Chapter 21b

Mineral Resources

Types of Resources

- *Geological Resources*
- Energy Resources
- Metals
- Nonmetallic Resources
- All are *nonrenewable resources*
  - Ground water an exception
- Resources vs. Reserves

Types of Geologic Resources

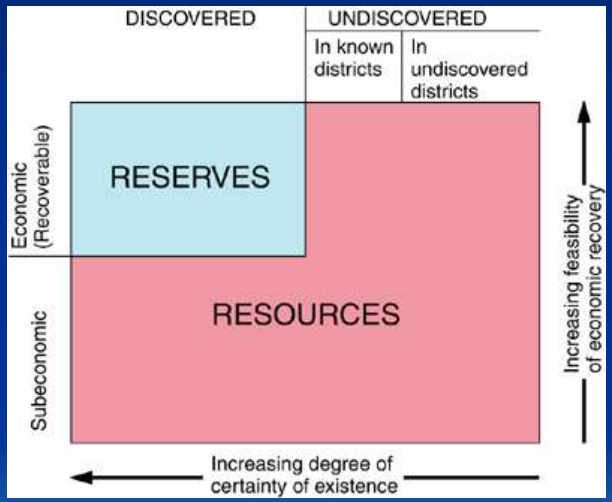
- Geologic resources can be grouped into three major categories:
  - *Energy resources* - petroleum (oil and natural gas), coal, uranium, geothermal resources
  - *Metals* - iron, copper, aluminum, lead, zinc, gold, silver, platinum, etc.
  - *Non-metallic resources* - sand and gravel, limestone, building stone, salt, sulfur, gems, gypsum, phosphates, etc.
    - Groundwater is included in this category

Metals & Ores

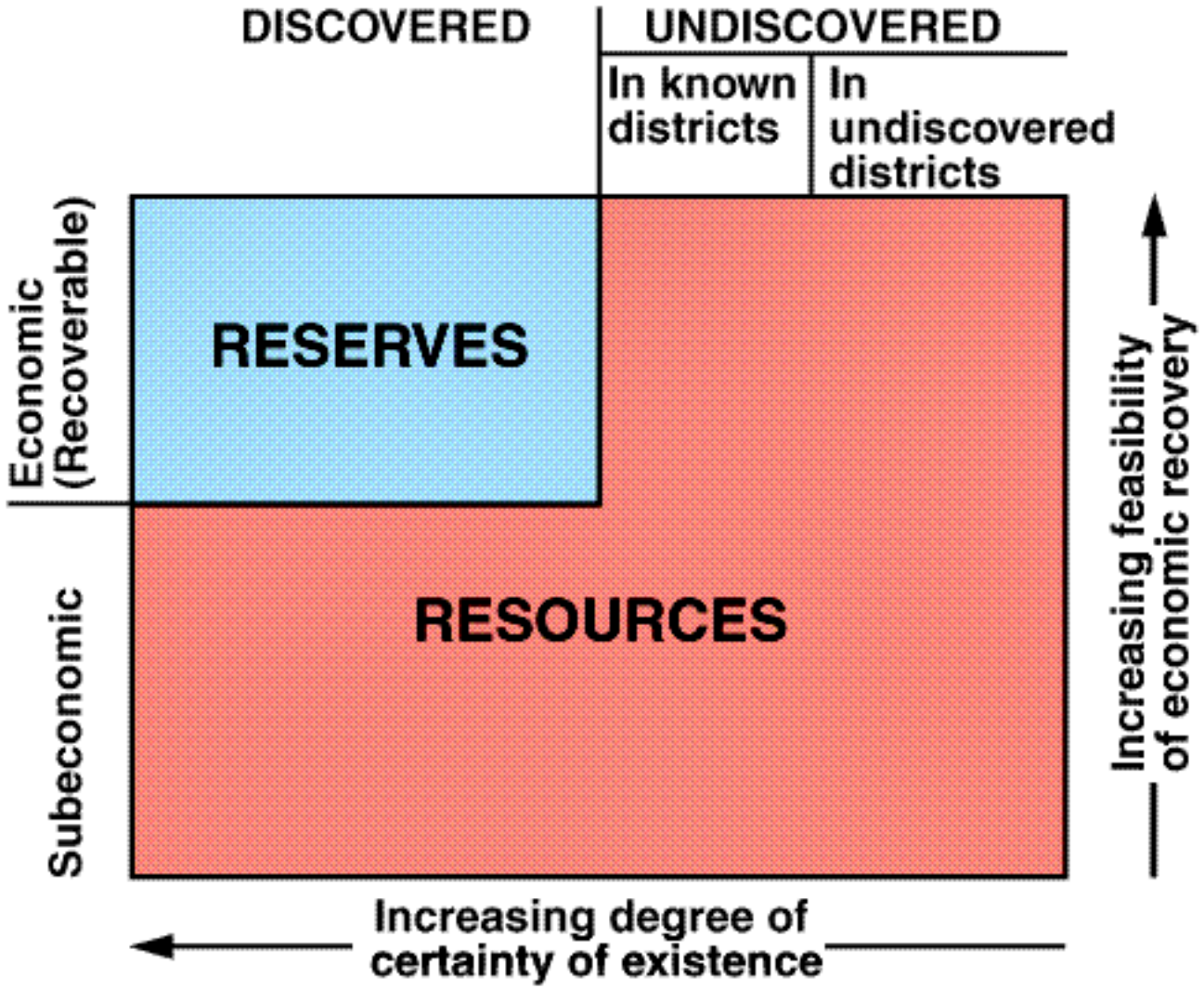
- *Ore = a mineral or aggregate of minerals which can be mined (extracted and processed) at a profit*

Resources and Reserves

- *Resources* - the total amount of a valuable geologic material in *all deposits*, discovered and undiscovered
- *Reserves* - discovered deposits of geologic resources that can be extracted *economically* and *legally* under present conditions
  - The *short-term* supply of a geologic materials



Differences in Reserves and Resources



Determining Whether Rock Is Ore

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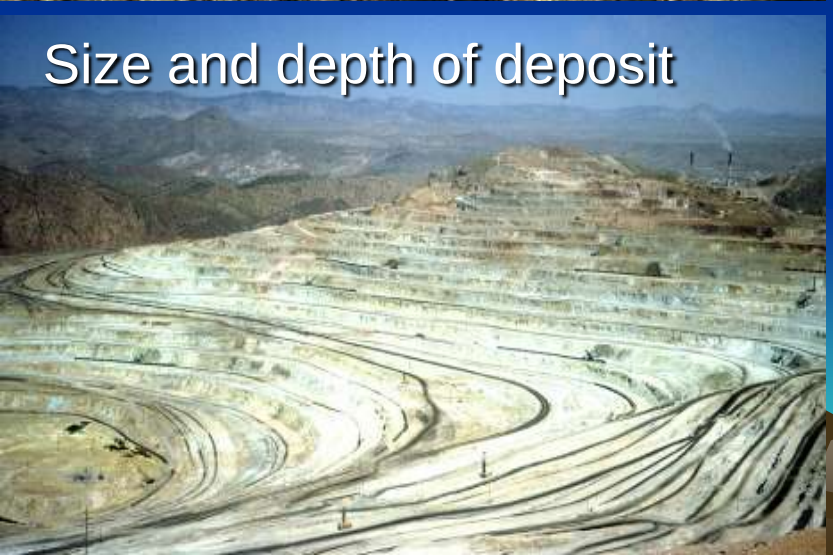


Geologic Resources and Earth's Systems

- *Geologic resources* are valuable materials of geologic origin that can be extracted from the Earth
  - Many geologic resources originate in the hydrosphere
    - Petroleum and coal come from organisms that lived and died in *water*
    - Halite (salt) and other evaporite minerals come from dry lake beds
  - Weathering interactions between geosphere, atmosphere and hydrosphere produce metal oxide *ores*
  - Humans (*biosphere*) interact directly with the geosphere, the hydrosphere, and the atmosphere when extracting and utilizing resources
  - Even *water*, when found beneath the Earth's surface, is a geologic resource (renewable)

Mineral Deposits and Ores

Mineral deposit: contains something valuable

Vein with only quartz: not a mineral deposit

Ore: can be mined at a profit

Origin of Metallic Ore Deposits

- Ores associated with igneous rocks
  - Crystal settling
  - Hydrothermal fluids
    - Contact metamorphism
    - Hydrothermal veins
    - Disseminated ore deposits
      - Porphyry copper
    - Hot springs
  - Pegmatites

Origin of Metallic Ore Deposits

- Ores formed by surface processes
  - Chemical precipitation in layers
  - Placer deposits
  - Supergene enrichment
- Metal ores and plate tectonics
  - Divergent plate boundaries
  - Convergent plate boundaries
- Mining
- Environmental effects

Metallic Ore Deposits

- Iron
- Copper
- Aluminum
- Lead
- Zinc
- Silver
- Gold
- Other metals

Nonmetallic Resources

- Construction materials
  - Sand & gravel
  - Stone
  - Limestone
  - Clay

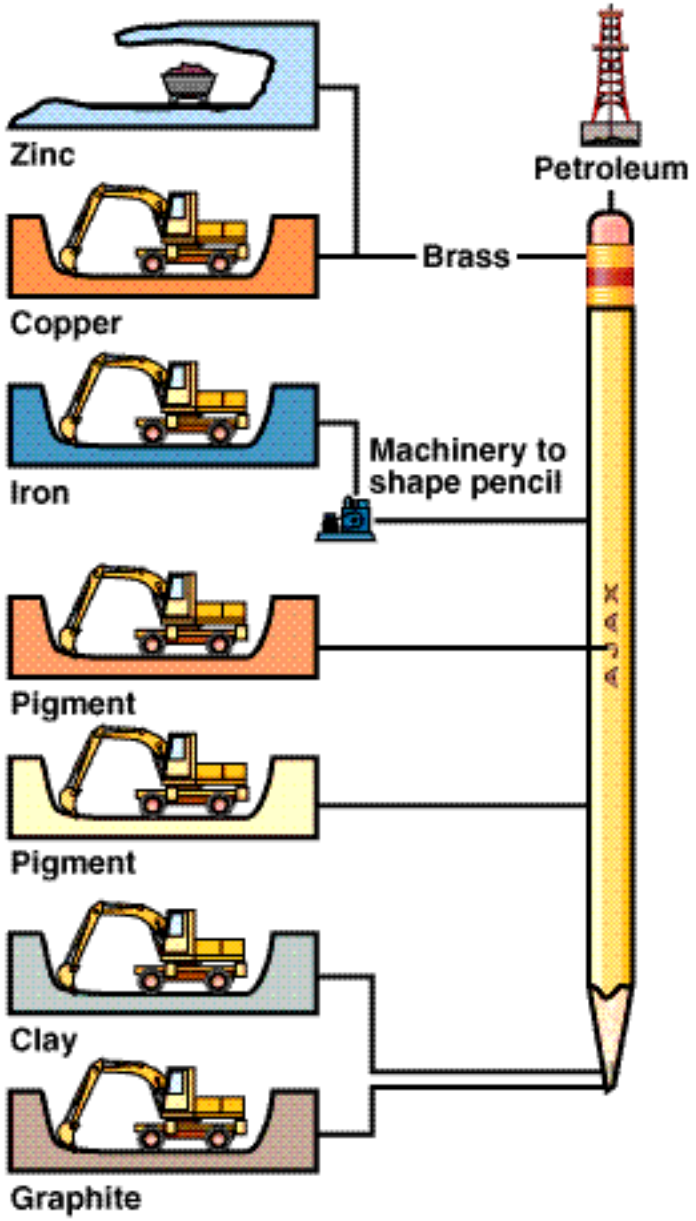
Nonmetallic Resources

- Fertilizers and evaporites
  - Fertilizers
    - Phosphate; nitrate; potassium compounds
  - Rock salt
  - Gypsum
  - Sulfur
- Other nonmetallics

Some Future Trends

- Ocean mining
- Metallic brines
- Improved tools & techniques
- The human perspective

A Pencil´s Mineral Resources



Hot or Deep Processes that Form Mineral Deposits

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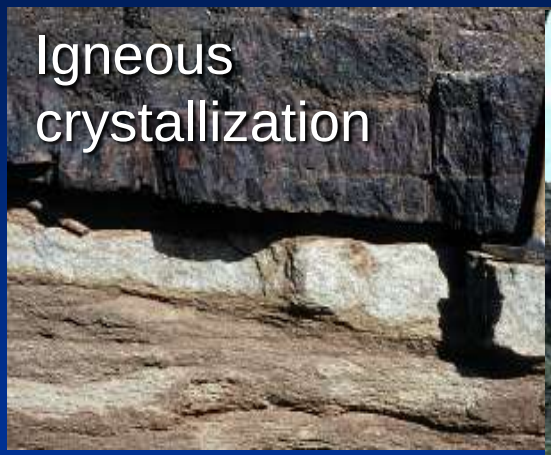
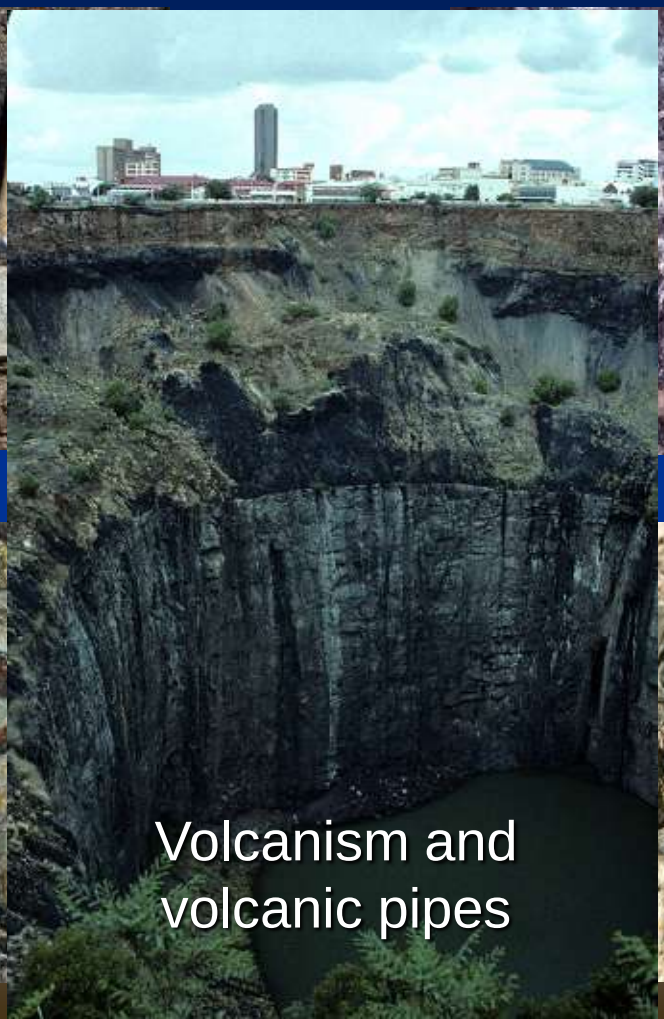
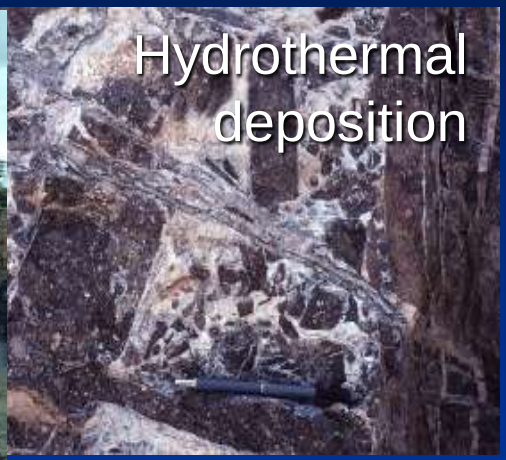
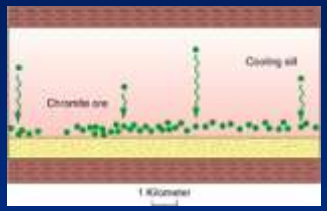


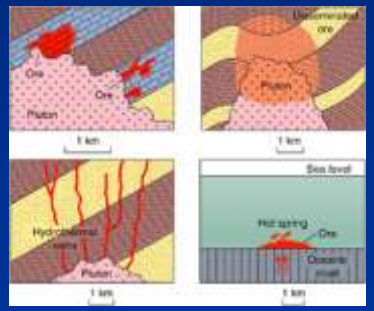


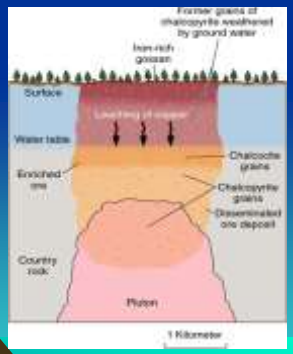


Metals and Ores

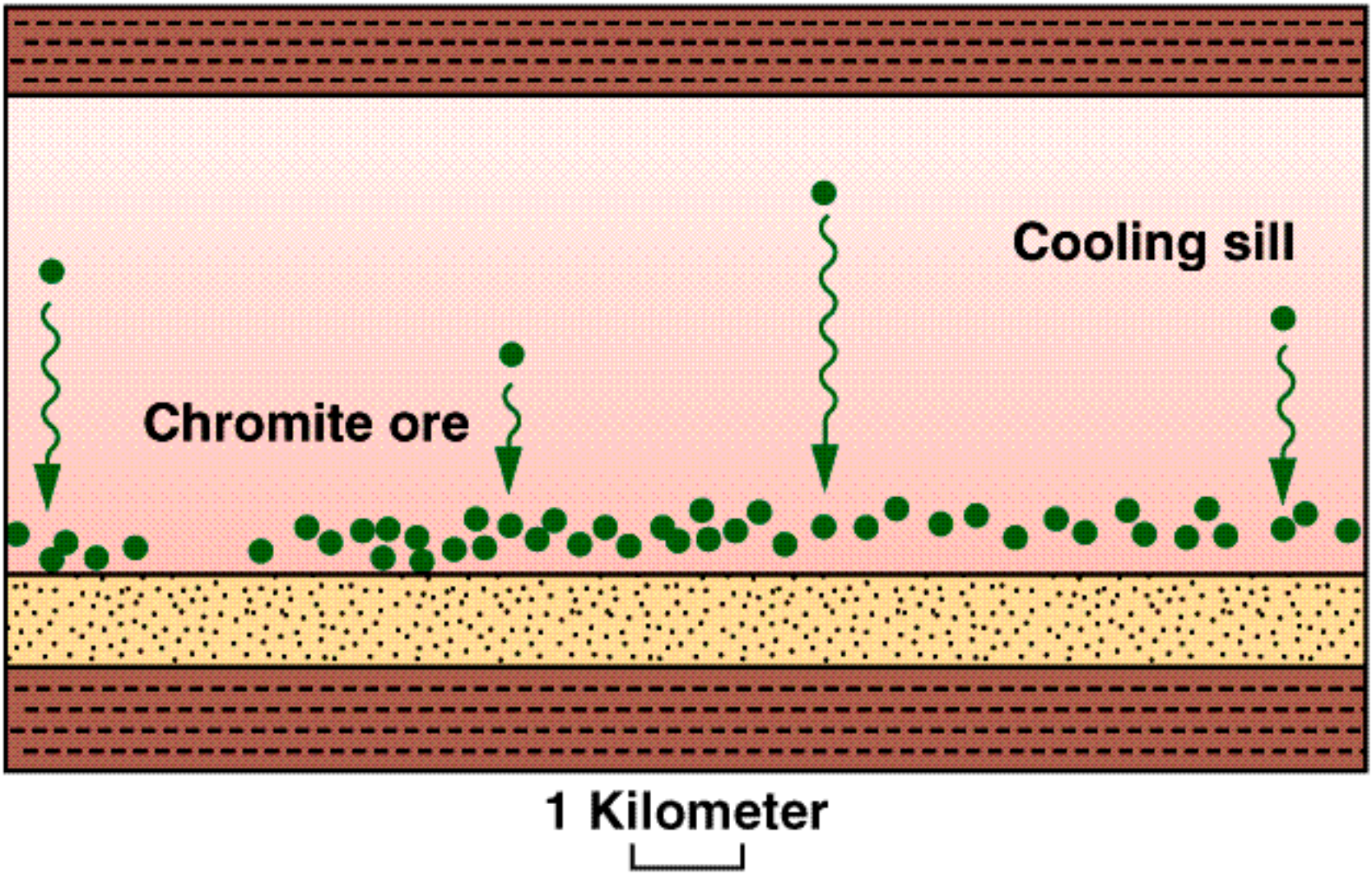
- Metal *ores* are naturally occurring materials that can be profitably mined
- Whether or not a mineral deposit is considered an ore depends on its *chemical composition*, *percentage of extractable metal*, and the *current market value* of the metal
- Metallic ore deposits can originate by *crystal settling* in igneous intrusions, from *hydrothermal fluids* cooling in pores and factures, by *chemical precipitation* in surface or groundwater, or by river sedimentation (*placers*)



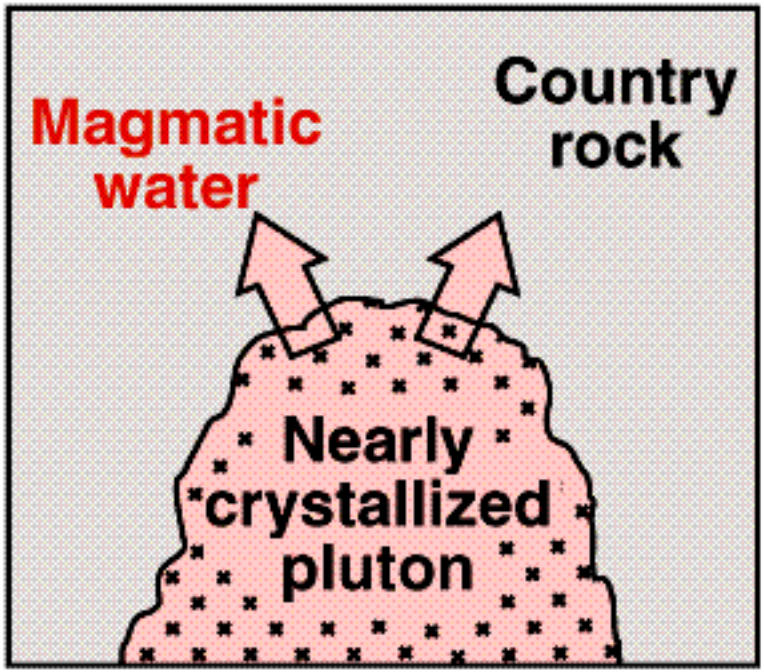




Early-Forming Minerals Settle



Hydrothermal Fluids' Origin



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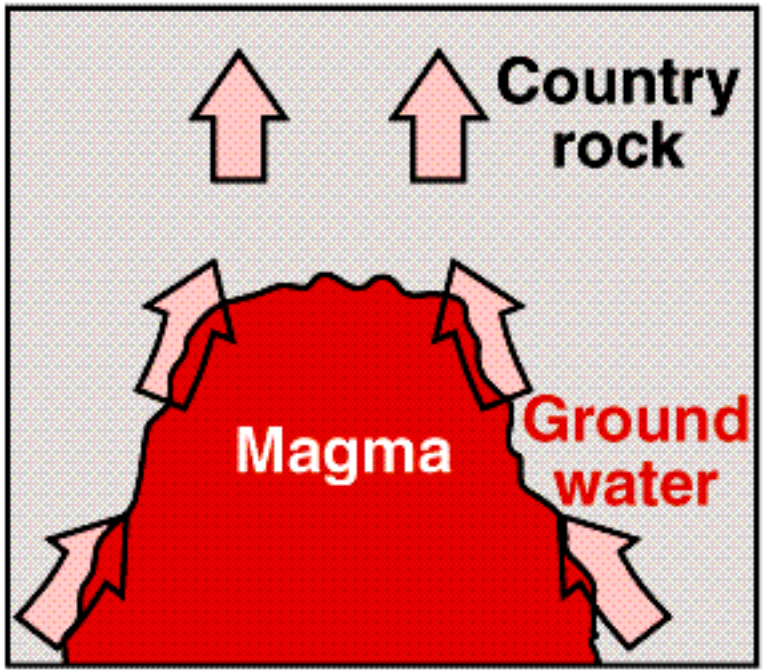
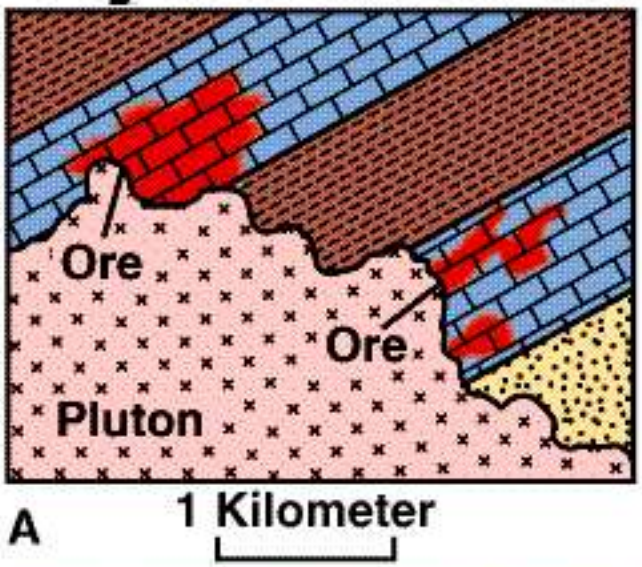
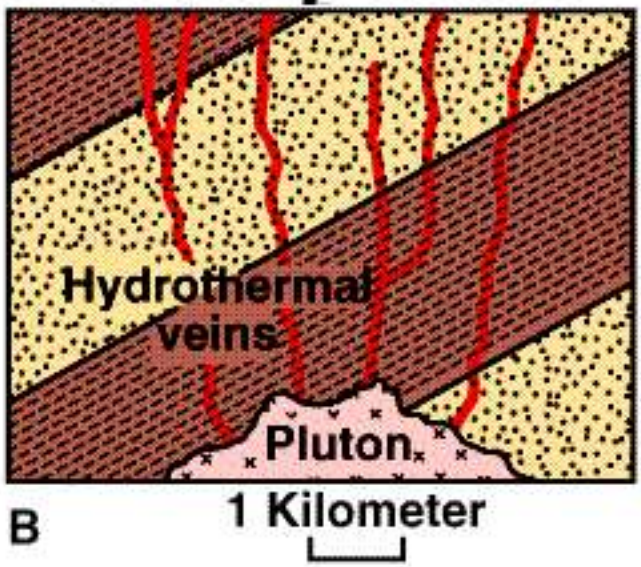


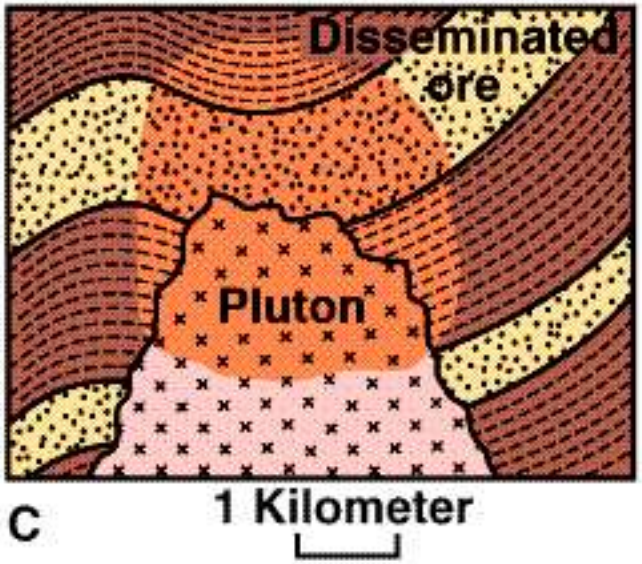
B

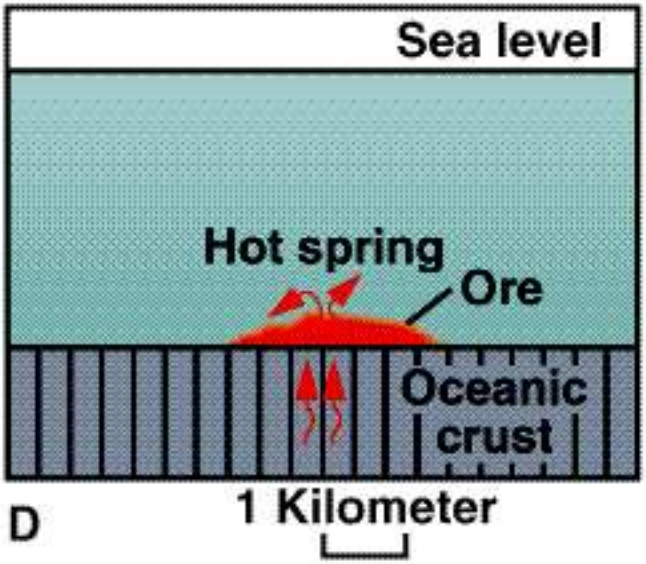
1 Kilometer

Hydrothermal Ore Deposits



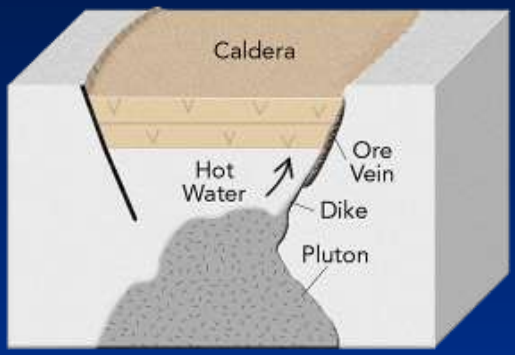




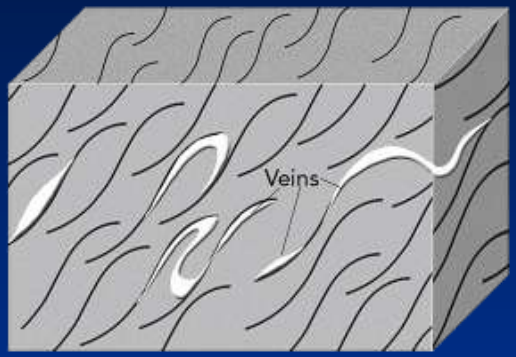


Hydrothermal Veins

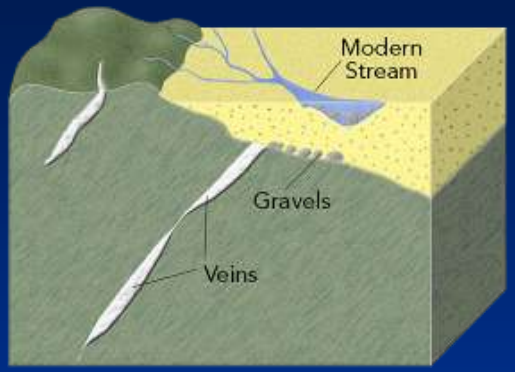
Gold- and Silver-rich Mineral Deposits



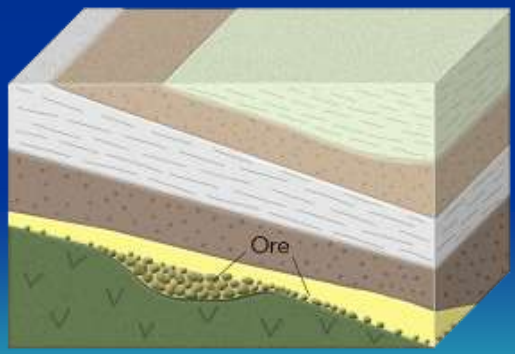
Veins from hot water



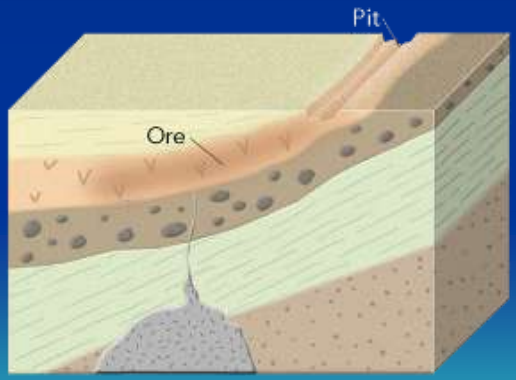
Veins in metamorphic rocks



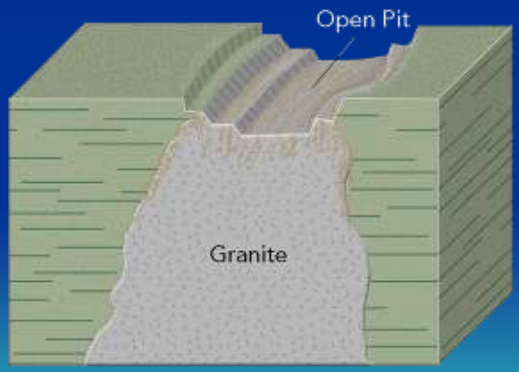
Gold in gravel



Gold-bearing conglomerates

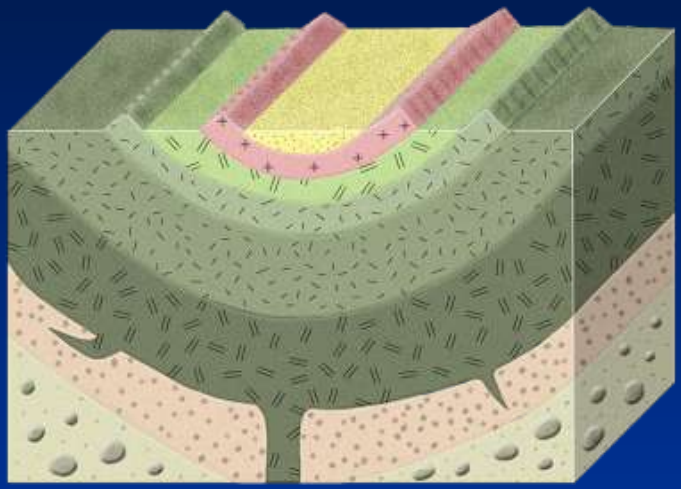


Low-grade gold deposits



By-product gold

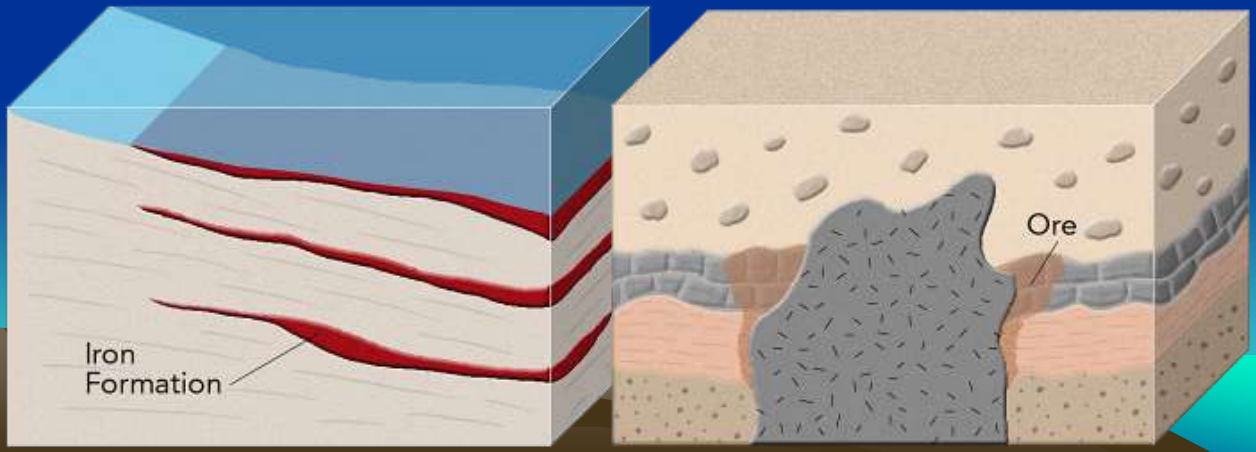
Geologic Setting of Other Metals



Platinum: crystallization of Pt-rich layers in mafic to ultramafic intrusions

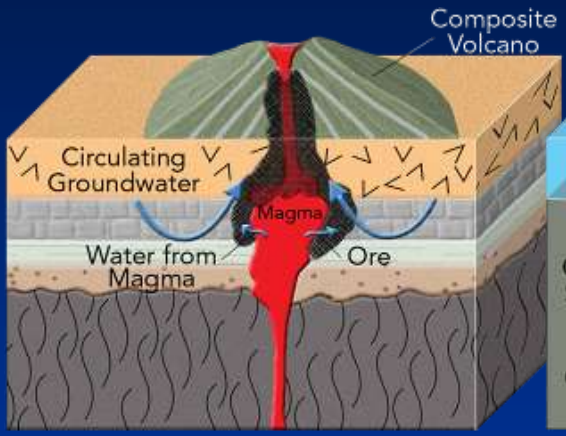
Iron: banded iron formations

Iron: replacement near intrusions

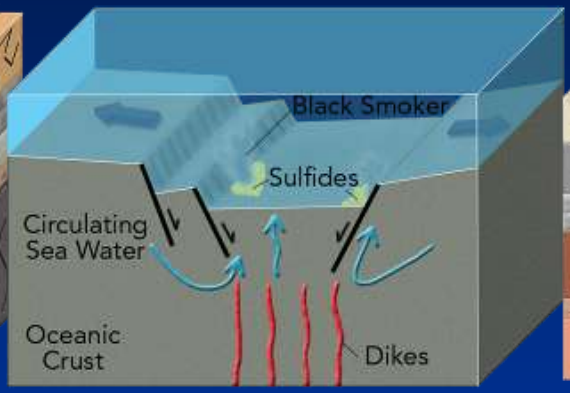


Locations of large gold deposits in the conterminous U.S.

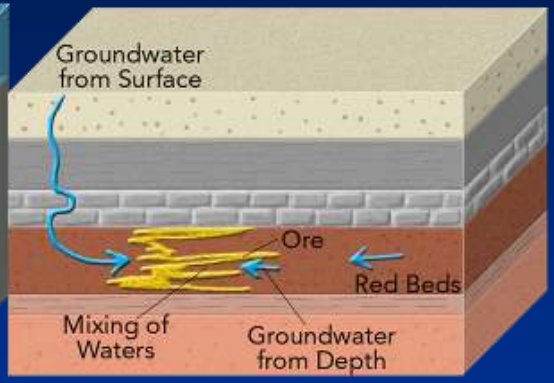
Copper Deposits



Porphyry copper deposits

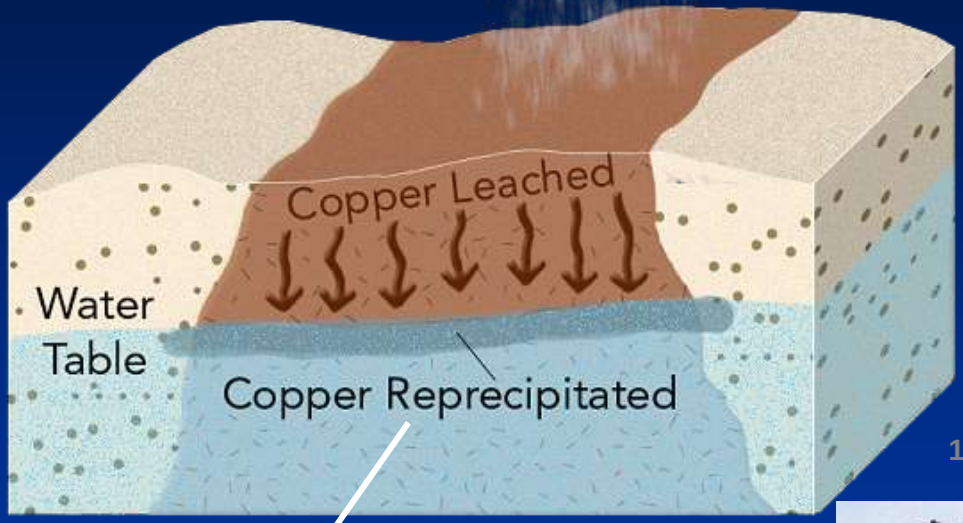


Massive sulfide deposits



Sedimentary copper deposits

How Copper Deposits Weather



Weathering leaches copper from top, leaving them reddish colored

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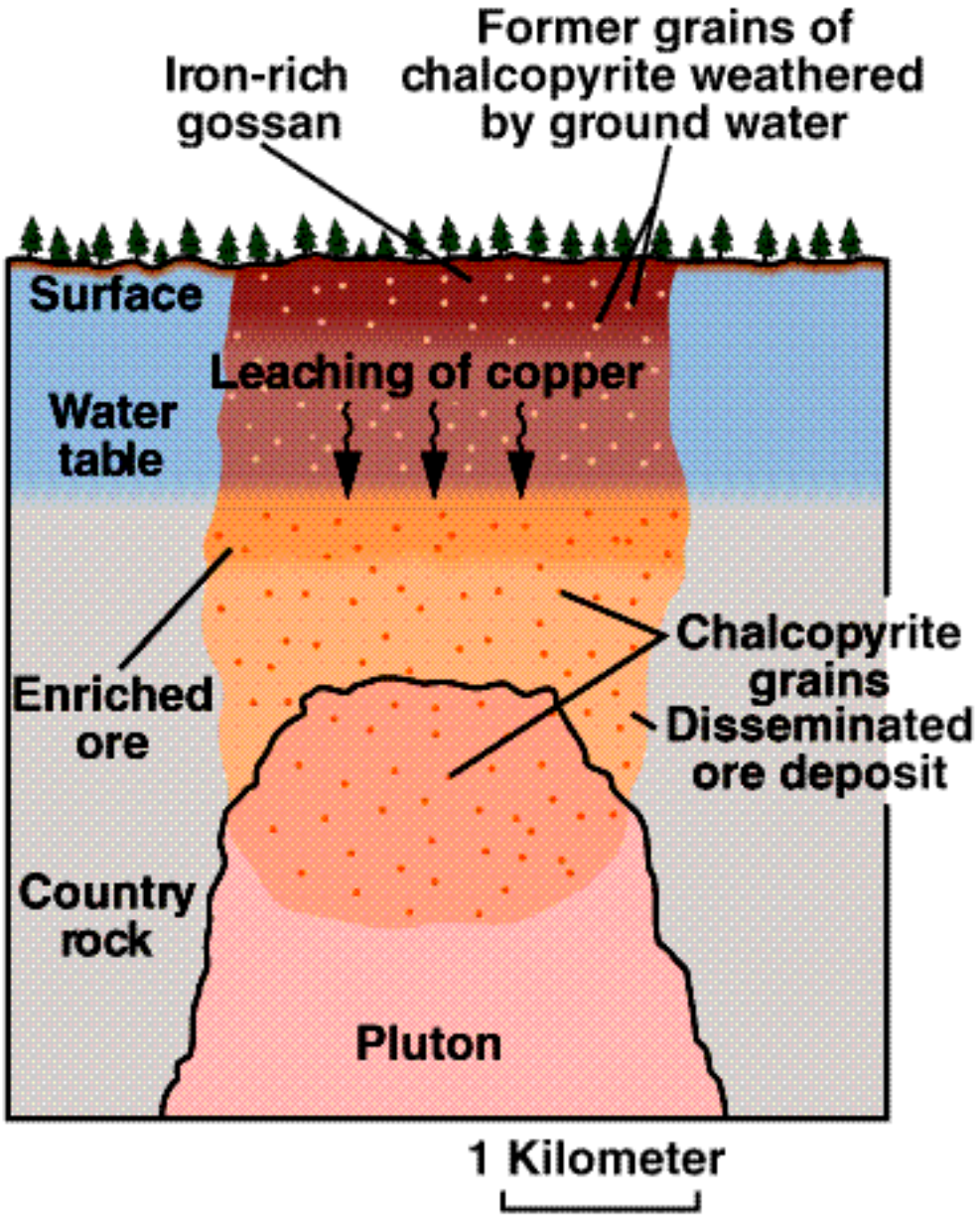
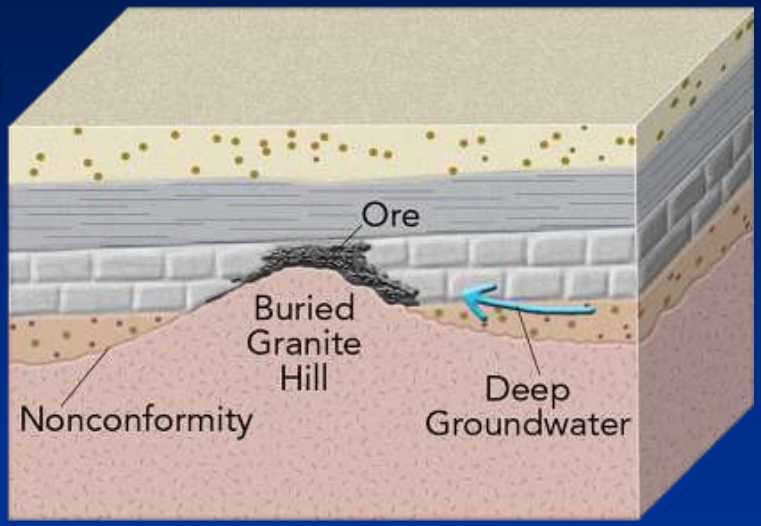
Copper reprecipitated at water table, enriching deposit

Supergene Enrichment

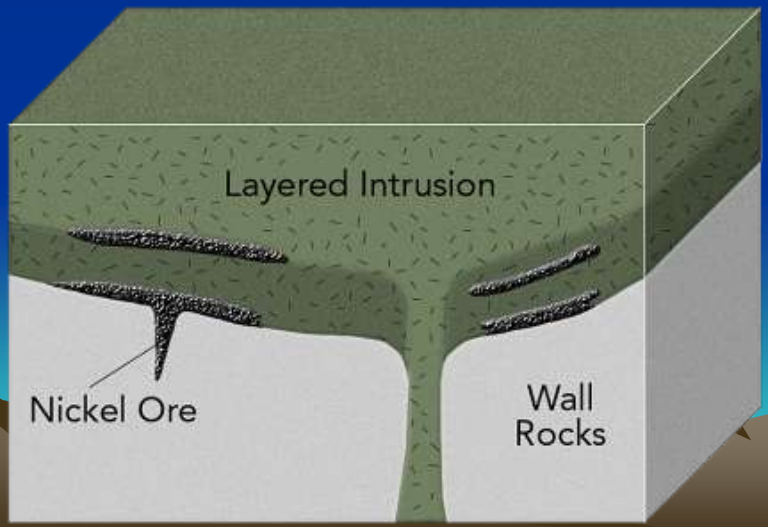


Two Other Types of Metal Deposits

Mississippi Valley lead-zinc deposits



Sudbury nickel deposits



Shatter cones (from impact)

Exploring for Mineral Deposits

Use geologic maps to identify favorable rocks and structures

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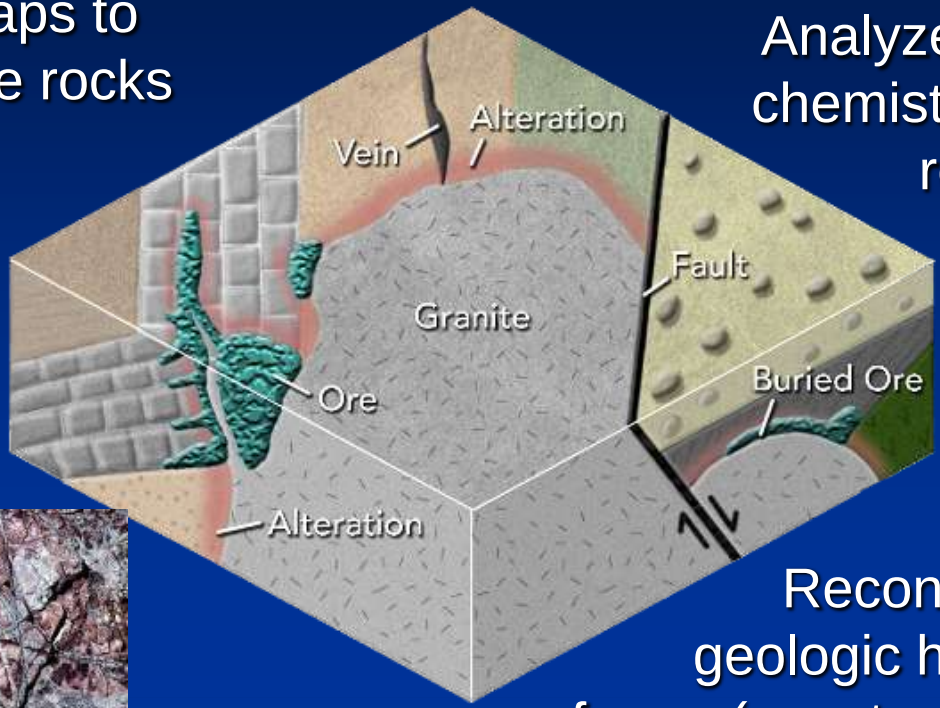
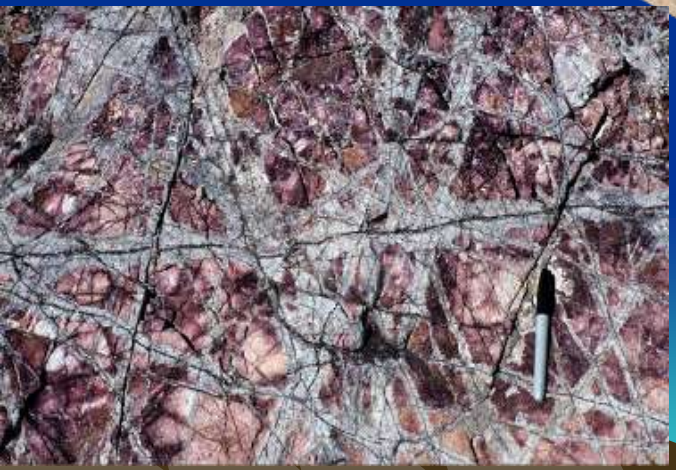


Analyze the chemistry of rocks

Look for rocks altered by fluids

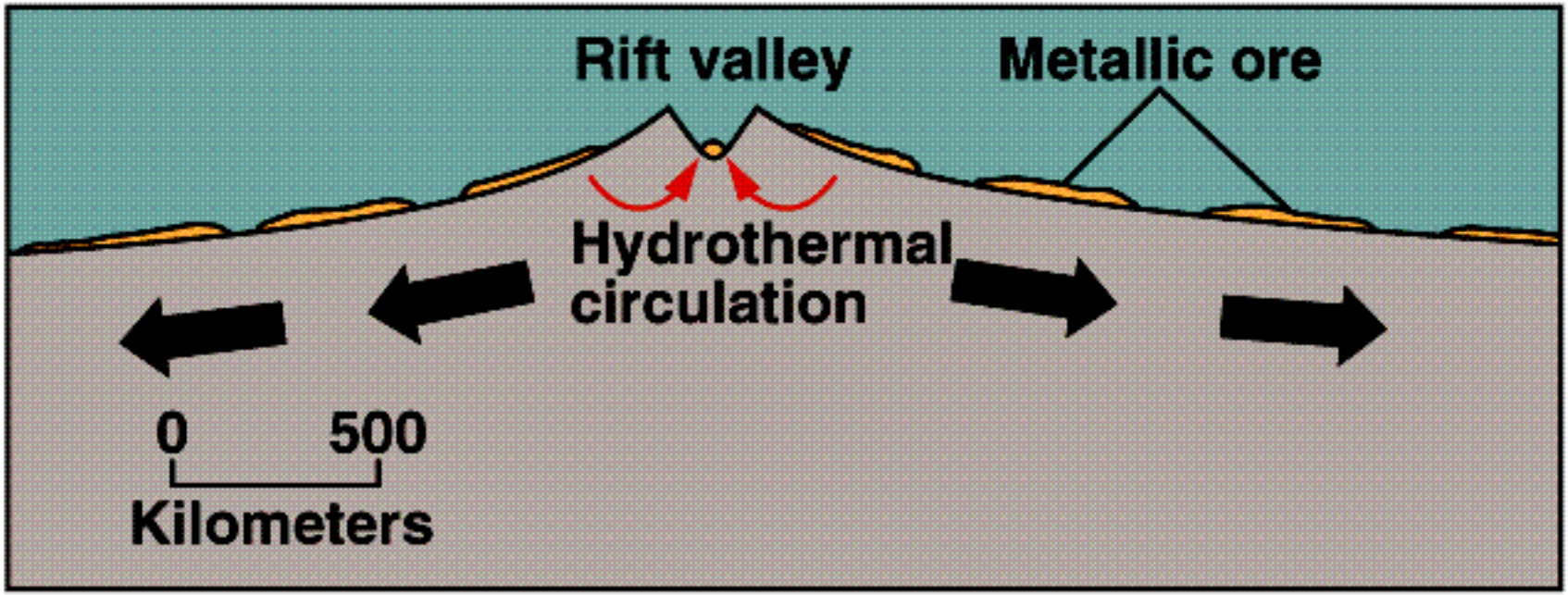


Chemically altered rocks

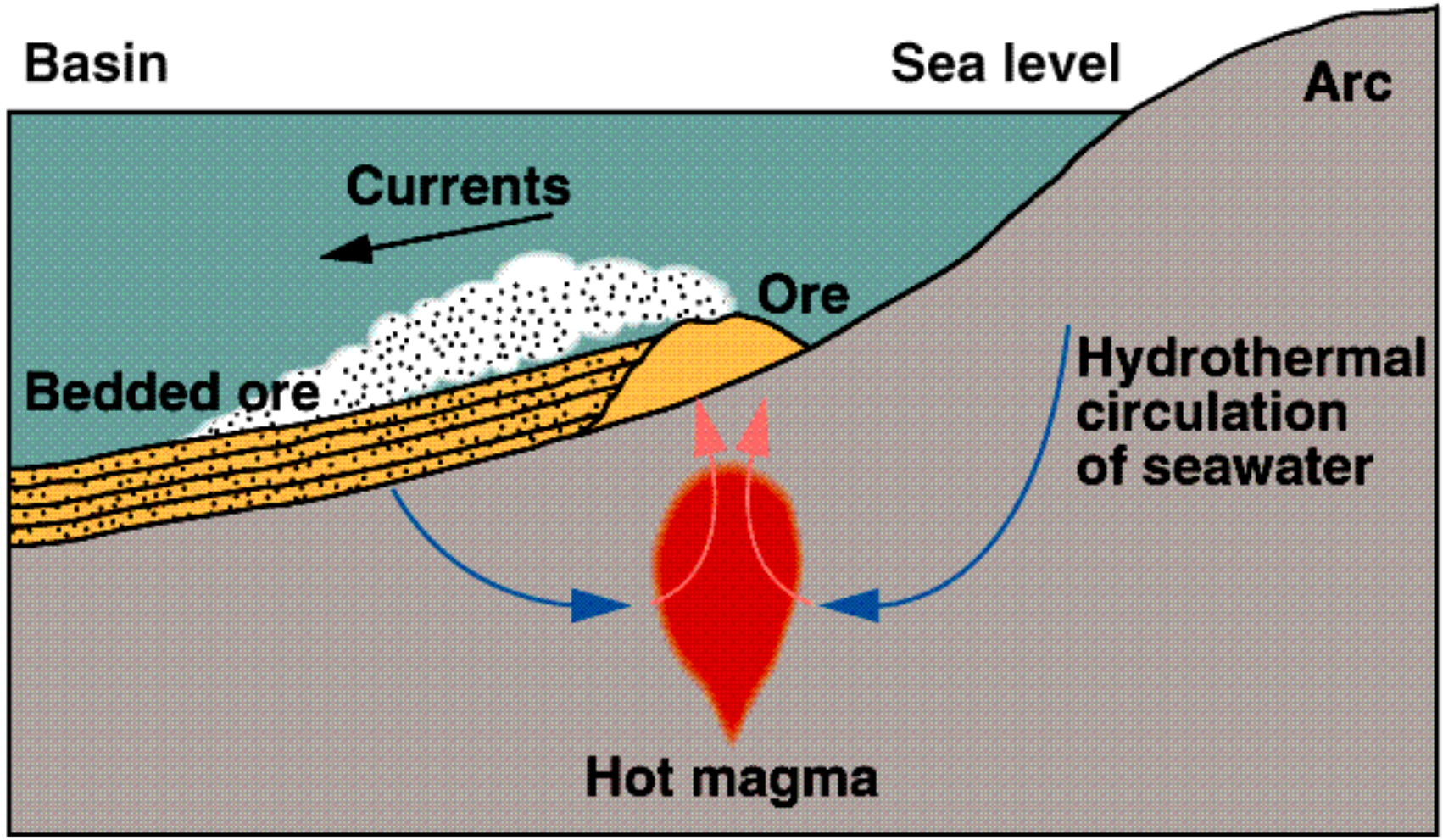
Reconstruct geologic history of area (events make, hide, or destroy deposit)

Banded Iron Ore

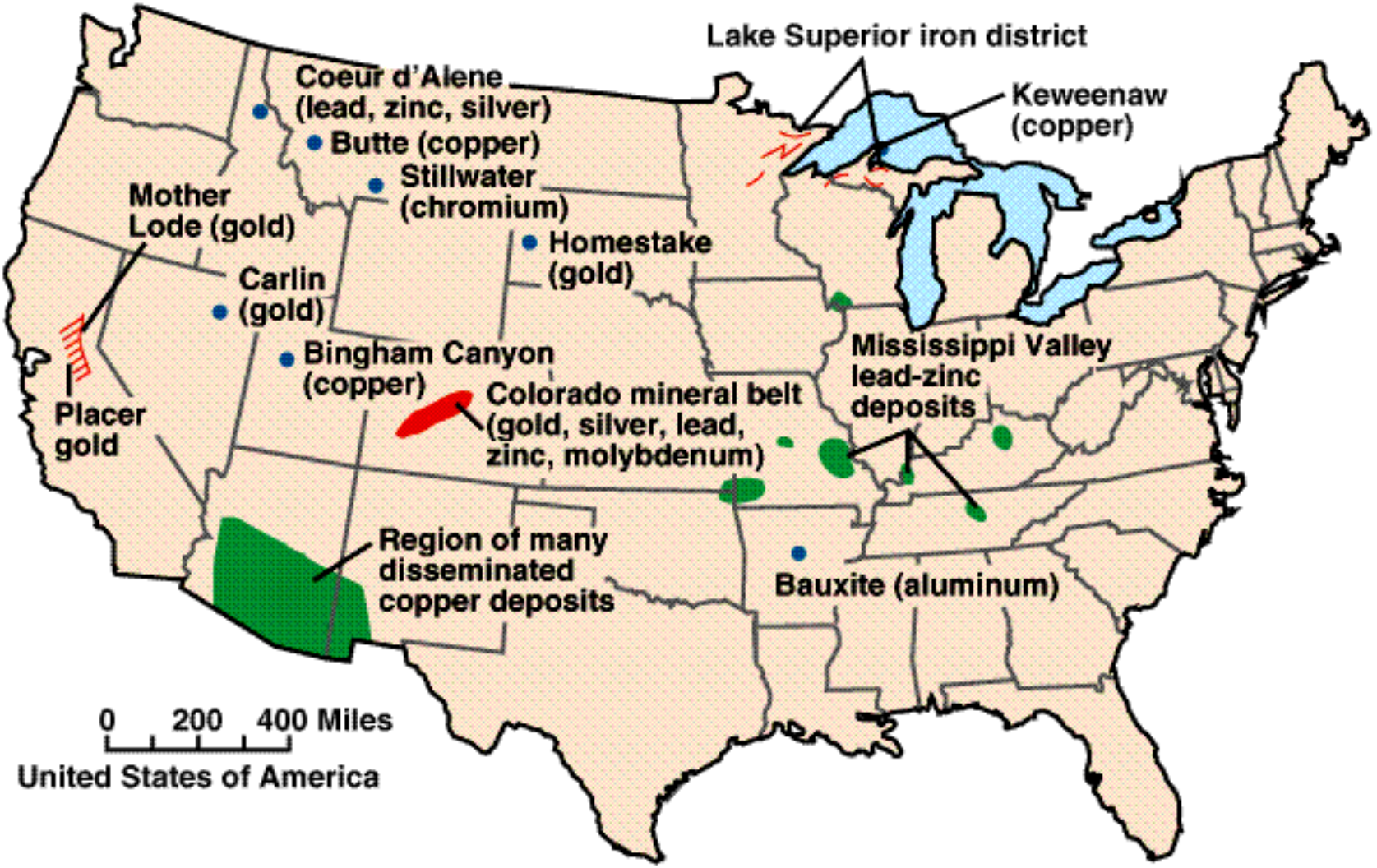
Sea-Floor Spreading Carries Metallic Ores



Metallic Ores Form Over Hot Springs

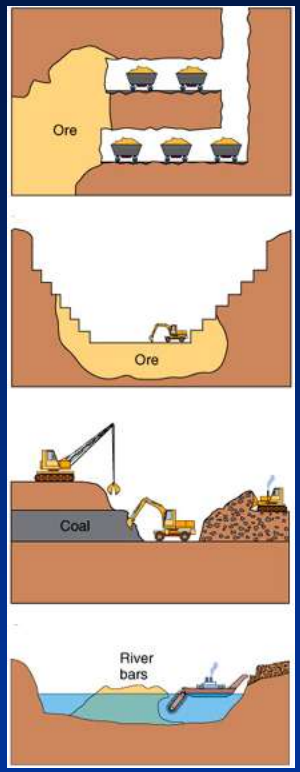


Metallic Ore Localities



Mining and Metals

- *Mining* can be carried out on Earth's surface (*strip mines*, *open-pit mines*, and *placer mines*) or underground
  - Metals mined using these techniques include iron, copper, aluminum, lead, zinc, silver, gold and many others
- Negative environmental effects of mining, including unsightly *tailings* piles, surface scars, land *subsidence*, and *acid mine drainage* must be minimized by law



Open-Pit, Copper Mine

Sluice Box

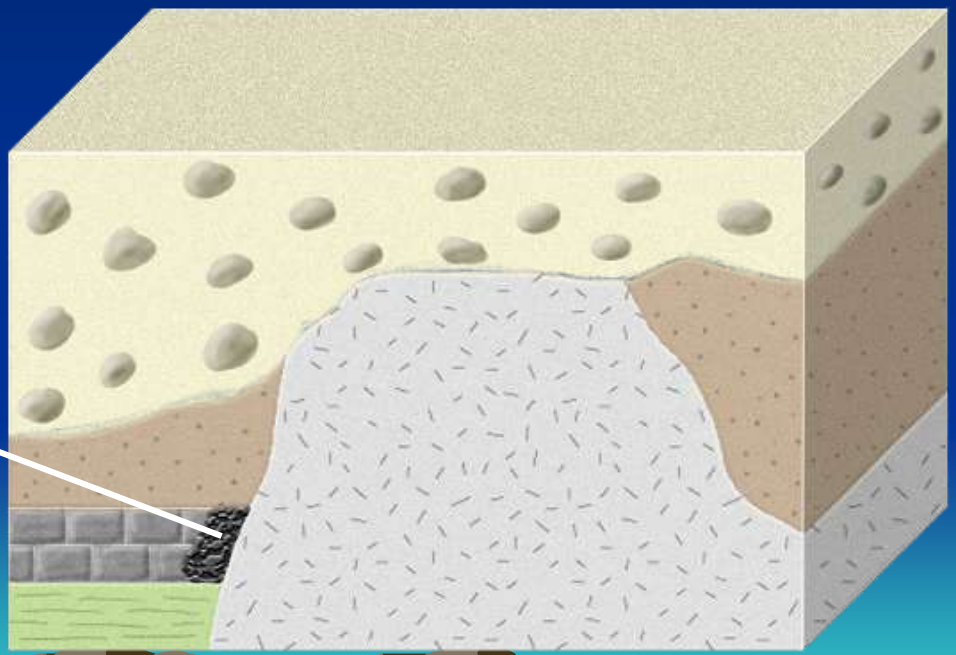
Hydraulic Gold Mining, Alaska

Gold Dredge

Finding Buried Mineral Deposits

Conduct surveys using geophysical methods, including magnetic surveys

Note where the magnetic strength is high over ore body



Extracting and Processing Minerals

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Surficial Processes that Form Mineral Deposits

18.09.c

Important Industrial Mineral Deposits

Sand and gravel

Crushed rock

Silica sand

Clay minerals

Salt

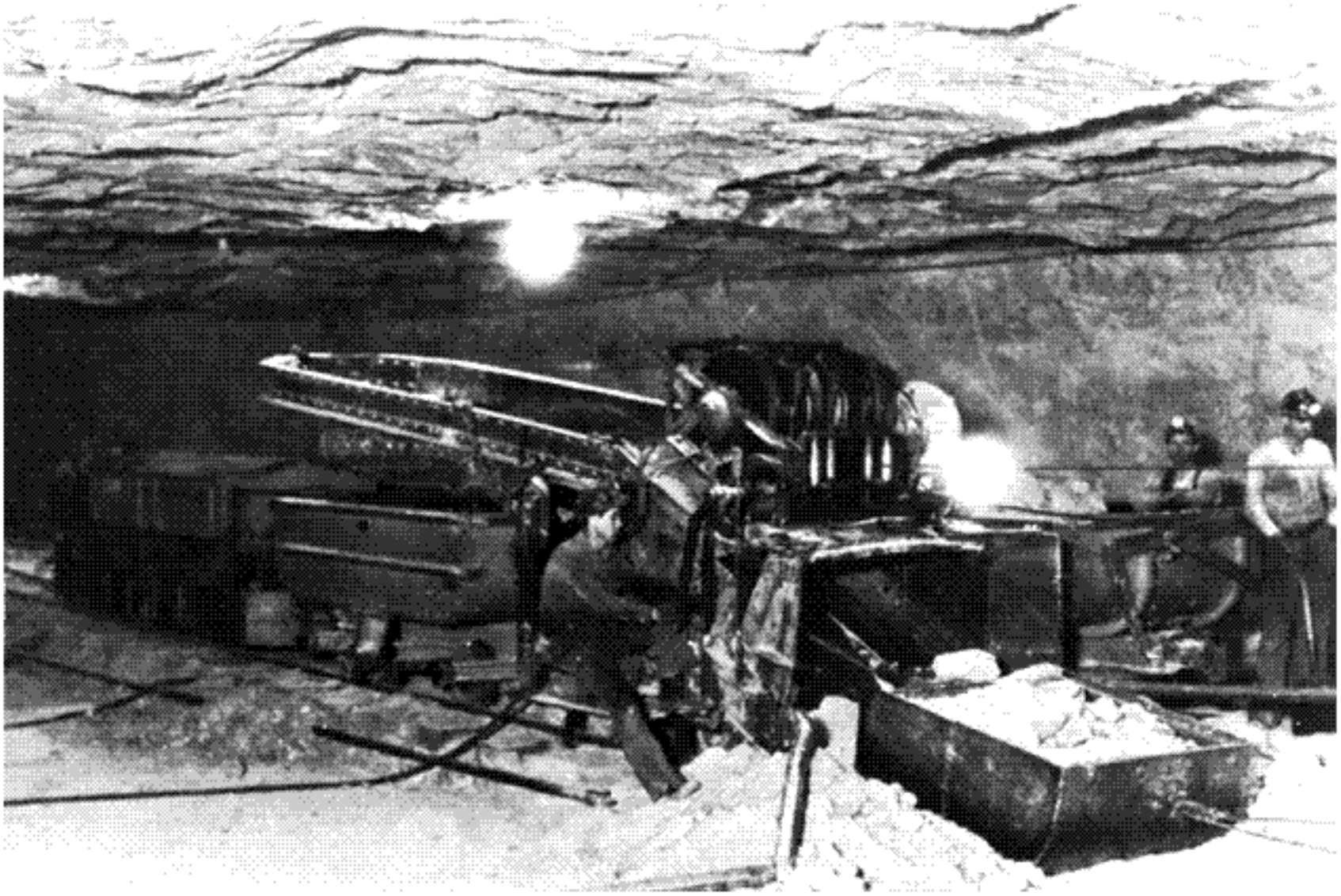
Phosphate

Non-metallic Resources

- *Non-metallic resources* are those that are not mined to extract a metal or as a source of energy
  - Such resources are used for *construction materials* (sand, gravel, limestone, and gypsum), *agriculture* (phosphate, nitrate and potassium compounds), *industrial uses* (rock salt, sulfur, asbestos), *gemstones* (diamonds, rubies), and for manufacture of *household and business products* (glass sand, fluorite, diatomite, graphite)
- *If it can't be grown, it must be mined*

Limestone Quarry

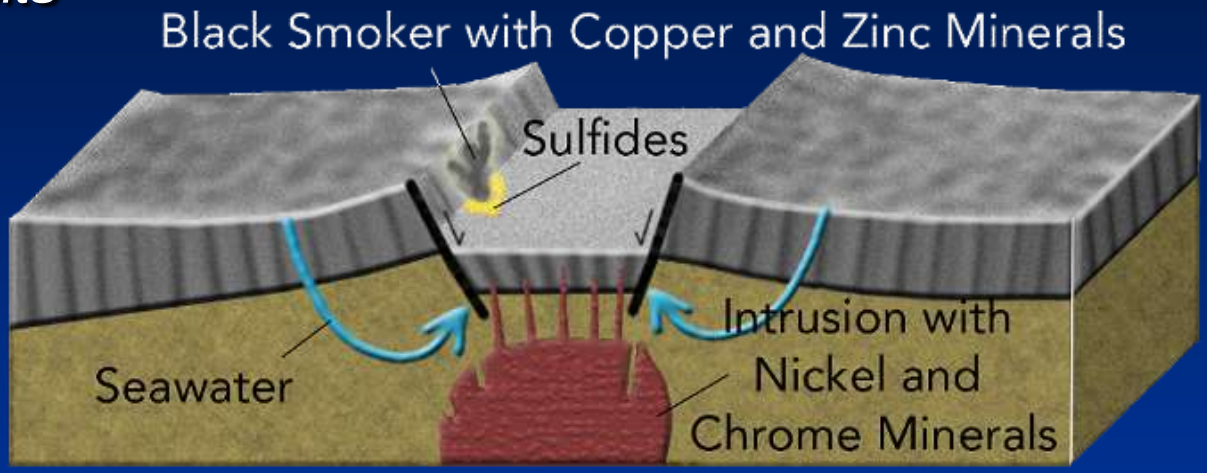
Potassium Mining



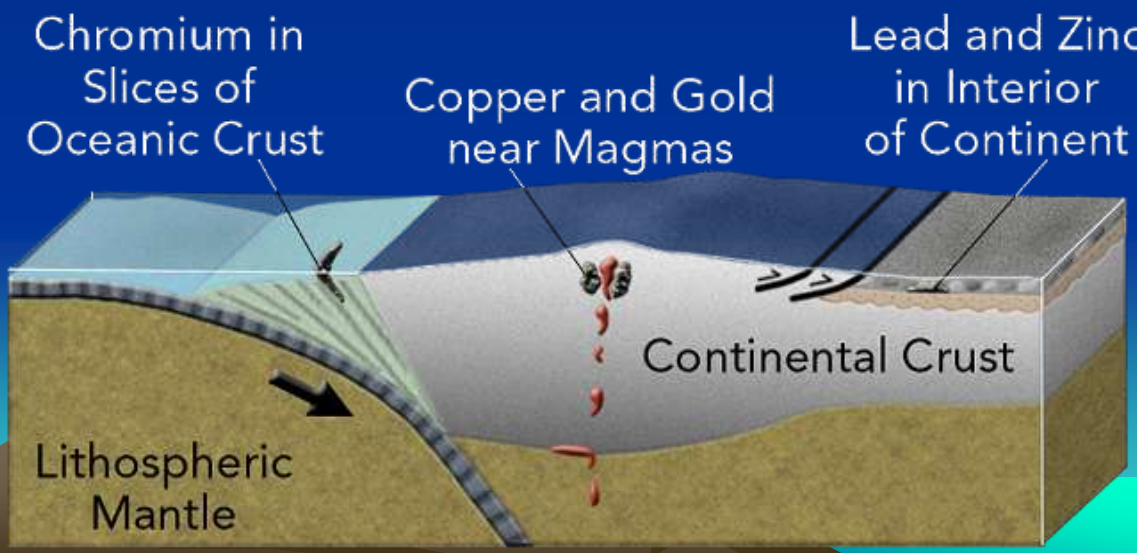
Pegmatite – gemstone - emeralds

how plate tectonics helps us explore for ore deposits

Divergent boundaries



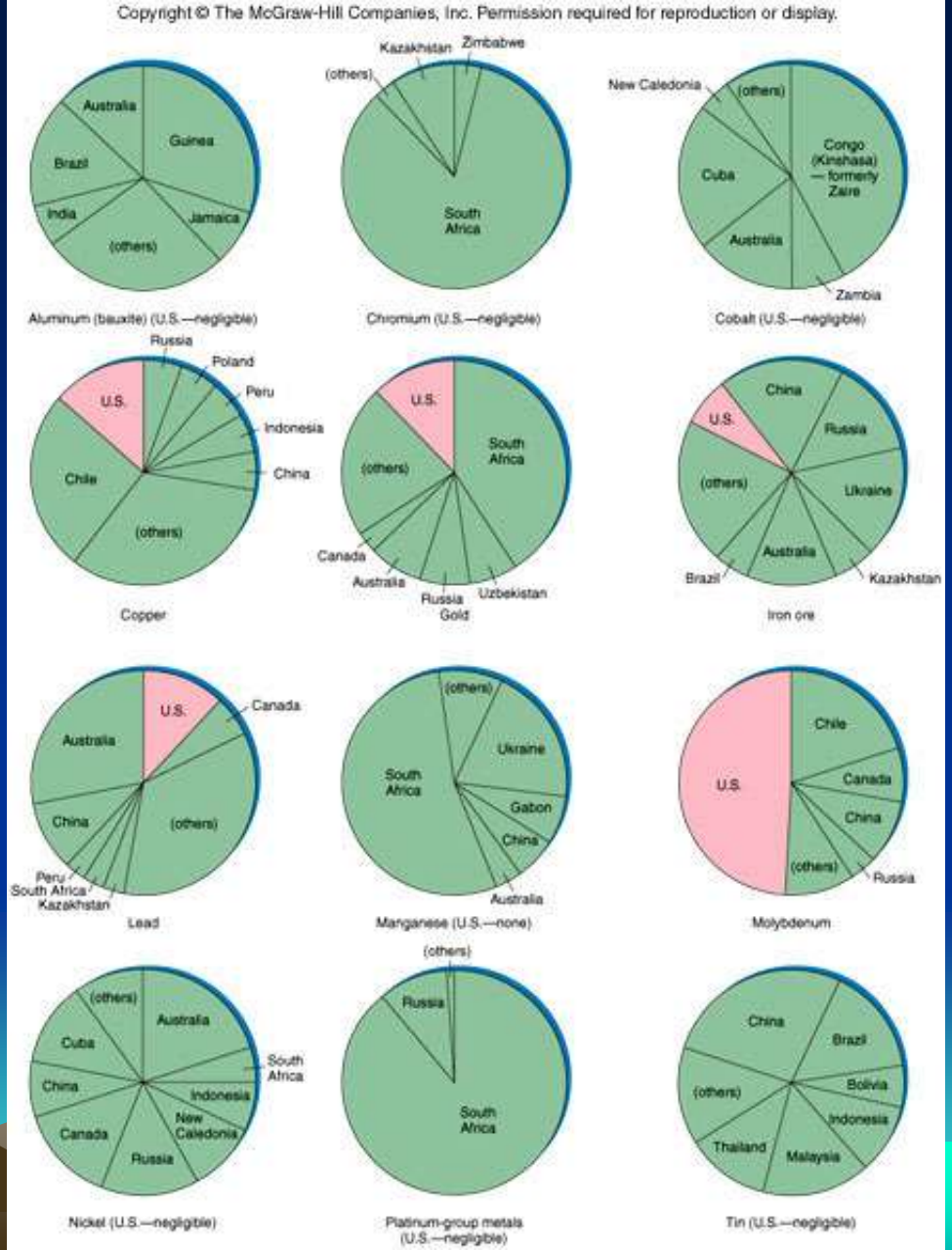
Convergent boundaries



Examples of Metals obtained from Ores

- Aluminum or Iron – appliances and vehicles
- Metals for conductors or semi-conductors
- Gems, gold, and silver – jewelry
- Lead from galena
- Copper from malachite and azurite
- Zinc from sphalerite
- Many other metals found in rocks

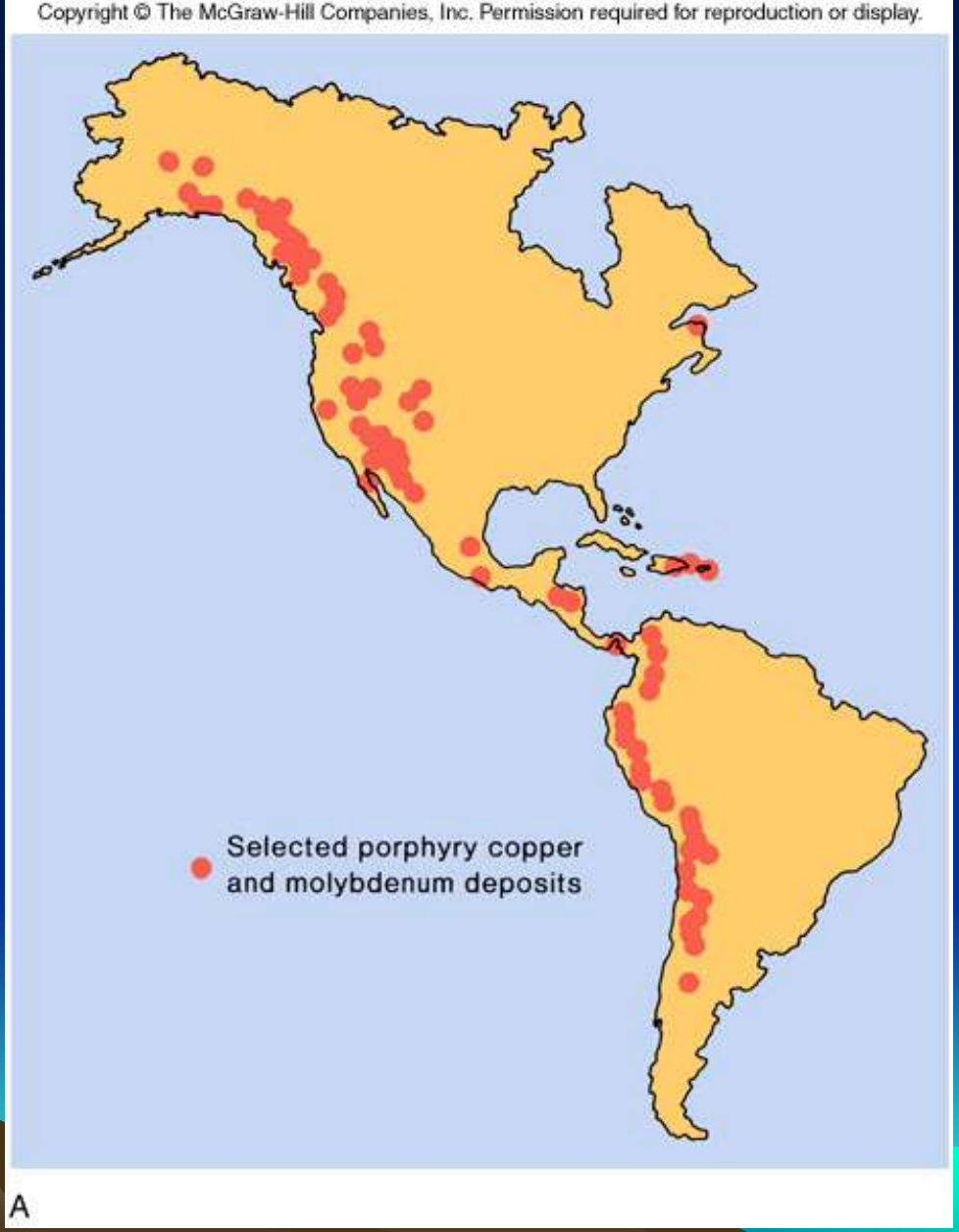
US supply of minerals



Distribution

- Globally, very un-even distribution
  - Some countries have plenty – export nations
  - Some countries have none – import nations
- Un-even distribution is reason wars are fought

Porphyry copper and molybdenum deposits

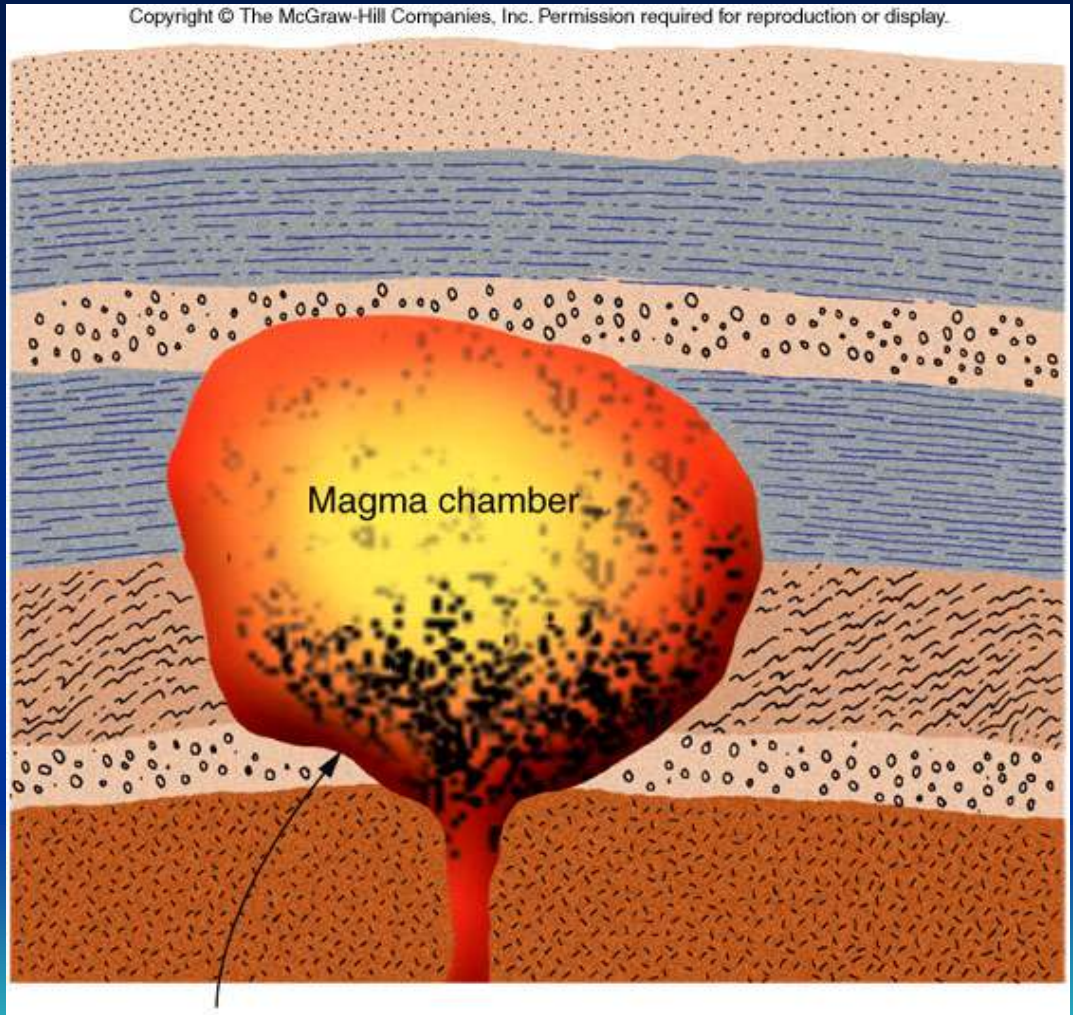


U.S. metal precious metal mine areas

Types of Mineral Deposits

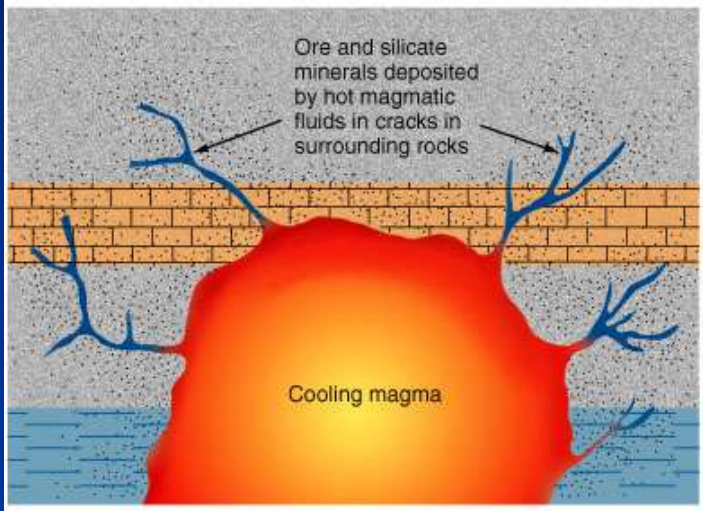
- Igneous Rocks and Magmatic Deposits
  - Pegmatite
  - Kimberlite
- Hydrothermal Ores
  - hydrothermal
- Relationship to Plate Margins
- Sedimentary Deposits
  - Banded iron formation
  - Evaporite
- Other low-temperature ore-forming processes
  - Placers
- Metamorphic Deposits

Magmatic segregation



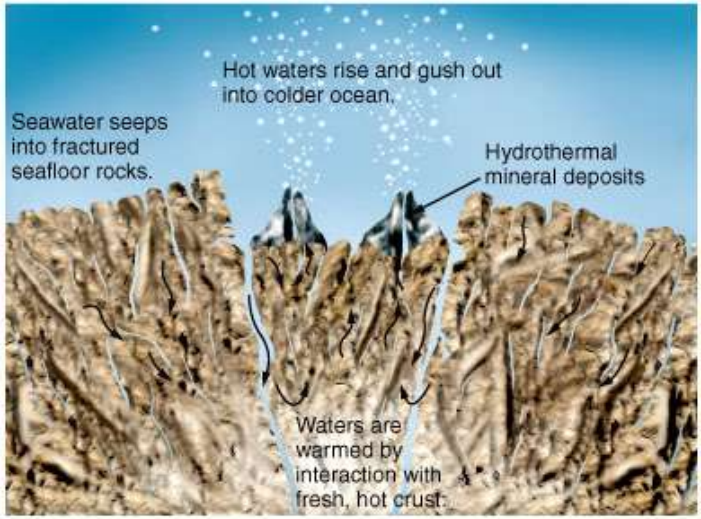
A dense mineral like chromite or magnetite may settle out of a crystallizing magma to be concentrated at the bottom of the chamber.

Hydrothermal deposits



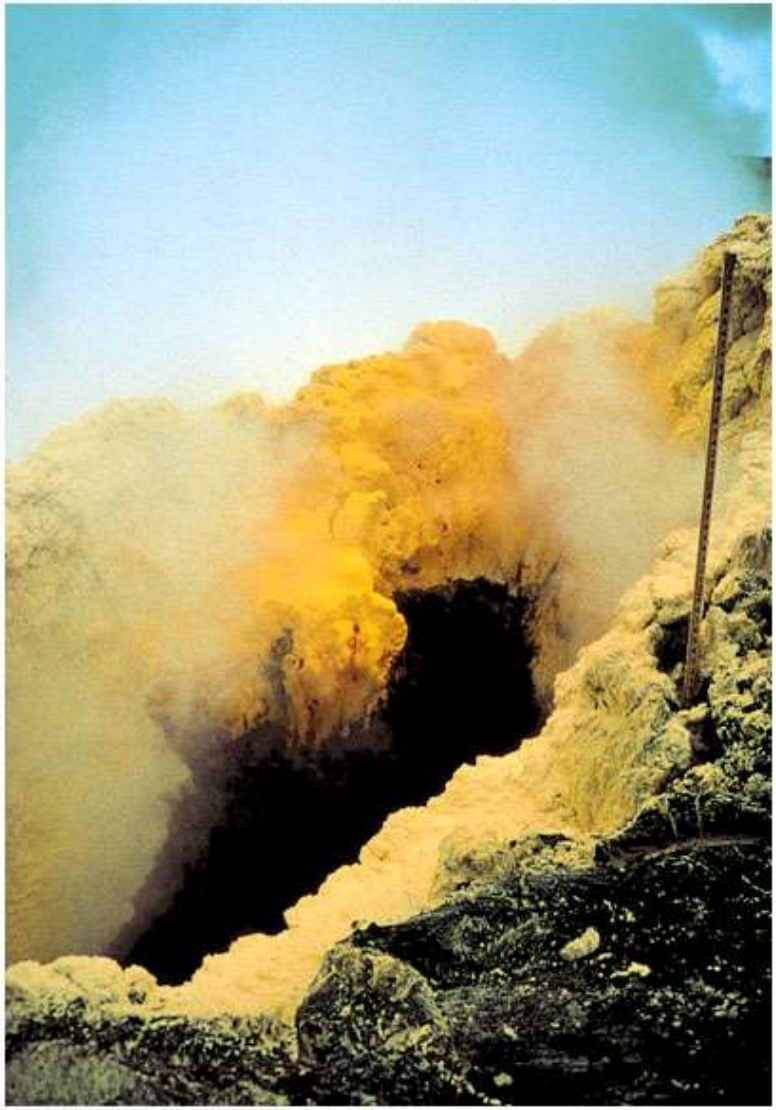
A

B

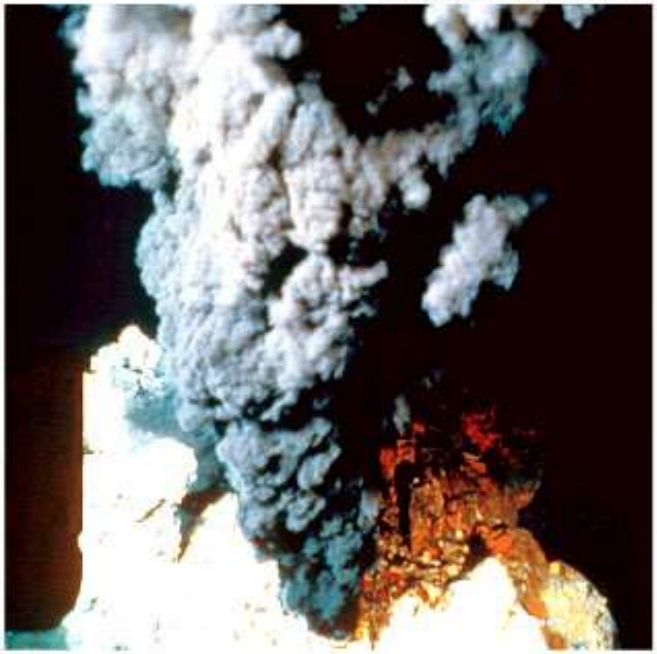


C

Sulfur deposits around volcanic fumaroles



Black Smokers and volcanic massive sulfide deposits



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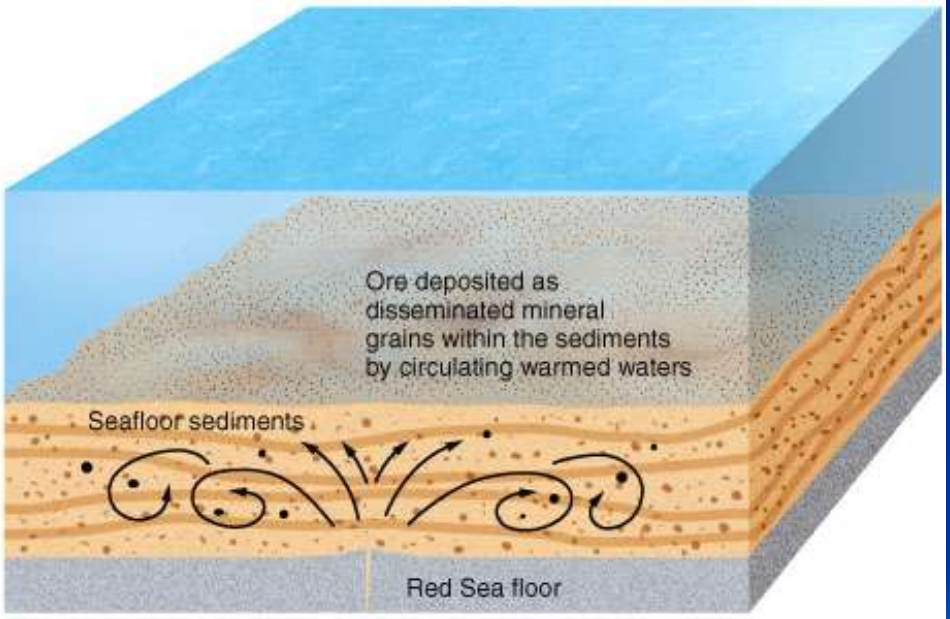
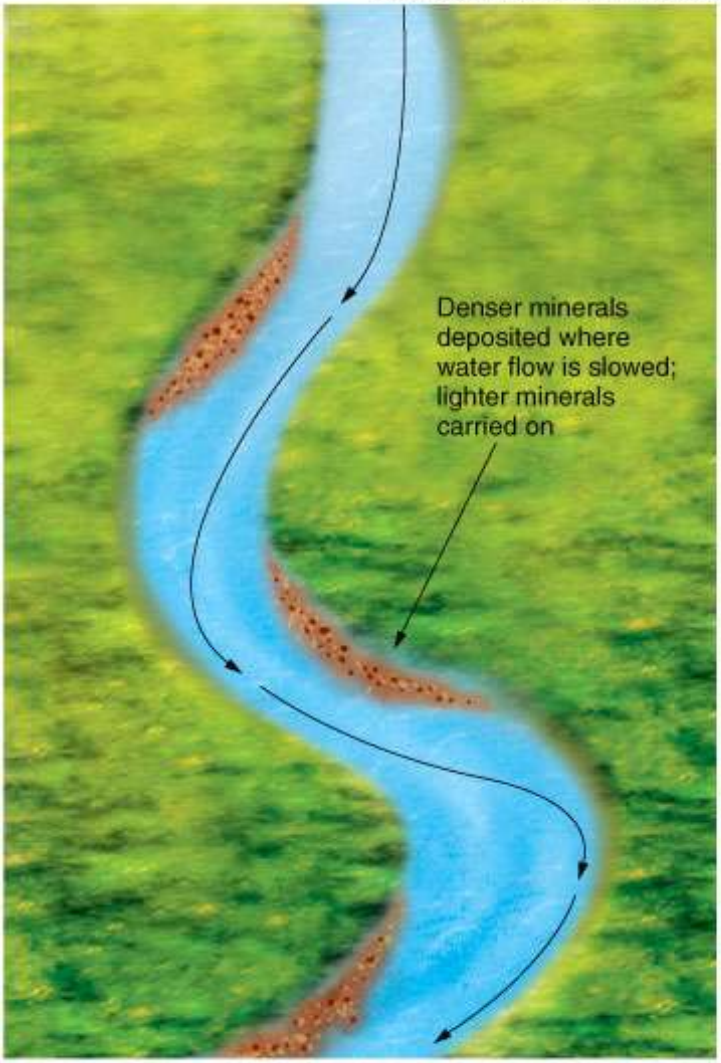


B

Placer gold deposits and hydraulicking



A

B

Mineral and Rock Resources Examples (uses)

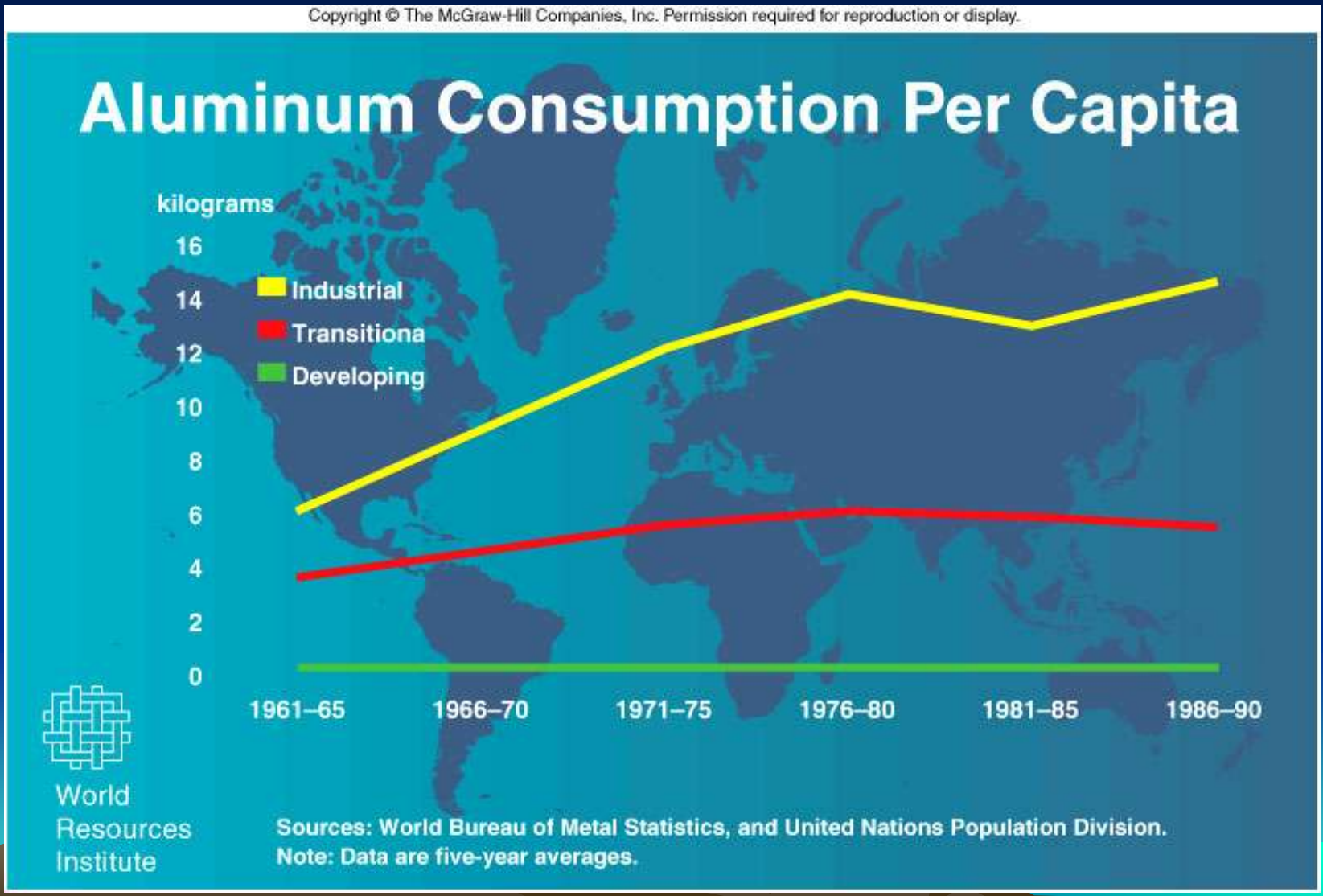
- Metals – iron, aluminum, copper, lead, zinc, nickel, cobalt, gold, silver, or platinum
- Nonmetallic Minerals – sulfides, lime (calcium carbonate), sulfur, halite, clay, gypsum, or potash
- Rock resources – most abundant quantity of earth resources we use
  - Sand, gravel, limestone, quartz-rich sand, marble, granite, and sandstone

Mineral Supply and Demand

- Global demand is always growing
  - About 2% pre-World War II for most metals
  - About 10 % World War II to mid-1970's
  - Demand is fluctuating now
- U.S. Mineral Production and Consumption
  - U.S. population is only 4.5% of the world but consumes many times its share of the world supply

US annual per capita consumption

Figure 12.12



Cement, Concrete, and Sheetrock

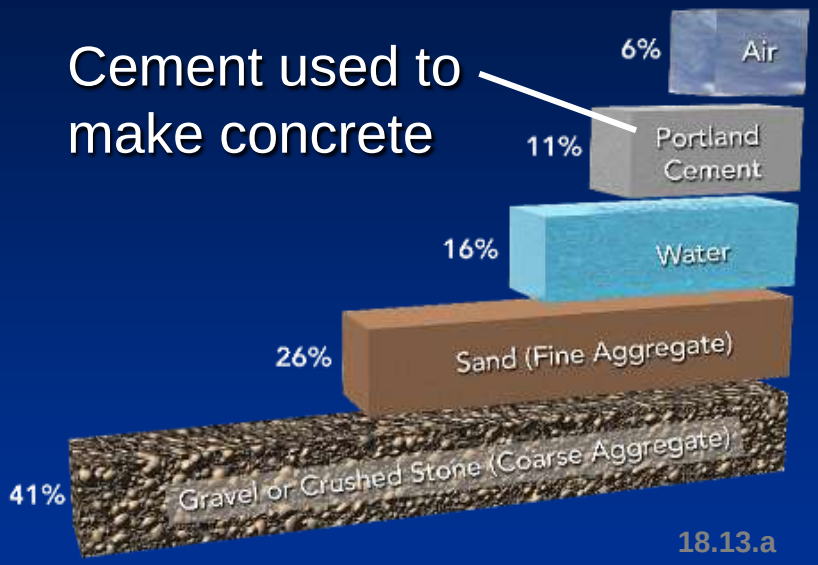


TABLE 12.1

U.S. Production and Consumption of Rock and Mineral Resources, 2002†

Material	U.S. Primary Production	U.S. Primary Production as % of World	U.S. Consumption	U.S. Consumption as % of World‡	U.S. Production as % of U.S. Consumption■ Primary	U.S. Production as % of U.S. Consumption■ Total
Metals						
aluminum[1]	2700	10.6	6400	25.2	42	61
chromium	0	0	413	3.2	0	37
cobalt	0	0	10.8	29.3	0	25
copper	1450	10.8	2700	20.1	54	57
iron ore	50,000	4.5	56,000	5.1	89	89
lead	450	15.5	1580	54.5	28	82
manganese	0	0	700	9.2	0	0
nickel	0	0	225	17.0	0	0
tin	0	0	54.0	23.4	0	25
zinc	740	8.3	1500	16.8	49	72
gold	300	11.8	170	6.7	176	156
silver	1470	7.8	5340	28.4	28	84
platinum group	16.9	4.6	ø	ø	ø	ø
Nonmetals						
clays	40,700	*	35,900	*	113	113
gypsum	16,100	15.6	31,800	30.9	51	75
phosphate	35,800	26.9	37,700	28.3	94	94
potash	1200	4.4	5600	20.7	21	21
salt	43,900	19.5	50,200	22.3	87	87
sulfur	9280	16.0	10,900	18.8	85	85
Construction						
sand and gravel, construction	1,130,000	*	1,130,000	*	100	100
stone, crushed	1,590,000	*	1,600,000	*	99	99
stone, dimension and facing	1300	*	* *	*	**	**

†All production and consumption figures in thousands of metric tons, except for gold, silver, and platinum-group metals, for which figures are in metric tons. One metric ton = 1000 kg = 2200 lb.

‡Assumes that overall, world production approximates world consumption. This may not be accurate if, for example, recycling is extensive.

■"Primary" and "Total" headings refer to U.S. production; total production includes production from recycled scrap.

*World data not available.

øConsumption data not available.

**Consumption not available in tonnage. However, $1.7 billion worth of dimension stone was imported (value of domestic production, $240 million, of which $89 million worth was exported).

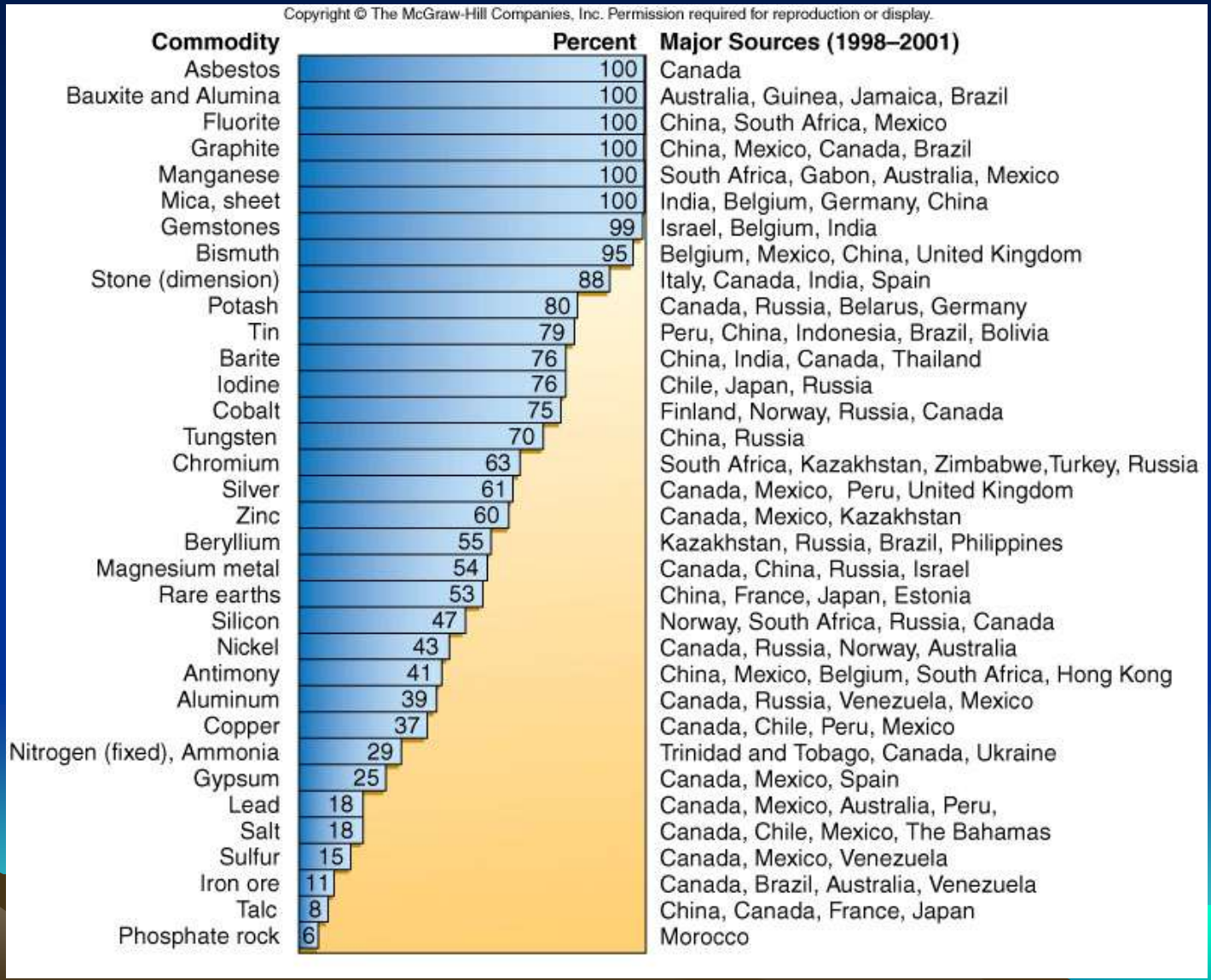
[1]Partly from bauxite imports.

Source: Mineral Commodity Summaries 2003, U.S. Geological Survey.

World Mineral Supply

- World demand is always fluctuating
- Commodities do not follow fluctuating trends
- Mineral reserves eventually will be depleted
- Import/export relationships will fluctuate
- Technology often allows more access to difficult or low grade ore deposits
- Future mineral-resource shortages will occur and cause international tension

US imports and suppliers of materials



Commodity	Percent	Major Sources (1998–2001)
Asbestos	100	Canada
Bauxite and Alumina	100	Australia, Guinea, Jamaica, Brazil
Fluorite	100	China, South Africa, Mexico
Graphite	100	China, Mexico, Canada, Brazil
Manganese	100	South Africa, Gabon, Australia, Mexico
Mica, sheet	100	India, Belgium, Germany, China
Gemstones	99	Israel, Belgium, India
Bismuth	95	Belgium, Mexico, China, United Kingdom
Stone (dimension)	88	Italy, Canada, India, Spain
Potash	80	Canada, Russia, Belarus, Germany
Tin	79	Peru, China, Indonesia, Brazil, Bolivia
Barite	76	China, India, Canada, Thailand
Iodine	76	Chile, Japan, Russia
Cobalt	75	Finland, Norway, Russia, Canada
Tungsten	70	China, Russia
Chromium	63	South Africa, Kazakhstan, Zimbabwe,Turkey, Russia
Silver	61	Canada, Mexico, Peru, United Kingdom
Zinc	60	Canada, Mexico, Kazakhstan
Beryllium	55	Kazakhstan, Russia, Brazil, Philippines
Magnesium metal	54	Canada, China, Russia, Israel
Rare earths	53	China, France, Japan, Estonia
Silicon	47	Norway, South Africa, Russia, Canada
Nickel	43	Canada, Russia, Norway, Australia
Antimony	41	China, Mexico, Belgium, South Africa, Hong Kong
Aluminum	39	Canada, Russia, Venezuela, Mexico
Copper	37	Canada, Chile, Peru, Mexico
Nitrogen (fixed), Ammonia	29	Trinidad and Tobago, Canada, Ukraine
Gypsum	25	Canada, Mexico, Spain
Lead	18	Canada, Mexico, Australia, Peru,
Salt	18	Canada, Chile, Mexico, The Bahamas
Sulfur	15	Canada, Mexico, Venezuela
Iron ore	11	Canada, Brazil, Australia, Venezuela
Talc	8	China, Canada, France, Japan
Phosphate rock	6	Morocco

World production and reserves

World Production and Reserves Statistics, 2002*

Material	Production	Reserves	Projected Lifetime of Reserves (years)	Estimated Resources
bauxite	141,000	22,000,000	156	55,000,000–75,000,000
chromium	13,000	1,600,000	123	12,000,000
cobalt	36.9	6700	182	11,000
copper	13,400	480,000	36	2,300,000†
iron ore	1,100,000	150,000,000	136	over 800,000,000
lead	2900	68,000	23	1,500,000
manganese	7,600	300,000	40	**
nickel	1320	61,000	46	130,000
tin	231	6100	26	**
zinc	8,900	200,000	22	1,900,000
gold	2530	42,500	17	100,000
silver	18,800	270,000	14	n.a.
platinum group	364	71,000	195	100,000
gypsum	103,000	**	**	**
phosphate	133,000	17,000,000	128	**
potash	27,000	8,300,000	307	250,000,000

Reserves include only currently economic deposits.

*All production, reserve, and resource figures in thousands of metric tons, except for gold, silver, and platinum-group metals, for which figures are in metric tons.

**Resources and reserves estimated as "large" but not quantified.

†Includes 0.7 billion tons copper estimated to occur in manganese nodules; "extensive" resources of nickel are also projected to occur in these nodules.

Source: Mineral Commodity Summaries 2003, U.S. Geological Survey.

Options - Minerals for the Future

- Consider controlling consumption rates
  - Reduce the consumption rates (unlikely)
  - Hold these rates steady (unlikely)
- Carefully consider the facts:
  - Globally the less developed nations are striving to achieve comparable standards of living as the technologically advanced countries enjoy
  - Countries that have the fastest-growing populations are not well endowed with mineral deposits and are the less developed countries of the world!

Projected Lifetimes of U.S. Mineral Reserves (assuming complete reliance on domestic reserves)*

Material	Reserves	Projected Lifetime (years)
bauxite†	20,000	6
chromium	0	0
cobalt	0	0
copper	35,000	13.0
iron ore	6,900,000	123
lead	8100	5.1
manganese	0	0
nickel	0	0
tin	20	0.4
zinc	30,000	20
gold	5600	33
silver	25,000	4.7
platinum group	900	**
gypsum	700,000	22
phosphate	1,000,000	26.5
potash	90,000	16.1

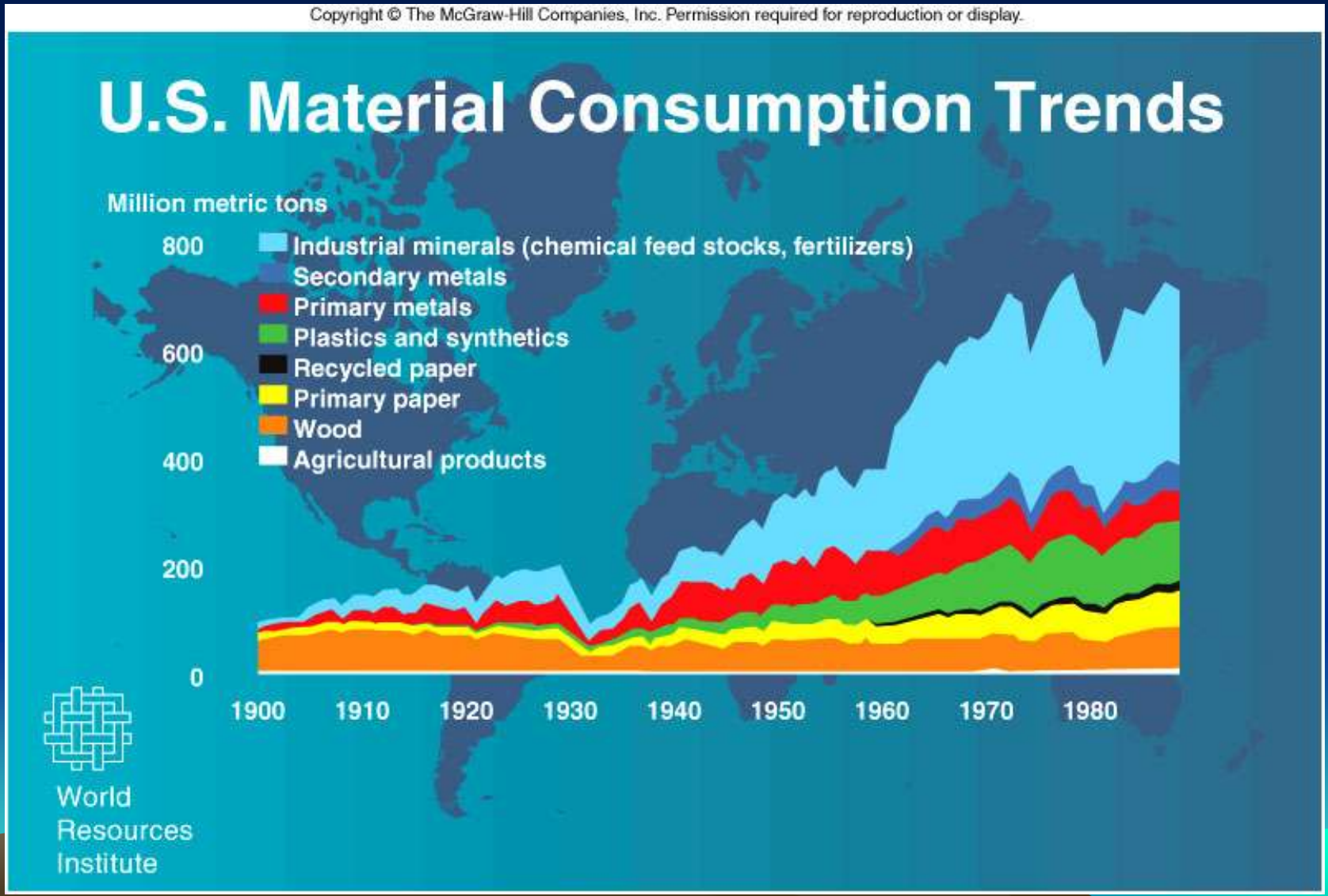
*Reserves in thousands of metric tons, except for gold, silver, and platinum-group metals, for which figures are in metric tons.

**Accurate consumption data not available.

†Note that bauxite consumption is only a partial measure of total aluminum consumption; additional aluminum is consumed as refined aluminum metal, of which there are no reserves.

Source: Mineral Commodity Summaries 2003, U.S. Geological Survey.

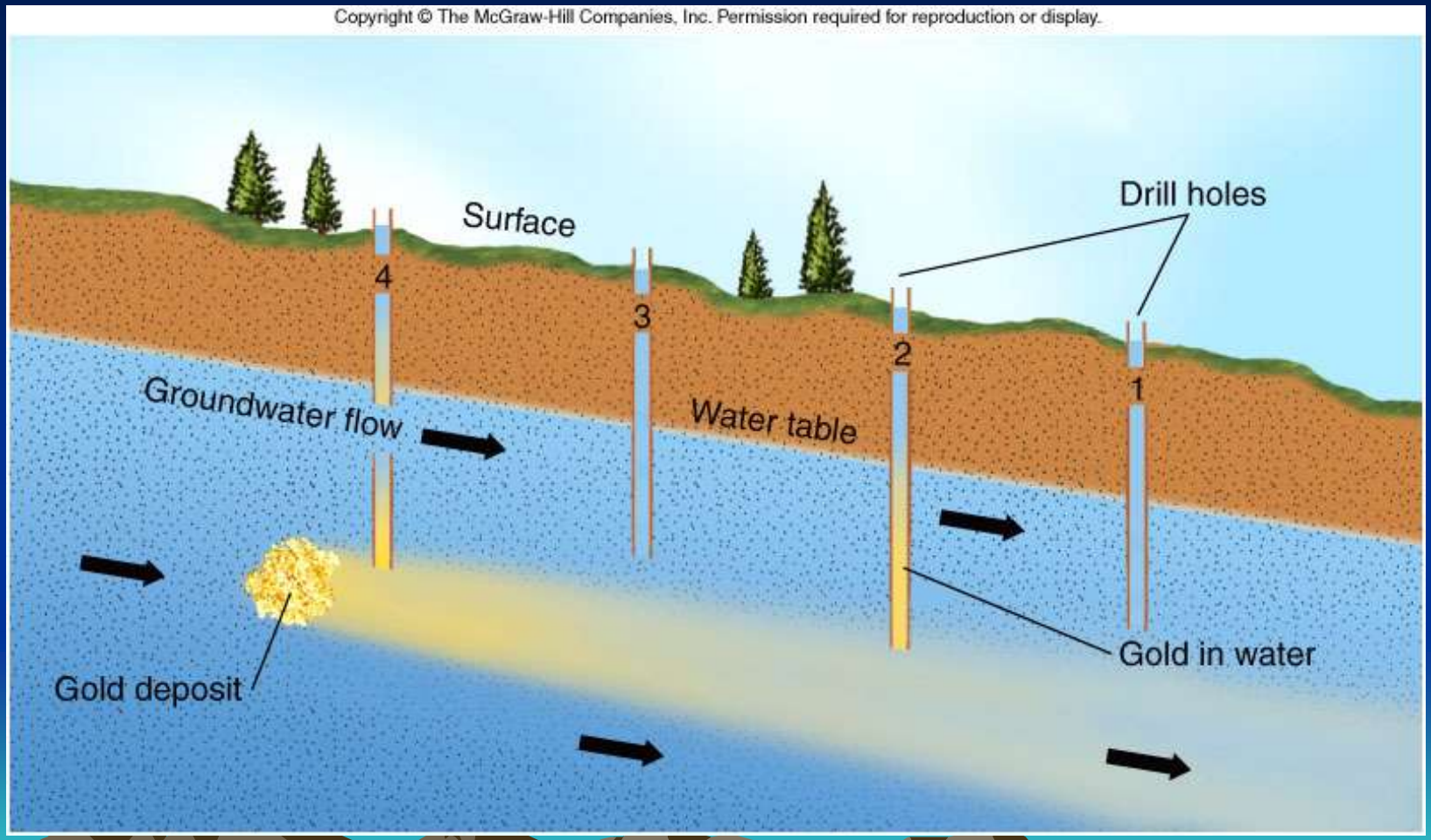
US minerals consumption



New Methods in Mineral Exploration

- Fact: the economically easy and profitable deposits are being depleted
- Geophysics is a useful aid to locating new deposits
  - Gravity survey
  - Magnetic survey
  - Electrical property survey
- Geochemical survey and prospecting is an increasingly popular exploration tool
- Remote sensing is expanding into exploration strategies

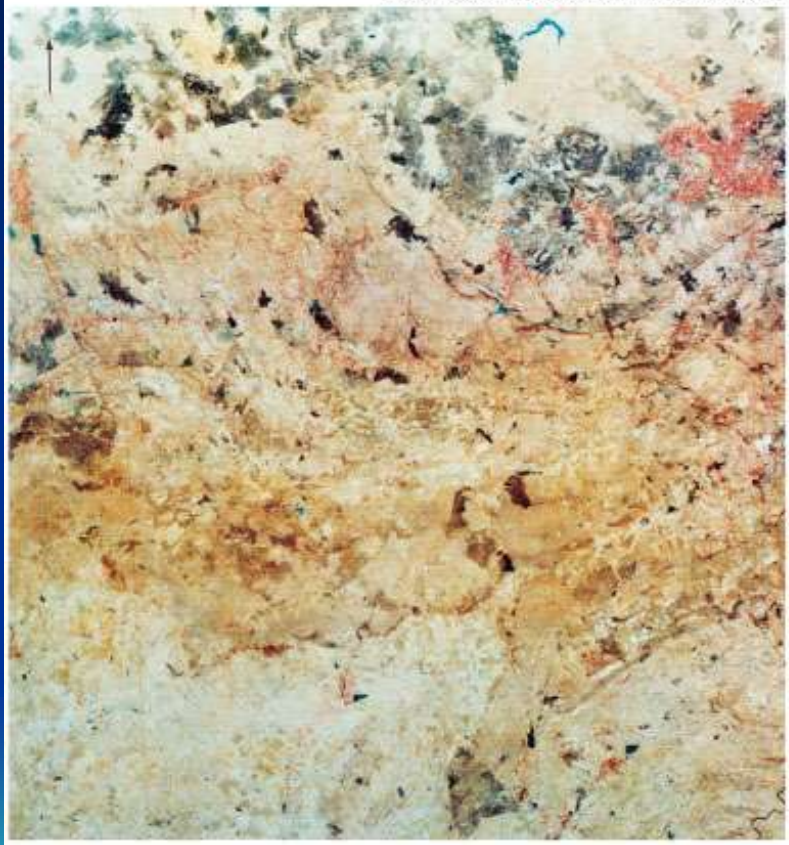
Exploration concepts



Remote Sensing

- Sophisticated but valuable exploration tools
- Useful to detect, record, and analyze energy emitted off the earth
  - Aerial photography
  - Satellites
  - Space shuttle, and other manned missions
- Remote sensing is backed up by '*ground truth'* activities
  - old fashioned geologic mapping
- Advances in the geological sciences are directed toward intigration of remote sensing, geochemistry, and geophysics

Remote sensing



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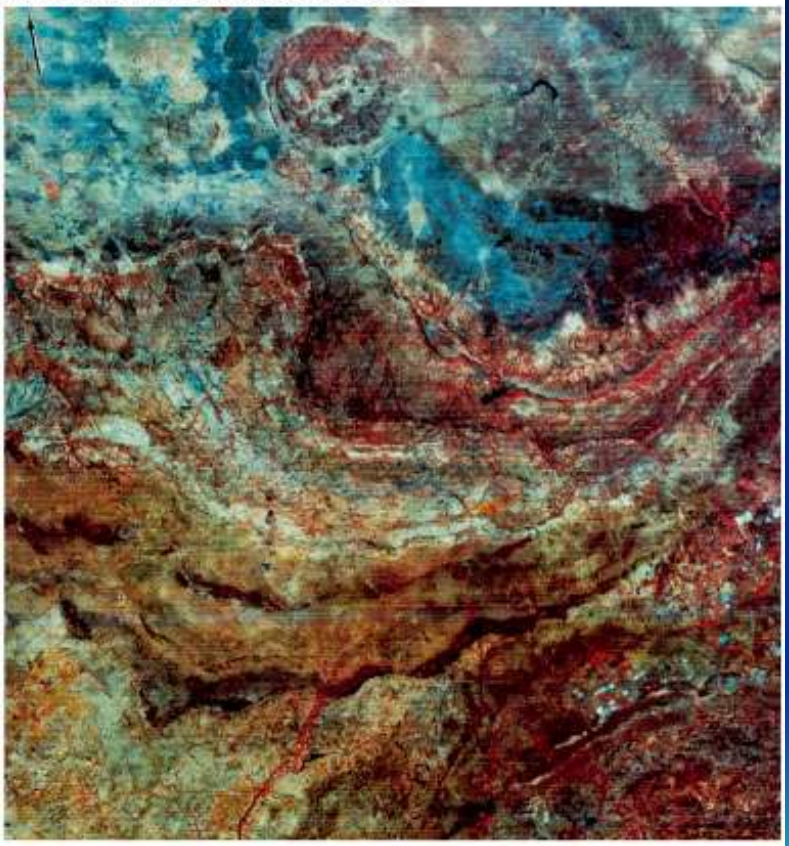
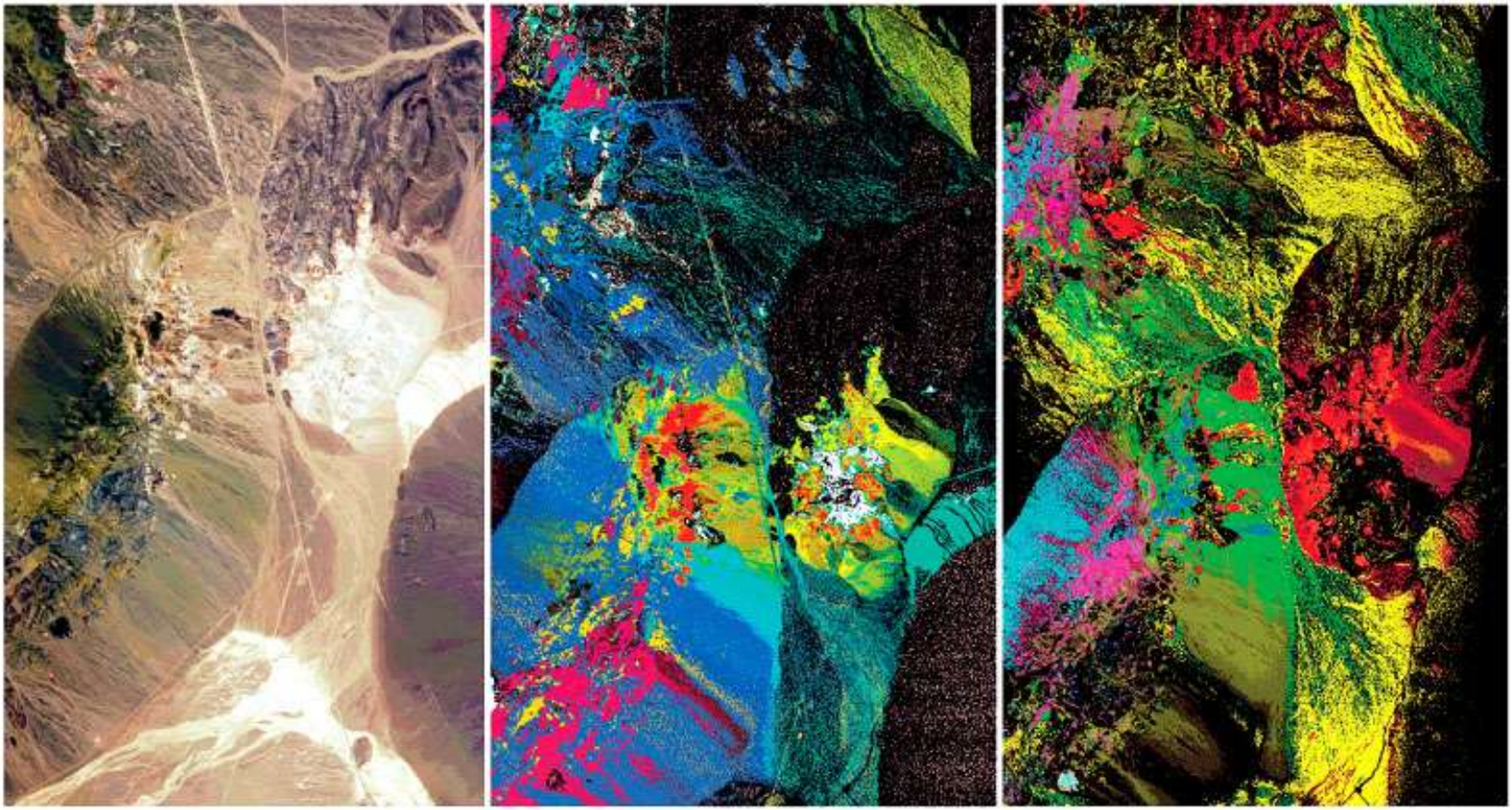


B

remote sensing

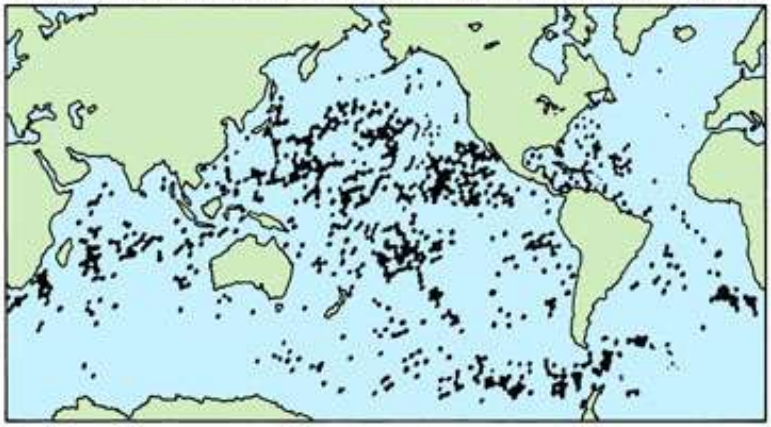


True Color | Minerals (vibrational absorption) | Minerals (electronic absorption)

Marine Mineral Resources

- Oceans – our new mineral frontier
- Sea water contains abundant dissolved minerals and many useful element
  - Most extraction techniques currently used are energy intensive and expensive
- Hydrothermal ore deposits along seafloor spreading ridges are a possible source of many materials
  - Currently, they are too deep - of limited benefit
- Manganese nodules are widely distributed on the ocean floors; a promising solution.
  - Many political, environmental, and legal obstacles must be over come before they can be mined

Manganese nodules



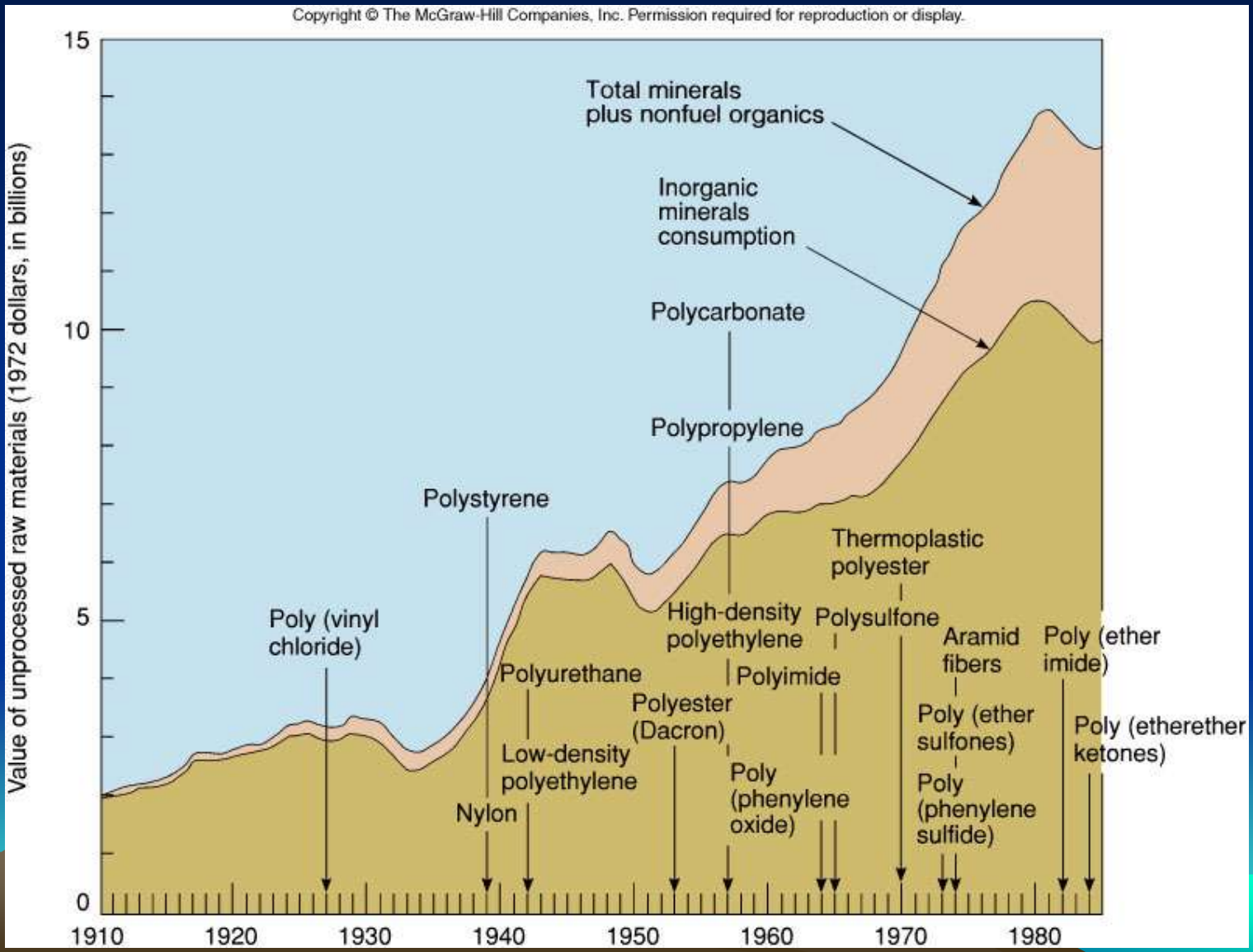
A

B

Conservation of Mineral Resources

- Overall need for resources is growing – must reduce this expansion
- Some mineral resources maybe substituted by other, more abundant resources
  - Plastics replacing automobile parts
- Recycling – many metals are successfully recycled
  - More recycling is required
  - Not all commodities are easy to recycle
- Measures to reduce demand must be the key

Raw materials consumption



Metal Recycling in the United States, 1986–2002 (recycled scrap as percentage of consumption)

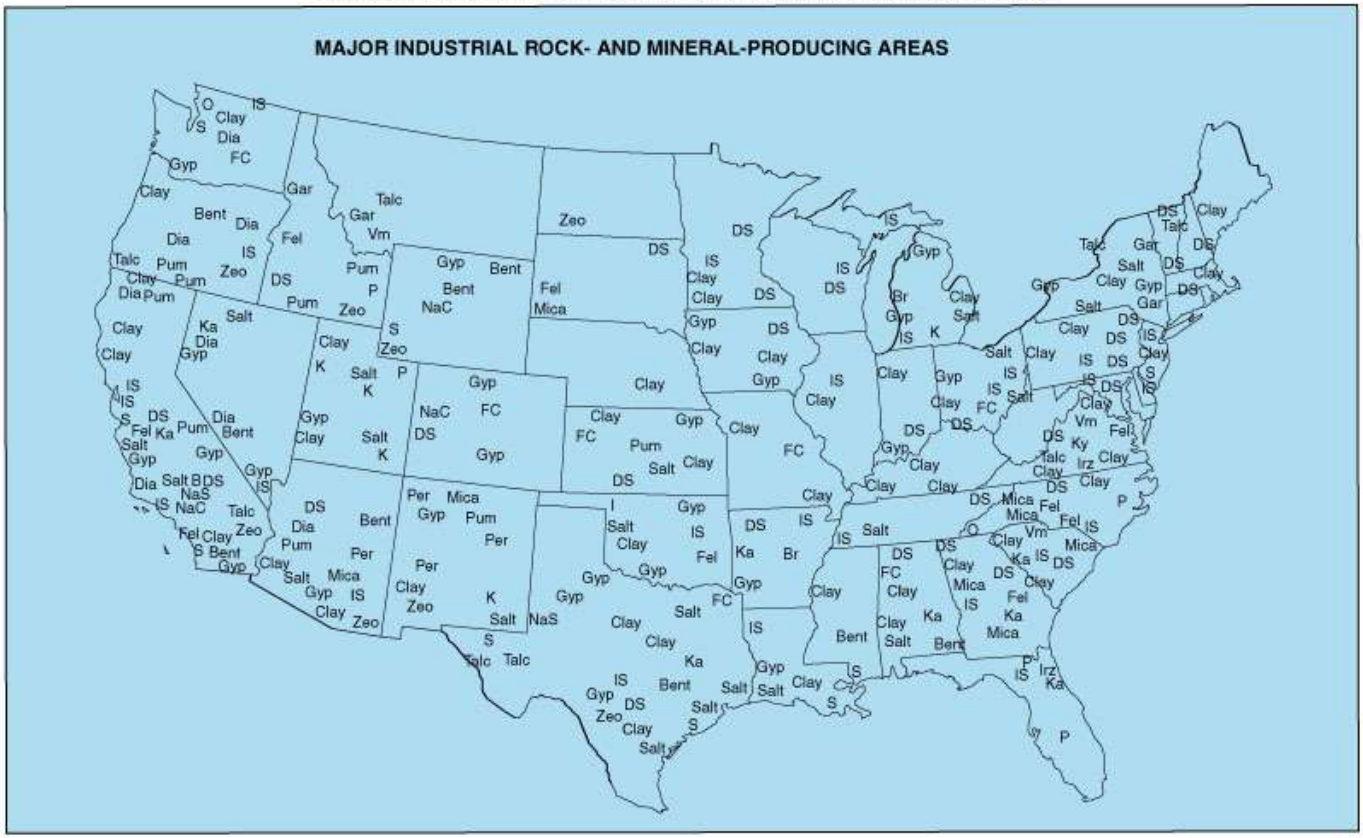
Metal	1986	1989	1992	1995	1999	2002
aluminum	15	22	30	25	20	20
chromium	21	21	26	22	20	37
cobalt	15	14	25	22	34	31
copper	22	25	42	39	33	32
lead	50	60	62	57	68	69
manganese	0	0	0	0	0	0
nickel	25	34	30	34	38	57
zinc	7	10	29	25	26	25

Source: Mineral Commodity Summaries 1990, 1993, 1996, 2000 and 2003, U.S. Geological Survey.

Impacts of Mining Activities

- Mining and mineral-processing activities can modify the environment in various ways
- Both underground mines and surface mines have their own sets of associated impacts
- Safety, hazards, and water and air pollution should not be overlooked
- Very stressful to the environment
  - Must be carefully planned
  - Must be safe to miners and their neighbors
  - Must be contained – water and air pollution is a major problem

Industrial minerals



Mineral symbols

Bent	Bentonite	Fel	Feldspar	Ka	Kaolin	Pum	Pumice and pumicite
B	Borates	Gar	Garnet	Ky	Kyanite	Salt	Salt
Br	Bromine	Gyp	Gypsum	Mica	Mica	NaC	Soda ash
Clay	Common clay	Irz	Ilmenite, rutile, and zircon	O	Olivine	NaS	Sodium sulfate
Dia	Diatomite	IS	Industrial sand	Per	Perlite	S	Sulfur
DS	Dimension stone	I	Iodine	P	Phosphate	Talc	Talc
FC	Fire clay			K	Potash	Vm	Vermiculite
						Zeo	Zeolites

Underground Mines

- Generally hard to see where they are located
  - Area of disturbance is local
- Miners place the tunnels close to the ore body to cut down on waste
- Once mines are closed they can be sealed with the non-ore rock (waste rock)
- Surface collapse general limited and controllable with modern mine reclamation practices
  - Old, abandoned, and forgotten mines are still a problem

Subsidence

A

B

Surface Mines

- Quarrying extracts rock to be used either intact (building blocks or facing stone) or crushed (cement-making and road bed)
- Open-pit
  - Mine a large ore body located near the surface
  - Permanent changes to local topography will occur
- Strip mining
  - Most ores occur in a layer that generally is parallel to the surface
  - The ore zone is overlain by vegetation, soil, non-ore rock that must be removed
  - Spoils banks are designed to collect the waste rock
  - Current reclamation law requires that it be return to the pit and the original soil replaced
  - Expensive but vital

A

B

C

A

B

C

D

Mineral Processing

- Mineral extraction
  - Ore rock is ground or crushed for extraction
  - The fine waste material is placed in lined tailings ponds
  - The tailings are exposed to wind and weather
  - Harmful elements such as mercury, arsenic, cadmium, or uranium can be leached out
  - The surface and subsurface water systems have to be contained
  - Chemicals used in ore extraction must be controlled
  - Smelting ores to extract metals can produce metal laden exhaust gas or ash, sulfur oxide and acid rain pollution and must be scrubbed before discharging