EARTH 471
Mineral Deposits

Introduction

Cum semper fuerit inter homines de metallis disensio, quod alii eis praeconium triburent, alii ea graviter vituperarent

– Georgius Agricola (1556)

“People were always divided in their opinion about mining, as some praised it highly while others condemned it fiercely”.

EARTH 471 – Course Objectives

- Describe the formation of major ore deposit types and identify their geological setting
- Recognize and describe metallic minerals of economic interest
- Interpret mineral textures using ore petrology
- Estimate the reserves of a mineral deposit using geochemical data and core logging
- Explain the life cycle of mining operations in Canada
- Discuss the economics of mineral deposits
- *Be able to hold a conversation with a Economic Geologist*

EARTH 471 – Grade Breakdown

Laboratories	5%
Lab Exam	15%
Commodity report	10%
Exploration report	30%
Mid Term (**Feb. 27**)	15%
Final Exam**	25%

**Final Exam will be scheduled by the Registrar and it is comprehensive

EARTH 471 Schedule

Lectures

Tu: 11:30–12:50 – PAS 1229

Th: 11:30–12:50 – PAS 1229

Labs (2 sections) – EIT 1009:

M: 9:30–12:20 (471–101)

W: 8:30–11:20 (471–102)

NO LAB ON MONDAY THE WEEK OF PDAC (March 5), NO LECTURE ON TUESDAY MARCH 6

LABS MOVE TO B1 370 (Computer Lab) THE WEEK OF MARCH 12

EARTH 471 – Laboratories (<u>5% of final grade</u>)

Labs can be completed in groups of 3–4 students.

L1) Ore Minerals
L2) Ore Petrography
L3) Ni–Cu–PGE
L4) VMS
L5) Au

Students have 1 week to complete each lab.

***LAB EXAM FEB 12th (101) and 14th (102) ***
(**<u>15% of final grade</u>**)

EARTH 471 – Exploration Report

30% of final grade is a team (4 students) report based on:

E1) Core logging
E2) Assay data reduction and reserve estimate
E3) Findings and recommendations report

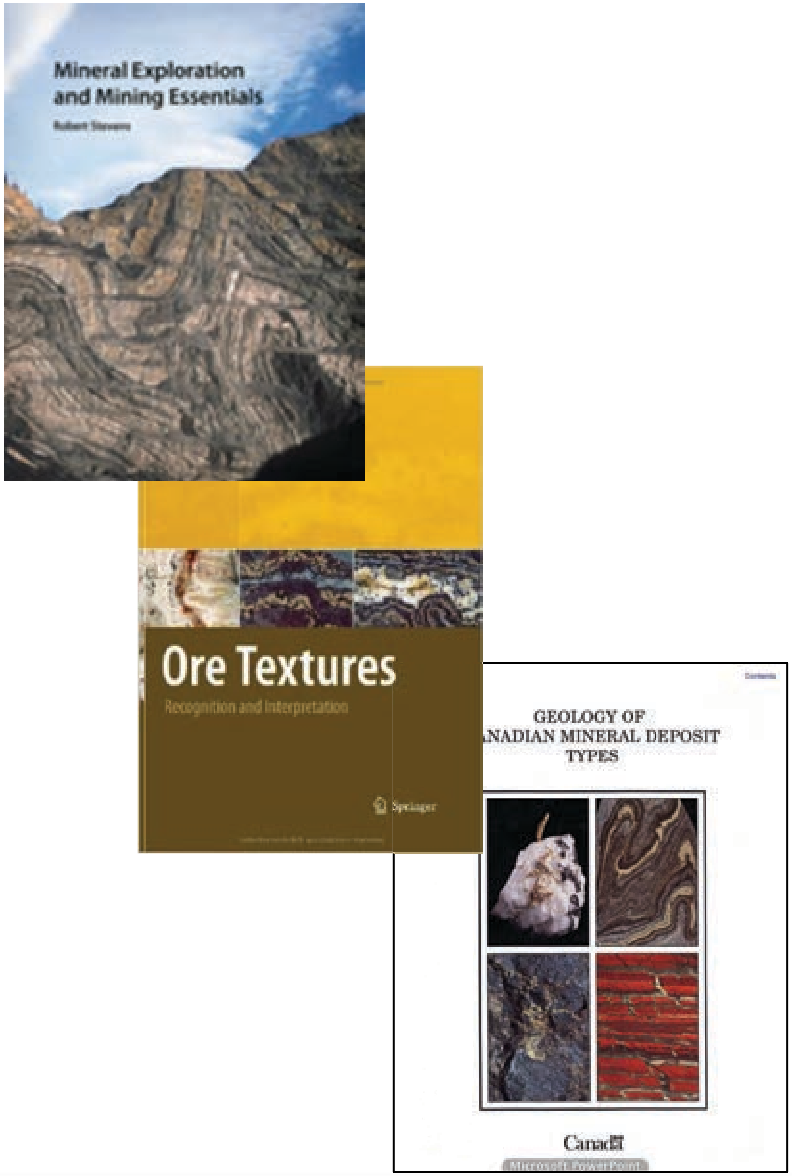
*Core samples are provided a real gold deposit in Ontario.

EARTH 471 Textbooks

Mineral Exploration and Mining Essentials, 2010, Robert Stevens **Available in the book shop**

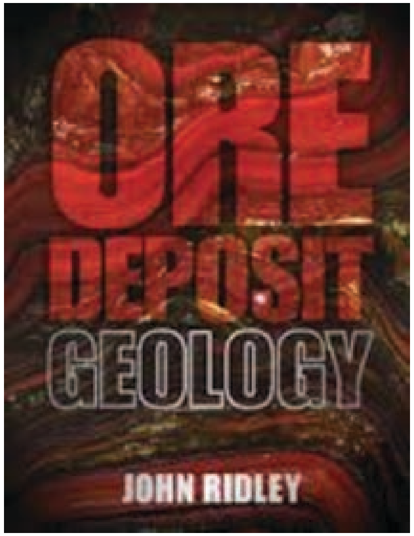
Ore textures and interpretation, 2009, Roger Taylor, Springer eBook **Available online through library**

Geology of Canadian mineral deposit types, 1995, Eckstrand et al. **Available online through NRCan**

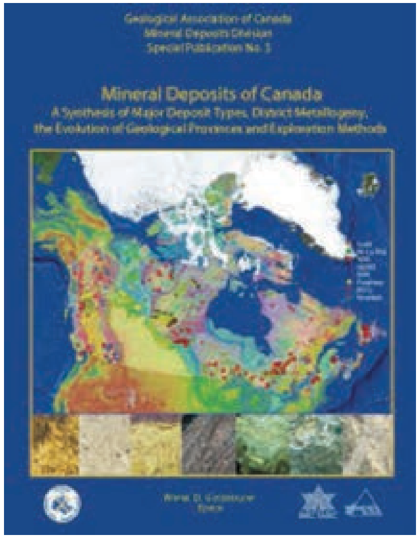


EARTH 471 Textbooks cont.

Ore Deposit Geology, Ridley, J.
2013
In Library



Mineral deposits of Canada,
Goodfellow, W. 2007
In Library



EARTH 471 – Commodity Report (10%)

This report is an assessment of the economic importance and geological setting of a particular commodity with a particular emphasis on Canada and Ontario.

Sign up for one of the commodities posted on the LEARN site (first come, first served).

The report will be 2 pages long with strict criteria for formatting and referencing found on the LEARN site.

The final electronic copy must be turned in to the dropbox on the LEARN site by Friday February 10th at 5:00pm. <u>TURNITIN</u> will be used

Late submissions will be subject to a 10% penalty for every 24 hours (or part thereof) after the deadline.

Academic Integrity

- Office of Academic Integrity provides relevant information for students, faculty and staff.
- Academic Integrity: In order to maintain a culture of academic integrity, members of the University of Waterloo community are expected to promote honesty, trust, fairness, respect and responsibility.
- Grievance: Students, who believe that a decision affecting some aspect of their university life has been unfair or unreasonable, may have grounds for initiating a grievance. Students should read Policy #70, Student Petitions and Grievances, Section 4. When in doubt, students must contact the department's/ school's administrative assistant who will provide further assistance.
- Plagiarism: Plagiarism is the act of directly copying material from another source word-for-word without acknowledging (citing) the source. Copying material from another student word-for-word (collusion) also constitutes plagiarism. It is unacceptable to claim another person's words as your own. Acts of plagiarism are not tolerated at the University of Waterloo and are subject to disciplinary action according to Policy 71, Student Discipline (see below). If you have not already done so, it is strongly recommended that you take the Academic Integrity Tutorial at http://www.lib.uwaterloo.ca/ait/.
- Discipline: Students are expected to know what constitutes academic integrity, to avoid committing academic offenses, and to take responsibility for their actions. Students who are unsure whether an action constitutes an offense, or who need help in learning how to avoid offenses (e.g., plagiarism, cheating) or about 'rules' for group work/collaboration should seek guidance from the course instructor, academic advisor, or the Associate Dean of Science for Undergraduate Studies. For information on categories of offenses and types of penalties, students should refer to Policy #71, Student Discipline. For information on typical penalties, students should check Guidelines for the Assessment of Penalties.
- Appeals: A decision or penalty imposed under Policy 33 (Ethical Behavior), Policy #70 (Student Petitions and Grievances) or Policy #71 (Student Discipline) may be appealed, if there is a ground. Students, who believe they have a ground for an appeal, should refer to Policy #72 (Student Appeals).

VIFs, OPD, etc.

Verification of Illness Forms (VIF's):

Science students should be aware that the only Verification of Illness forms (VIFs) accepted for accommodation for missed assessments will be those issued by the University of Waterloo´s Health Services, when this service is open (https://uwaterloo.ca/health-services/). VIFs issued by walk-in clinics will not be accepted, except when obtaining a VIF from Health Services is not possible. If a student is sick on a weekend, during off-hours, while out of town or receiving ongoing care from a family physician or specialist, it is acceptable to provide documentation from other health service providers. Information should include (1) date of the physician assessment, (2) dates of illness, (3) level of incapacitation and (4) whether the diagnosis was made by the physician or based on description by the student. Keeping the playing field level for all of our students is a priority. Students are reminded that obtaining a VIF under false pretences is an academic offense. For tests and exams, a student found guilty of misrepresentation will receive a failing grade in the course and be suspended. Any questions concerning this policy can be directed to an undergraduate advisor in the Science Undergraduate Office.

Student travel plans not considered acceptable grounds for granting an alternative examination time. Only illness and extenuating circumstances (such as a death in the family) will be considered.

Students with Disabilities:

AccessAbility Services, located in Needles Hall, Room 1132, collaborates with all academic departments to arrange appropriate accommodations for students with disabilities without compromising the academic integrity of the curriculum. If students require academic accommodations to lessen the impact of their disability, they should register with AccessAbility Services at the beginning of each academic term.

Ecetera:

Please read and be familiar with the university policies regarding service interruptions in LEARN. It is recommended you download all course content so you have a copy of it and can access it at all times.

Turnitin

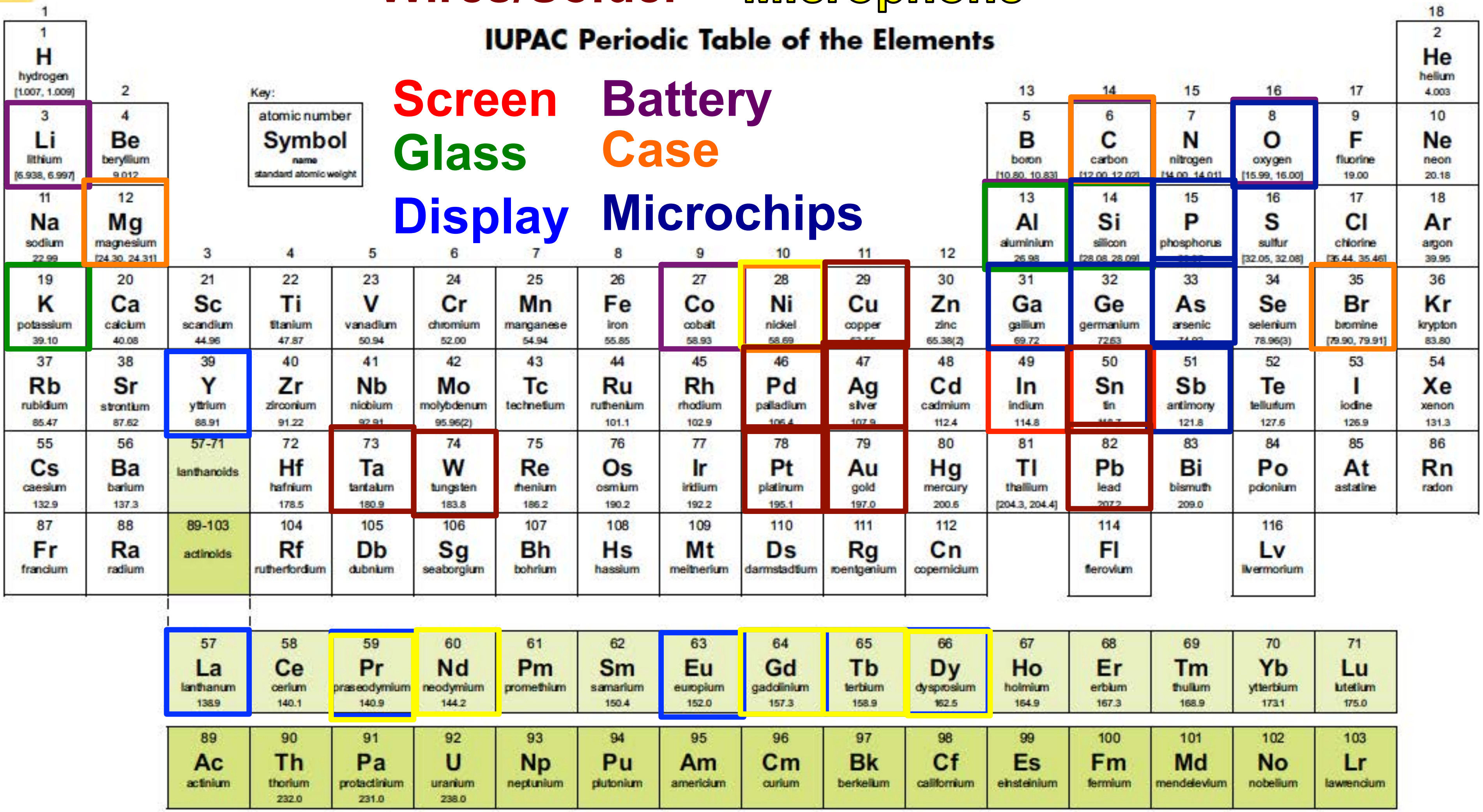
Turnitin.com: Text-matching software (Turnitin®) will be used to screen assignments in this course. This is being done to verify that use of all materials and sources in assignments is documented. Students will be given an option if they do not want to have their assignment screened by Turnitin®. In the first week of the term, details will be provided about arrangements and alternatives for the use of Turnitin® in this course.

External organizations offering access to course materials (e.g., OneClass; CourseHero):

The educational materials developed for this course, including, but not limited to, lecture notes and slides, handout materials, examinations and assignments, and any materials posted to Learn, are the intellectual property of the course instructor. These materials have been developed for student use only and they are not intended for wider dissemination and/or communication outside of a given course. Posting or providing unauthorized audio, video, or textual material of lecture content to third-party websites violates an instructor's intellectual property rights, and the Canadian Copyright Act. Recording lectures in any way is prohibited in this course unless specific permission has been granted by the instructor. Failure to follow these instructions may be in contravention of Policy 71 (Student Discipline). Participation in this course constitutes an agreement by all parties to abide by relevant University policies and guidelines – see Faculty, Staff and Students Entering Relationships with External Organizations Offering Access to Course Materials.

Why should anyone care about mineral deposits?

Wires/Solder Microphone



Wires/Solder **Microphone**

IUPAC Periodic Table of the Elements

Screen **Battery**

An average smartphone requires at least 33 different elements, each of which need to be:

- Extracted from the Earth as constituents in minerals (<u>mining</u>)
- Processed to (nearly) pure elements
- Shipped, manufactured into a product
- Sold to you (the consumer)

Mineral

1) In mineralogy and petrology: an inorganic substance with a definite chemical composition and a characteristic crystal structure

2) In **economic geology**: any natural occurring, but non-living, material found in, or on, Earth for which a use can be found

Mineral groups in economic geology:

1. Precious metals
2. Base metals (non-ferrous)
3. Ferrous metals
4. Non-metallic minerals
5. Fusionable metals and fuels (energy minerals)
6. Industrial minerals and rocks
7. Gems and gemstones

Precious metals

- Gold, silver and platinum group elements (PGEs).

Gold: 0.0000004 wt% in the crust

- The search for gold has been a driving force for human exploration and colonization
- Soft, malleable, very conductive and resistant to corrosion

Silver:

- Currency in early Mediterranean cultures
- Mainly used in jewellery, silverware, photography, solders and industrial applications

Precious metals

- Gold, silver and platinum group elements (PGEs).

Platinum Group elements:

- Platinum, Palladium, Osmium, Ruthenium, Iridium and Rhodium
- Excellent catalysts

Base metals (non-ferrous)

- Copper, zinc, lead, nickel, tin, aluminum
- Form the 'backbone' of mineral deposit exploration
- Canada is one of the World's largest producers
- We will focus our attention on the base and precious metals throughout this course


Escondida copper mine, Chile, BHP Billiton


Hemlo Gold Mine, Ontario

Ferrous metals

Iron, molybdenum, chromium, cobalt, manganese, and tungsten

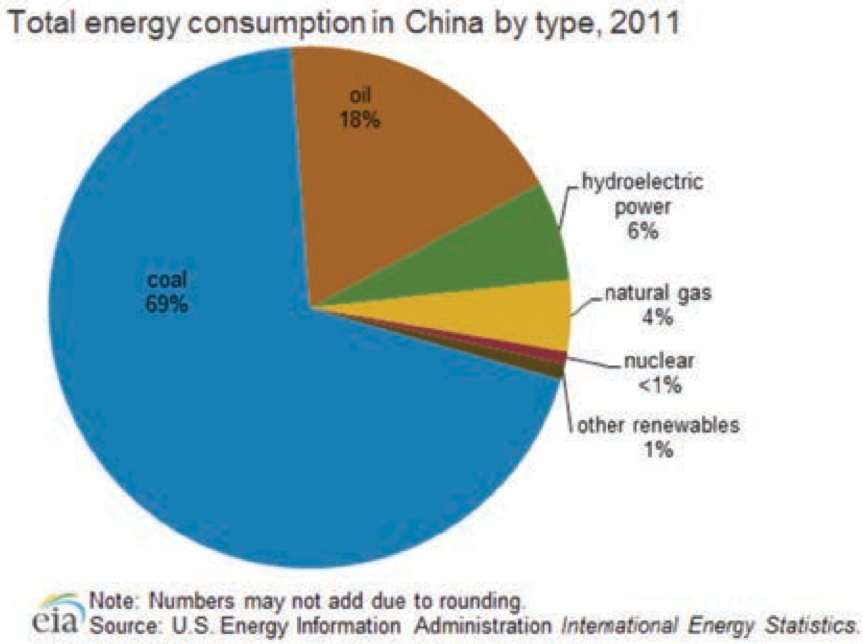
Iron

- 5.6 wt% of the crust
- Found in many minerals (hematite and magnetite most important Fe ore minerals)
- Accounts for 94% of metals used throughout human history and most other metals (Ni, Cr, Mo, Mn, Co, W) are used to make alloys with iron
- Essential for infrastructure

Wiki Commons

Fusionable metals and fuels (Energy Minerals):

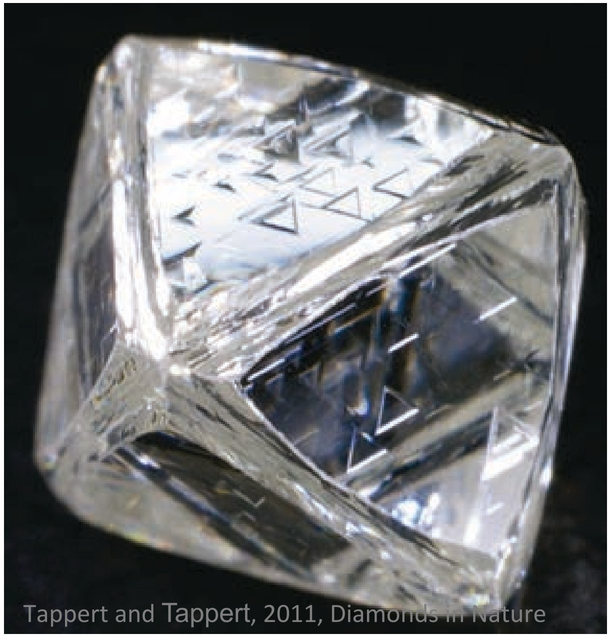
- Uranium
- Oil and Gas
- Coal



Gems and gemstones

- Diamond
- Emerald
- Ruby
- Sapphire

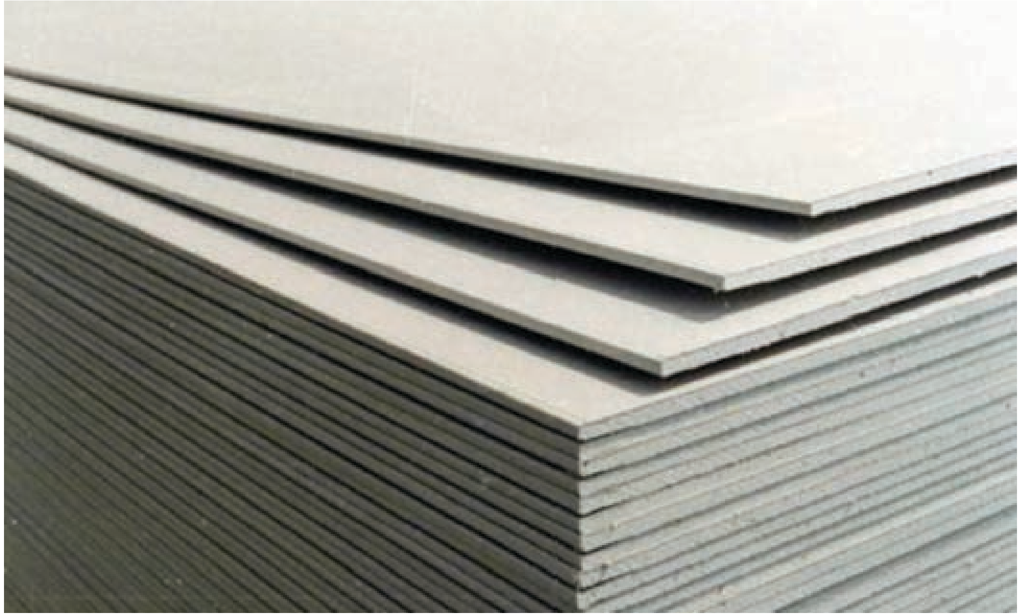

Baffin Island Sapphire, True North Gems


Tappert and Tappert, 2011, Diamonds in Nature


Greenland Ruby, True North Gems

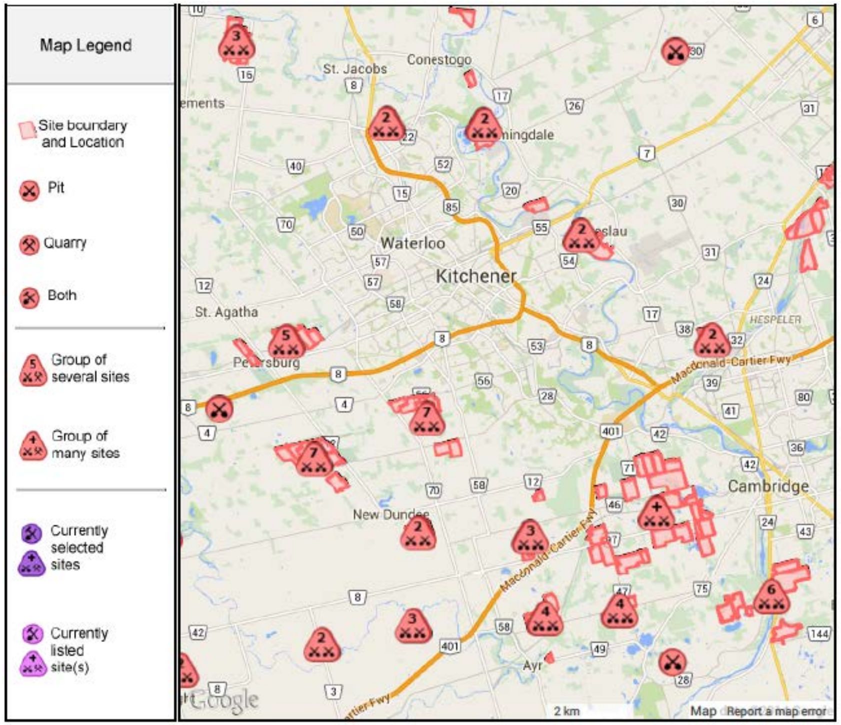
Non-metallic minerals

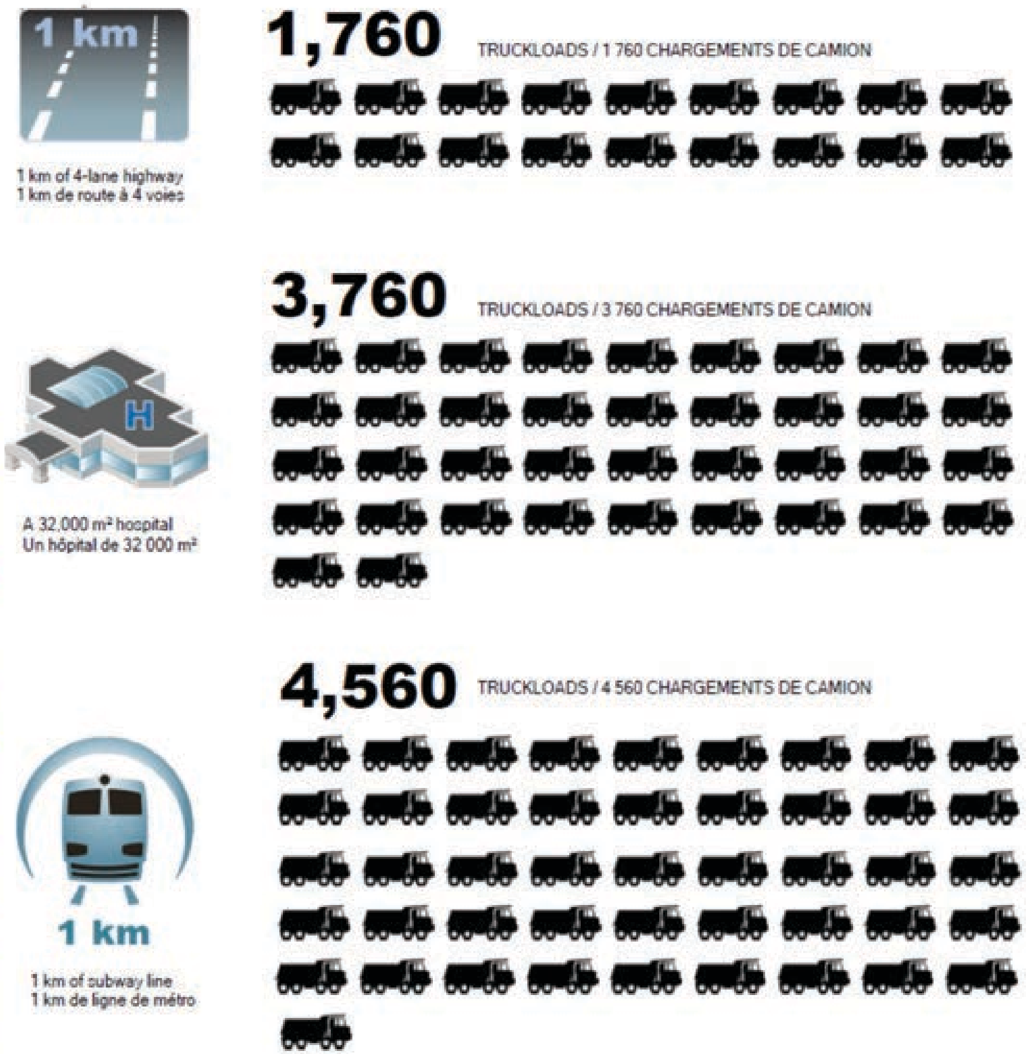
- Potash: agriculture, fertilizer
- Gypsum: construction
- Kaolin: porcelain, paper
- Salt: Food, de-icer



Industrial minerals

- Aggregate: gravel, sand, and clay
- Building stone
- Very important commodity in Southern Ontario





http://www.ontario.ca/environment-and-energy/aggregate-resources

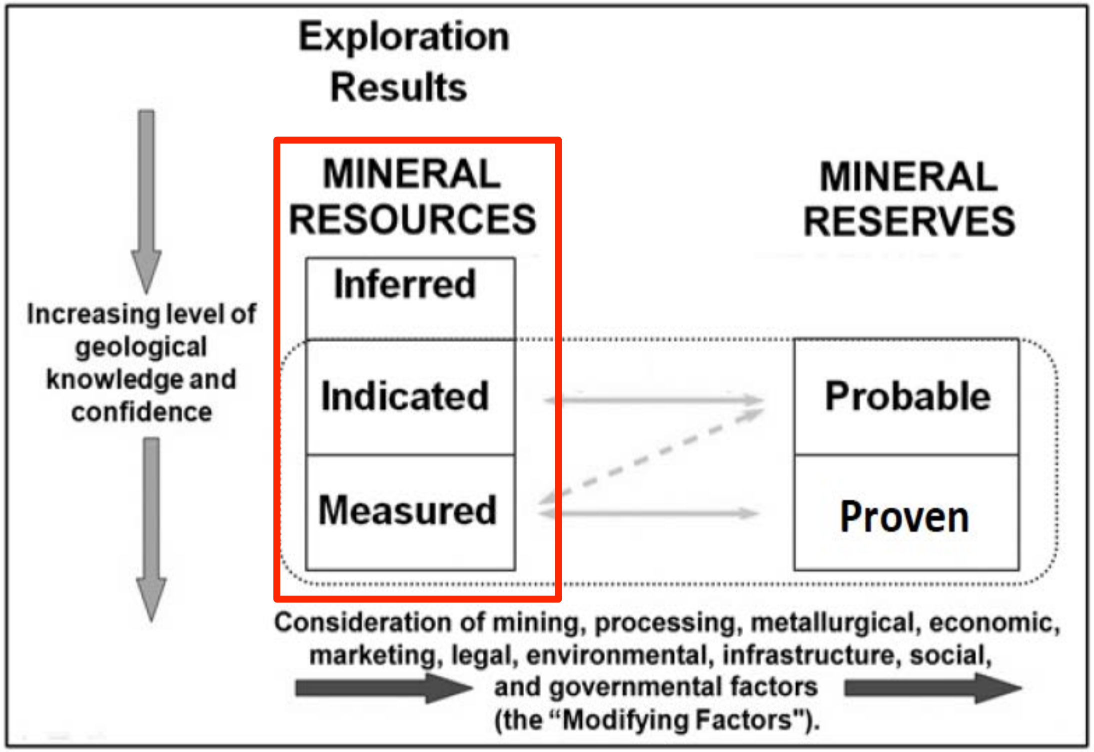
Economic Geology

1) **Scientific Study**
   - Understanding the distribution, characteristics and genesis of mineral deposits
2) **Exploration**
   - Apply the results of scientific study to discover and evaluate new deposits (e.g. using geology, geophysics, geochemistry)
3) **Exploitation**
   - Continue to investigate the ore deposit, expand reserves and optimize extraction

Mineral Resource:

"A concentration or occurrence of solid material of economic interest in or on the Earth's crust in such form, grade or quality and quantity that there are reasonable prospects for eventual economic extraction."

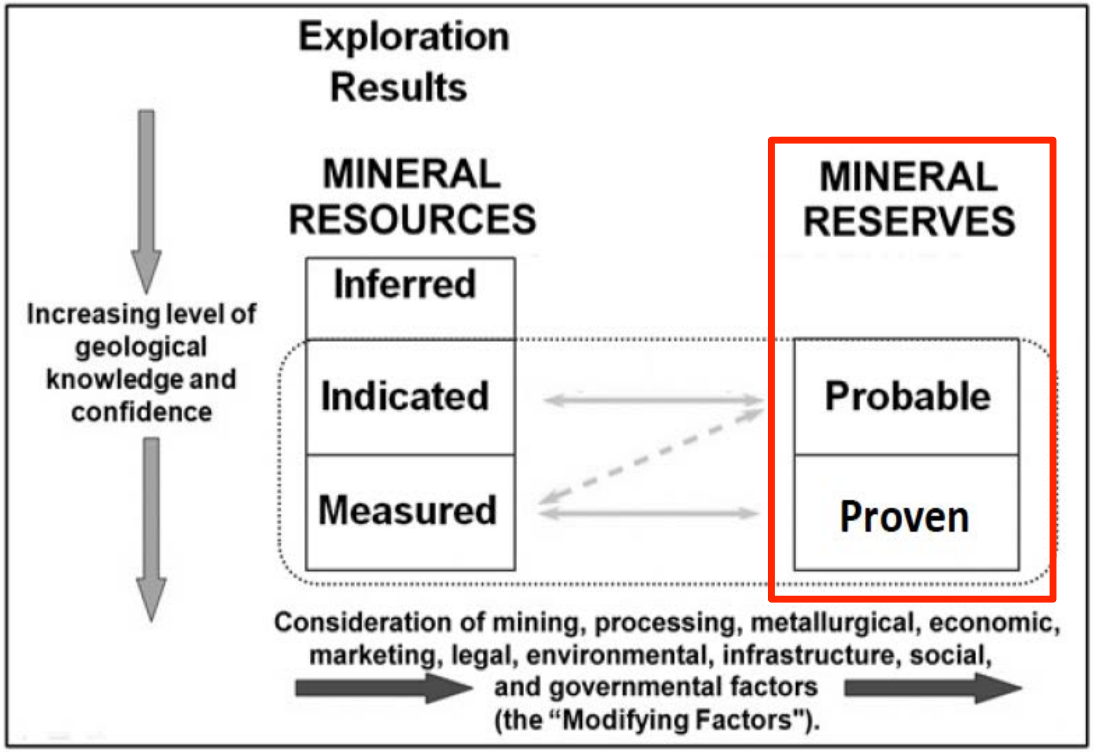
– CIMMP (2014)



Mineral Reserve:

"Economically mineable part of a Measured and/or Indicated Mineral Resource"

– CIMMP (2014)

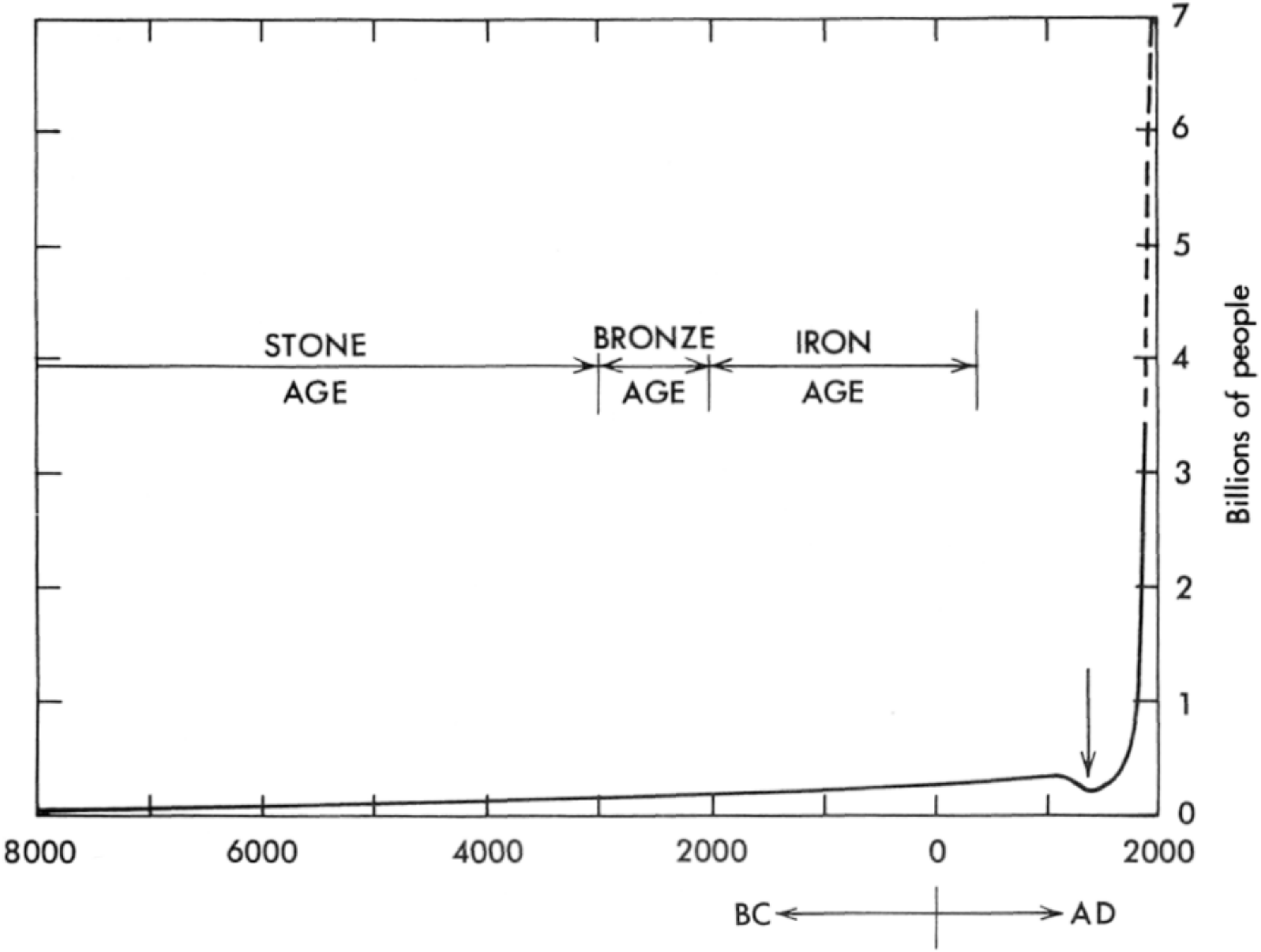


Society, Economics and Mineral Deposits

"If we remove metals from the service of man, all methods and sustaining health and more carefully preserving the course of life are done and away with. If there were no metals, men would pass a horrible and wretched existence in the midst of wild beasts; …will anyone be so foolish or obstinate as not to allow that metals are necessary for food and clothing and that they tend to preserve life?"

– *De Re Metallica, Georgius Agricola, 1556*

From Craig et al. 1988



Stone Age: non-metallic

Tripcevich & Contreras, 2013

Obsidian (volcanic glass)

- Used at least 2 million years ago
- Sharper than steel, some surgeons still use glass knives for surgery
- Isotropic, uniform physical properties, conchoidal fracture

Salt

- Traded long before recorded history
- Preservative, antiseptic, taste improver
- Roman soldier's pay consisted of salt (*salarium*), hence the word "Salary"

http://www.southafrica.net

Iron hyroxides

- Mainly symbolic (possible functional)
- The use (and therefore extraction and processing) of earliest *Homo sapiens*
- Decorative, but also used in medicine and food preservative

Stone Age: metals

- Metals used before 15,000 B.C.E
- Mostly gold and copper because these occur in their *native* states

Gold and copper objects recovered at the excavation of Huari tombs at Huayuncalla (700 AD). Gold disks are about 25 cm in diameter, tupus at lower left are 15–20 cm, knobs at lower right are 4.5–6 cm

Gold

- Occurred as scattered grains/nuggets big enough to see with the eye
- Jewellery, decorative

Copper

- Malleable, easily worked
- Used in weaponry
- ~4,000 B.C.E. copper was extracted from *ore minerals* by smelting with charcoal

~3,000 B.C.E. other metals (silver, tin, lead, zinc) were being extracted from ore minerals and made into alloys…

Stone Age ➔ Bronze Age

Smelting: process by which fire is used to liberate metal from oxides, carbonates or sulfides

Malachite smelting:

1. Heat malachite inside a kiln (such as one used for pottery), and the result is:

$Cu_2(CO_3)(OH)_2 = 2CuO + CO_2 + H_2O$

2. Heat copper oxide in a oxygen-poor fire, charcoal burns to produce CO instead of CO_2:

$CuO + CO = \underline{Cu} + CO_2$

Accidental smelting of Sn and Cu produced bronze.

Benzoni woodcut showing sopletes in use with a crucible (Brooks et al., 2013)

Mycenaean, 1350-1200 BC, Wikicommons

Iron Age

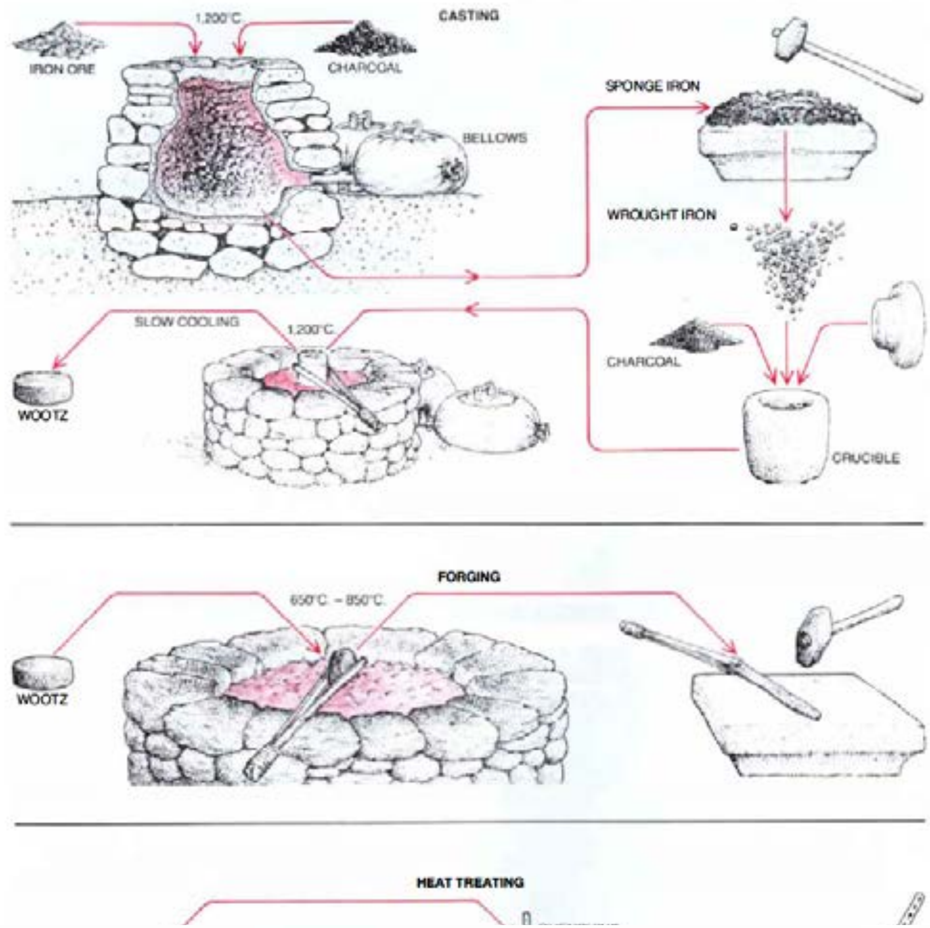
Gold is for the mistress—silver for the maid—
Copper for the craftsman cunning at his trade.
Good! Said the Baron, sitting in his hall,
But iron—Cold Iron—is master of them all.

– *Rudyard Kipling, 'Cold Iron', 1910*

Scientific America (1985)

Iron Age

- Iron ore more difficult to smelt than copper ore
- Iron slag pounded with hammer while molten to removing impurities leaving behind solid elemental Fe
- Iron was cast into alloys
- Probably by chance at first, C released from the charcoal used in the process alloyed with the iron producing STEEL
- Stronger than bronze



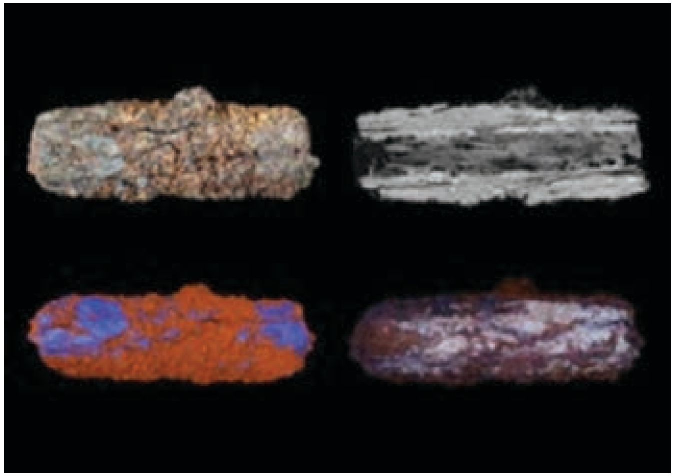
TYPICAL MANUFACTURING PROCEDURE for a Damascus sword began with the casting of an ultrahigh-carbon steel, called wootz, in Indian foundries. Iron ore and charcoal were mixed and heated to about 1,200 degrees Celsius in a shallow stone hearth. The iron was reduced (stripped of oxygen) by reactions with carbon from the charcoal, and it acquired a spongy consistency. Impurities were expelled from the sponge iron by hammering; the result was bits of wrought iron, which has a low carbon content. The carbon content was then increased by heating pieces of wrought iron with charcoal in a clay crucible, which was sealed to prevent the iron from oxidizing again. When a sloshing sound indicated the presence of some molten matter, the crucible was allowed to cool slowly in the furnace. Wootz was widely traded in the form of cakes several inches in diameter. Near Eastern smiths forged a Damascus blade from an individual cake that was probably heated to between 650 and 850 degrees C.; ultrahigh-carbon steels are ductile in that temperature range. The craftsmen hardened the finished blades by reheating them and then quenching them in water, brine or some other liquid.

Side Note: Tutankhamun's tomb

- King Tutankhamen's tomb contained vast quantities of gold and, on him, an iron dagger. On his person is where the most valuable items were kept.
- During this time, iron was not common – thought to be sourced only from meteorites
- 2500 years ago iron was more valuable than gold!

Comelli et al. (2016, Meteorics and Planetary Science

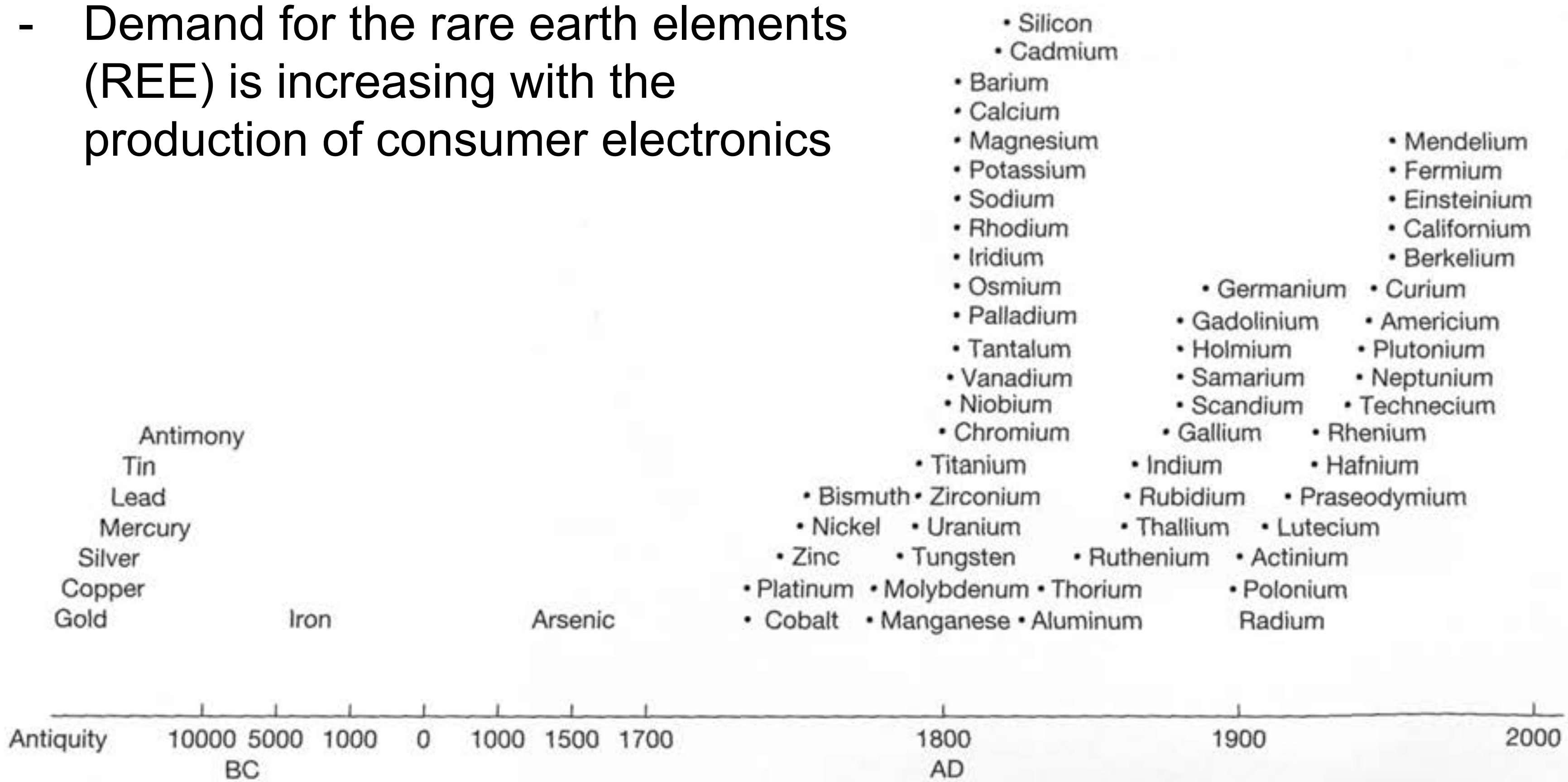
Ancient iron bead found in different tomb: microstructure consistent with a cold-worked iron meteorite.



http://www.geolsoc.org.uk/Geoscientist/Archive/April-2014/Iron-from-the-sky

Modern times

- We have found a use for most elements that occur in nature
- Demand for the rare earth elements (REE) is increasing with the production of consumer electronics



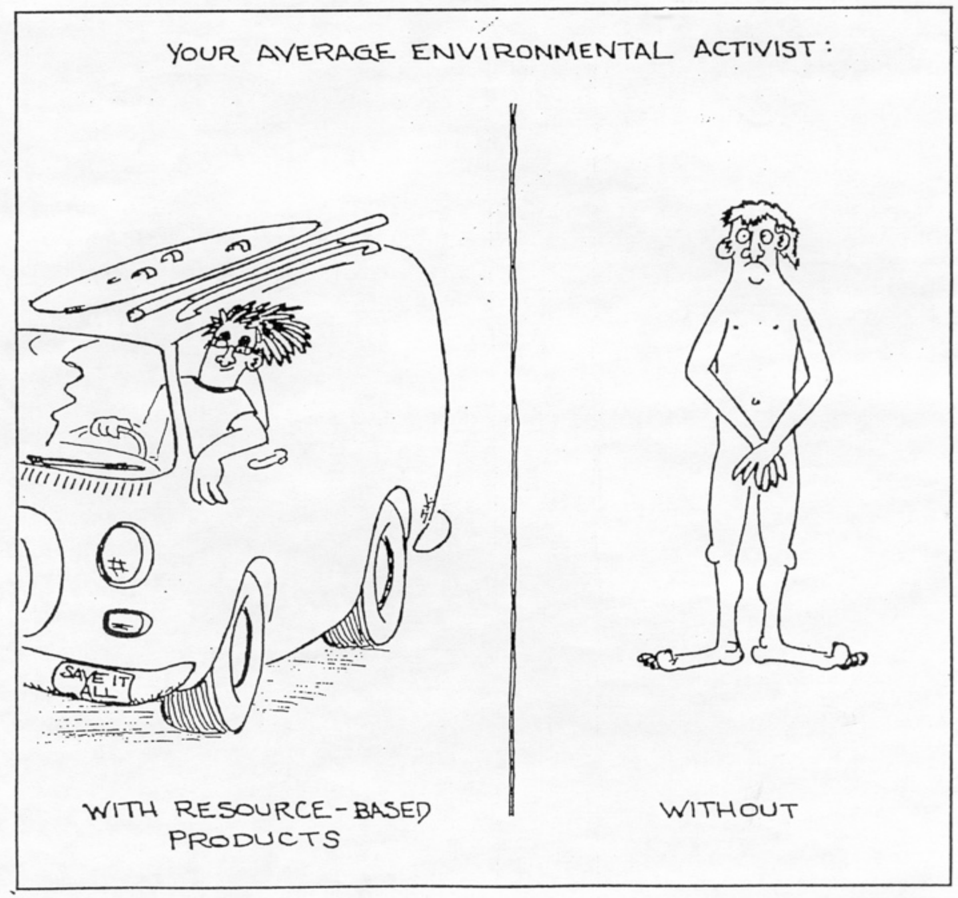
Standard of living

Mineral resources are used to increase our standard of living (imagine a world without electricity, roads, cars, or…even…the internet!)

Developed countries (~15% of the world) enjoy a high standard of living

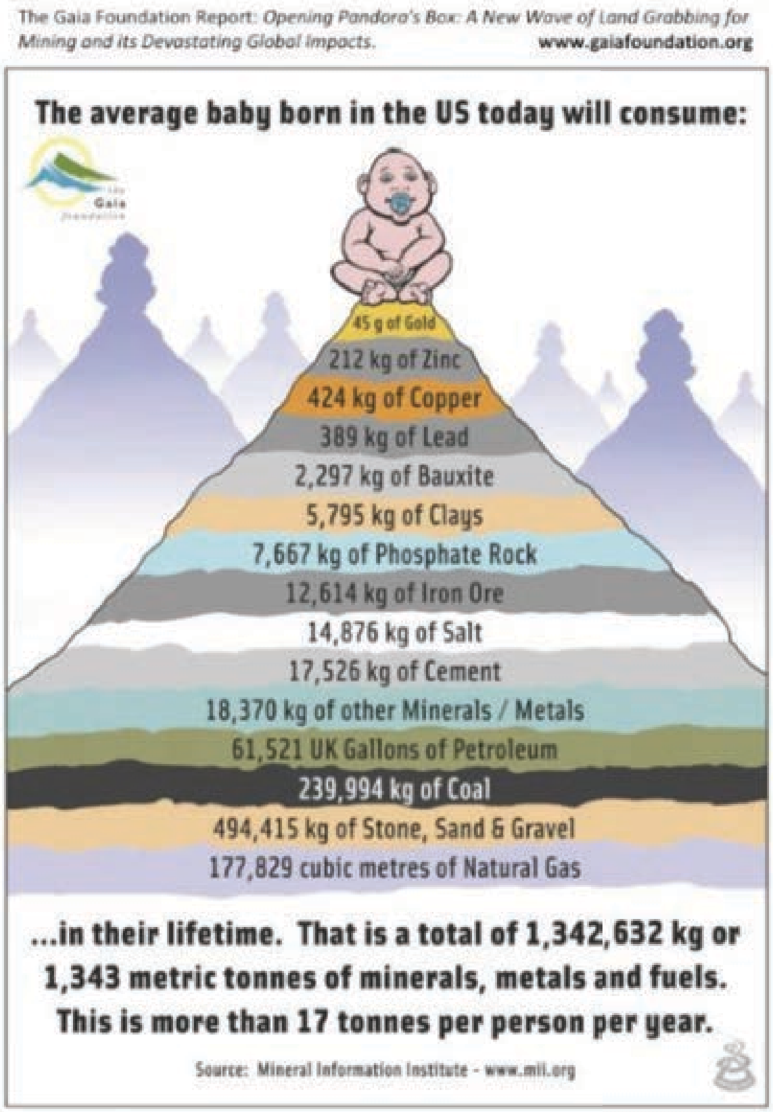
Developing countries consume the majority of the world's metals, oil and natural gas

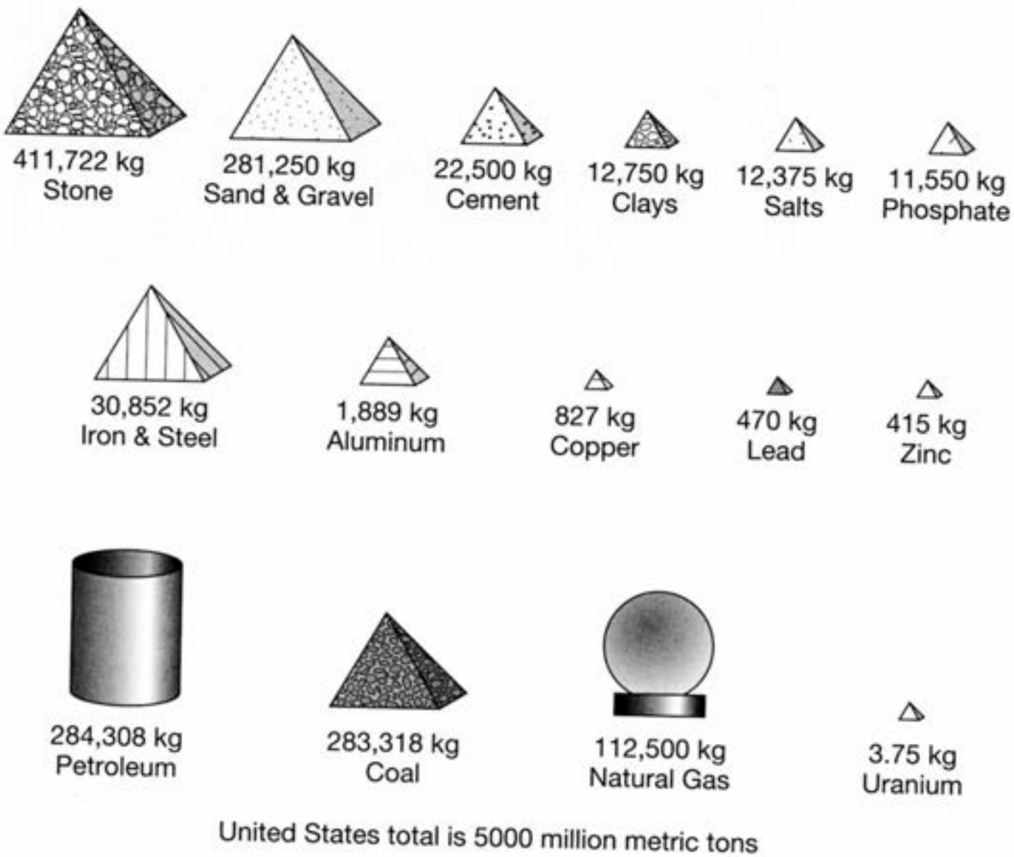
> In developing countries, to increase the standard of living, we need to increase production of mineral resources.



Northern Miner Magazine

Standard of living





Economics of Mineral Deposits

Mineral deposit becomes an Ore deposit when it has the potential to yield a profit:

Profit = revenue (income) – operating expenses

Revenue:

- Income made from selling the commodity

Operating expenses include:

- Equipment (trucks, drills, crushing, milling)
- Fuel and electricity
- Personnel (salaries, benefits)
- Environmental protection/cleanup
- Consulting (geologists, engineers)
- Taxes: can be highly variable depending on the Country/ Province and Government Policy

Mineral Commodity Prices

1. Free (Open) Market
   - Supply and Demand
   - Metal exchanges (London Metal Exchange (LME), New York Mercantile Exchange (NYME))
   - Gold, silver, copper, platinum, nickel, lead…
   - Transportation costs minimal (e.g. gold bars)
   - Quality of commodity not variable (e.g. most gold is 995/1000 pure)

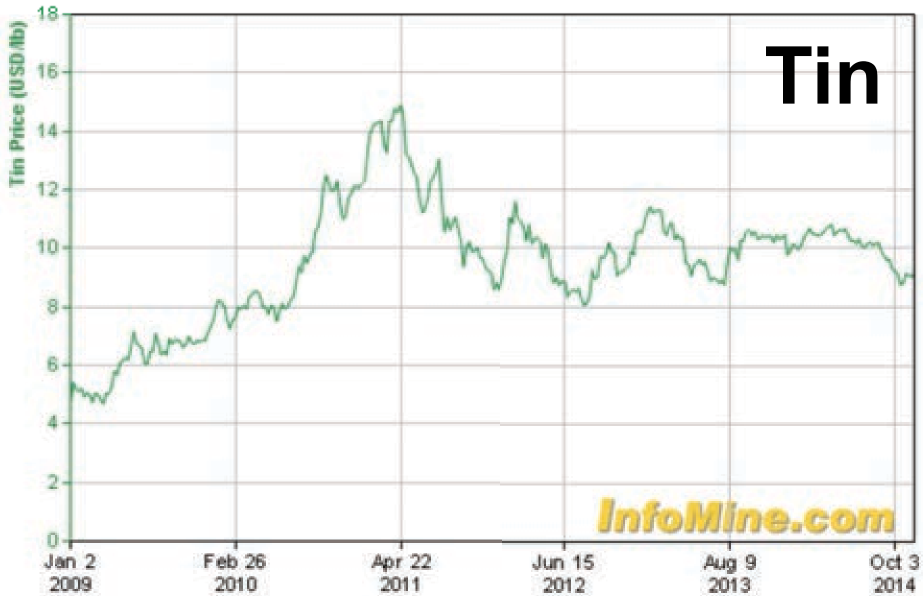
2. Contract
   - Producer sells directly to buyer
   - titanium, tungsten, uranium, coal, potash
   - For coal and potash (bulk commodities), transportation costs are important to consider
     - Prices often quoted as *free on board* (FOB), an all-in price for the product delivered to a port (e.g. Vancouver)
     - Quality (purity) of commodity also taken into account

Open Market

- Mineral commodity prices respond to short-term changes in supply and demand
- Commodity futures markets (e.g. LME) sell *contracts* for delivery of commodities at a certain date and price
- Sold/bought on an open market – so the buyer never needs to receive the commodities (this increases the *liquidity* of the market)

Open Market

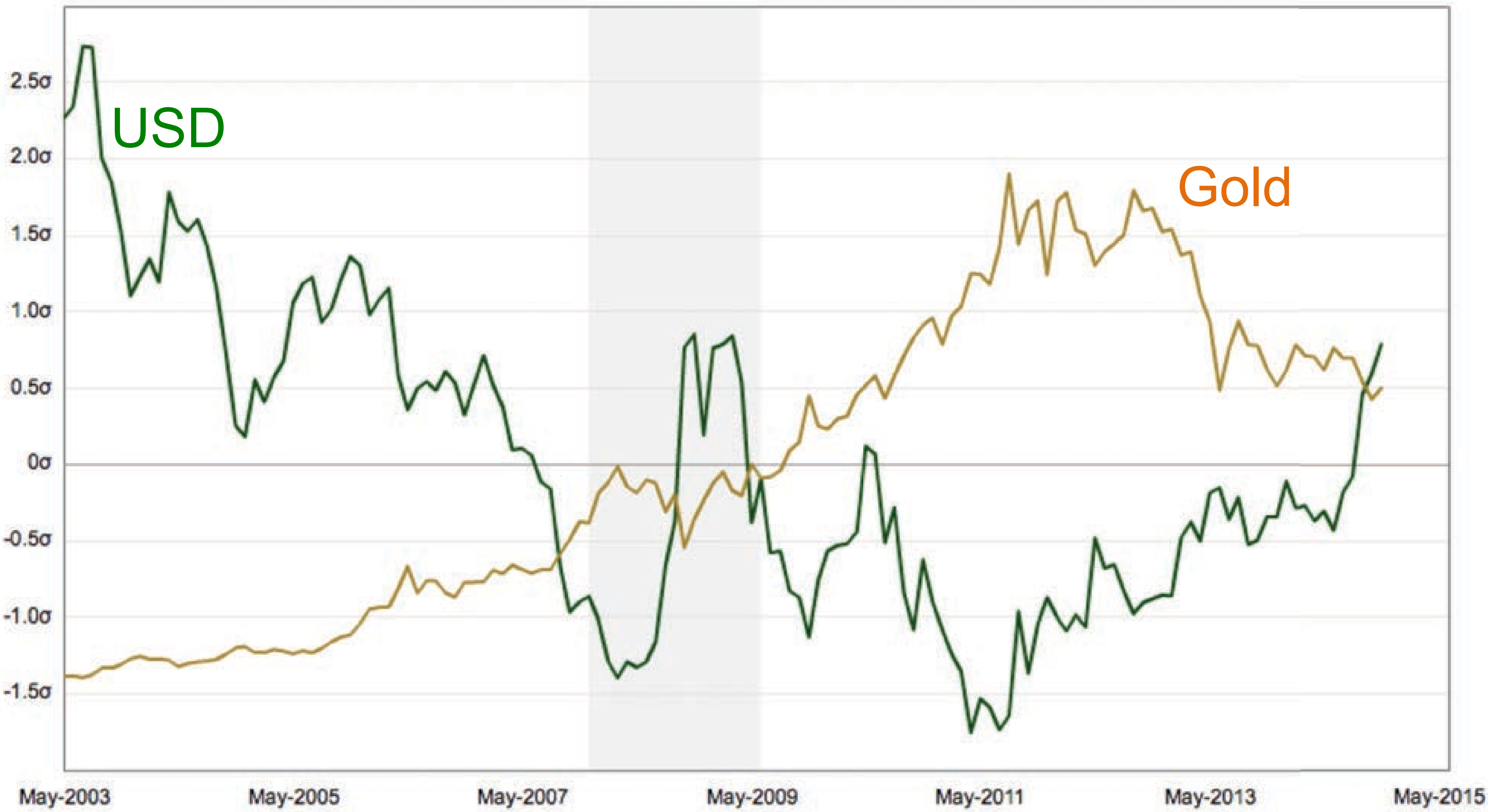
- US Dollars (USD $)
- Per ounce (oz) for precious metals (troy oz = 31.1g)
- Per pound (lb) for base metals
- Per metric tonne (1000 kg) for potash, coal, iron ore and sometimes metals



Some controls on Mineral Commodity prices:

1. US Dollar
2. Supply
3. Demand
4. Global Economy
5. Politics

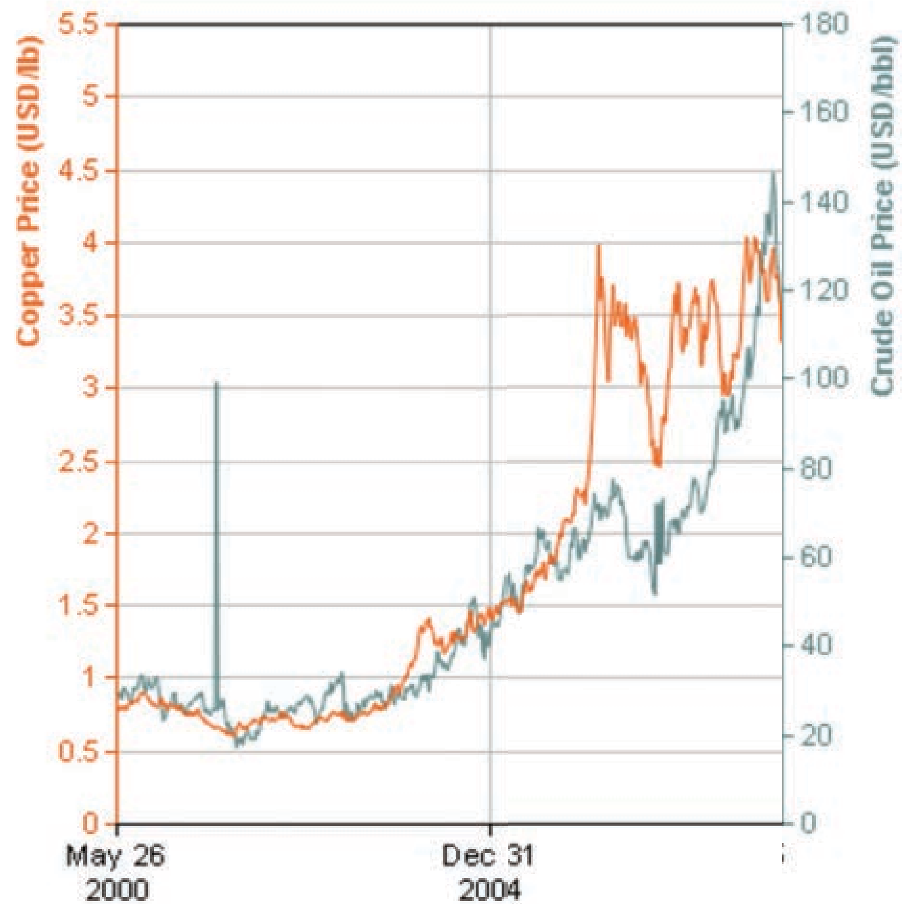
1. USD and the variation in gold prices



http://www.macrotrends.net/1335/dollar-gold-and-oil-chart-last-ten-years

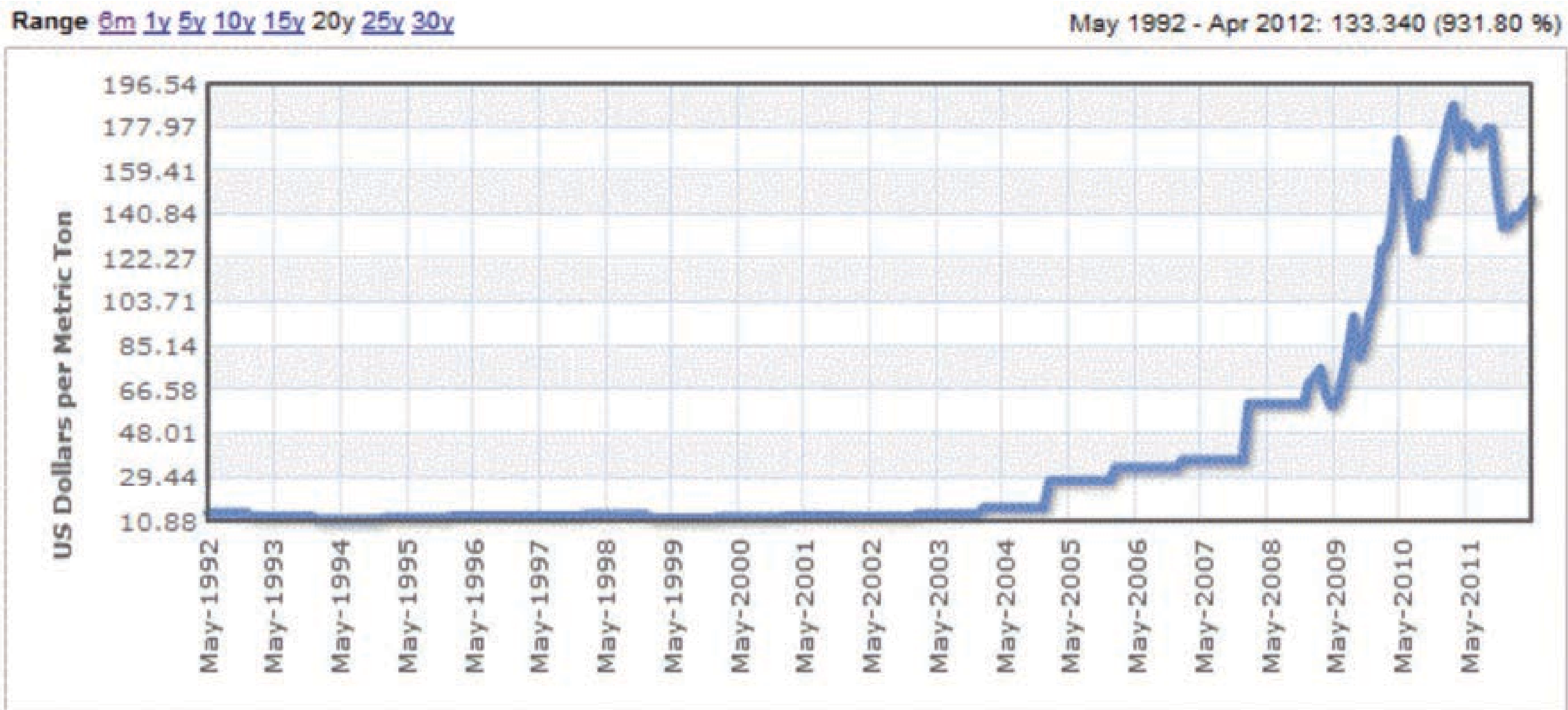
2. Supply

- US goes to war in 2003
- Several oil sources are considered insecure
- Oil Prices rise
- Transportation/exploration costs rise
- Metal prices rise



3. Demand

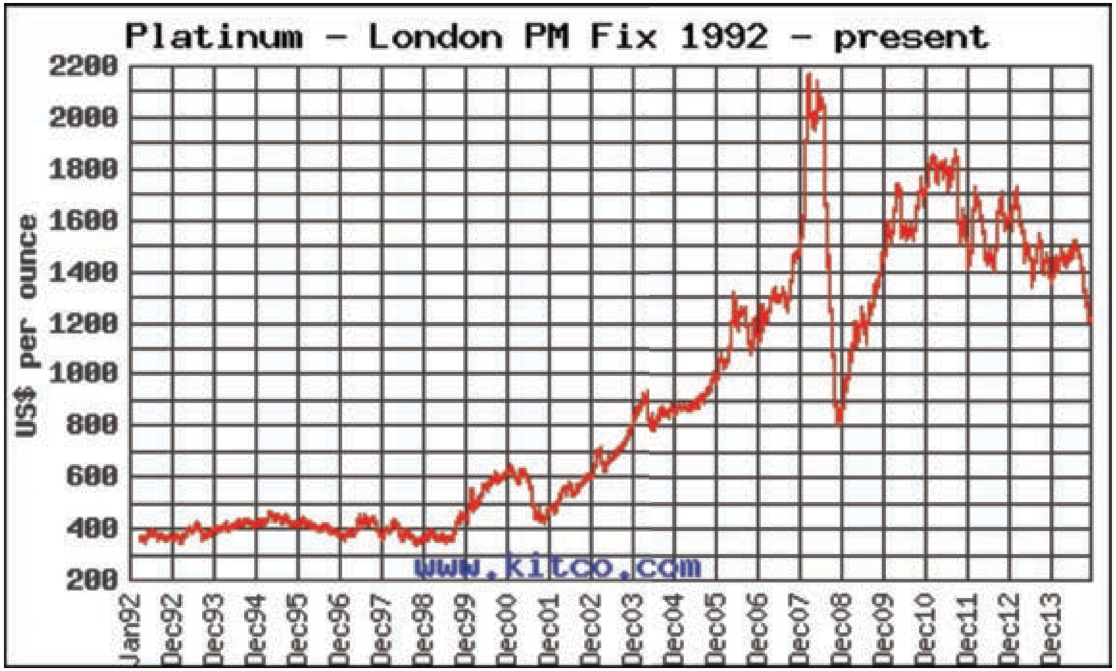
2004–2009: China and India increase their demand for Iron ore to build infrastructure – supply doesn't change much. Iron ore prices increase substantially.

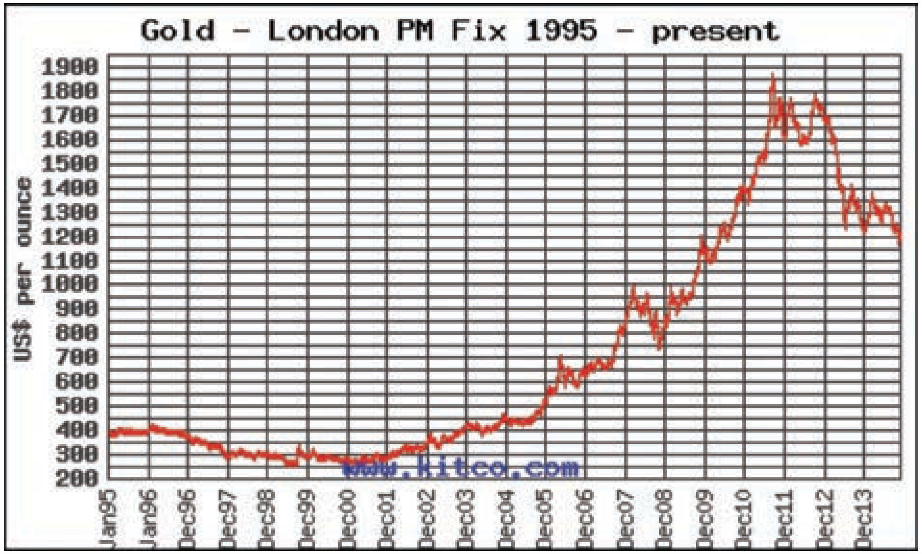


http://www.blue-point-trading.com

4. Global Economy

- US mortgage crisis in Dec 2007
- Investors avoid high risk – invest in gold
- Lots of 'we buy your gold' ads at this time (they were quite annoying!)

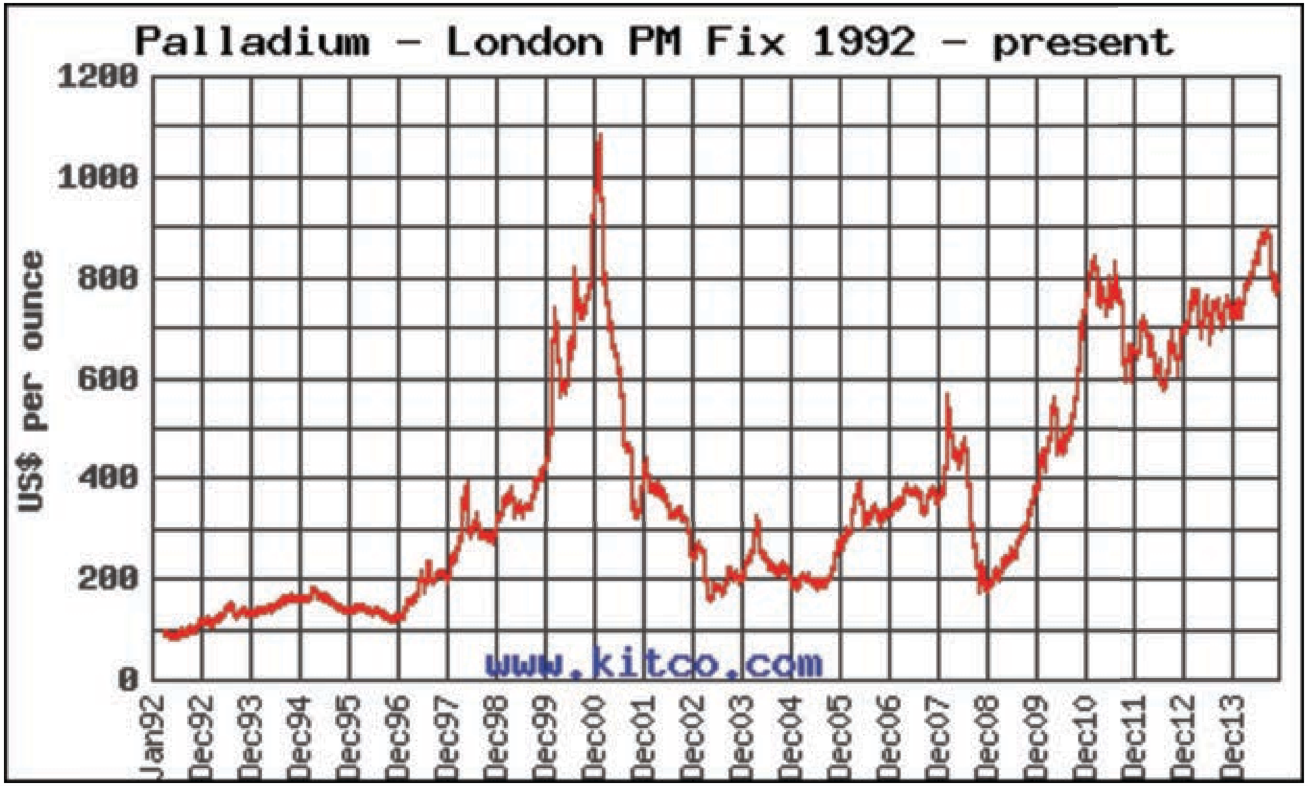




5. Politics

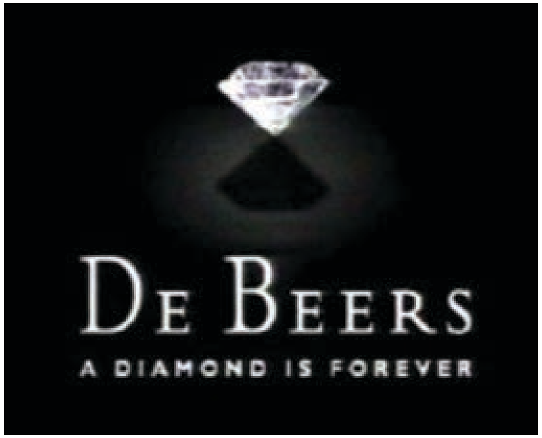
2000: Rumors that the main producer of Palladium (Russia) will stop selling.

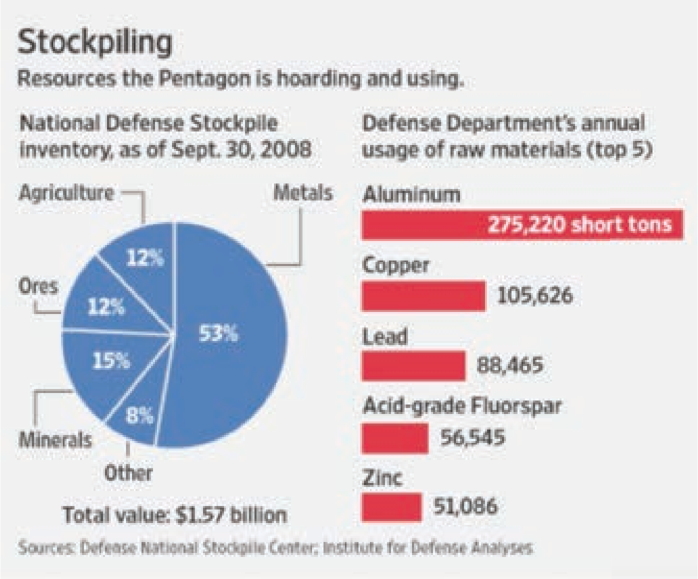
- Tech boom causes high demand for Pd (e.g. exhaust systems in cars)
- Worried about supply, Ford buys as much Pd as it can at ~$1000/oz
- Russia continued to supply Pd, prices dropped to $300/oz
- Ford lost $1 billion
- The rumor mill can lead to large swings in mineral commodity prices



Other economic considerations

- <u>Cartels / monopolies</u>
  - Monopoly (single individual or organization) or Cartel (group of individuals or organizations) controls supply (hence price) of commodity
  - e.g. De Beers in the early 1900s
  - Generally not successful
- <u>Stockpiles of strategic minerals</u>
  - Considered important for national defense
  - During the Cold War, the US government stockpiled uranium
  - Can release these commodities into the market and affect prices
- <u>Recycling</u> technologies and techniques
- <u>Government subsidies</u>……





Wall Street Journal

Case study in subsidies

Canada's Emergency Gold Mining Assistance Act (1958–1974)

- Nearly constant price of $35/ounce for gold from 1934 to the 1960s
- Costs rose, and gold mining companies were forced out of business
- Because Canada was a major gold producer, the government subsidized the producers with ~$5/ounce
- Total of $302 million dollars from 1958–1972 on 61.8 million ounces of gold

REPORT ON
THE ADMINISTRATION OF
THE EMERGENCY GOLD MINING
ASSISTANCE ACT

mint.ca

Who does the mining and how is it paid for?

Participants in exploration and mining

<u>Prospectors</u>

- Generally little or no formal training – but some of the best field people with years of experience looking at rocks and minerals
- Stake the ground around a <u>showing</u> and hope to entice companies to <u>option</u> it

<u>Junior exploration companies (Juniors)</u>

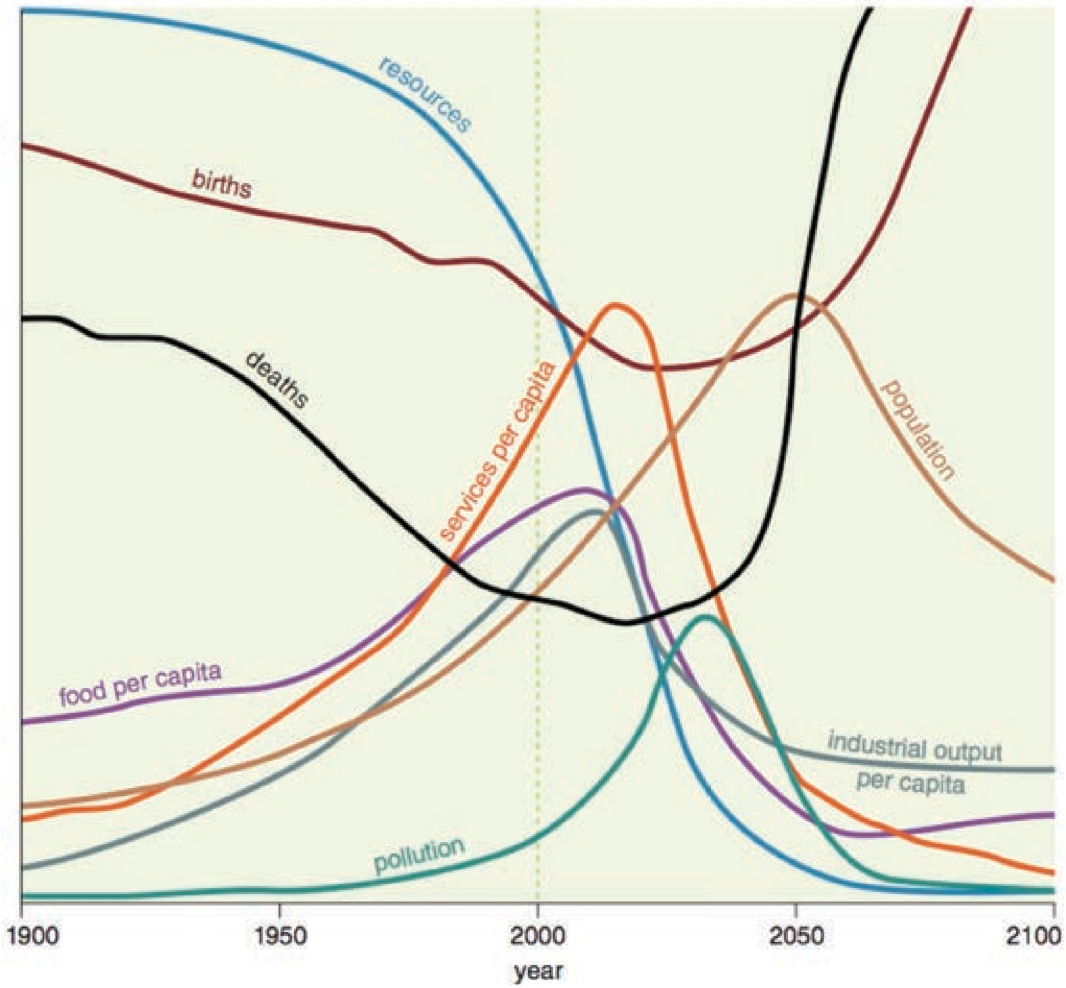
- Focused on exploration and discovery
- Publically listed on the stock exchange
- Few employees (~5–30)
- Generally do not operate mines (no mines = no revenue)
- Raise funds on the stock market (e.g. TSX)
- Currently (early 2015), Juniors are struggling to find investors
- The goal is to work a deposit enough and attract the attention of a major mining company that will buy them out…

Participants in exploration and mining

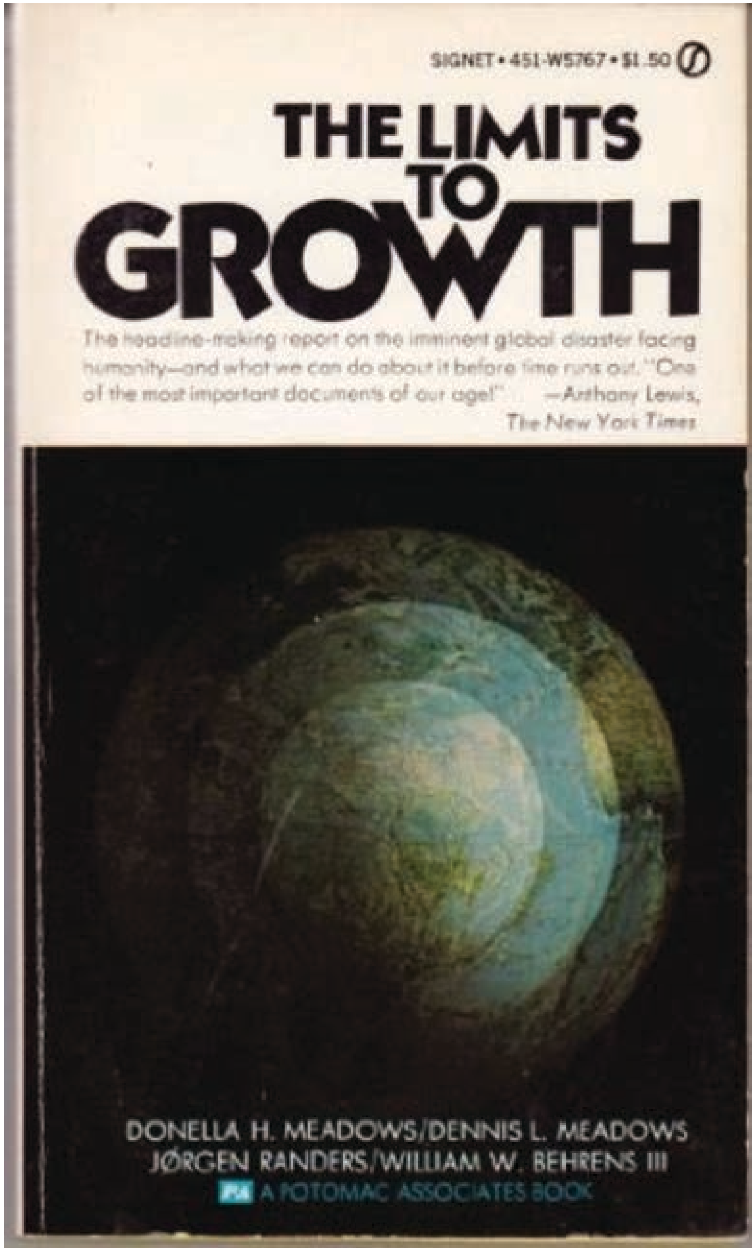
Intermediate and Senior mining companies (Majors)

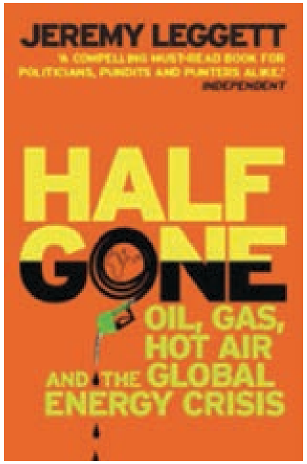
- Operate one or more mines
- Range from companies with one mine extracting one commodity to large multinational companies with many mines that extract many commodities
- Interested in 'world-class' mineral deposits that have the potential to develop into large mining operations
- Large exploration budgets, but rarely focus on 'risky' deposits and focus on expanding reserves through drilling programs
- Buy into deposits or Junior companies after discovery has been made

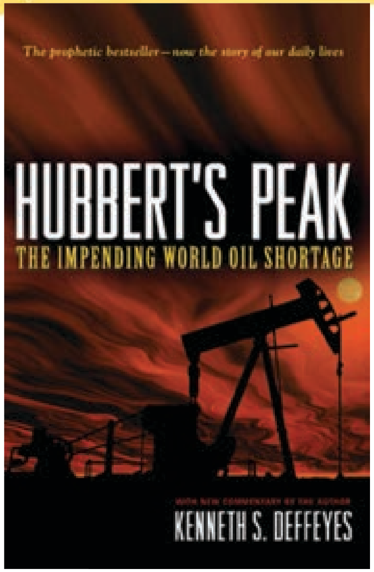
Will we run out of resources?

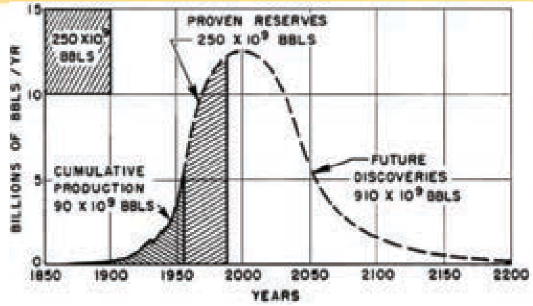


http://ourfiniteworld.com/2012/01/25/more-reasons-why-we-are-reaching-limits-to-growth/




JEREMY LEGGETT
'A COMPELLING MUST-READ BOOK FOR POLITICIANS, PUNDITS AND PUNTERS ALIKE'
INDEPENDENT
HALF GONE
OIL, GAS, HOT AIR AND THE GLOBAL ENERGY CRISIS


The prophetic bestseller—now the story of our daily lives
HUBBERT'S PEAK
THE IMPENDING WORLD OIL SHORTAGE
KENNETH S. DEFFEYES


250 X 10⁹ BBLS
PROVEN RESERVES 250 X 10⁹ BBLS
CUMULATIVE PRODUCTION 90 X 10⁹ BBLS
FUTURE DISCOVERIES 910 X 10⁹ BBLS
BILLIONS OF BBLS / YR
0
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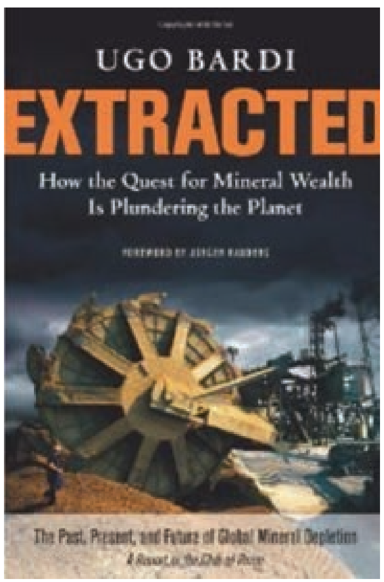
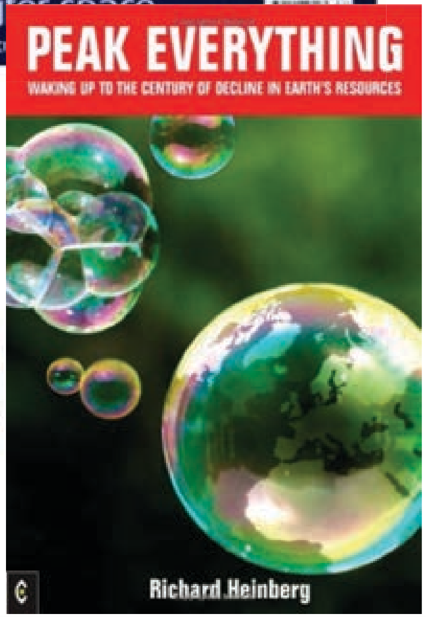
10
15
1850
1900
1950
2000
2050
2100
2150
2200
YEARS


WEEKLY
NEWS IDEAS INNOVATION
THE BEST JOBS IN SCIENCE
NewScientist
SPECIAL INVESTIGATION
WORLD STRIPPED BARE
The shocking state of the Earth's mineral resources
ANIMAL EMOTIONS
GRATEFUL WHALES
EMPATHIC ELEPHANTS
JOYFUL CROWS
Art in ou


UGO BARDI
EXTRACTED
How the Quest for Mineral Wealth Is Plundering the Planet
The Past, Present, and Future of Global Mineral Depletion


PEAK EVERYTHING
WAKING UP TO THE CENTURY OF DECLINE IN EARTH'S RESOURCES
Richard Heinberg

DON'T PANIC

"It is commonly held that mineral resources are finite and that mining is therefore an unsustainable activity by its very nature… The paradox, however, is that although global minerals and metals production continues to grow strongly to meet demand, most remaining mineral resources also continue to grow and are often reported to be sufficient for at least a few decades or more."

– Mudd *et al.* 2013, Economic Geology

An ***ore deposit*** is a *mineral deposit* that can be mined at a profit. Mineral deposits can become ore deposits by:

- Advances in technology that allow cheaper extraction/milling/separation
- Price of commodity and/or by-products increases

Therefore, there are no finite quantities of ore deposits – as long as humanity continues to need minerals and innovate new technologies and techniques, we will not run out of resources.

Case study: Natural Gas in the USA

"Gas imports must grow" – Alan Greenspan, Federal Reserve Chairman, 2004

- In 2003, 20% of US electricity and ½ of home heating came from natural gas
- Greenspan was concerned that the US was running out of natural gas supplies and needed to become an importer
- Furthermore, he suggested the US should construct Liquefied-natural gas (LNG) import facilities (55 new ports were planned in March 2005)
- Only 5 built and are rarely used…why?
- The extraction of gas from shale has revolutionized the natural gas industry – the US will soon be an exporter of natural gas
- There is even talk of converting the existing LNG import facilities to LNG export facilities
- The technological advances that permit 'tight' gas extraction from shale has *increased the global resources of natural gas*

Major technological breakthroughs in mining

Steam shovel (late-19th century)

- Prior to this, ore was moved by carts via manpower or horse/oxen
- Allowed much more material to be moved and sent for processing

Froth flotation (Australia 1902–1915)

- Prior to this, average grade of Cu was 2.5% (narrow vein deposits in underground mines)
- Currently, average grade <0.6% in 1991 (made open-pit Cu mines economically feasible)

Steam shovel working at Mount Morgan Mine, 1905, WikiCommons


http://commons.wikimedia.org/wiki/File:Froth_flotation.JPG

<u>Gigantic haul trucks</u> (mid-20th century)

- 1974 General Motors Terex 33-19 Titan hauler

<u>Computers</u> (late 20th century)

- Improved statistical analysis of geochemical data, more robust estimates of resources versus reserves

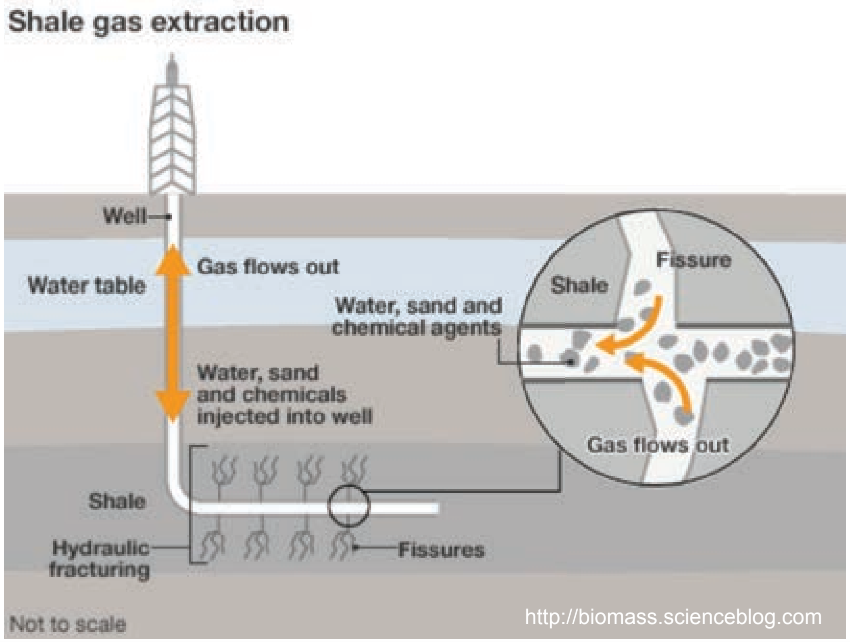
<u>Directional Drilling</u> (late 20th century)

- Allowed access to difficult oil/ gas reservoirs

<u>Fracking</u> (a fairly modern technique)

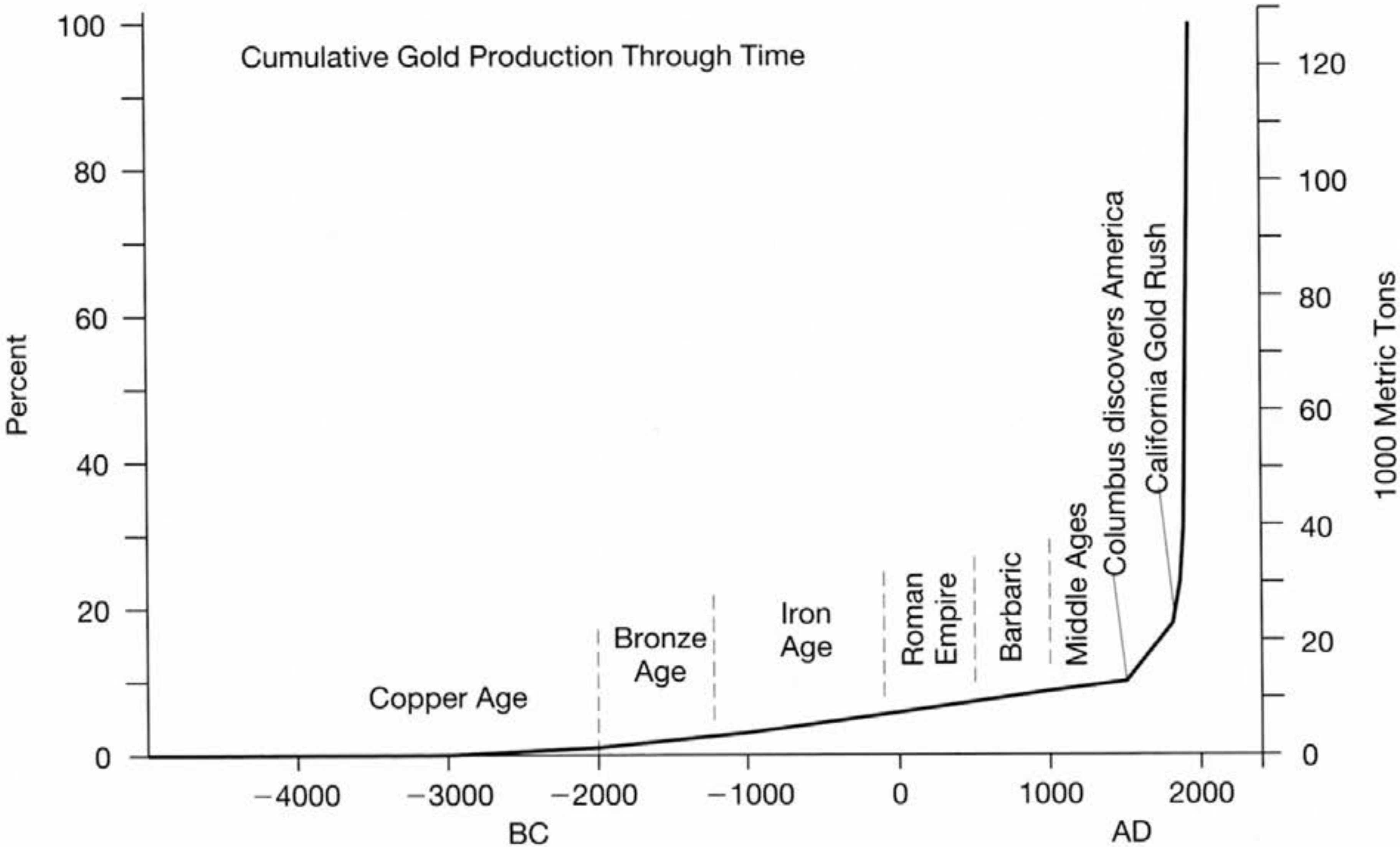
- Liberate 'tight' gas from shale


Building Giant Earthmovers, Orelemann

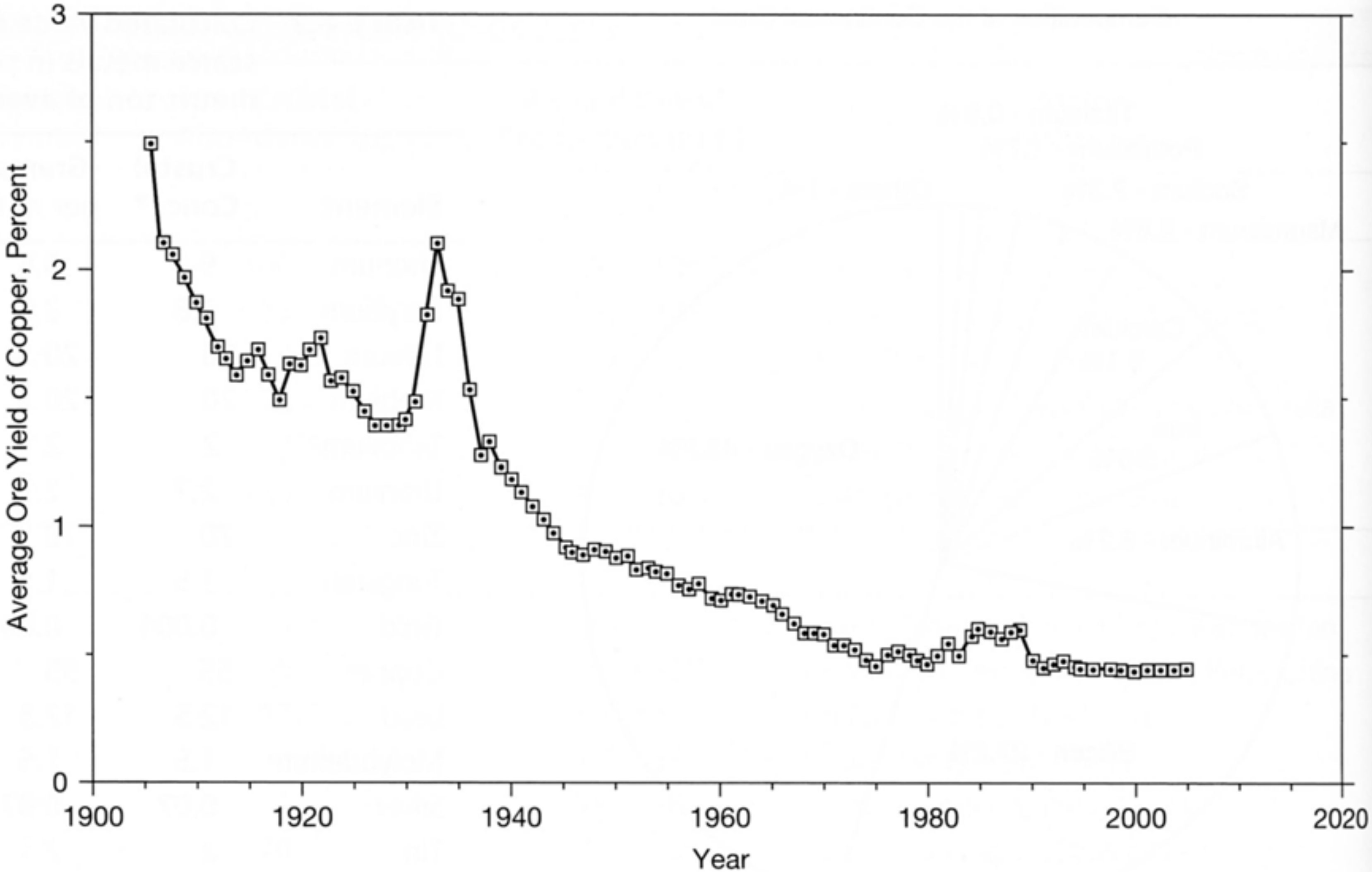


http://biomass.scienceblog.com

Technological innovation:



Technological innovation:



Take home messages:

Mineral groups: Precious metals, base metals, ferrous metals, non-metallic minerals, fusionable metals and fuels, industrial minerals, gems

Classification: *Mineral resource vs. mineral reserve*

Commodity Prices*: Open Market vs. Contract*

Controls on prices*:* US dollar, supply, demand, global economy, politics

Technological innovation decreases production costs and can make more deposits *economic.*