ME589/Geol 571 Advanced Topics

Geology and Economics of Strategic and Critical Minerals Commodities

Other critical commodities

Virginia T. McLemore

Comments on Quizzes

- Economics will prevail, which means metallurgists won't risk lowering copper or gold recovery to improve tellurium recovery.
- Cripple Creek probably has enough Te to process as a byproduct, but it is costly to add a circuit to the mill and there is the risk it could affect the Au recovery, and will the Te price hold

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)

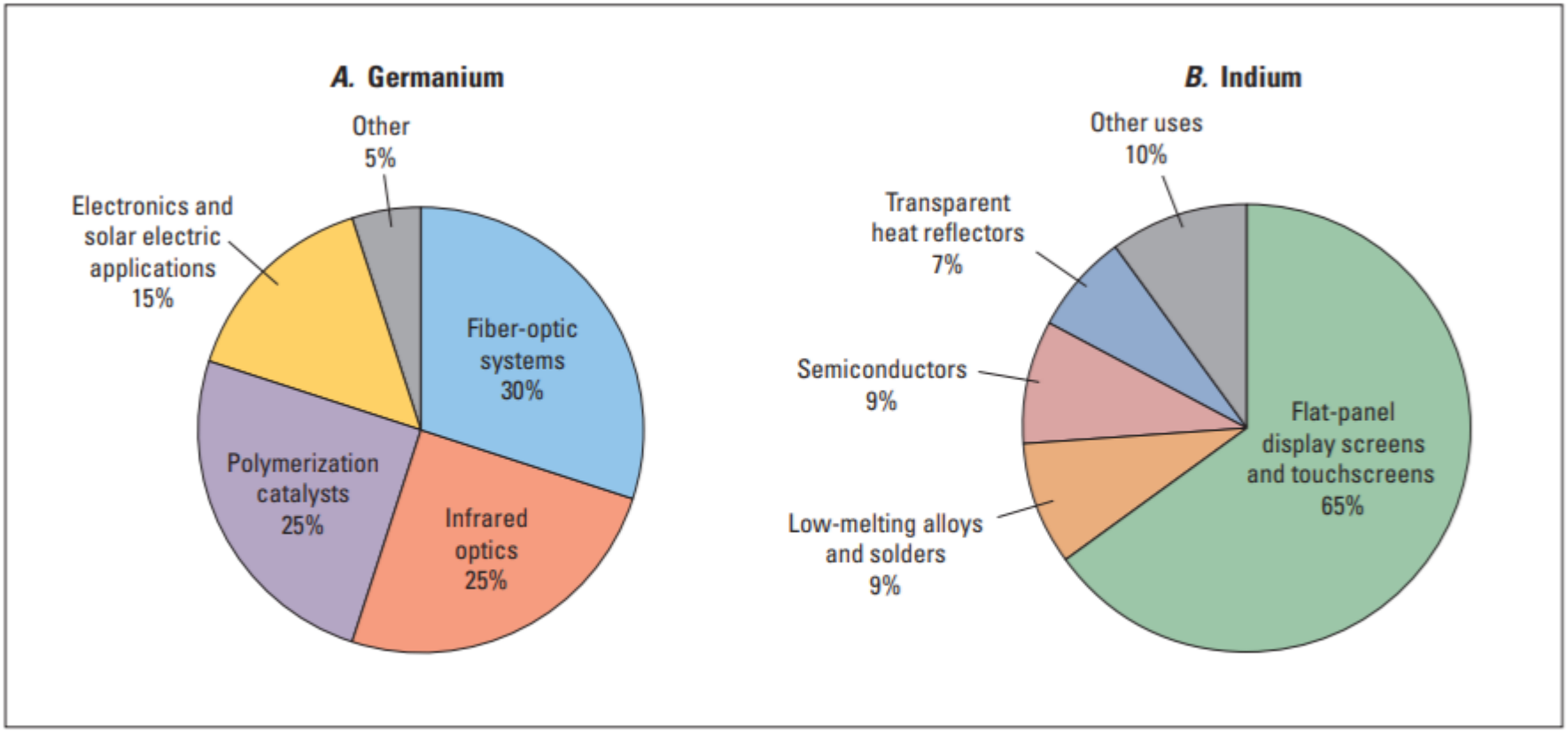

Figure I2. Pie charts showing major end uses of *A*, germanium and *B*, indium as a percentage of world consumption in 2012. Data are from Guberman (2013a) and Tolcin (2013a).

PP1802Germanium

Germanium—production

Salient Statistics—United States:	2015	2016	2017	2018	2019[e]
Production:					
Primary refinery	—	—	—	—	—
Secondary refinery	W	W	W	W	W
Imports for consumption:					
Germanium metal	20,100	11,000	11,100	11,800	14,000
Germanium dioxide[1]	14,300	15,200	12,000	12,400	13,000
Total exports[2]	5,000	4,780	3,670	4,880	3,300
Shipments from Government stockpile	—	—	—	—	—
Consumption, estimated[3]	34,000	30,000	30,000	30,000	30,000
Price, annual average, dollars per kilogram:[4]					
Germanium metal	1,792	1,087	1,082	1,543	1,240
Germanium dioxide	1,211	830	731	1,084	920
Net import reliance[5] as a percentage of estimated consumption	>75%	>50%	>50%	>50%	>50%

World Refinery Production and Reserves:[8]

	Refinery production[e]		Reserves[9]
	2018	2019	
United States	W	W	Data on the recoverable germanium content of zinc ores are not available.
China	94,900	85,000	
Russia	6,000	6,000	
Other countries[10]	30,000	40,000	
World total (rounded)[11]	130,000	130,000	

http://minerals.usgs.gov/minerals/pubs/mcs/2020/mcs2020.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)

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]	$Cu_{11}Ge(Cu,Ge,Fe,Zn,W,Mo,As,V)_{4-6}S_{16}$	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

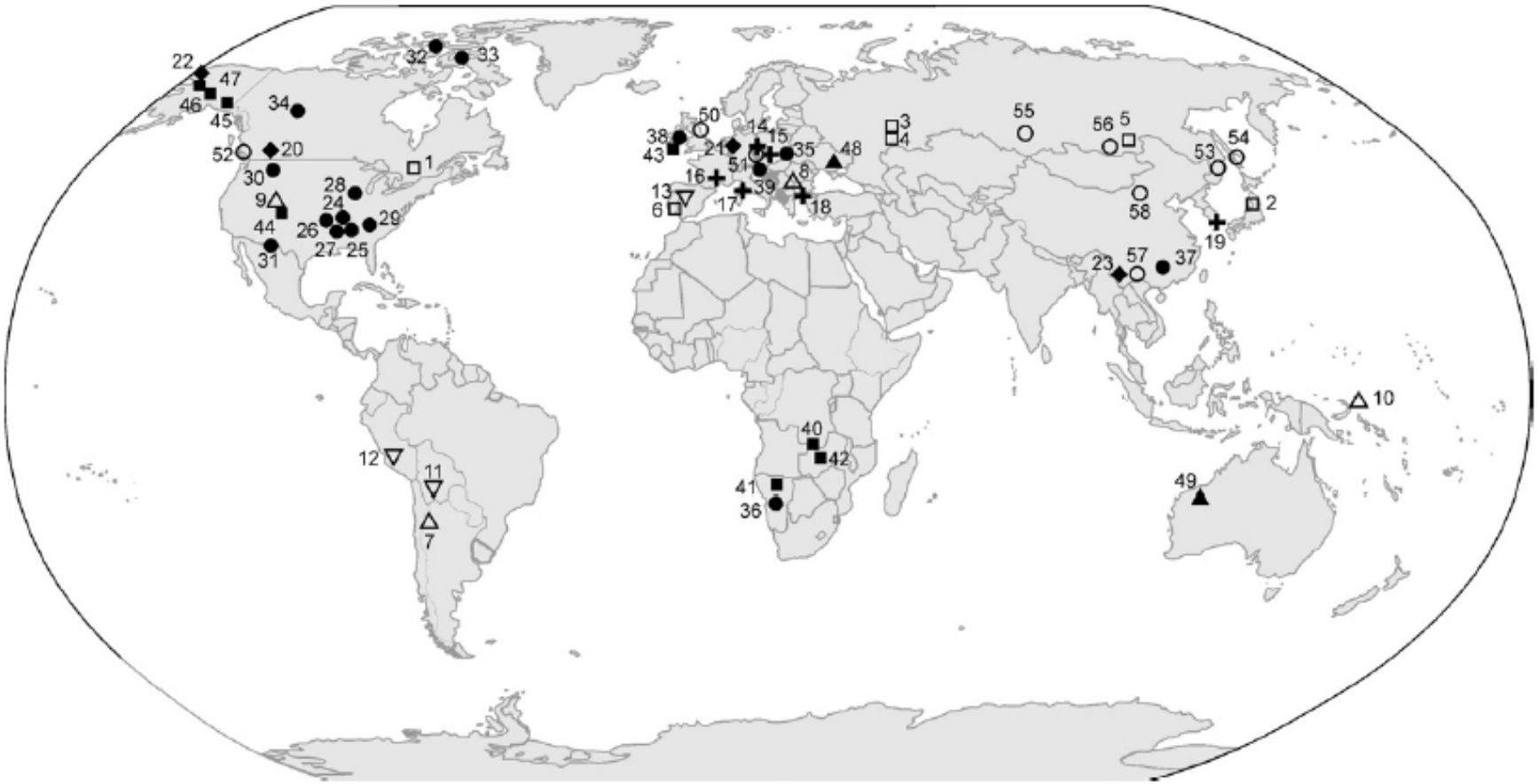

Fig. 1. Germanium-bearing ore deposits. □ Volcanic-hosted massive sulphide (VHMS) Cu–Zn(–Pb)(–Ba) deposits: 1 Abitibi–Belt: Kidd Creek, Noranda, Bousquet 2 Mine, Canada; 2 Kuroko-type (and Besshi-type) deposits, Japan; 3 Gaiskoje, Russia; 4 Bakr Tau, Russia; 5 Gorevskoe and Ozernoe, Russia; 6 Iberian 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

Deposit type	Short name	Characteristics	Metals present (and source of information)
Volcanogenic massive sulfide deposits	VMS	Stratiform Cu-Pb-Zn sulfide deposits in submarine mafic to felsic volcanic terranes that form at the sea floor by venting of hydrothermal fluids driven by magmatic heat and volatiles	Cu-Zn-Pb-Au-Ag with Be, Bi, Cd, Co, Cr, Ga, Ge, Hg, In, Mn, Mo, Ni, Se, Sn, Te, and PGE (Shanks and Thurston, 2010)
Sedimentary exhalative deposits	SEDEX	Stratiform, often finely laminated, Zn-Pb-Ag sulfide deposits in carbonaceous and pyrite shales and siltstones that form by exhalation of hydrothermal fluid on the sea floor without any direct igneous association	Zn-Pb-Ag with As, Bi, Cd, Co, Cu, Ga, Ge, Hg, In, Mn, Ni, Sb, Se, Sn, and Tl (Goodfellow and Lydon, 2007; Kelley and others, 2004; Slack and others, 2004)
Mississippi Valley-type Zn-Pb deposits	MVT	Strata-bound epigenetic Zn-Pb sulfide replacement deposits along faults and permeable zones and open-space fill in solution collapse breccias in dolostone and limestone. Not associated with igneous activity	Zn-Pb with Cu, Ni, and Co (Leach and others, 2005)
Kipushi-type Zn-Pb-Cu replacement bodies in carbonate rocks	Carbonate replacement deposits (CRD)	Strata-bound epigenetic Zn-Pb-Cu sulfide ore deposits in irregular pipe-like bodies associated with collapse breccias and faults as well as lenticular bodies subparallel to the bedding. Association with igneous activity is unclear	Zn-Pb-Cu with Ag, As, Bi, Cd, Co, Ga, Ge, Mo, Re, Sb, Sn, and W (Kampunzu and others, 2009)
Polymetallic Zn-Sn vein and fissure-filling deposits	Polymetallic vein deposits	Polymetallic sulfide veins forming dense arrays in volcanic rocks, eroded volcanic-intrusive complexes, porphyry stocks, and associated breccia	Zn-Cu-Pb-Sn-In with Ag, As, Bi, Co, Ga, Mn, Ni, Sb, Se, and W (Ishihara and others, 2011)
Coal and lignite deposits	None	Ge concentrated in organic matter of coal seams that have been affected by hydrothermal activity and are generally associated with siliceous layers	Ge in coal with As, Ba, Sb, U, and W

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

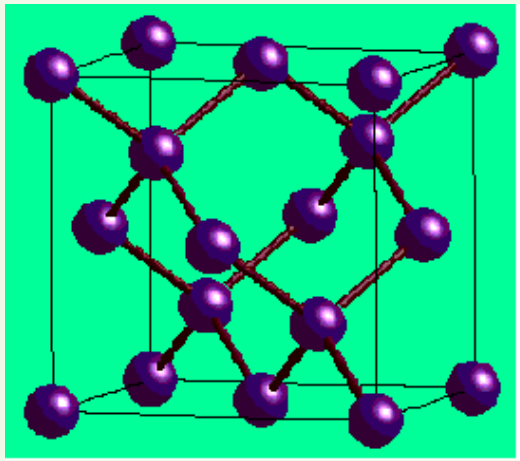
Physical Characteristics

- **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.

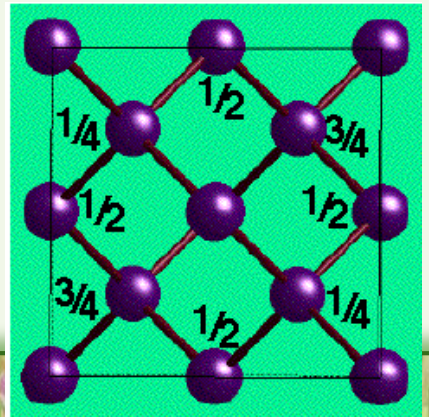
Mineralogy

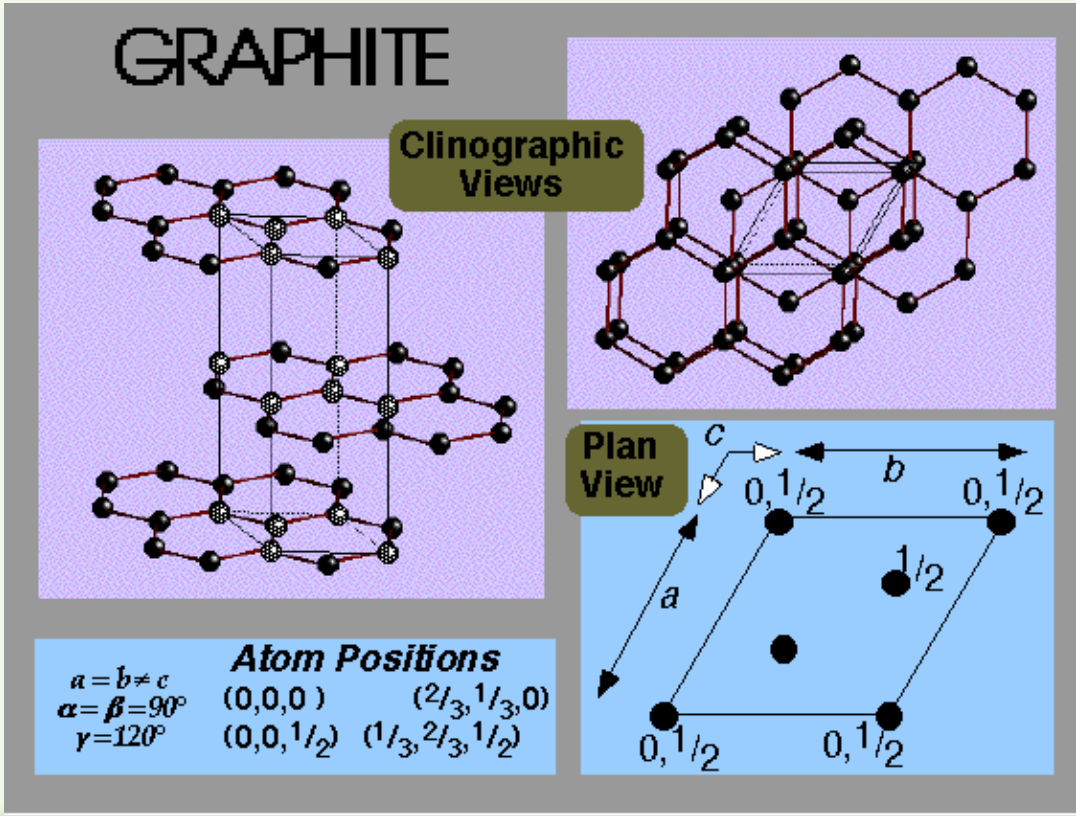
Graphite is a native element composed only of carbon. It has the same composition as diamond, however it has very different structures.

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



Unit Cell





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

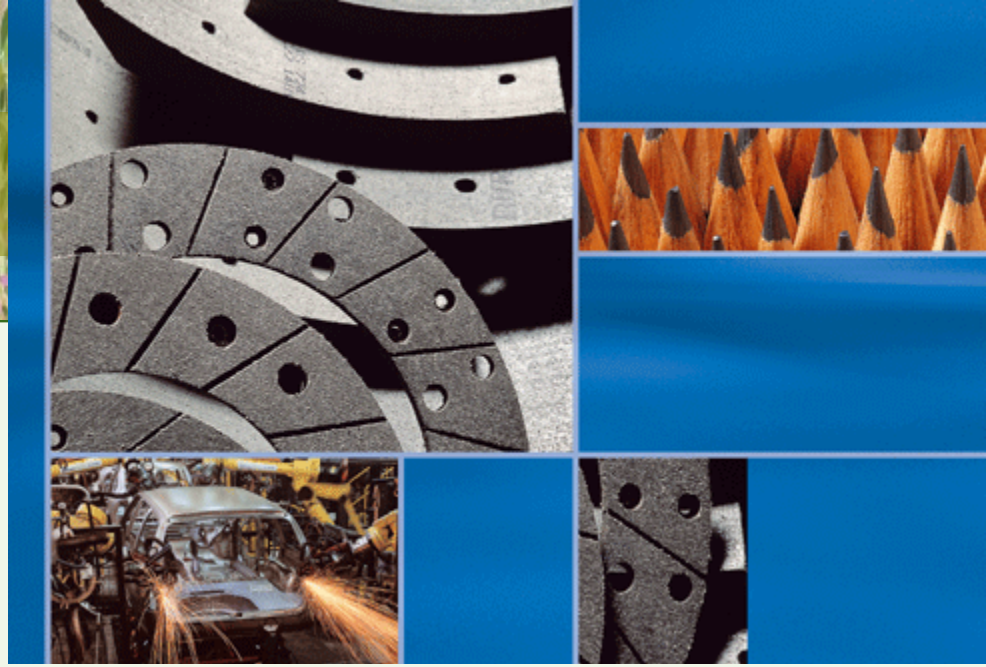
Graphite—uses

- 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

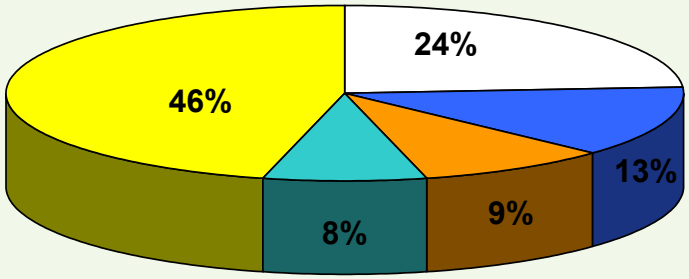
END-USES



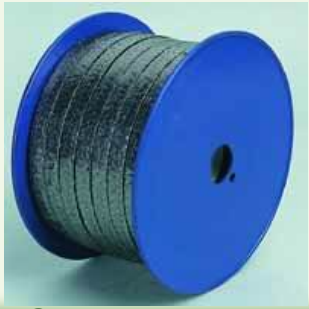
Main uses are in refractors, lubricants, brake linings, foundry molds, and electrodes (batteries). Non-traditional applications include expanded graphite and graphite foils (a thin graphite cloth).

Graphite Foils

Uses of natural graphite in 2004



- refractory applications
- brake linings
- foundry operations
- lubricants
- steelmaking and other uses (pencils, battery...)



Graphite Packing

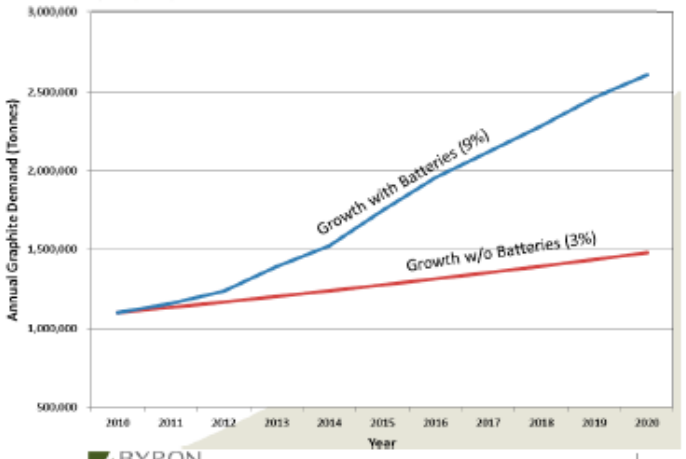
Expanded Graphite

	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**



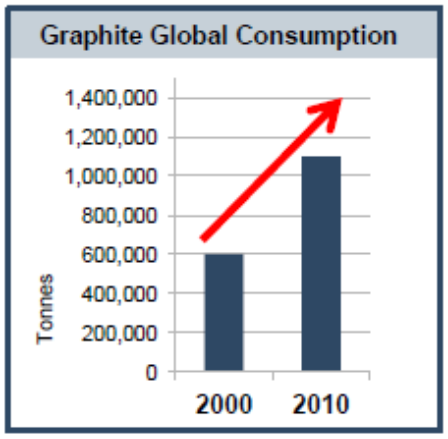
Source: Cormark Securities

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:	2015	2016	2017	2018	2019[e]
Production, mine	—	—	—	—	—
Imports for consumption	46,700	38,900	51,900	70,700	58,000
Exports	11,600	14,300	13,900	10,400	6,600
Consumption, apparent[1]	35,100	24,700	38,000	60,300	52,000
Price, imports (average dollars per ton at foreign ports):					
Flake	1,710	1,920	1,390	1,520	1,300
Lump and chip (Sri Lankan)	1,800	1,880	1,900	1,890	2,370
Amorphous	454	571	451	310	438
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: Reserves for Mozambique and Tanzania were revised based on information reported by graphite-producing companies and the Governments of those countries.

	Mine production		Reserves[2]
	2018	2019[e]	
United States	—	—	(3)
Austria	1,000	1,000	(3)
Brazil	95,000	96,000	72,000,000
Canada	40,000	40,000	(3)
China	693,000	700,000	73,000,000
Germany	800	800	(3)
India	35,000	35,000	8,000,000
Korea, North	6,000	6,000	2,000,000
Madagascar	46,900	47,000	1,600,000
Mexico	9,000	9,000	3,100,000
Mozambique	104,000	100,000	25,000,000
Namibia	3,460	3,500	(3)
Norway	16,000	16,000	600,000
Pakistan	14,000	14,000	(3)
Russia	25,200	25,000	(3)
Sri Lanka	4,000	4,000	(3)
Tanzania	150	150	18,000,000
Turkey	2,000	2,000	90,000,000
Ukraine	20,000	20,000	(3)
Vietnam	5,000	5,000	7,600,000
Zimbabwe	2,000	2,000	(3)
Other	200	200	(3)
World total (rounded)	1,120,000	1,100,000	300,000,000

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.

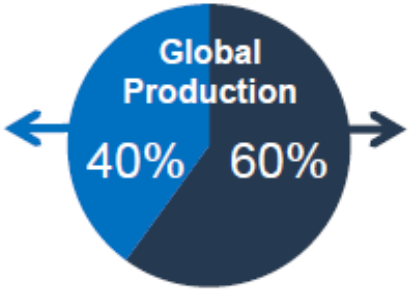
Graphite—geology

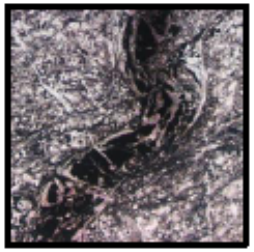
Types of Natural Graphite :

- 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

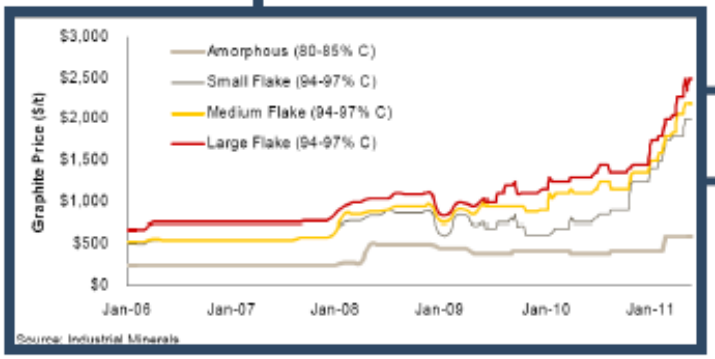
Highest Price, Lowest Supply
High Purity: 85%-98% carbon

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:

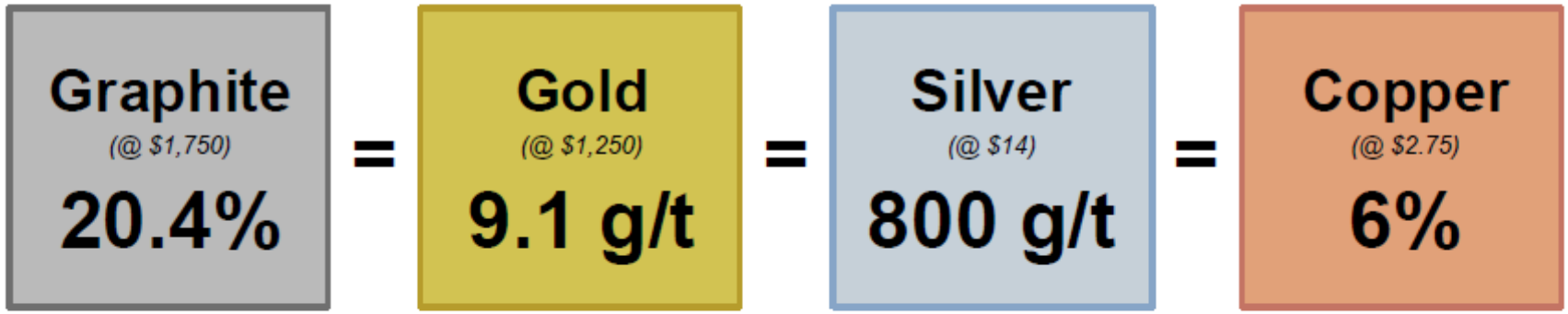
- is found in metamorphic rocks uniformly distributed through the ore body or in concentrated lens shaped pockets.
- Graphite flake occurs as a scaly or lamella form in certain metamorphic rocks such as limestone, gneisses and schists.
- Carbon concentrations vary between 5% and 40%.
- Flake graphite 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

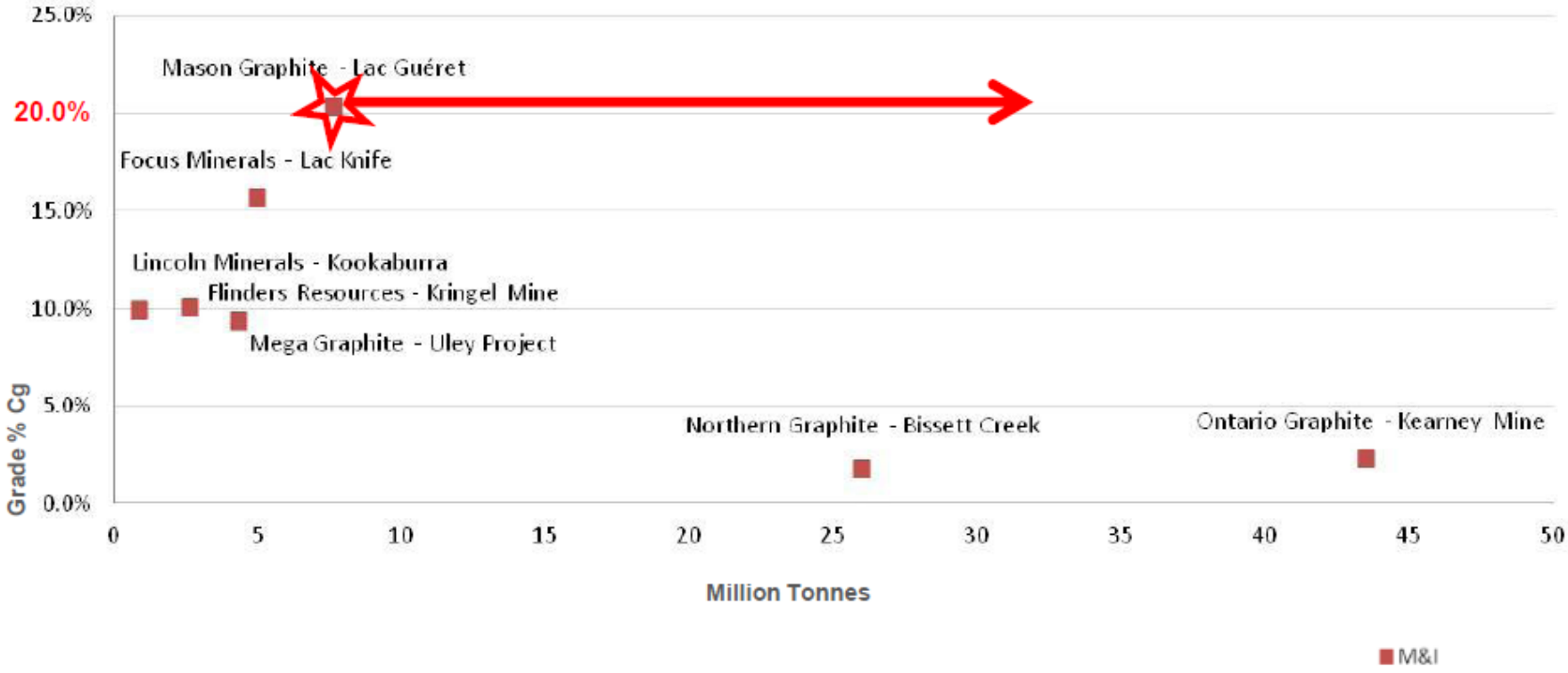
Size	Kilograms of Flake per Ton of Ore
+50 mesh	3.0–7.0
–50 +100 mesh	3.5–19.0
–100 mesh	4.0–35.0
Total flake	17.5–~65.0

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

Trans: 2012-45
Bottom: 29-32
Mistress: 134,9-150

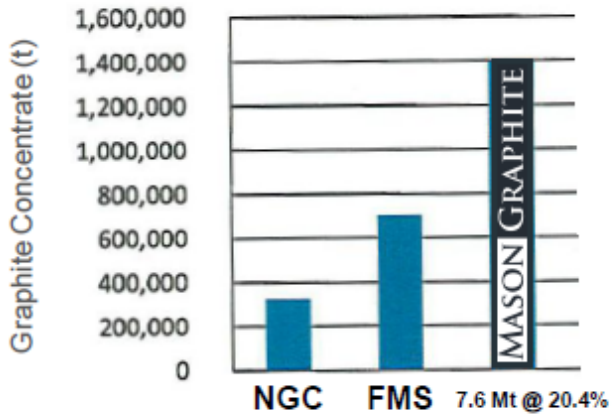


MASON GRAPHITE


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

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

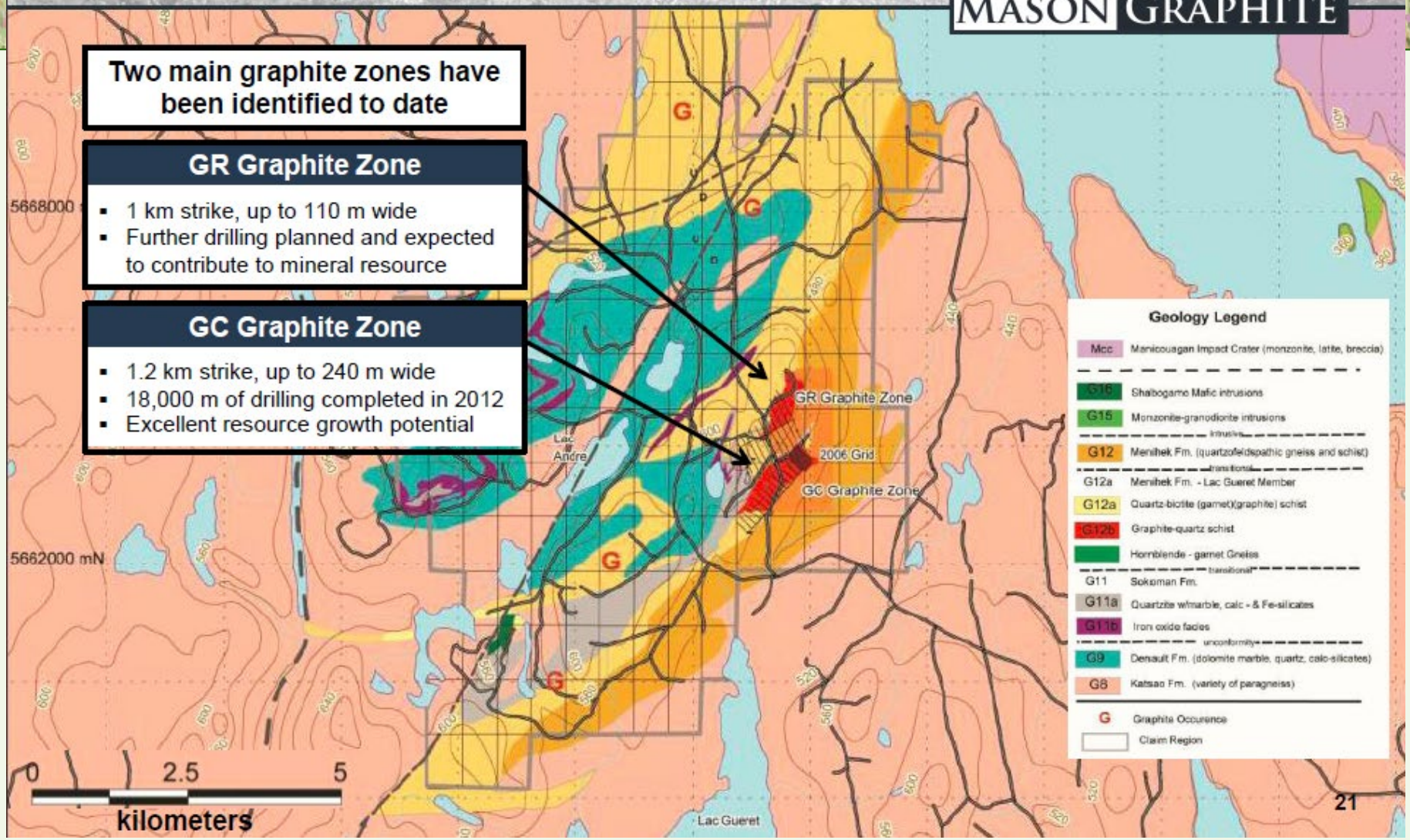
Two main graphite zones have been identified to date

GR Graphite Zone

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

GC Graphite Zone

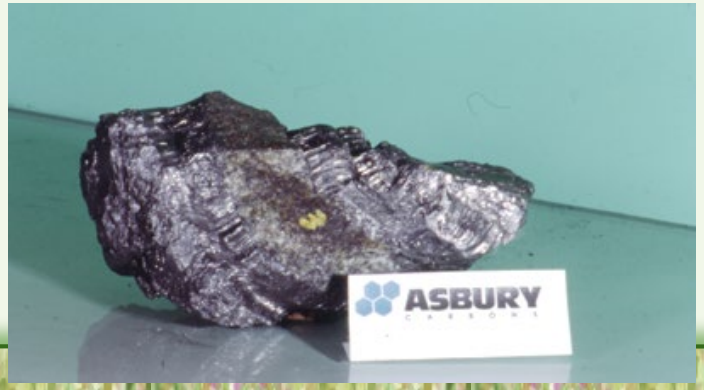
- 1.2 km strike, up to 240 m wide
- 18,000 m of drilling completed in 2012
- Excellent resource growth potential



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

Primary Crusher

Mill

Flotation Cells

Dryers

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.

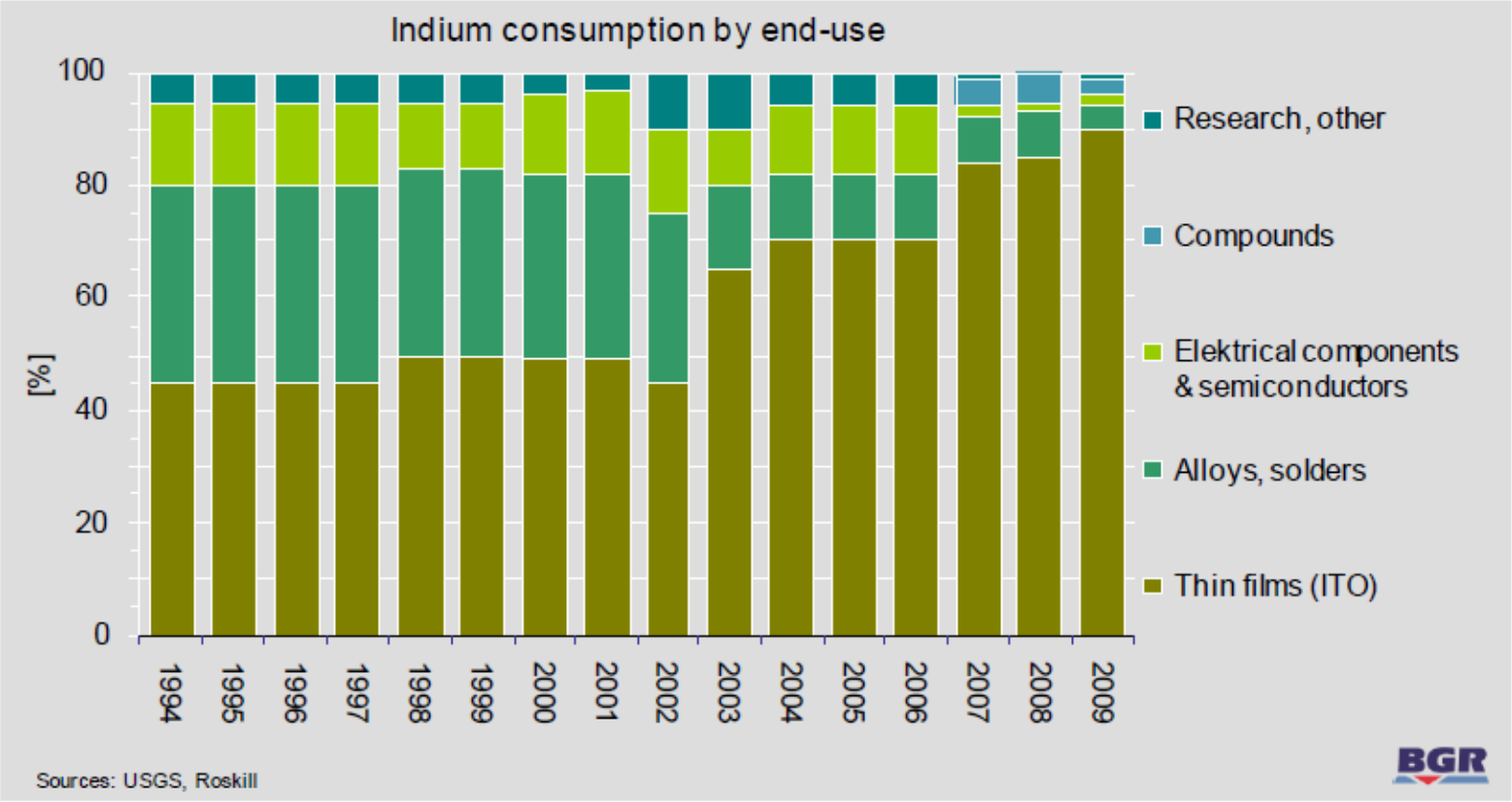
Chemical concentration - Concentration with the use of chemical agents is used to remove impurities that remain in the graphite after the mechanical concentration process. Some firms make high purity graphite (98% - 99%carbon) by leaching concentrate with strong acids or alkalis.

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.

Indium Wire

Appearance
silvery lustrous gray

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

Salient Statistics—United States:	2015	2016	2017	2018	2019e
Production, refinery	—	—	—	—	—
Imports for consumption	140	160	127	125	110
Exports	NA	NA	NA	NA	NA
Consumption, estimated[1]	140	160	127	125	110
Price, annual average, dollars per kilogram:					
New York dealer[2]	520	345	363	375	390
Duties unpaid in warehouse, Rotterdam[3]	410	240	225	291	210
Net import reliance[4] as a percentage of estimated consumption	100	100	100	100	100

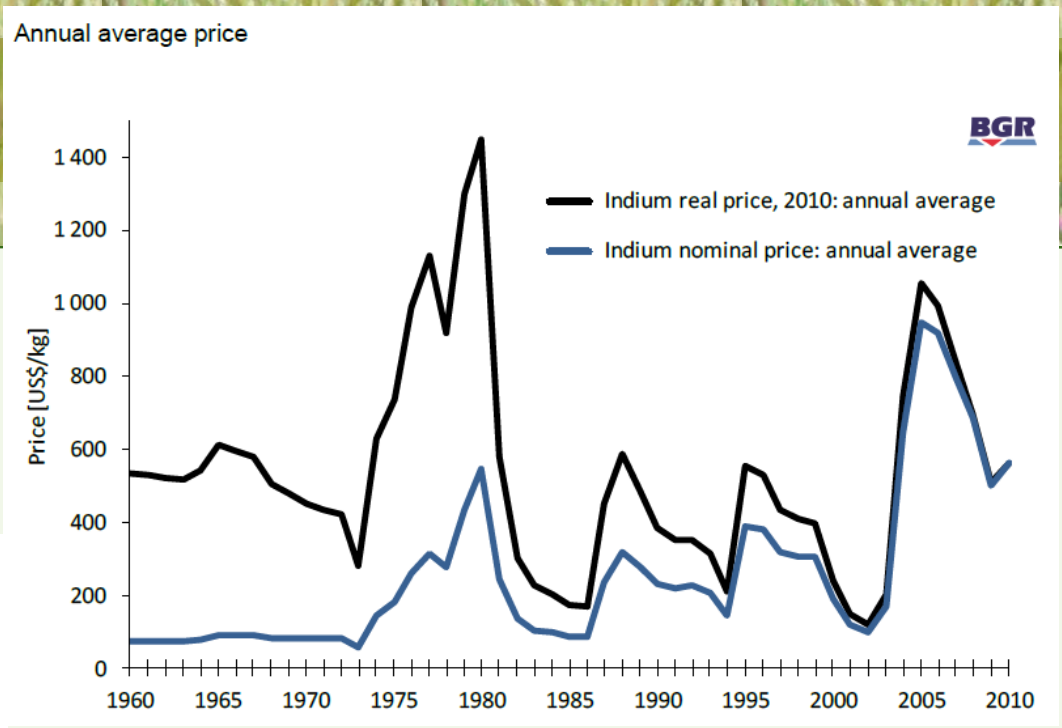
World Refinery Production and Reserves:

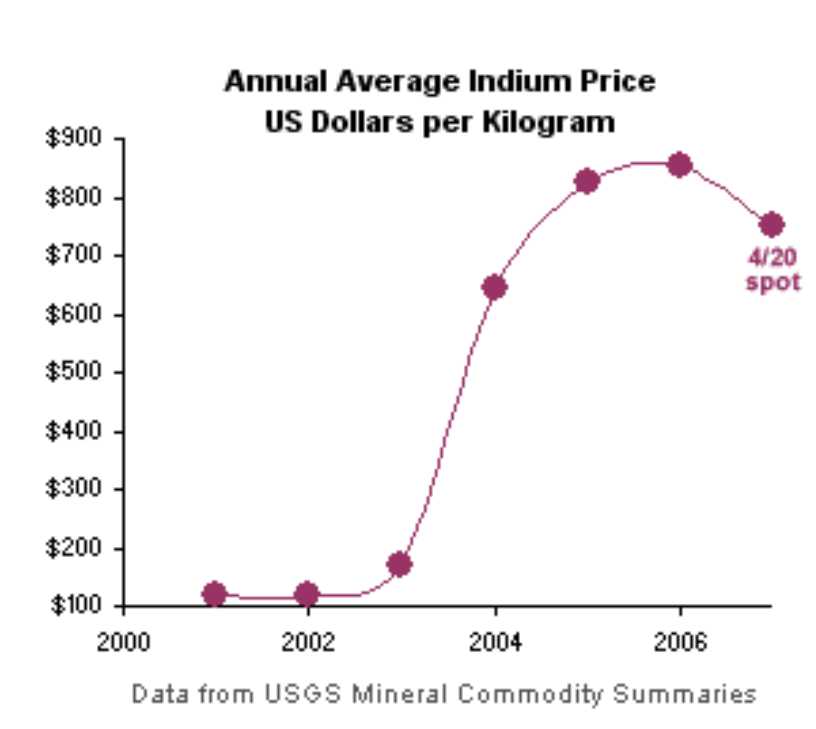
	Refinery production 2018	Refinery production 2019e
United States	—	—
Belgium	22	20
Canada	58	60
China	300	300
France	40	50
Japan	70	75
Korea, Republic of	235	240
Peru	11	10
Russia	5	5
World total (rounded)	741	760

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.

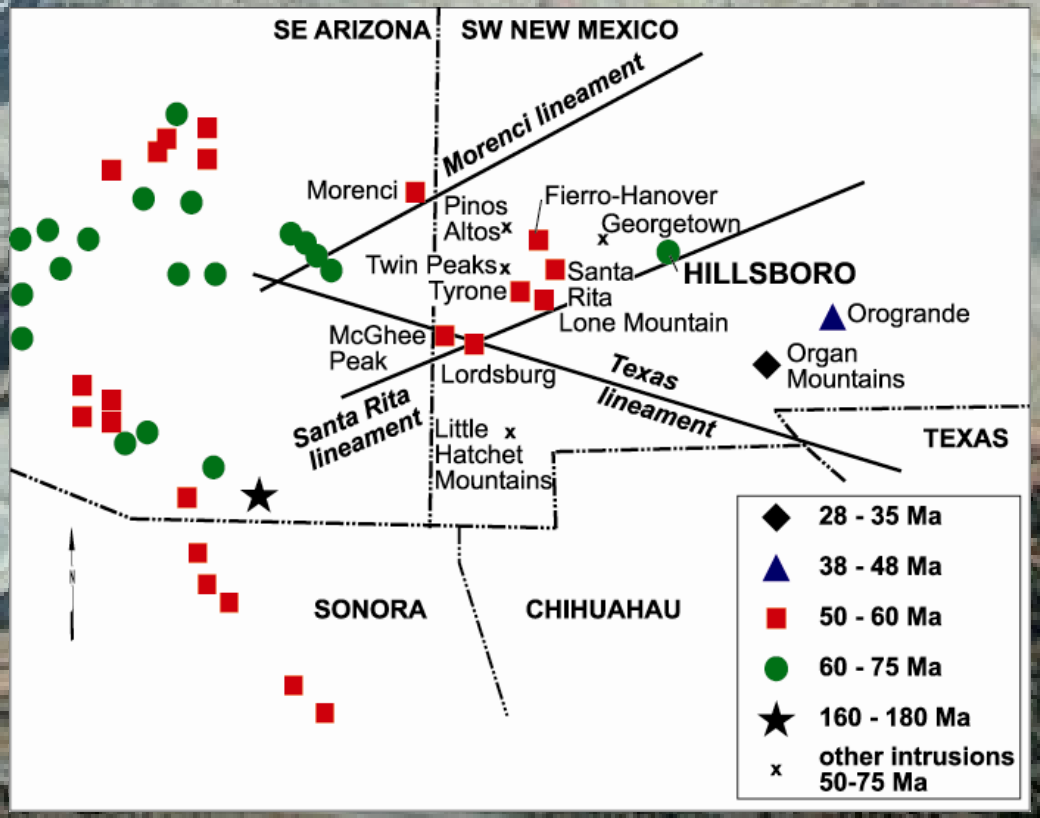
Geographic Areas Where the Highest Indium Values are Between 100-1000 ppm

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



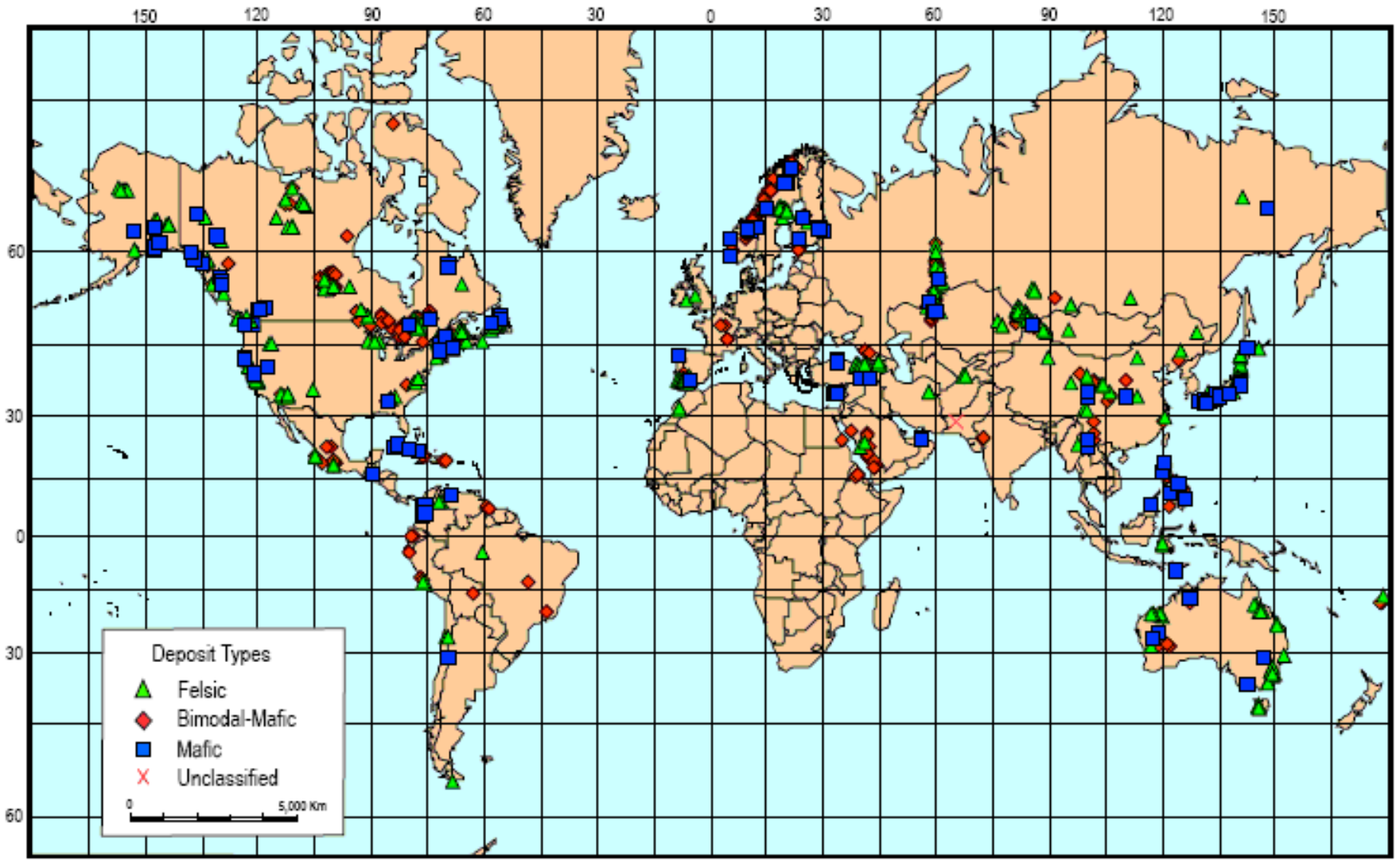


Figure 24. World map showing the distribution of volcanogenic massive sulfide deposit subtypes.

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

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:	2015	2016	2017	2018	2019e
Production	W	W	W	W	W
Imports for consumption	2,750	3,140	3,330	3,420	2,500
Exports	1,790	1,520	1,960	1,660	1,700
Consumption, estimated[1]	2,000	3,000	3,000	3,000	2,000
Price, annual average, battery-grade lithium carbonate, dollars per metric ton[2]	6,500	8,650	15,000	17,000	13,000
Employment, mine and mill, number	70	70	70	70	70
Net import reliance[3] as a percentage of estimated consumption	>25	>50	>50	>50	>25

World Mine Production and Reserves: Reserves for Argentina, Australia, Brazil, Chile, the United States, and Zimbabwe were revised based on new information from Government and industry sources.

	Mine production		Reserves[5]
	2018	2019e	
United States	W	W	630,000
Argentina	6,400	6,400	1,700,000
Australia	58,800	42,000	[6]2,800,000
Brazil	300	300	95,000
Canada	2,400	200	370,000
Chile	17,000	18,000	8,600,000
China	7,100	7,500	1,000,000
Namibia	500	—	NA
Portugal	800	1,200	60,000
Zimbabwe	1,600	1,600	230,000
Other[7]	—	—	1,100,000
World total (rounded)	[8]95,000	[8]77,000	17,000,000

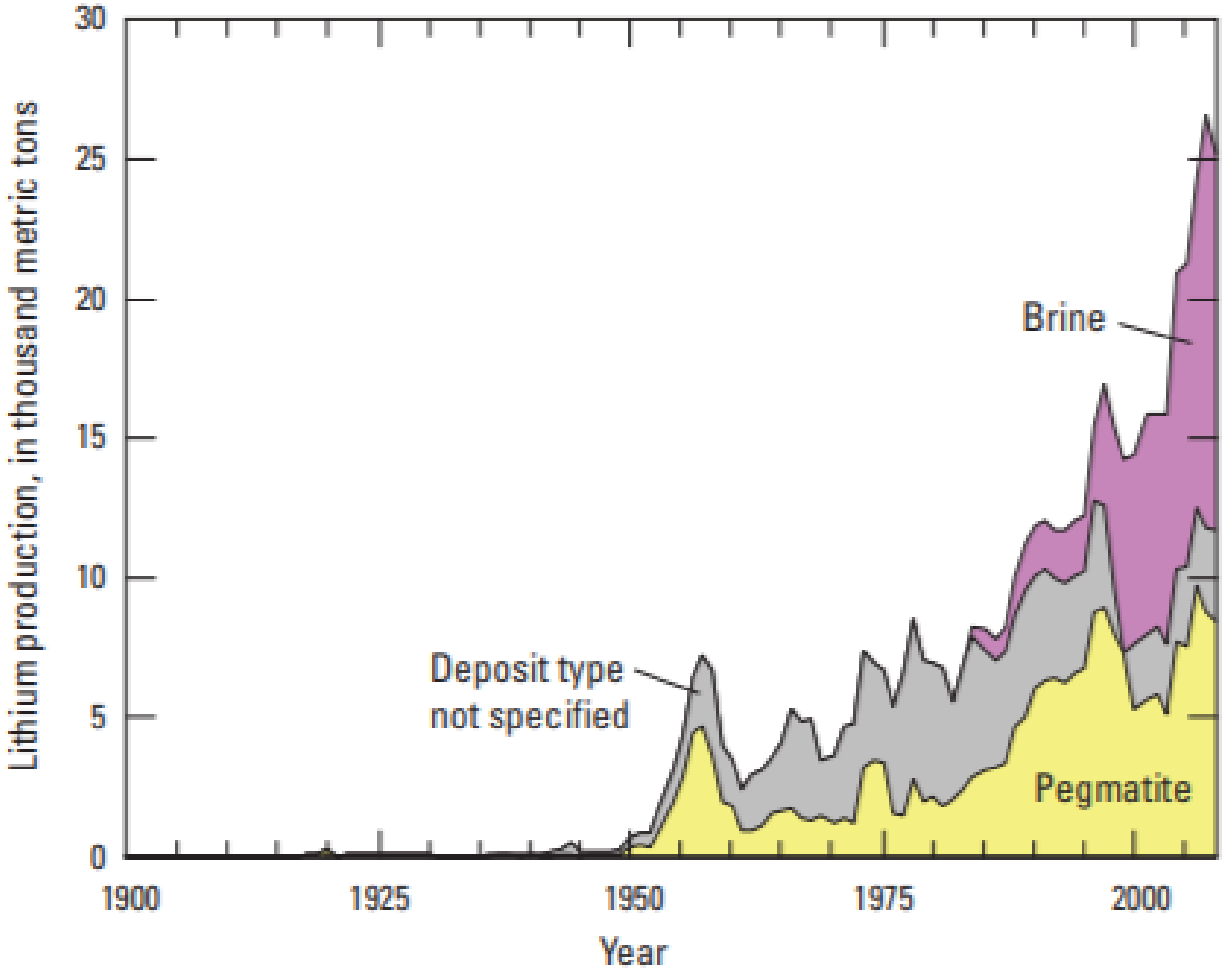
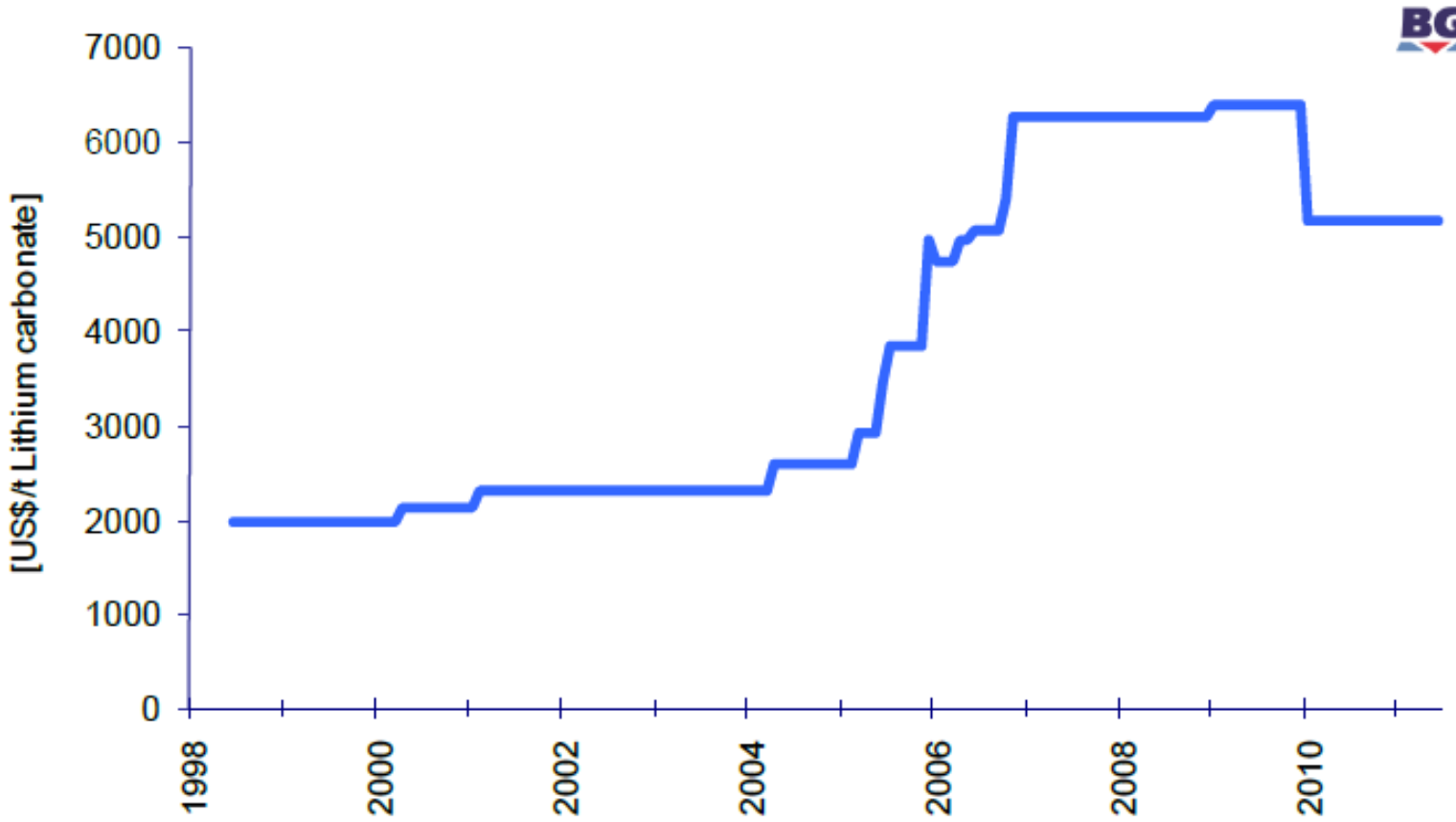


Figure K1. Graph showing world lithium production from 1900 to 2007, by deposit type and year. The layers of the graph are placed one above the other, forming a cumulative total. Modified from Mohr and others (2010).

pp1802k

Price

Lithium carbonate price, USA, delivered continental, large contracts



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

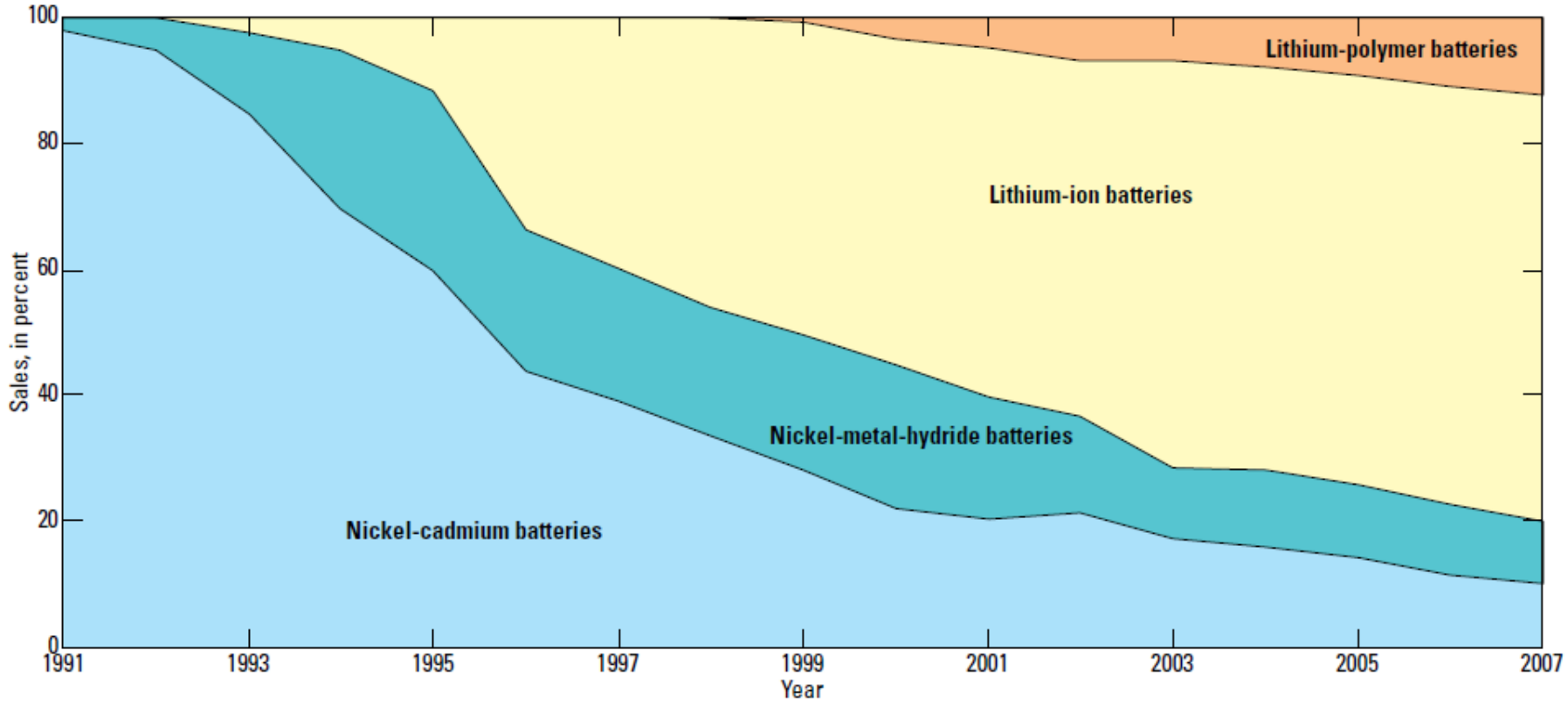


Figure 2. Chart showing sales of rechargeable batteries worldwide from 1991 through 2007. Values are expressed as percentage of total global sales of rechargeable batteries. Data are from Wilburn (2007) and Takashita (2008).

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

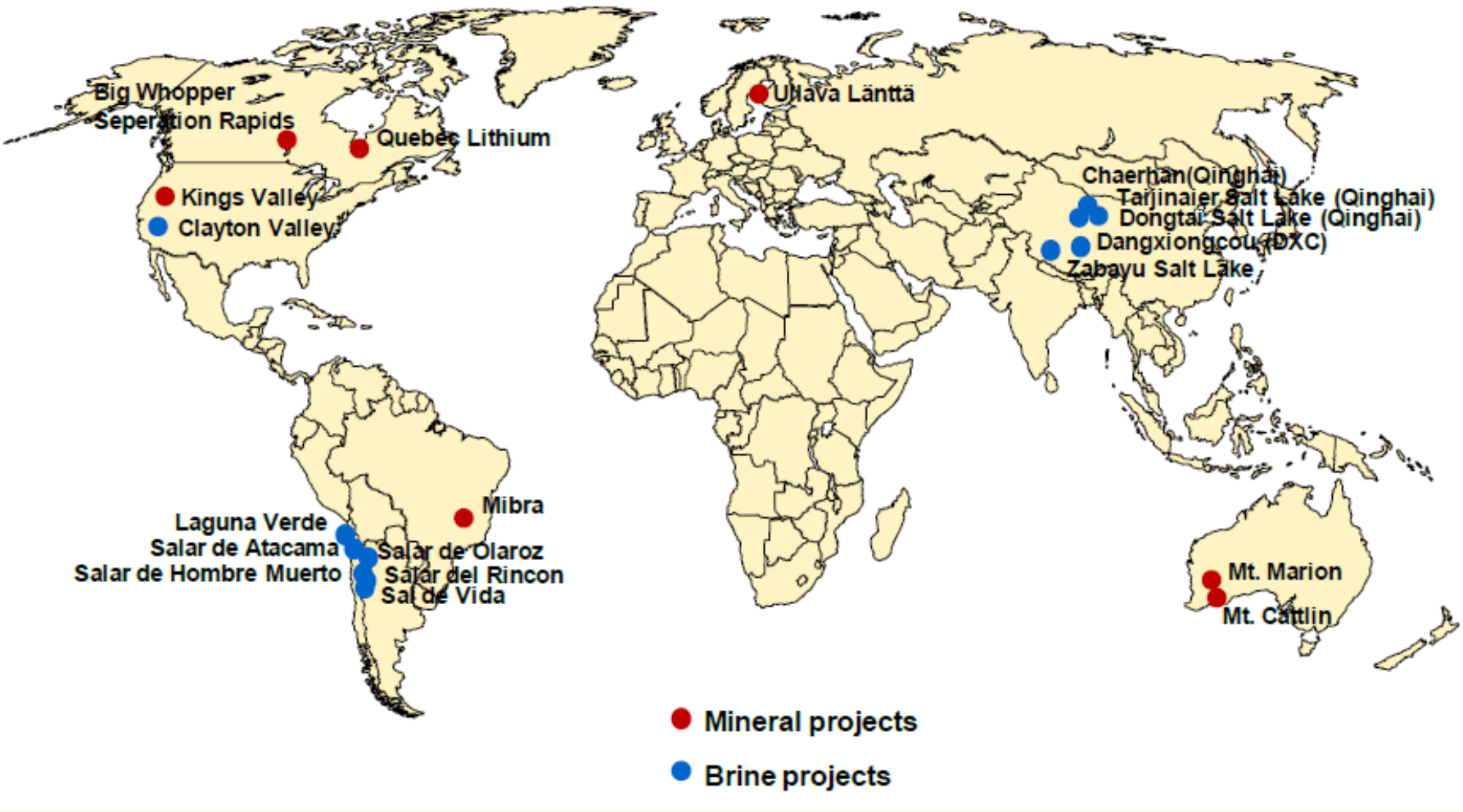
[1]Other countries produce small amounts of lithium but are not included here.

[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)*

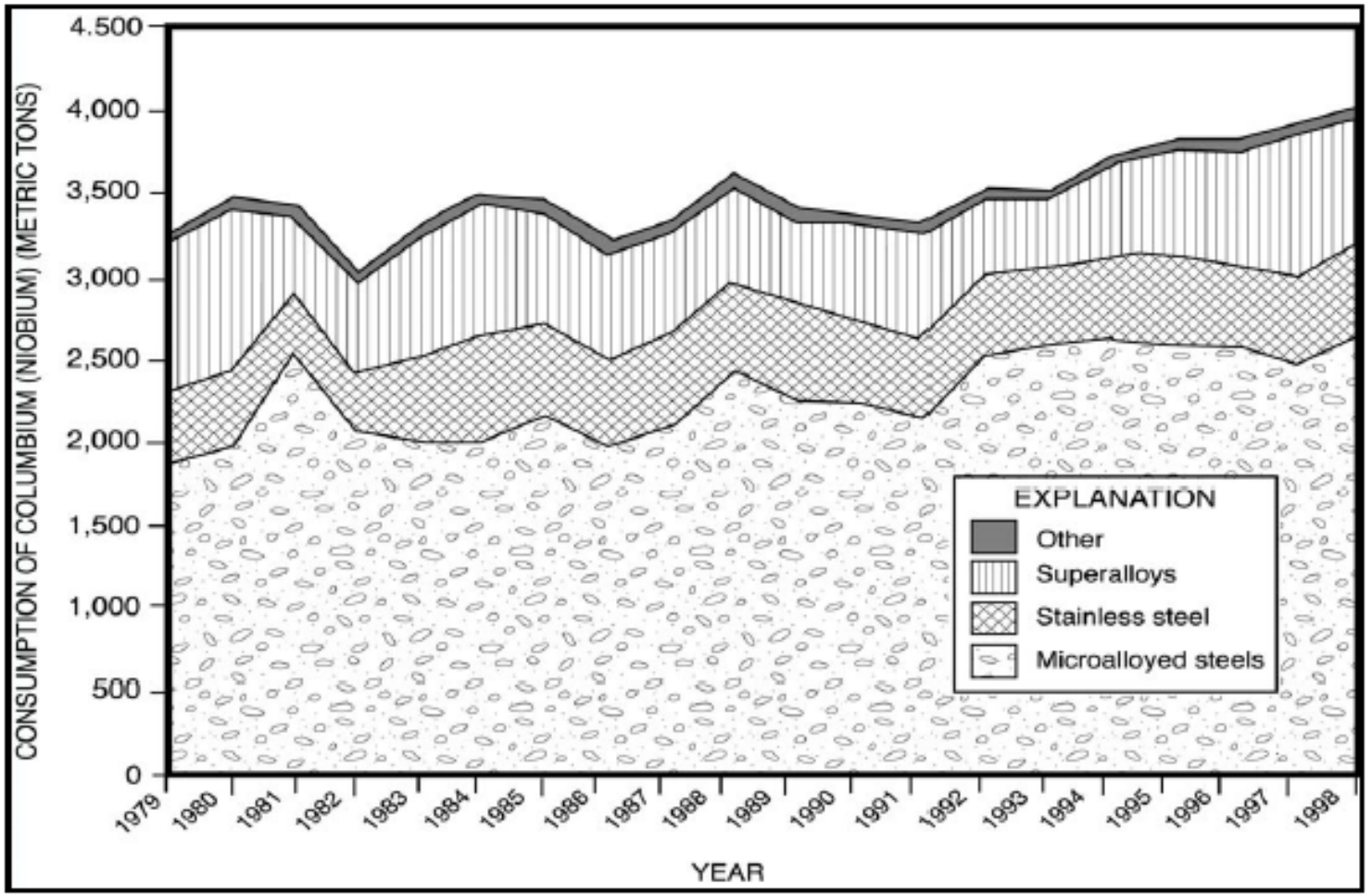


Figure 2. U.S. columbium end-use patterns, 1979-98, in metric tons contained columbium.

Production—niobium

Salient Statistics—United States:	2015	2016	2017	2018	2019[e]
Production, mine	—	—	—	—	—
Imports for consumption[1]	8,520	8,250	9,330	11,200	11,000
Exports[1]	1,430	1,480	1,490	955	570
Shipments from Government stockpile	—	—	—	—	—
Consumption:[e]					
Apparent[2]	7,080	6,730	7,780	10,100	9,900
Reported[3]	7,510	7,370	7,640	7,130	6,000
Unit value, ferroniobium, dollars per kilogram[4]	24	21	20	21	23
Net import reliance[2] as a percentage of apparent consumption	100	100	100	100	100

World Mine Production and Reserves: The reserves data for the United States and Brazil were revised based on information reported by niobium-producing companies and the Governments of those countries.

	Mine production		Reserves[7]
	2018	2019[e]	
United States	—	—	210,000
Brazil	59,000	65,000	11,000,000
Canada	7,700	7,600	1,600,000
Other countries	1,460	1,500	NA
World total (rounded)	68,200	74,000	>13,000,000

USGS Mineral Yearbooks

Production—tantalum

Salient Statistics—United States:	2015	2016	2017	2018	2019[e]
Production:					
Mine	—	—	—	—	—
Secondary	NA	NA	NA	NA	NA
Imports for consumption[1]	1,240	1,060	1,460	1,660	1,300
Exports[1]	657	604	549	681	440
Shipments from Government stockpile	—	—	—	—	—
Consumption, apparent[2]	587	460	907	978	870
Price, tantalite, dollars per kilogram of Ta_2O_5 content[3]	193	193	193	214	162
Net import reliance[4] as a percentage of apparent consumption	100	100	100	100	100

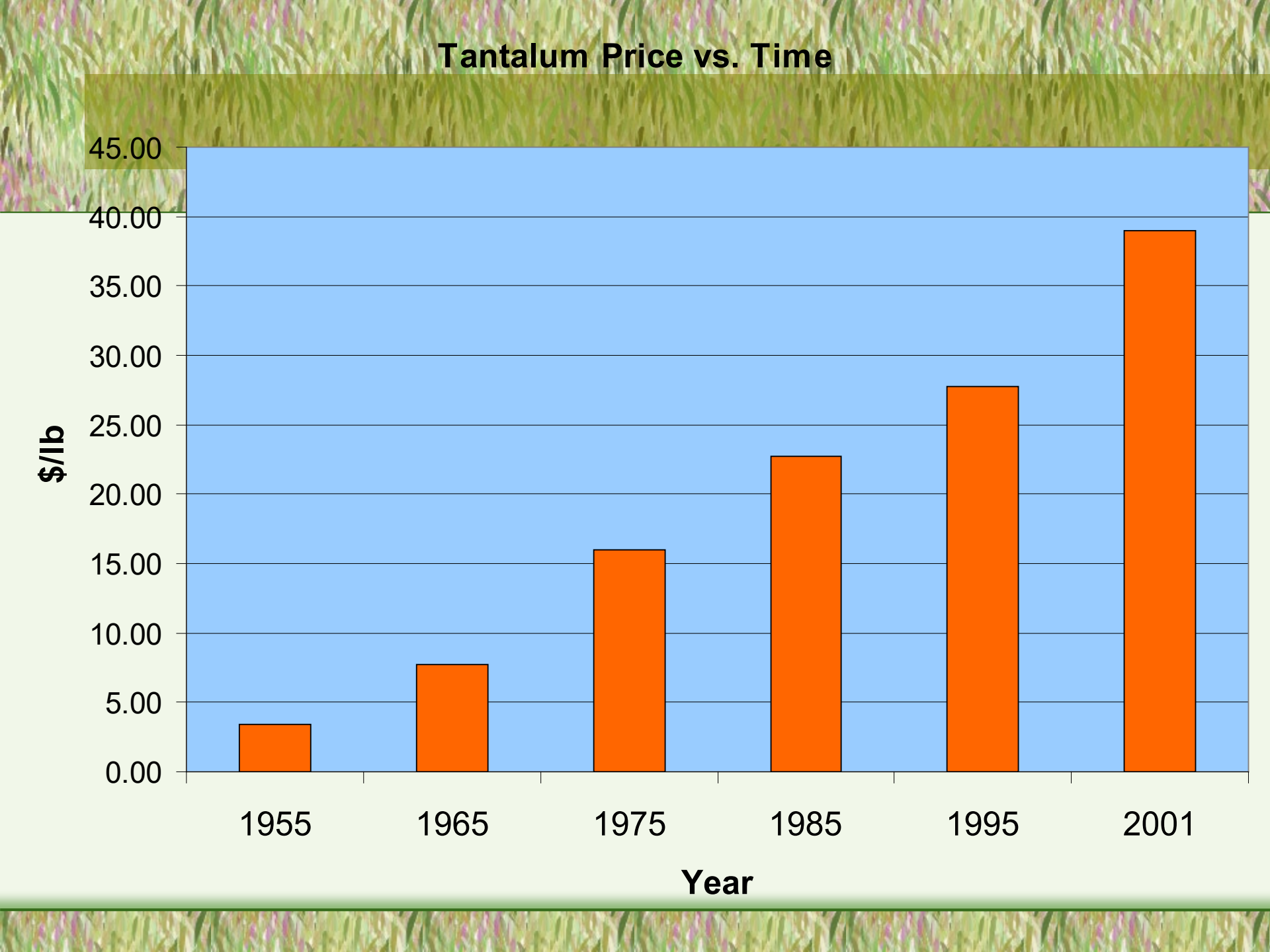
USGS Mineral Yearbooks

Production—tantalum

World Mine Production and Reserves: Reserves for Australia were revised based on Government and industry information.

	Mine production		Reserves[8]
	2018	2019[e]	
United States	—	—	—
Australia	23	20	[9]55,000
Brazil	250	250	34,000
Burundi	23	32	NA
China	90	100	NA
Congo (Kinshasa)	740	740	NA
Ethiopia	70	40	NA
Nigeria	200	210	NA
Russia	38	38	NA
Rwanda	421	370	NA
Other countries	40	39	NA
World total (rounded)	1,890	1,800	>90,000

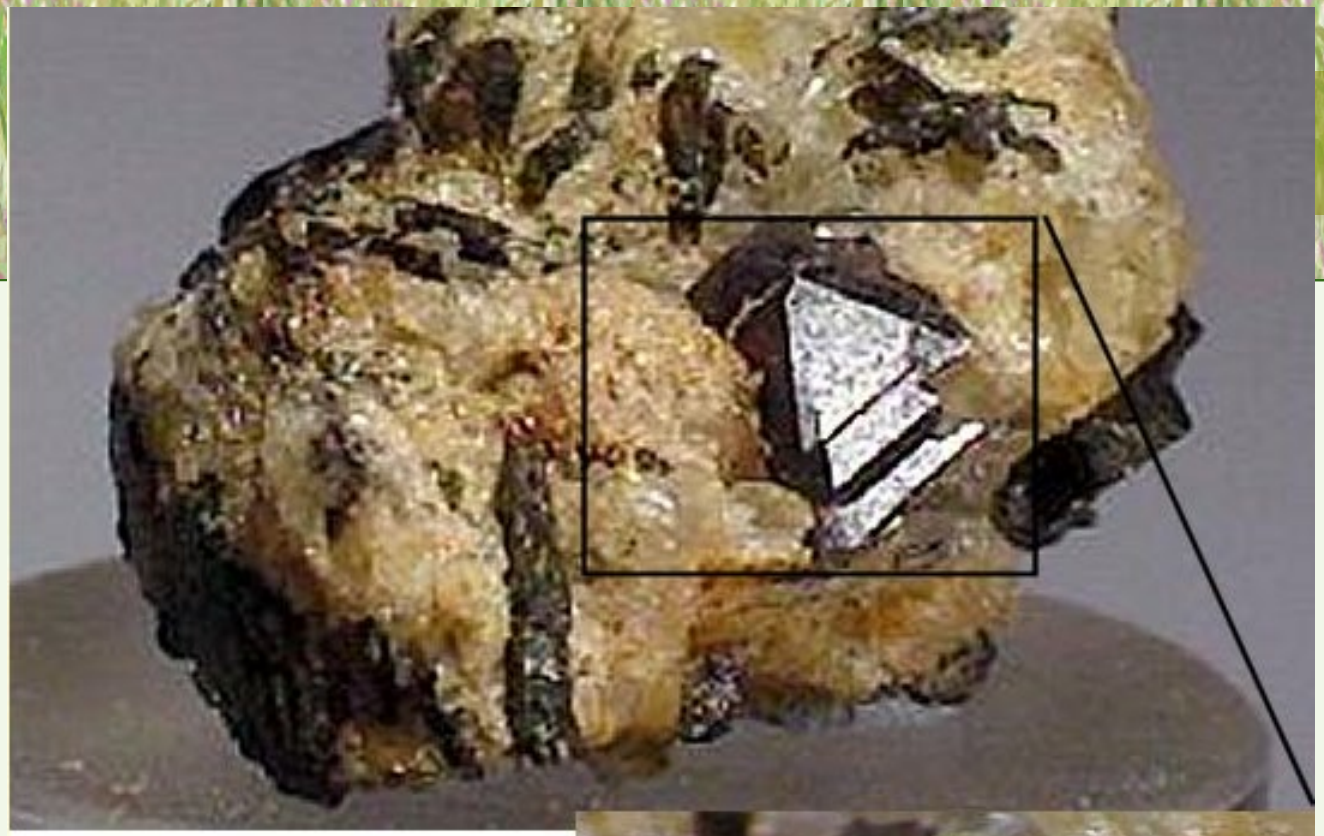
USGS Mineral Yearbooks


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



Closeup of rectangular area.

Lauzon Farm, Oka, Quebec, Canada. 3.9 x 2.9 cm.

http://www.webmineral.com/specimens/Pyrochlore.shtml

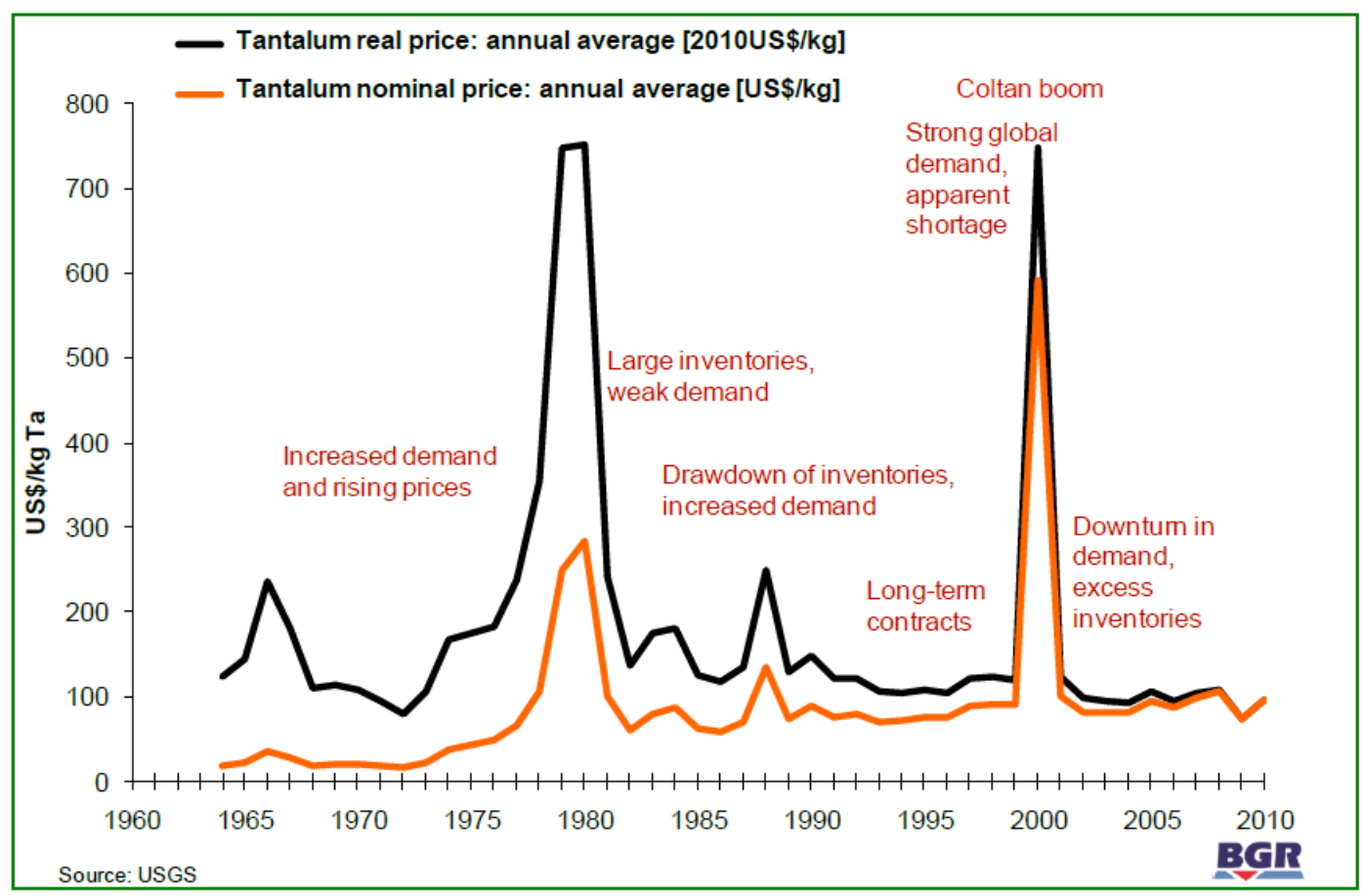
Companhia Brasileira de Metalurgia e Mineração (CBMM), open pit mine for Nb, Minas Gerais, Brazil

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

Tantalum

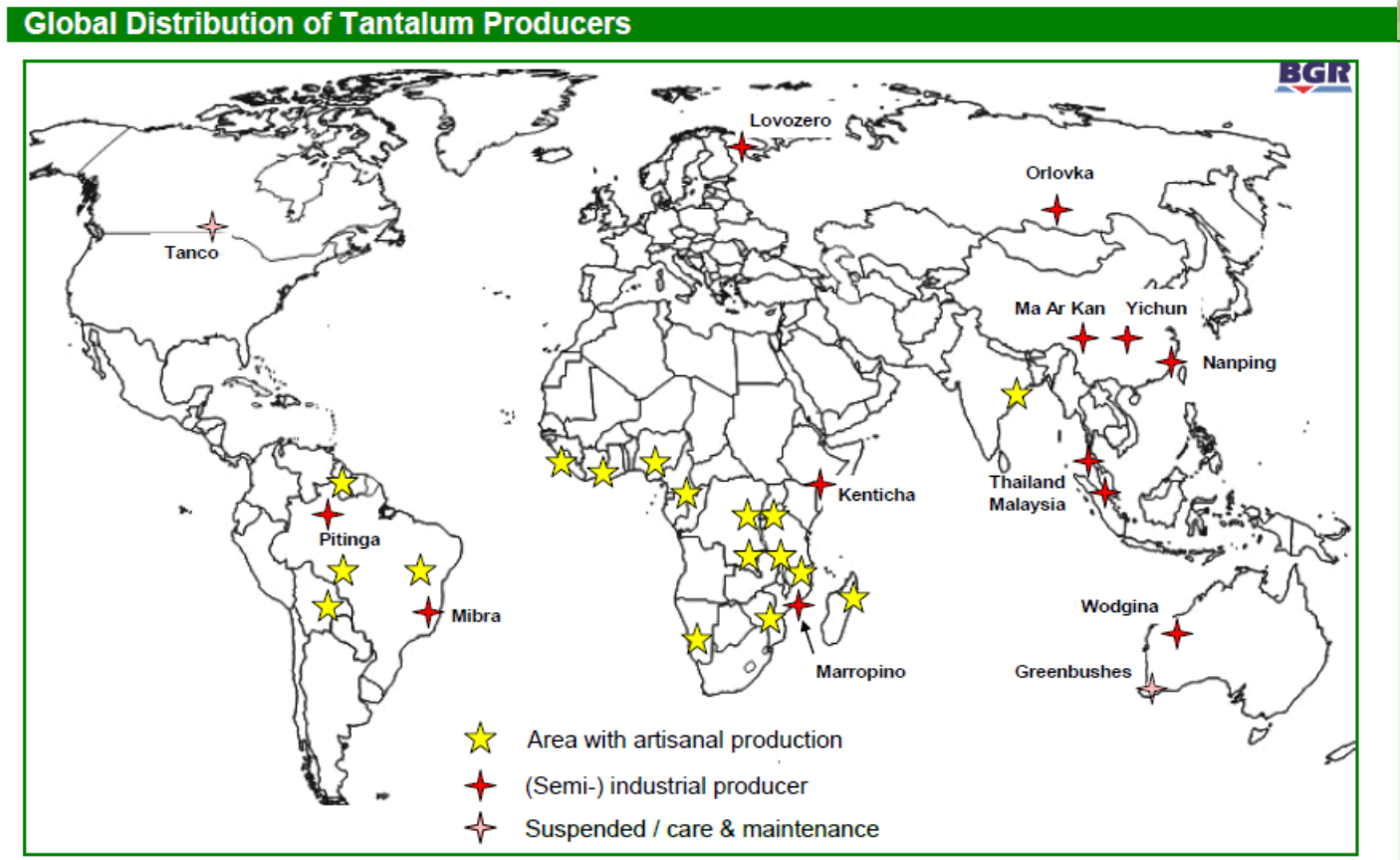
- Minerals--tantalite and columbite or niobite
- Best deposits--Granitic rare-metal pegmatites and rare-metal granites
- Grades--0.015 - 0.02 % Ta_2O_5

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

Cesium

Cesium

- Cs
- Atomic number 55
- 3 ppm in the earth's crust
- Soft, silvery-golden alkali metal
- melting point of 28.5 °C (83.3 °F), which makes it one of only five elemental metals that are liquid at or near room temperature
- cesium transmits and partially absorbs violet light preferentially while other colors (having lower frequency) are reflected; hence it appears yellowish

Cesium

- One of the most important critical minerals
- Critical to future advances in healthcare, defense, and the 5G revolution
- It's the "cesium standard" that allows us to measure time accurately. That means it's the key to data transmission infrastructure of mobile networks, the internet, and GPS

Cesium

- healthcare industry, it's vital in strategic organic chemistry, including in x-ray radiation and for cancer treatments
- oil and gas industry, it's vital for drilling fluids that prevent blow-outs in high-temperature, high-pressure wells
- catalyst promoters, glass amplifiers, and photoelectric cell components, to crystals in scintillation counters, and getters in vacuum tubes

Cesium

- the most electropositive of all stable elements
- the heaviest of the stable metals
- extremely pyrophoric, ignites spontaneously when in contact with air, and explodes violently in water or ice at any temperature above -116 ° C

Cesium

	Reserves[1]
Australia	7,100
Canada	120,000
Namibia	30,000
Zimbabwe	60,000
World total (rounded)	220,000

USGS Commodity Summary

Cesium

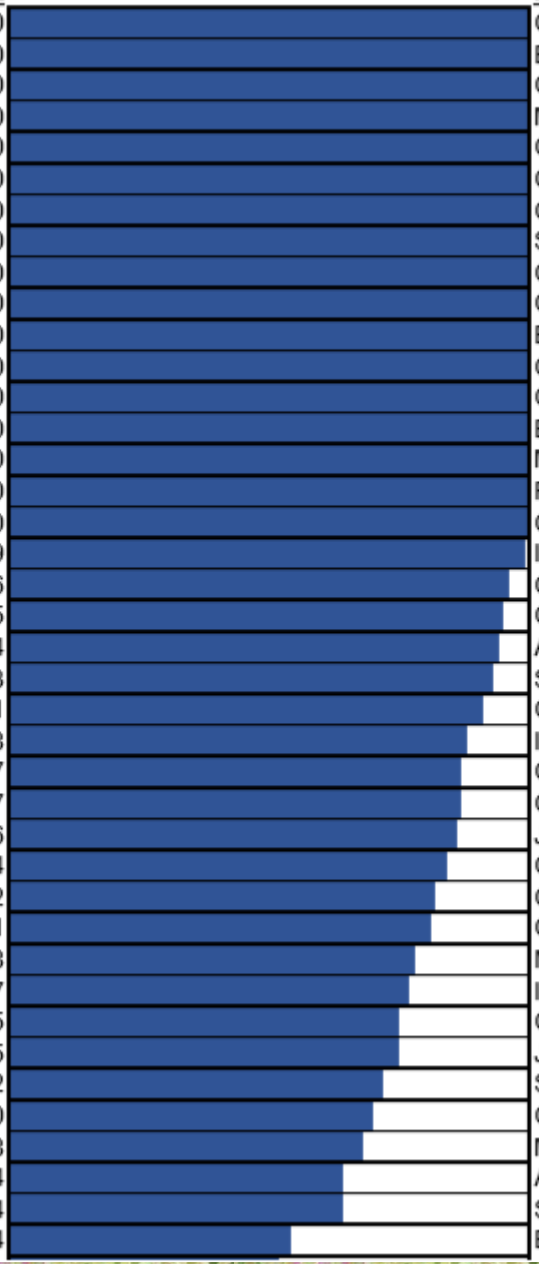
- Found in pegmatites in China and Canada
- Mineral pollucite $(Cs, Na)_2 Al_2Si_4 O_{12} \cdot 2H_2O$

Other critical and strategic minerals

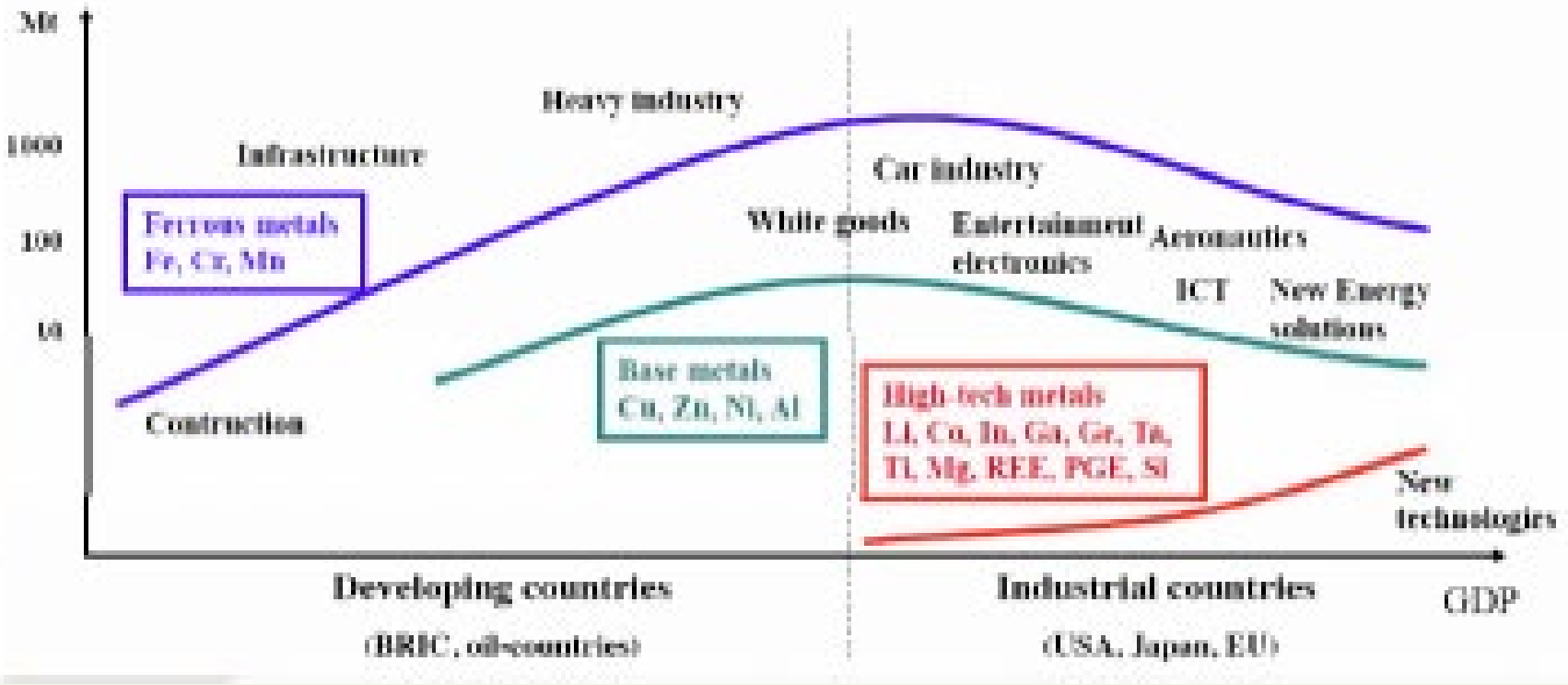
Summary comments

2019 U.S. NET IMPORT RELIANCE[1]

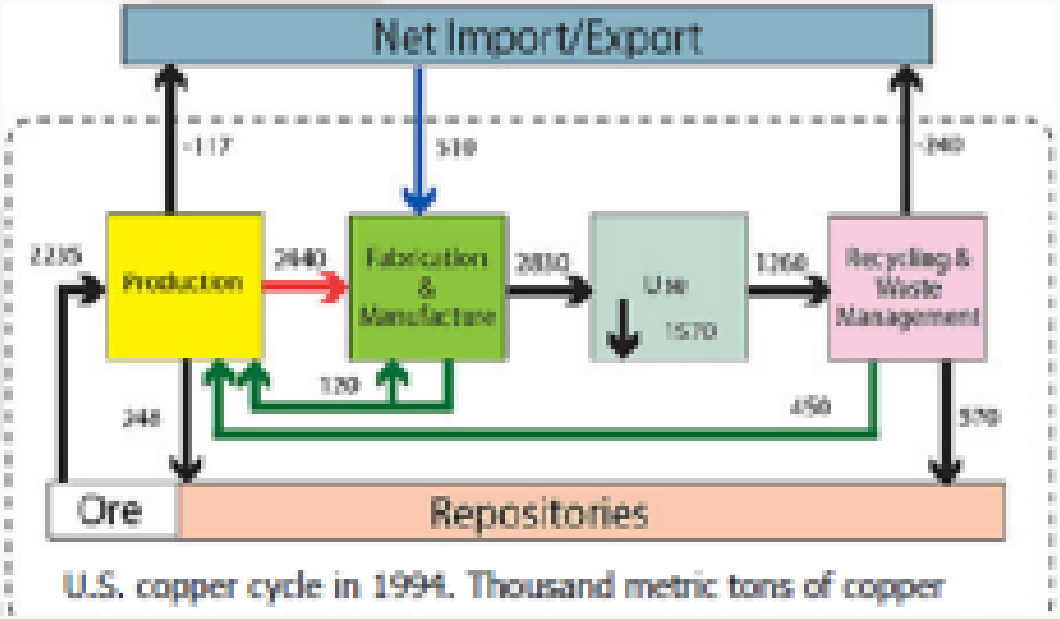
Commodity	Percent	Major import sources (2015–18)[2]
ARSENIC (all forms)	100	China, Morocco, Belgium
ASBESTOS	100	Brazil, Russia
CESIUM	100	Canada
FLUORSPAR	100	Mexico, Vietnam, South Africa, China
GALLIUM	100	China, United Kingdom, Germany, Ukraine
GRAPHITE (natural)	100	China, Mexico, Canada, India
INDIUM	100	China, Canada, Republic of Korea, Taiwan
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, Germany
RARE EARTHS[3] (compounds and metal)	100	China, Estonia, Japan, Malaysia
RUBIDIUM	100	Canada
SCANDIUM	100	Europe, China, Japan, Russia
STRONTIUM	100	Mexico, Germany, China
TANTALUM	100	Rwanda, Brazil, Australia, Congo (Kinshasa)
YTTRIUM	100	China, Estonia, Republic of Korea, Japan
GEMSTONES	99	India, Israel, Belgium, South Africa
BISMUTH	96	China, Belgium, Mexico, Republic of Korea
TELLURIUM	>95	Canada, China, Germany
VANADIUM	94	Austria, Canada, Russia, Republic of Korea
TITANIUM MINERAL CONCENTRATES	93	South Africa, Australia, Canada, Mozambique
POTASH	91	Canada, Russia, Belarus, Israel
DIAMOND (industrial stones)	88	India, South Africa, Botswana, Australia
BARITE	87	China, India, Morocco, Mexico
ZINC (refined)	87	Canada, Mexico, Australia, Peru
TITANIUM (sponge)	86	Japan, Kazakhstan, Ukraine, China, Russia
ANTIMONY (metal and oxide)	84	China, Thailand, Belgium, India
RHENIUM	82	Chile, Germany, Kazakhstan, Canada
STONE (dimension)	81	China, Brazil, Italy, Turkey
COBALT	78	Norway, Japan, China, Canada
TIN (refined)	77	Indonesia, Malaysia, Peru, Bolivia
ABRASIVES, fused Al oxide (crude)	>75	China, Hong Kong, France, Canada
BAUXITE	>75	Jamaica, Brazil, Guinea, Guyana
CHROMIUM	72	South Africa, Kazakhstan, Russia
PEAT	70	Canada
SILVER	68	Mexico, Canada, Peru, Poland
GARNET (industrial)	64	Australia, India, South Africa, China
PLATINUM	64	South Africa, Germany, Italy, Russia
ALUMINA	54	Brazil, Australia, Jamaica, Canada



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

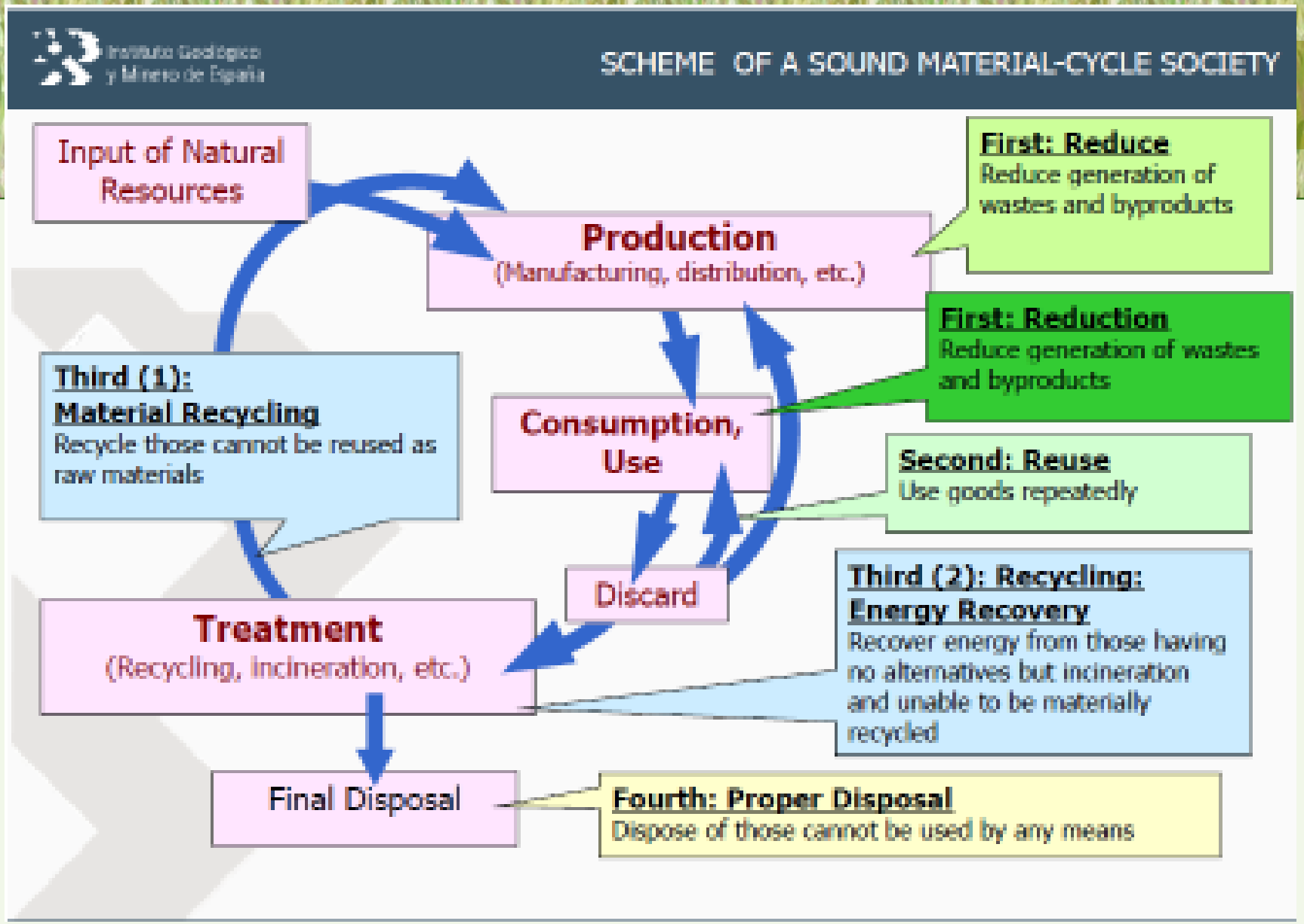
Red: processing of domestic copper ore

Green : recycled material

Blue: imported material in semifinished or finished products

2,8 Mt used:

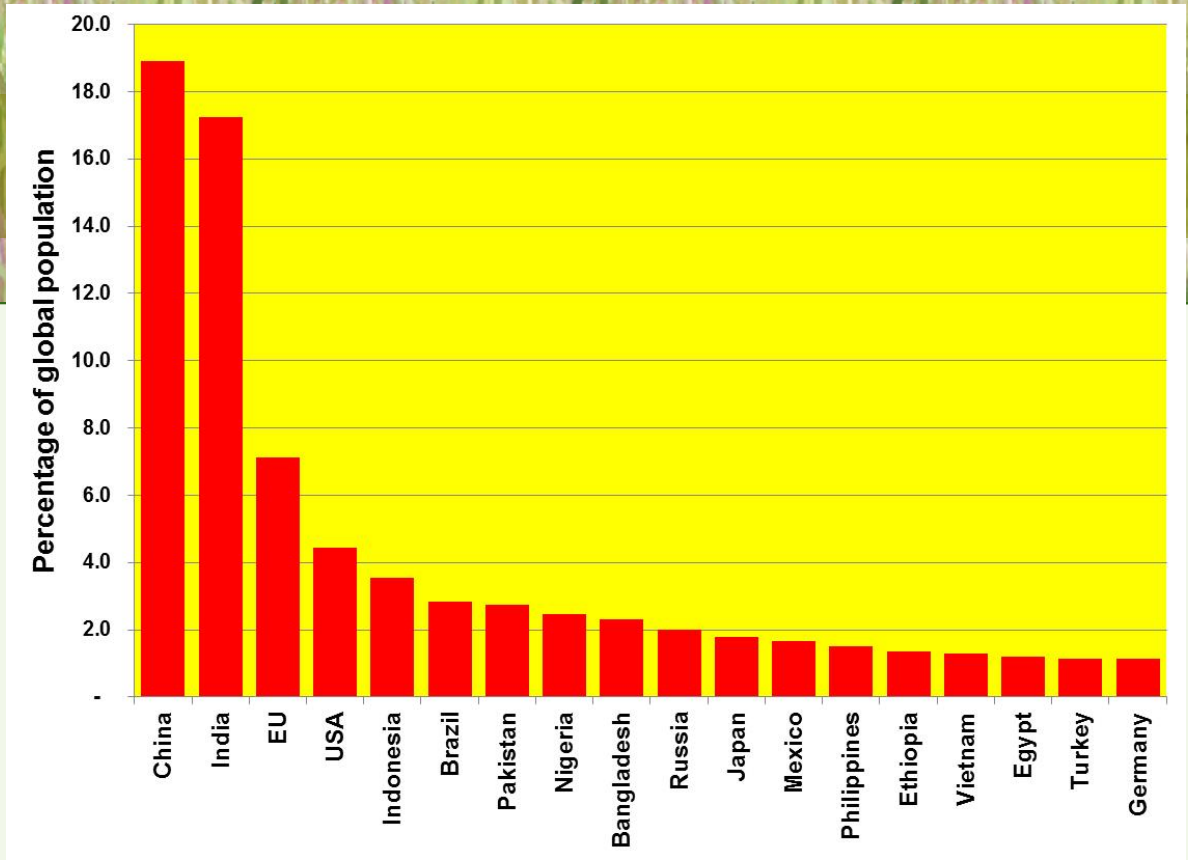
- 70% primary
- 16% secondary
- 13% tertiary



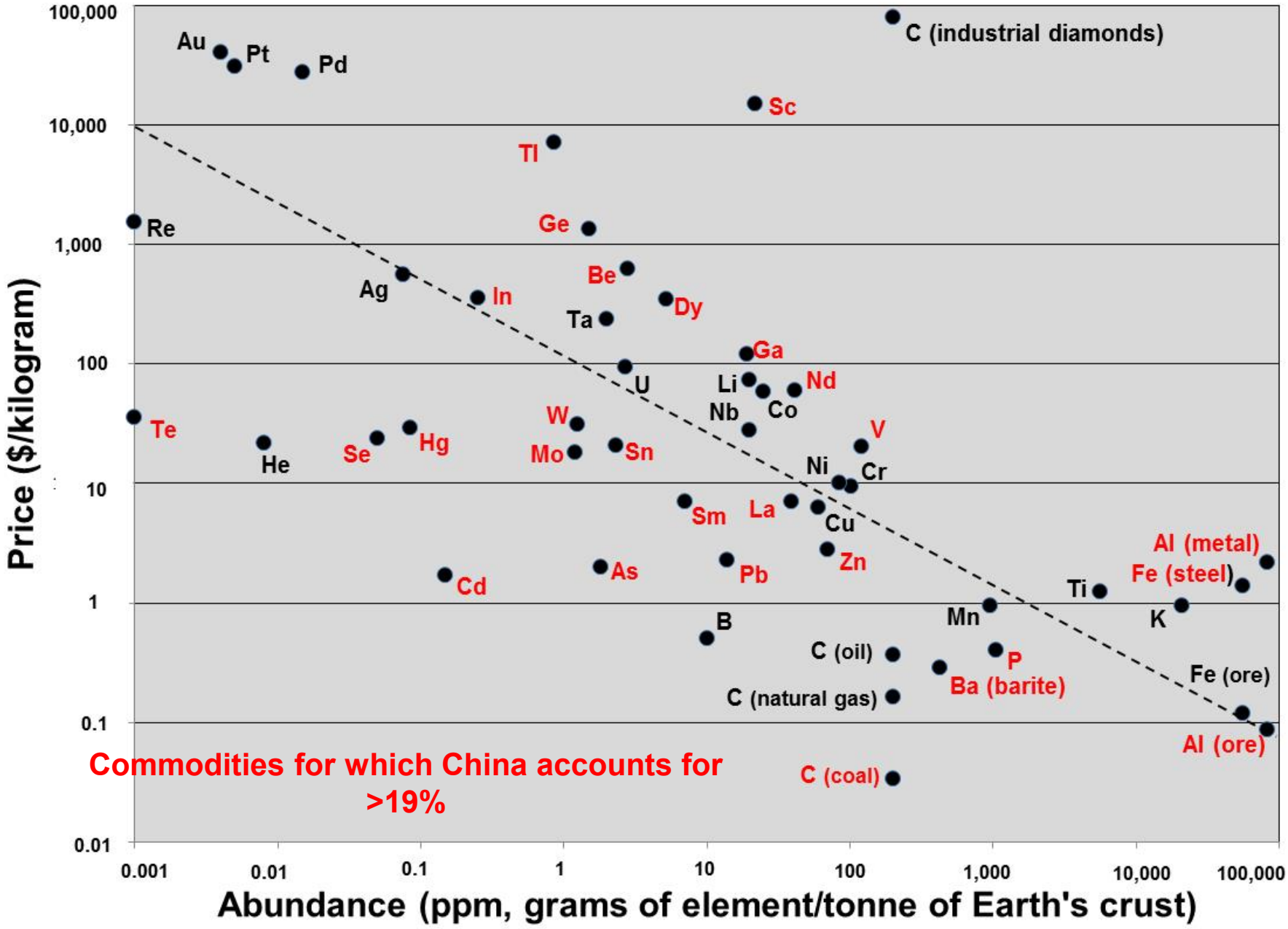
http://www.kotu.oulu.fi/projektit/oms/map3/Manuel_Regueiro.pdf

- 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).



Percentage of global population by country. With approximately 20% of the world's population, China produces well over 20% of the world's supply of many mineral and energy commodities, some of which are highlighted on this graph (population data from CIA, coal production data from EIA, other mineral commodity data from USGS; DRC = Democratic Republic of Congo). (Jon Price, 2019)


Price ($/kilogram)
100,000
10,000
1,000
100
10
1
0.1
0.01
Au
Pt
Pd
C (industrial diamonds)
Sc
Tl
Re
Ge
Be
Ag
In
Dy
Ta
Ga
U
Li
Nd
Nb
Co
Te
W
V
He
Se
Hg
Mo
Sn
Ni
Cr
Sm
La
Cu
Al (metal)
Fe (steel)
Zn
As
Pb
Cd
Ti
Mn
K
B
C (oil)
P
Fe (ore)
Ba (barite)
C (natural gas)
Al (ore)
C (coal)
Commodities for which China accounts for >19%
0.001
0.01
0.1
1
10
100
1,000
10,000
100,000
Abundance (ppm, grams of element/tonne of Earth's crust)

Price (2019)

Arrowhead clipart from www.firstpeople.us

Critical and strategic minerals will change with time.

$CuIn_xGa_{(1-x)}Se_2$ or CIGS, for solar panels?
CdTe , GaAs, and Ge for solar panels?
Nd for magnets for wind and other electrical turbines?
Li, Co, and V for different types of batteries?