150	
Huludao Zinc	China	50	
Zhuzhou Smelter Group	China	?	
Dowa Metals & Mining Co.	Japan	70	150
Asahi Pretec Corp.	Japan		200
Mitsubishi Mat. Group	Japan		96
Korea Zinc	South Korea	100	100
Umicore SA	Belgium	30	
Teck Resources Ltd	Canada	~75	
Xstrata Plc.	Canada	?	
Doe Run	Peru	45	

Price


Annual average price
BGR
Indium real price, 2010: annual average
Indium nominal price: annual average
Price [US$/kg]
1 400
1 200
1 000
800
600
400
200
0
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010


Annual Average Indium Price
US Dollars per Kilogram
$900
$800
$700
$600
$500
$400
$300
$200
$100
2000
2002
2004
2006
4/20
spot
Data from USGS Mineral Commodity Summaries

Mineralogy

- indit ($FeIn_2S_4$)
- roquesit ($CuInS_2$)

Sphalerite	<5— 12,500
Chalcopyrite	<5— 9,800
Stannite	400— 2100
Digenite	1100
Cassiterite	200— 700
Galena	500
Pyrite	100

http://pubs.usgs.gov/of/2005/1209/2005-1209.pdf

Geology

- Base metal deposits
  - Chalcopyrite
  - Sphalerite
  - Stannite
- Tin and tungsten vein deposits
  - Difficult to recover
- Volcanic massive sulfide deposits
- Porphyry deposits
- Skarn deposits
- Bauxite deposits
- Zinc deposits
- Black shale deposits
- Coal
- Mississippi-valley type deposits
- Pegmatites
- Sandstone-hosted base-metal deposits

Geology

Geographic Areas Where the Highest Indium Value Equals or Exceeds 1000 ppm

Mount Pleasant, New Brunswick; Canada
Bingham district, Utah; U.S.A.
Central district, New Mexico; U.S.A.
Central City district; Colorado; U.S.A.

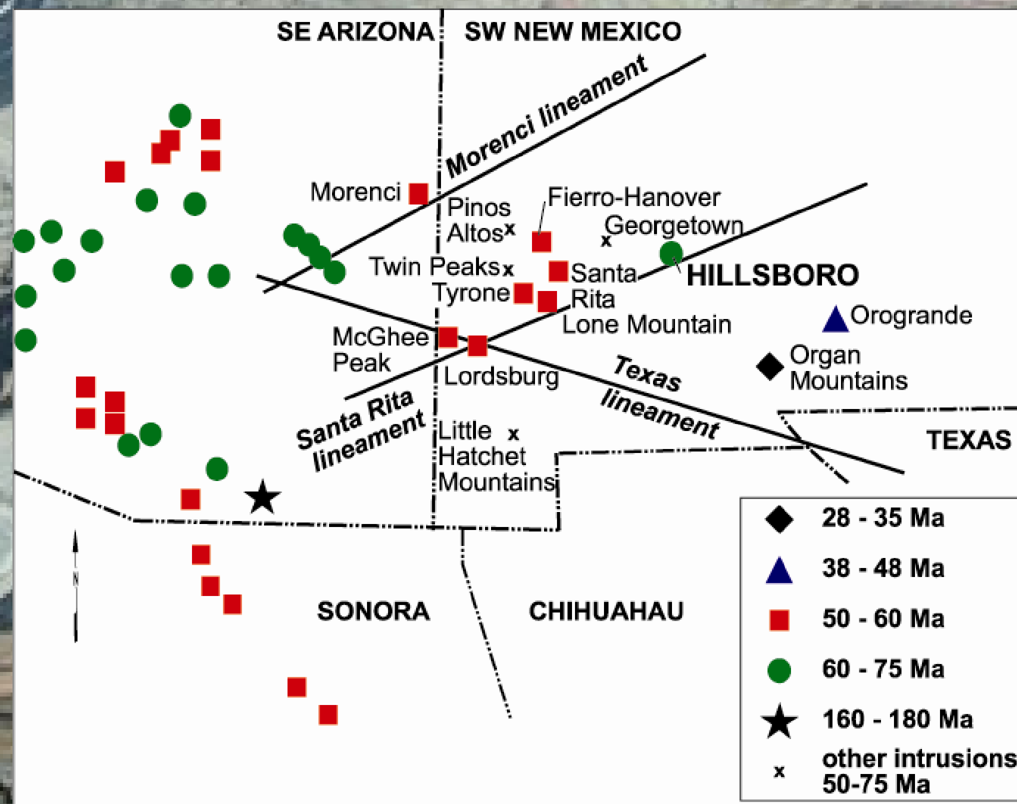
Geographic Areas Where the Highest Indium Values are Between 100-1000 ppm

Cornwall; England
Balmat-Edwards district, New York; U.S.A.
Maine, New Hampshire, Connecticut, and Rhode Island; U.S.A.
Rammelsberg mine, Germany
Argentina, various areas
Yugoslavia, various areas
Metaline district, Washington; U.S.A.
Coeur d'Alene district, Idaho; U.S.A.
Pinos Alto district [incl. Cleveland mine], New Mexico; U.S.A.

http://pubs.usgs.gov/of/2005/1209/2005-1209.pdf

Porphyry copper deposits

- Current
  - Gold
  - Silver
  - Molybdenum
- Possible
  - Tellurium
  - Gallium
  - Germanium
  - Indium
  - Others



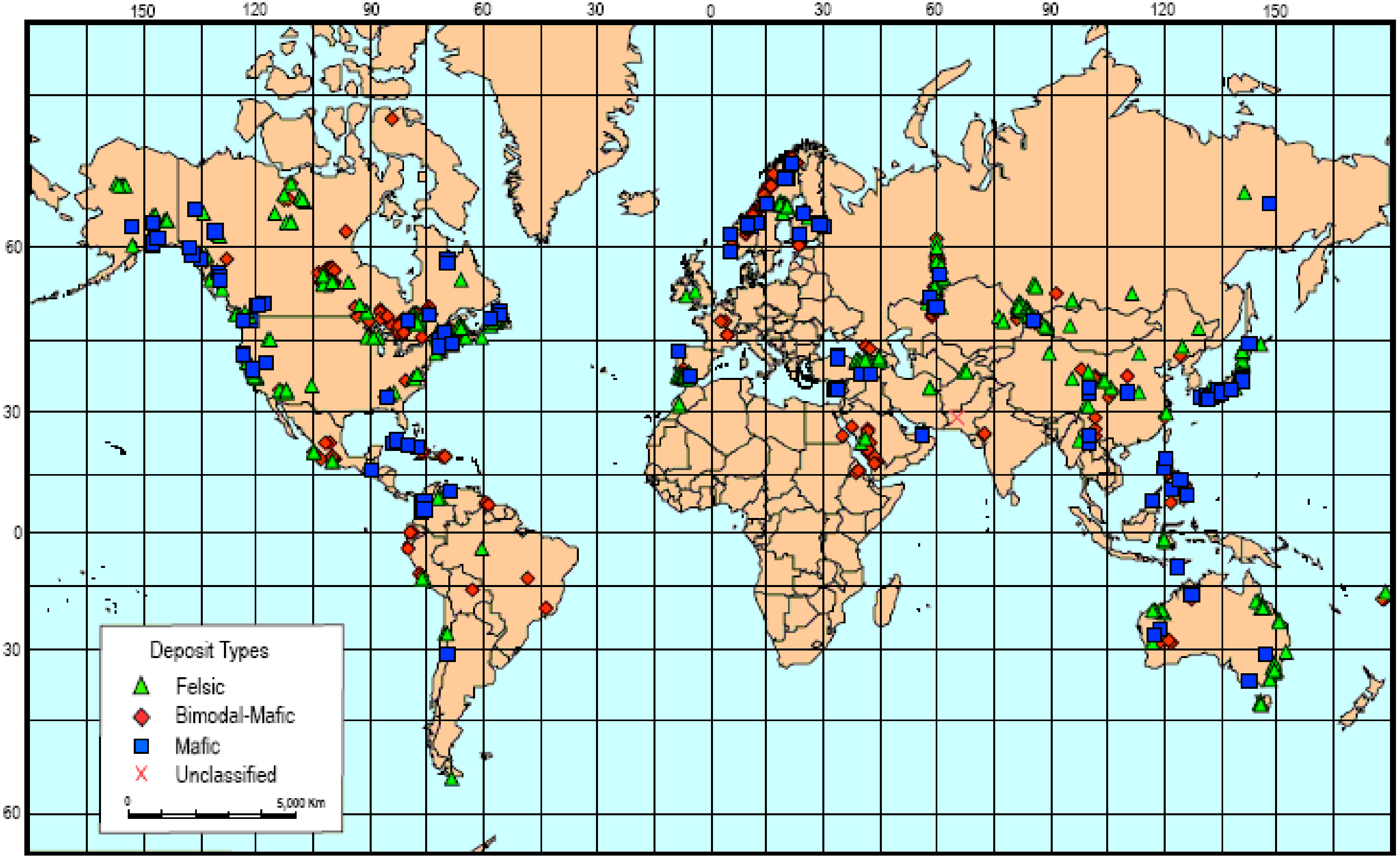


Figure 24. World map showing the distribution of volcanogenic massive sulfide deposit subtypes.

http://pubs.usgs.gov/of/2009/1034/of2009-1034_text.pdf

2006 Indium Reserve Base - Metric Tons From indium content of zinc ores	
Canada	2000
China	1300
United States	600
Russia	300
Japan	150
Peru	150
Other Countries	1500
Total	6000

http://geology.com/articles/indium.shtml

Lithium

Lithium—introduction

- Lightest of all metals
- 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

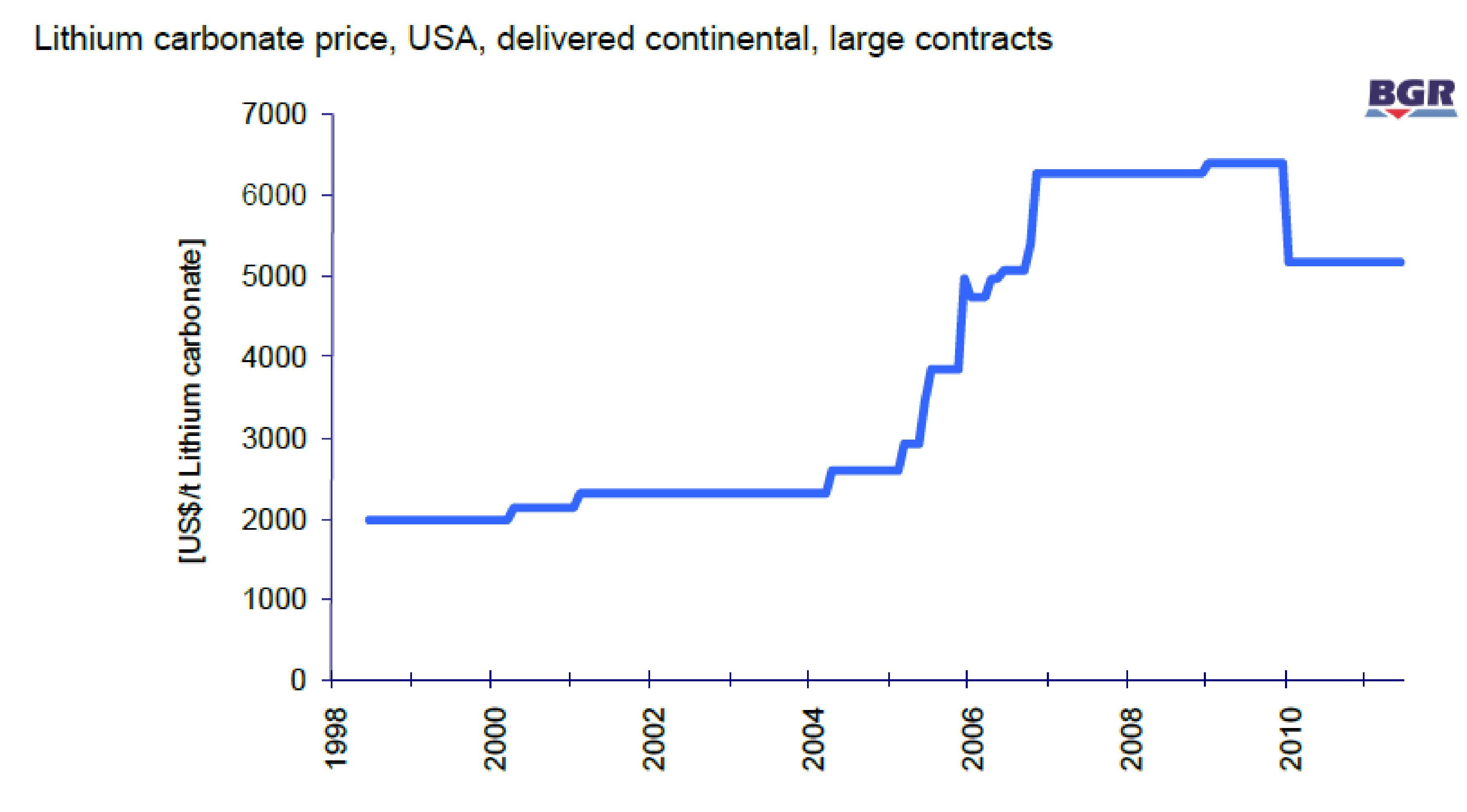
Lithium—production

Salient Statistics—United States:	2010	2011	2012	2013	2014[e]
Production	W	W	W	[1]870	W
Imports for consumption	1,960	2,850	2,760	2,210	2,100
Exports	1,410	1,310	1,300	1,230	1,300
Consumption:					
Apparent	W	W	W	W	W
Estimated	1,100	[2]2,000	[2]2,000	1,800	[2]2,000
Price, annual average, battery-grade lithium carbonate, dollars per metric ton[3]	5,180	5,180	6,060	6,800	6,600
Employment, mine and mill, number	70	70	70	70	70
Net import reliance[4] as a percentage of apparent consumption	>50%	>80%	>60%	>50%	>50%

World Mine Production and Reserves: The reserves estimates for Australia and Brazil have been revised based on new information from Government and industry sources.

	Mine production		Reserves[5]
	2013	2014[e]	
United States	870	W	38,000
Argentina	2,500	2,900	850,000
Australia	12,700	13,000	1,500,000
Brazil	400	400	48,000
Chile	11,200	12,900	7,500,000
China	4,700	5,000	3,500,000
Portugal	570	570	60,000
Zimbabwe	1,000	1,000	23,000
World total (rounded)	34,000	[6]36,000	13,500,000

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

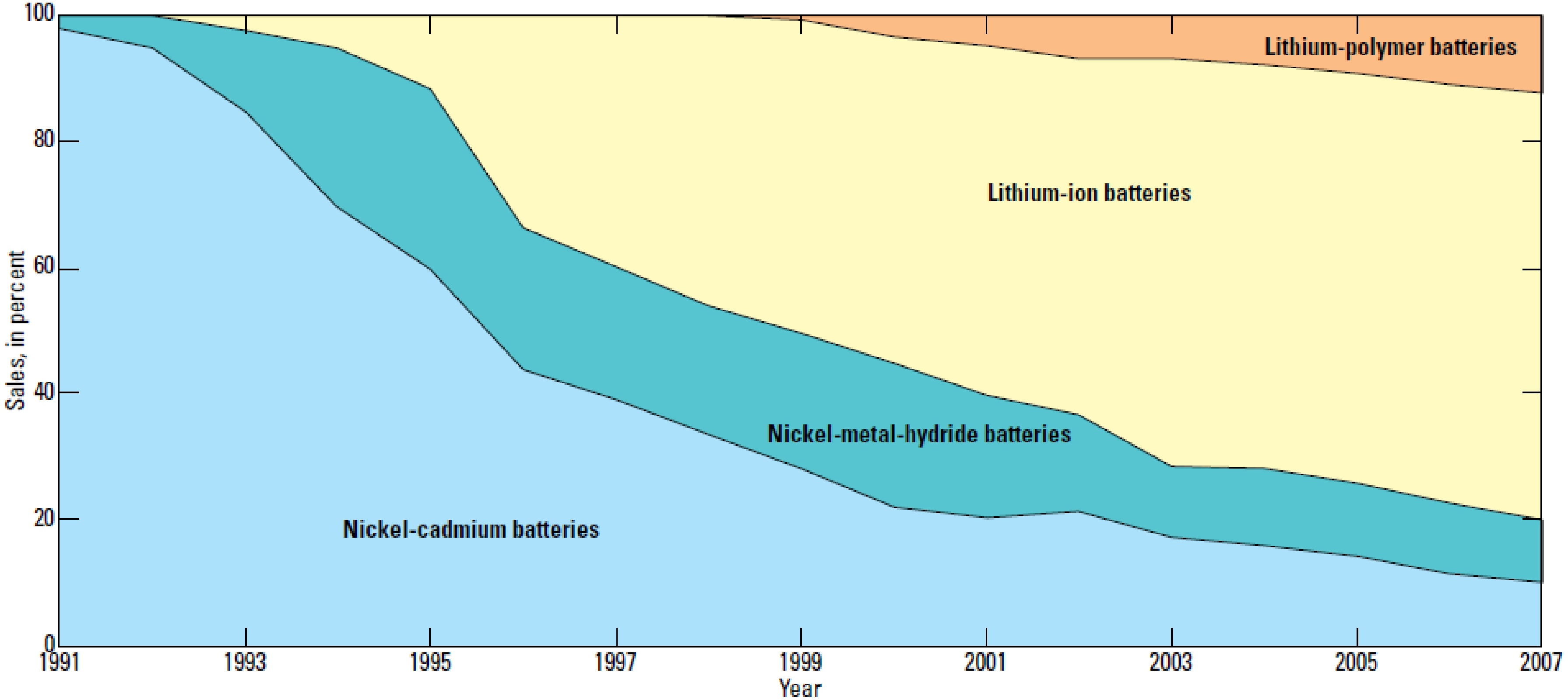


Figure 2. Chart showing sales of rechargeable batteries worldwide from 1991 through 2007. Values are expressed as percentage of total global sales of rechargeable batteries. Data are from Wilburn (2007) and Takashita (2008).

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

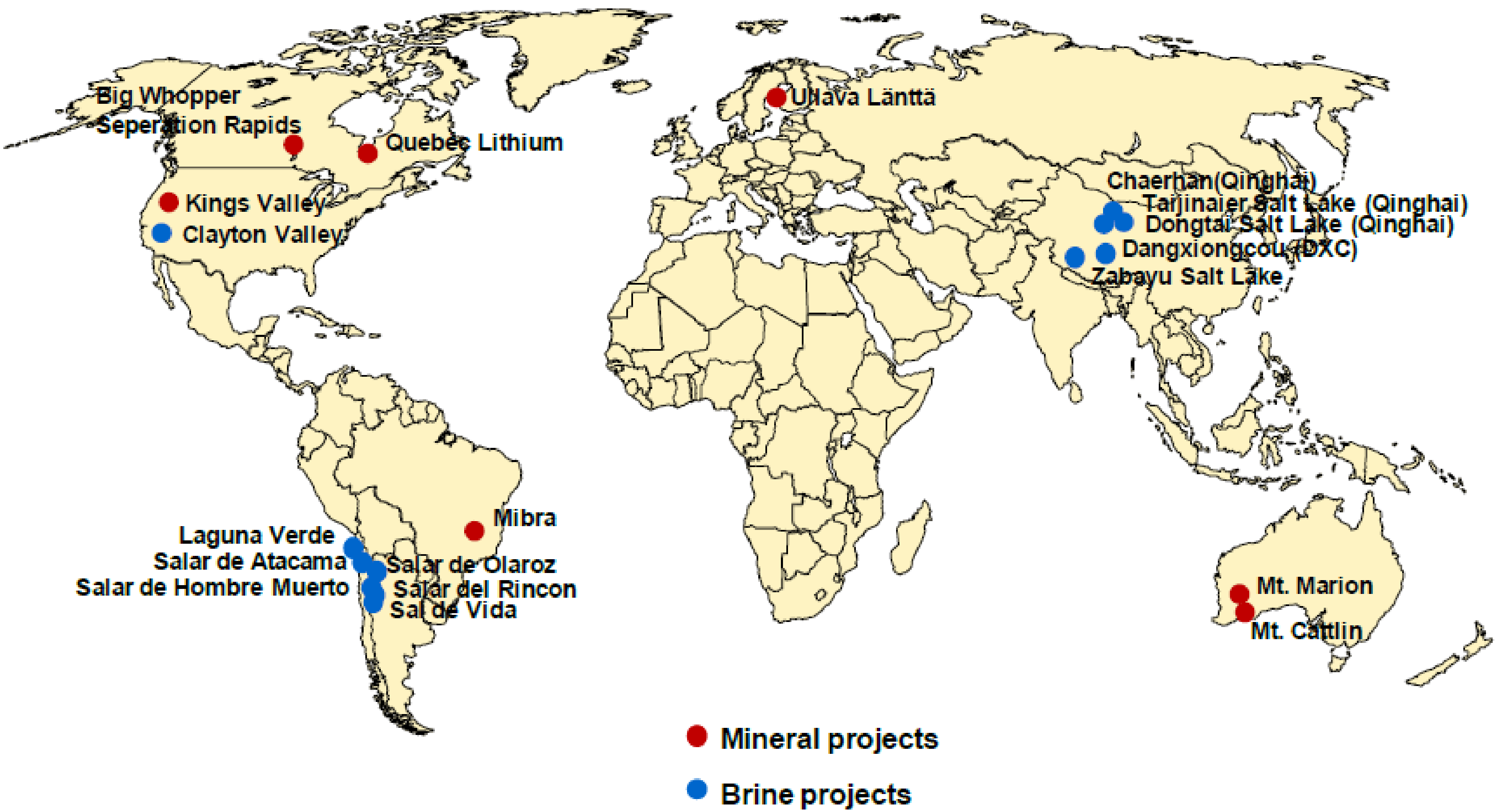
[1]Other countries produce small amounts of lithium but are not included here.

[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



Niobium and tantalum

Niobium and tantalum—introduction

- Columbium
- Nb
- found with tantalum Ta

Niobium—uses

- Carbon steels, 33%
- Superalloys, 23%
- Stainless and heat-resisting steels,18%
- High-strength low-alloy steels, 16%
- Alloy steels, 9%
- Other, 1%

Tantalum—uses

- capacitors
  - automotive electronics
  - pagers
  - personal computers
  - portable telephones
- electrical applications

TABLE 4

REPORTED CONSUMPTION, BY END USE, AND INDUSTRY STOCKS OF FERROCOLUMBIUM AND NICKEL COLUMBIUM IN THE UNITED STATES 1/

(Metric tons of contained columbium)

End use	2000	2001
Steel:		
Carbon	1,370	1,300
Stainless and heat-resisting	682	660
Full alloy	(2/)	(2/)
High-strength low-alloy	1,090	1,030
Electric	(2/)	(2/)
Tool	(2/)	(2/)
Unspecified	--	--
Total	3,140	2,990
Superalloys	942	1,230
Alloys (excluding alloy steels and superalloys)	(3/)	(3/)
Miscellaneous and unspecified	10	11
Grand total	4,090	4,230
Stocks, December 31:		
Consumer	NA	NA
Producer 4/	NA	NA
Total	NA	NA

NA Not available. -- Zero.

1/ Data are rounded to no more than three significant digits; may not add to totals shown.

2/ Included with "Steel: High-strength low-alloy."

3/ Included with "Miscellaneous and unspecified."

4/ Ferrocolumbium only.

USGS Commodity Summaries

Niobium—uses *(USGS OF01-348)*

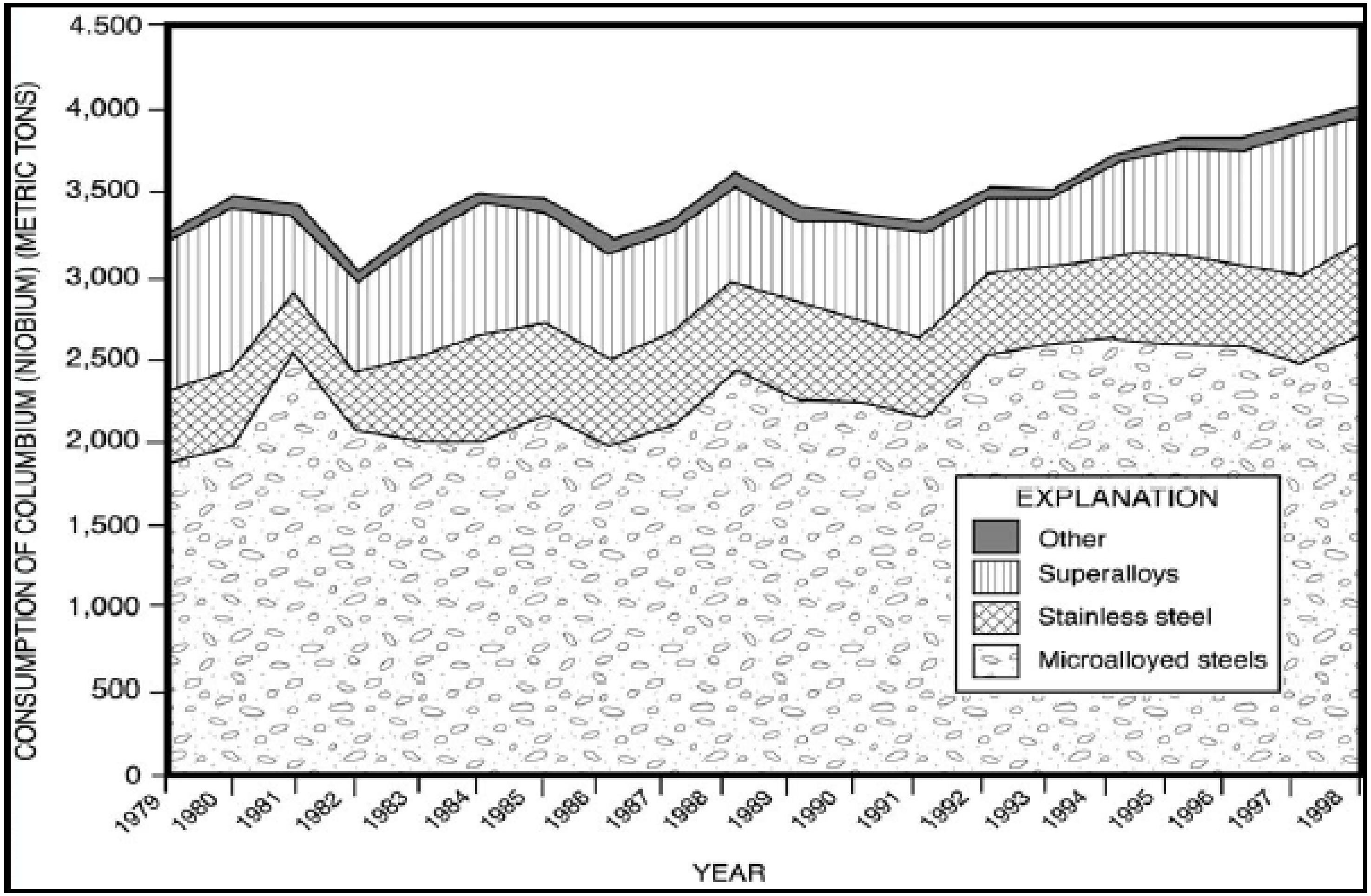


Figure 2. U.S. columbium end-use patterns, 1979-98, in metric tons contained columbium.

Production—niobium

Salient Statistics—United States:	2010	2011	2012	2013	2014[e]
Production:					
Mine	—	—	—	—	—
Recycling	NA	NA	NA	NA	NA
Imports for consumption[e, 1]	8,490	9,520	10,100	8,580	11,000
Exports[e, 1]	281	363	385	435	1,000
Government stockpile releases[e, 2]	—	—	—	—	—
Consumption:[e]					
Apparent	8,210	9,160	9,730	8,140	10,000
Reported[3]	5,590	9,060	7,460	7,500	8,000
Unit value, ferroniobium, dollars per metric ton[4]	37,781	41,825	43,658	43,415	42,000
Net import reliance[5] as a percentage of apparent consumption	100	100	100	100	100

World Mine Production and Reserves:

	Mine production 2013	Mine production 2014[e]	Reserves[6]
United States	—	—	—
Brazil	53,100	53,000	4,100,000
Canada	5,260	5,000	200,000
Other countries	1,000	1,000	NA
World total (rounded)	59,400	59,000	>4,300,000

USGS Mineral Yearbooks

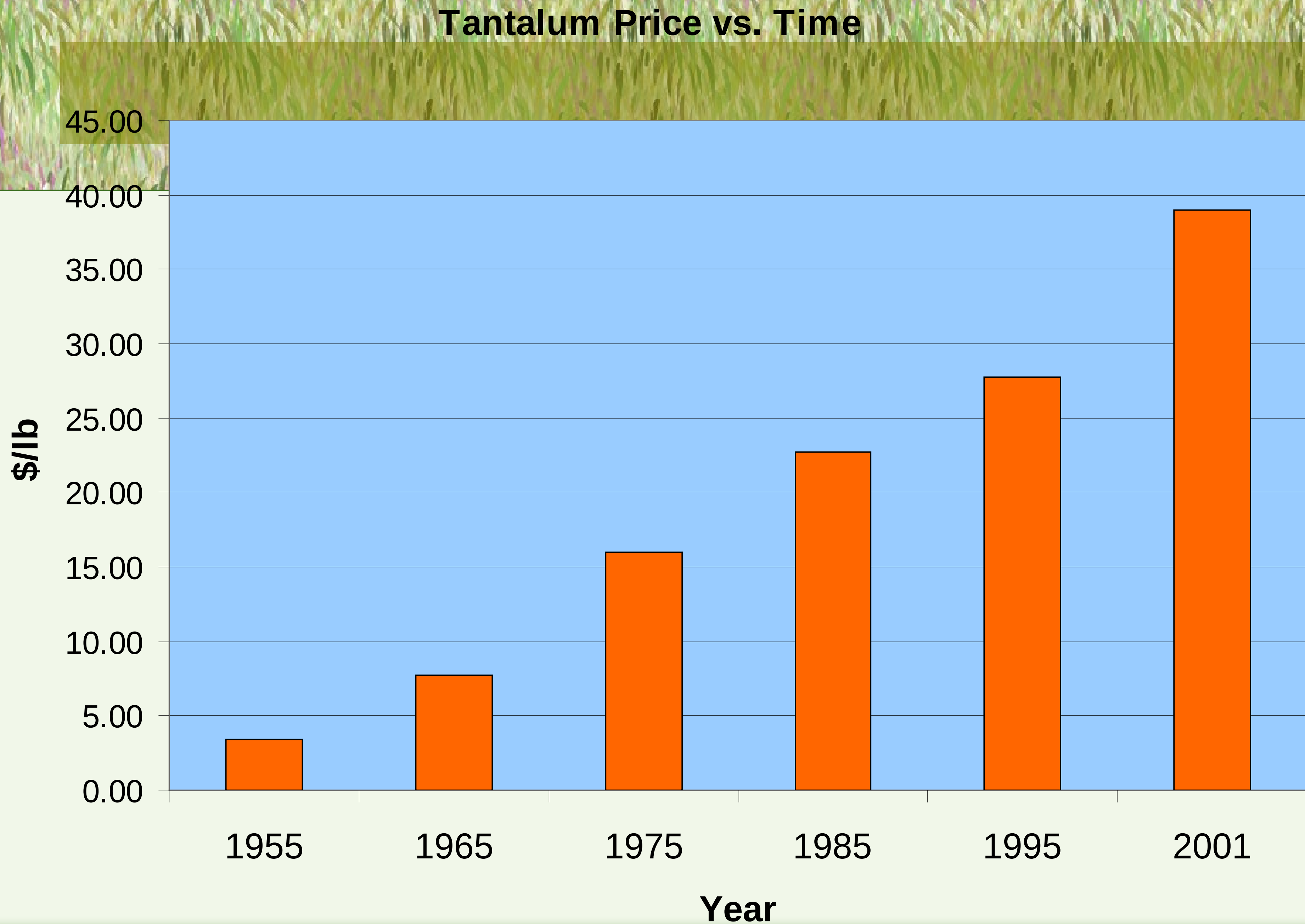
Production—***tantalum***

Salient Statistics—United States:	2010	2011	2012	2013	2014[e]
Production:					
Mine	—	—	—	—	—
Secondary	NA	NA	NA	NA	NA
Imports for consumption[e, 1]	1,600	1,850	1,010	1,100	921
Exports[e, 1]	438	648	577	844	782
Government stockpile releases[e, 2]	—	—	—	—	—
Consumption, apparent	1,160	1,210	437	260	139
Price, tantalite, dollars per pound of Ta_2O_5 content[3]	54	125	108	118	110
Net import reliance[4] as a percentage of apparent consumption	100	100	100	100	100

World Mine Production and Reserves:

	Mine production[7]		Reserves[8]
	2013	2014[e]	
United States	—	—	—
Australia	—	—	[9]67,000
Brazil	98	98	36,000
Burundi	20	14	NA
Canada	5	—	NA
China	60	60	NA
Congo (Kinshasa)	170	180	NA
Ethiopia	8	40	NA
Mozambique	115	85	NA
Nigeria	60	60	NA
Rwanda	250	250	NA
World total (rounded)	786	787	>100,000

USGS Mineral Yearbooks

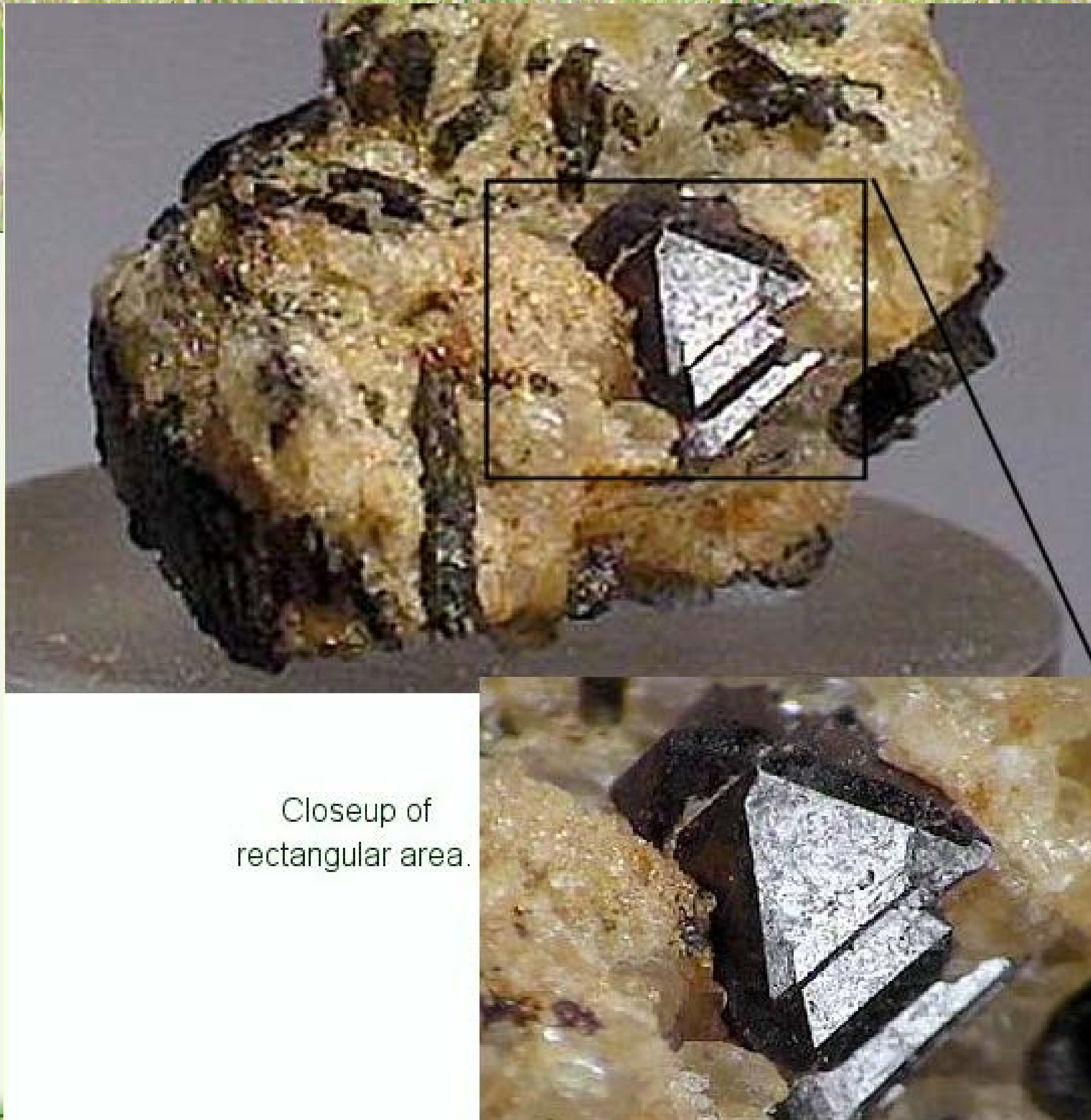


Tantalum Price vs. Time
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
$/lb
1955
1965
1975
1985
1995
2001
Year

Niobium—geology

http://www.tanb.org/niobium1.html

- pyrochlore [(Ca,Na)2 Nb2(O,OH,F)^{7}] in carbonatite and alkaline igneous deposits
- pegmatites (Columbite and tantalite)
- alluvial deposits
- largest deposit in Araxá, Brazil, owned by Companhia Brasileira de Metalurgia e Mineração (CBMM) (460 million tons of 3.0% Nb2O5, or 500 yrs reserves)
- Niobec mine in Quebec
- tin slags produced from the smelting of cassiterite ores



Lauzon Farm, Oka, Quebec, Canada. 3.9 x 2.9 cm.
http://www.webmineral.com/specimens/Pyrochlore.shtml

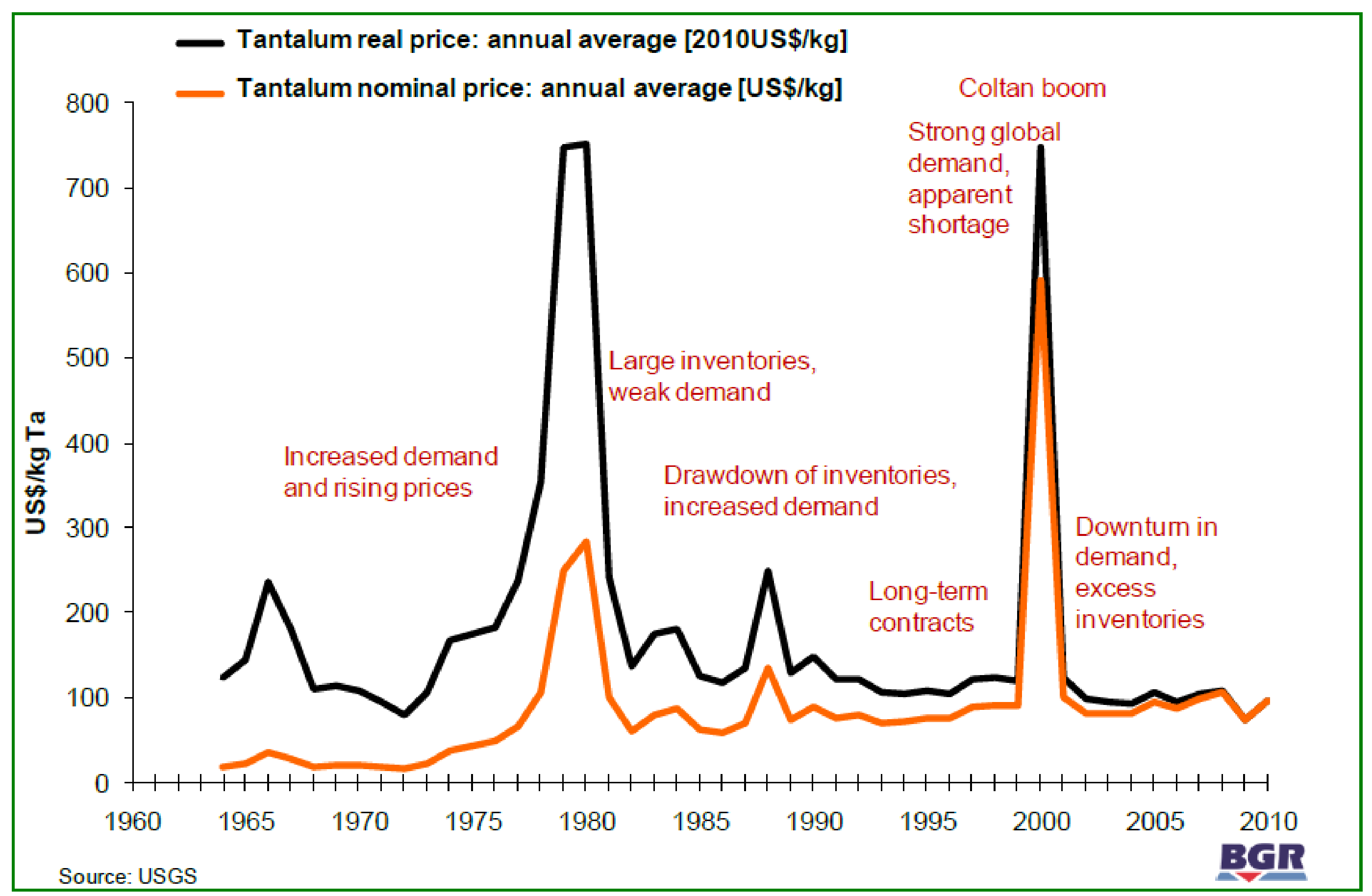
Companhia Brasileira de Metalurgia e Mineração (CBMM), open pit mine for Nb, Minas Gerais, Brazil

http://www.us.cbmm.com.br/english/sources/mine/operat/f_operat.htm

Tantalum

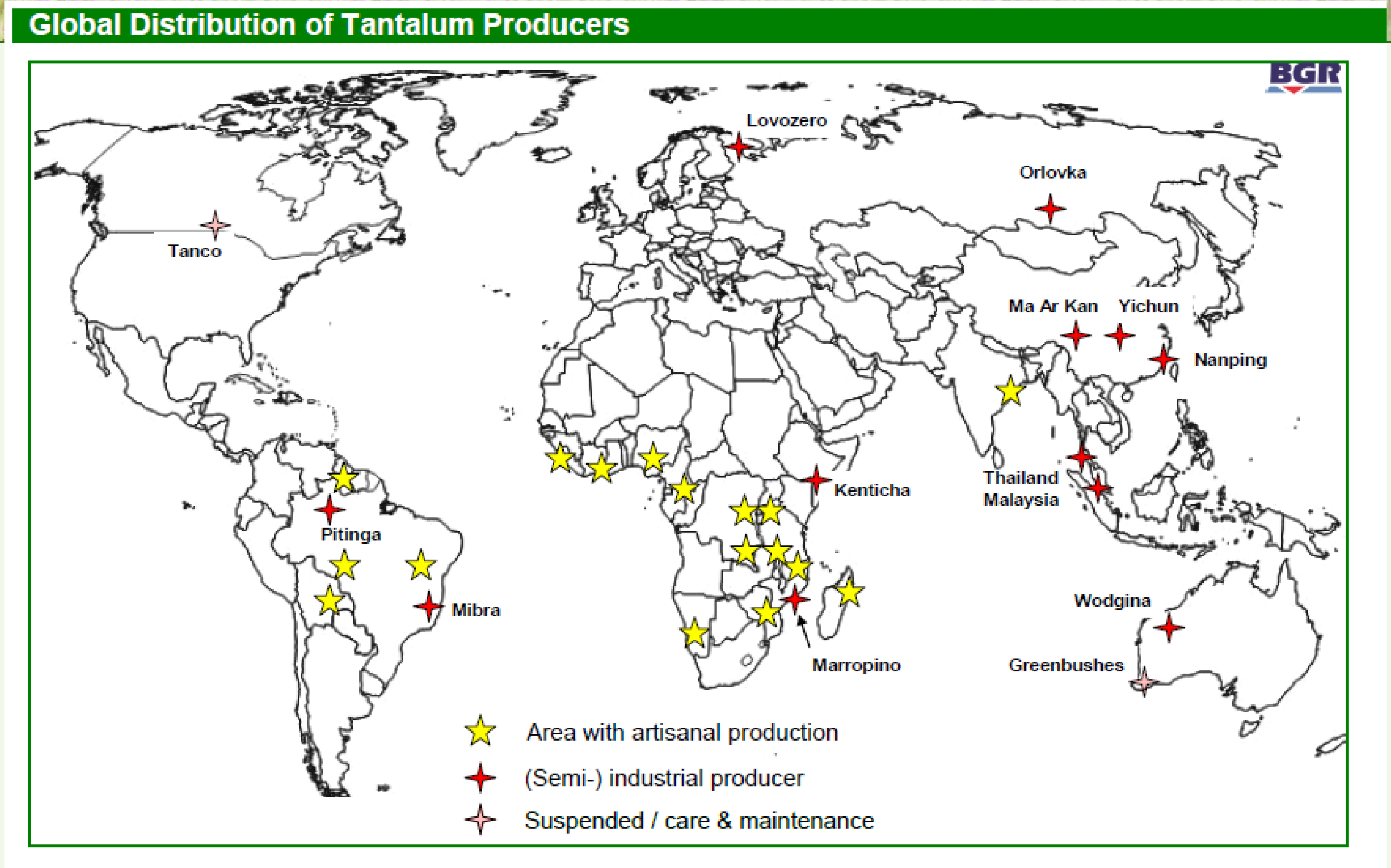
- Minerals--tantalite and columbite or niobite
- Best deposits--Granitic rare-metal pegmatites and rare-metal granites
- Grades--0.015 - 0.02 % $Ta2O5$

Tantalium—price



http://www.polinares.eu/docs/d2-1/polinares_wp2_annex2_factsheet2_v1_10.pdf

Tantalium—deposits



http://www.polinares.eu/docs/d2-1/polinares_wp2_annex2_factsheet2_v1_10.pdf

Other critical and strategic minerals

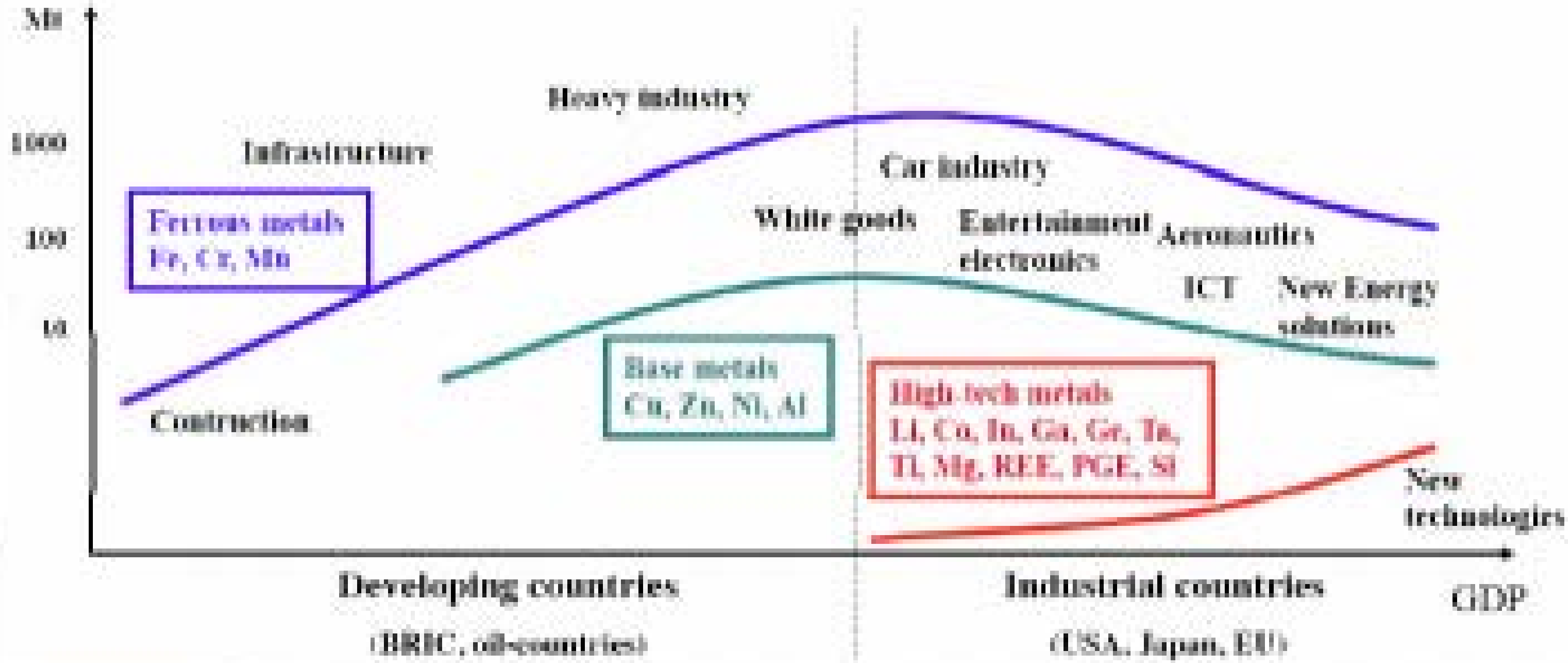
- Chromium
- Cobalt
- Manganese
- Platinum-group metals

Summary comments

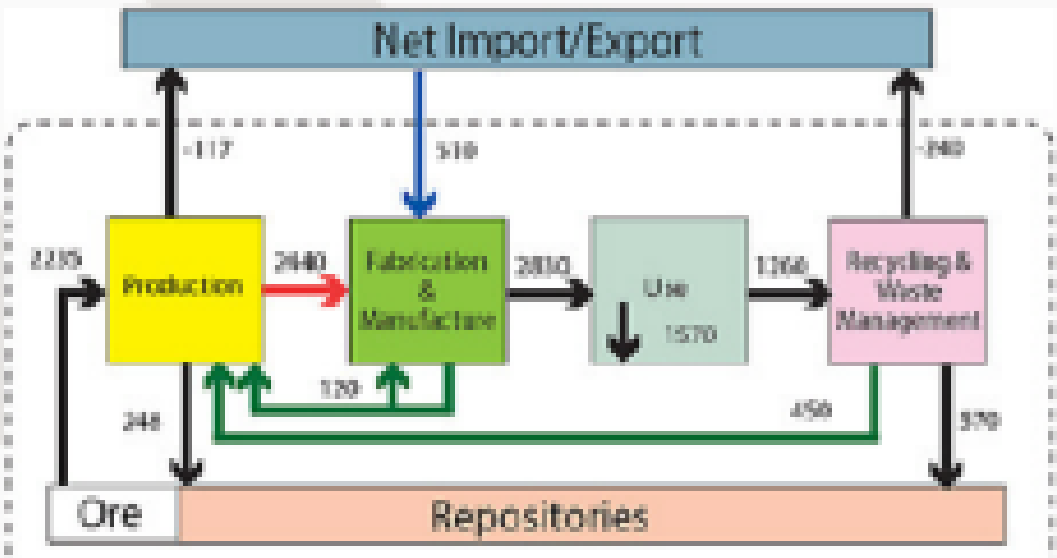
2014 U.S. NET IMPORT RELIANCE[1]

Commodity	Percent	Major import sources (2010–13)[2]
ARSENIC	100	Morocco, China, Belgium
ASBESTOS	100	Brazil, Canada
BAUXITE	100	Jamaica, Brazil, Guinea, Australia
CESIUM	100	Canada
FLUORSPAR	100	Mexico, China, South Africa, Mongolia
GRAPHITE (natural)	100	China, Mexico, Canada, Brazil
INDIUM	100	China, Canada, Belgium, Japan
IODINE	100	Chile, Japan
MANGANESE	100	South Africa, Gabon, Australia, Georgia
MICA, sheet (natural)	100	India, China
NIOBIUM (columbium)	100	Brazil, Canada
QUARTZ CRYSTAL (industrial)	100	China, Japan, Romania, United Kingdom
RUBIDIUM	100	Canada
SCANDIUM	100	China
STRONTIUM	100	Mexico, Germany, China
TANTALUM	100	China, Germany, Kazakhstan, Russia
THALLIUM	100	Germany, Russia
THORIUM	100	India, France
VANADIUM	100	Czech Rep., Canada, Rep. of Korea, Austria
GALLIUM	99	Germany, United Kingdom, China, Ukraine
GEMSTONES	97	Israel, India, Belgium, South Africa
GERMANIUM	95	China, Belgium, Russia, Canada
BISMUTH	94	China, Belgium, Peru, United Kingdom
TITANIUM MINERAL CONCENTRATES	91	South Africa, Australia, Canada, Mozambique
DIAMOND (dust grit, and powder)	86	China, Ireland, Rep. of Korea, Romania
PLATINUM	85	Germany, South Africa, United Kingdom, Canada
ANTIMONY	84	China, Belgium, Mexico, Bolivia
POTASH	84	Canada, Russia, Israel, Chile
GARNET (industrial)	83	Australia, India, China
RHENIUM	83	Chile, Poland, United Kingdom
STONE (dimension)	83	China, Brazil, Italy, Turkey
ZINC	81	Canada, Mexico, Peru
BARITE	79	China, India, Morocco, Mexico
SILICON CARBIDE (crude)	77	China, South Africa, Netherlands, Romania
COBALT	76	China, Norway, Russia, Finland
TIN	74	Peru, Bolivia, Indonesia, Malaysia
CHROMIUM	72	South Africa, Kazakhstan, Russia, Mexico
PALLADIUM	65	Russia, South Africa, United Kingdom, Norway
PEAT	64	Canada
SILVER	63	Mexico, Canada, Poland, Peru
RARE EARTHS[3]	59	China, France, Japan, Estonia
NICKEL	54	Canada, Russia, Australia, Norway
TITANIUM (sponge)	51	Japan, Kazakhstan, China
MAGNESIUM COMPOUNDS	43	China, Brazil, Australia, Canada
TUNGSTEN	43	China, Bolivia, Canada, Germany
SILICON	40	Russia, Brazil, Canada, Venezuela
NITROGEN (fixed)—AMMONIA	36	Trinidad and Tobago, Canada, Russia, Ukraine
ALUMINUM	33	Canada, Russia, United Arab Emirates, China

Growing Demand for Earth Resources



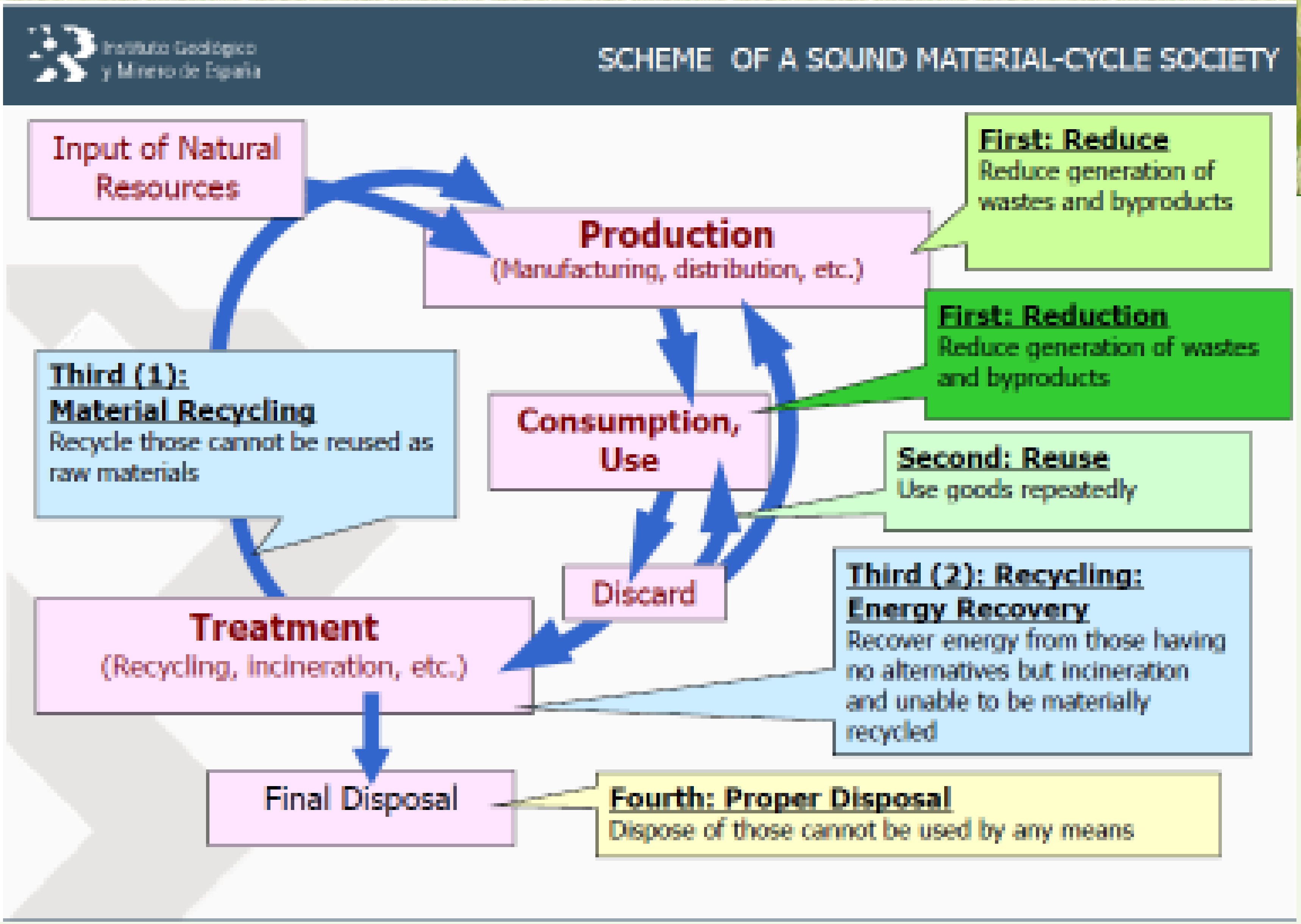
- **Material Flow Analysis:** systematic accounting of the flows and stocks of materials within a system defined in space and time.
- **Fossil fuels:** consumed when burned to generate usable energy
- **Nonfuel minerals:** can be recycled after initial use
  - **primary resources:** extracted from Earth's 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).