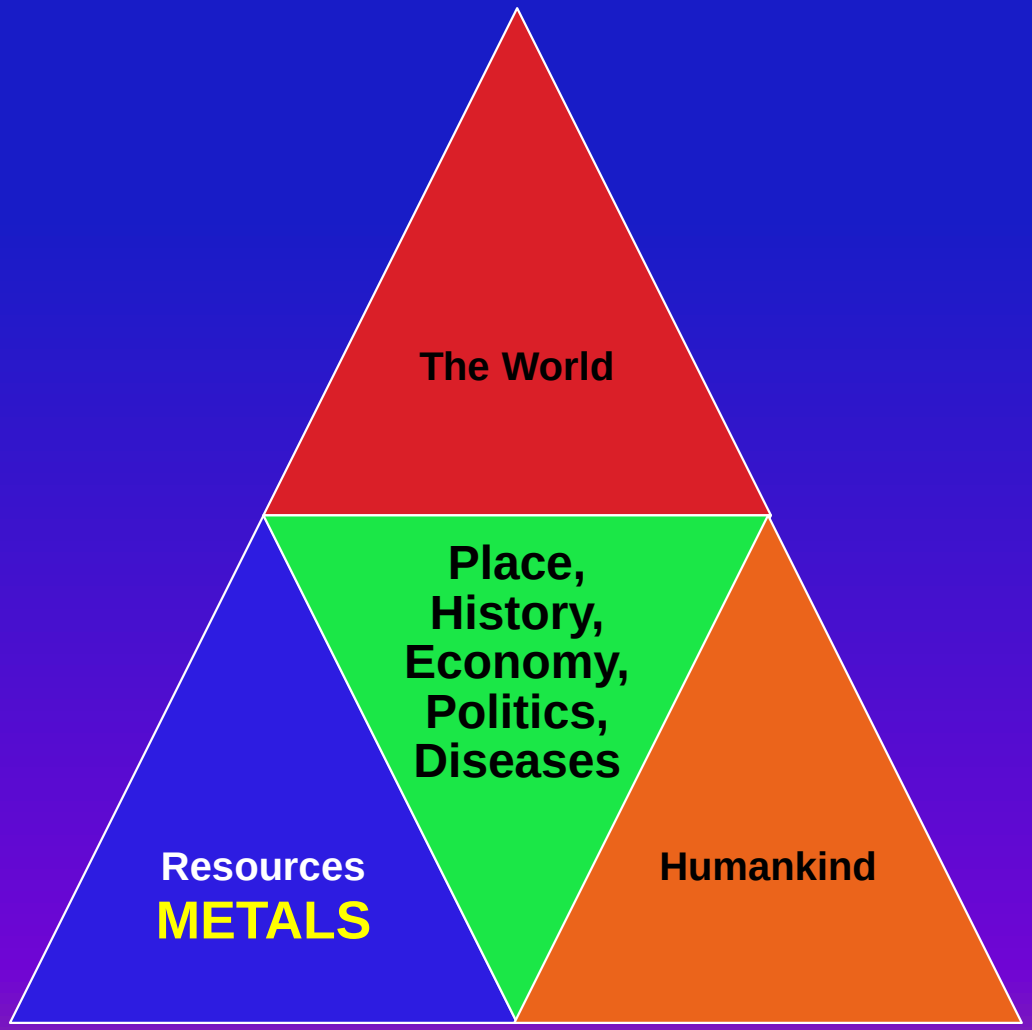
LECTURE # 4

The World, its Resources, and Humankind
Topics of Study



METALS

An Opinion on the Discovery of Metals

Need + Serendipity

Observation ⇨ Imagination +

THINKING OUTSIDE THE BOX

HUMANKIND and METALS

Metals made possible advances in

- agriculture,
- transportation,
- communication,
- technology, and
- warfare

The industrial revolution has been entirely dependent on metallurgy

METALS

Metals - Greek: "*metallon*" = mine, quarry

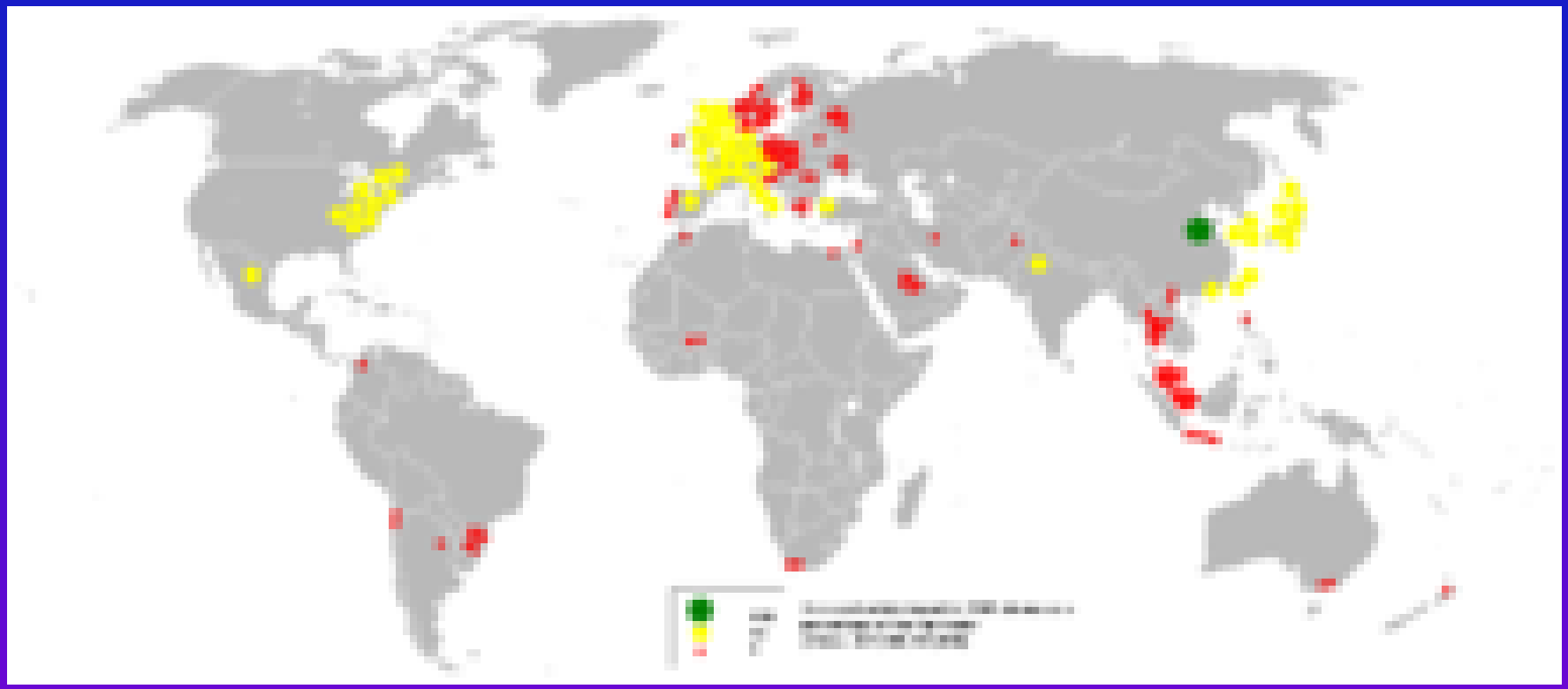
Definition: Materials hard, dense, opaque, shiny, with good electrical and thermal conductivity

Fusible, malleable, ductile

Gold leaf transmits green light

Lithium = least dense; Osmium = densest

Metals and Ore Imports - 2005



Metals in Earth Crust

	Parts per million
Iron	50,000
Copper	70
Lead	16
Tin	2
Silver	0.1
Gold	0.005

Metal Ores and Properties

Prospecting techniques ⇨ exploration ⇨ examination ⇨ mining (surface or subsurface)

Metals are found in ores (mixed with other metals)

Pyrometallurgy or Hydrometallurgy – purifying methods

Melting temperature:

Tin	231°C
Lead	328°C
Silver	961°C
Gold	1063°C
Copper	1083°C
Iron	1538°C – not possible in antiquity

Timeline of materials in human life and technology (1)

29,000 BC – First pottery – Mesopotamia

28,000 BC – First jewelry

3,000 BC – **Copper metallurgy**

2,000 BC – **Bronze** for weapons and armor

1,600 BC – **Crude iron** metallurgy – Hittites

1,300 BC – **Steel** invented (iron + charcoal)

1,000 BC – Glass invented – Phoenicians

1,000 BC – **Pewter** used in China and Egypt

1,000 BC – Vegetable dyes – Phoenicians

50s BC – Glassblowing - Phoenicians

Timeline of materials in human life and technology (2)

3rd Cent. – **Cast iron** – China

671 CE – First missile weapon ("Greek fire") – Byzantium

8th Cent. – **Porcelain** invented – China

1000 – Gunpowder invented – China

1340 – **First blast furnaces - iron production** – Liège, Belgium

1540 – First book on metallurgy – *Della Pirotechnia* – *V. Biringuccio*

1555 – *De Re Metallica* – G. Agricola - Mining, metallurgy

1590 – **Glass lenses** – Netherlands. Antonie van Leeuvenhoek

Father of Microbiology (1632-1723) made first microscope

1664 – **Water pipes of cast iron** - Versailles

The Fertile Crescent in Mesopotamia

Assyria 2500 – 612 BC

The Assyrian kingdom was well organized

Major source of **metal ore,** as well as **lumber**

The priesthood became a major power in the Assyrian society

Long wars fought that helped build Assyria into a warrior society

Social position of women was lower than in the neighboring societies.

Assyria was open to homosexual relationships between men

Assyrian domination spanned from the Caucasus Mountains in the north to Egypt, Libya, and Arabia in the south, and from Cyprus in the west to Persia and the Caspian Sea in the east

Decline due to civil wars and **political instability**

Assyria conquered by Alexander Macedon in 322 BC

The Akkadian Empire and the direction of its military campaigns

Akkadian Empire and Sargon of Akkad (2334–2279 BC)

Trade extended from the **silver mines** of Anatolia to the **lapis lazuli** mines in modern Afghanistan, the **cedars** of Lebanon, and the **copper** of Magan

Consolidation of the city-states of Sumer and Akkad ⇨

Growing economic and political power

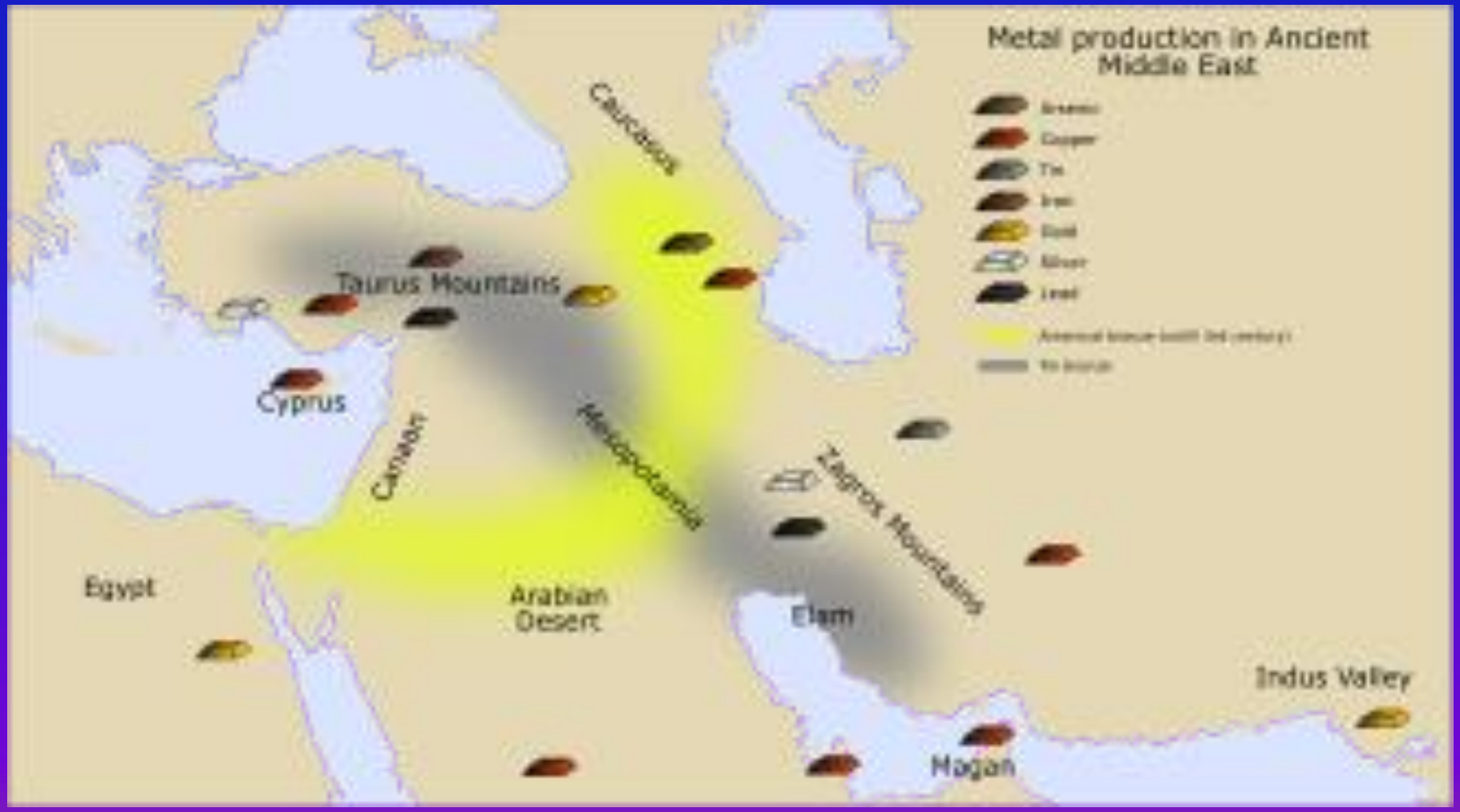
The empire's breadbasket was the rain-fed agricultural system of Assyria and a **chain of fortresses** built to control the **imperial wheat production**

Many cruel battles

Sargon: “God of Akkad” ⇨ destruction of Akkad

Resources ⇨ Trade ⇨ Dominance

Metal Production in Ancient Middle East



Mycenaean Civilization

Innovations in: Engineering, Architecture, Military infrastructure

⇨ **Metal work**, defensive walls

⇨ The **script** = first written record of the Greek language

Gold ornaments

Homer's *Iliad* written in 8th cent. BC

Extensive trade and political influence in Asia Minor (Hittites)

Well-defined three classes:

- King and his court
- People
- Slaves

MESOAMERICA

6000 BC - the early inhabitants of Mesoamerica were domesticating plants

Barley and wheat cultivated

All regions of Mesoamerica cultivated the base crops of **maize, beans, and squashes**

All Mesoamerican cultures used stone age technology

c.1000 AD **copper**, **silver**, and **gold** were worked

Mesoamerica lacked draft animals. **Did not use the wheel,** and possessed few domesticated animals

The principal means of **transport** were on foot or by **canoe**

1500 BC – 1697 CE – Mesoamerica – Olmec, Maya, Zapotec

OLMEC – Southeast Mexico (Veracruz and Tabasco)

Well-watered alluvial soil ⇨ **High soil productivity** ⇨ Rich class

The elite class demanded the production of the symbolic and sophisticated luxury artifacts

Luxury artifacts made from materials such as **jade, obsidian, magnetite (iron oxide)** ⇨ extensive trading network in Mesoamerica

Colossal heads and **jewelry**

- Bloodletting
- **First writing** 900 BCE - 650 BCE
- The concept of **zero**
- **Calendar**

Decline caused by earthquake

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ALLOYS

Mixture of two or more elements in which the main component is a metal

Modifying the properties for a desirable effect: **Harder, non-corrosive, luster, color, cost**

Alloys: **Bronze, brass**

Hundreds of alloys have been produced

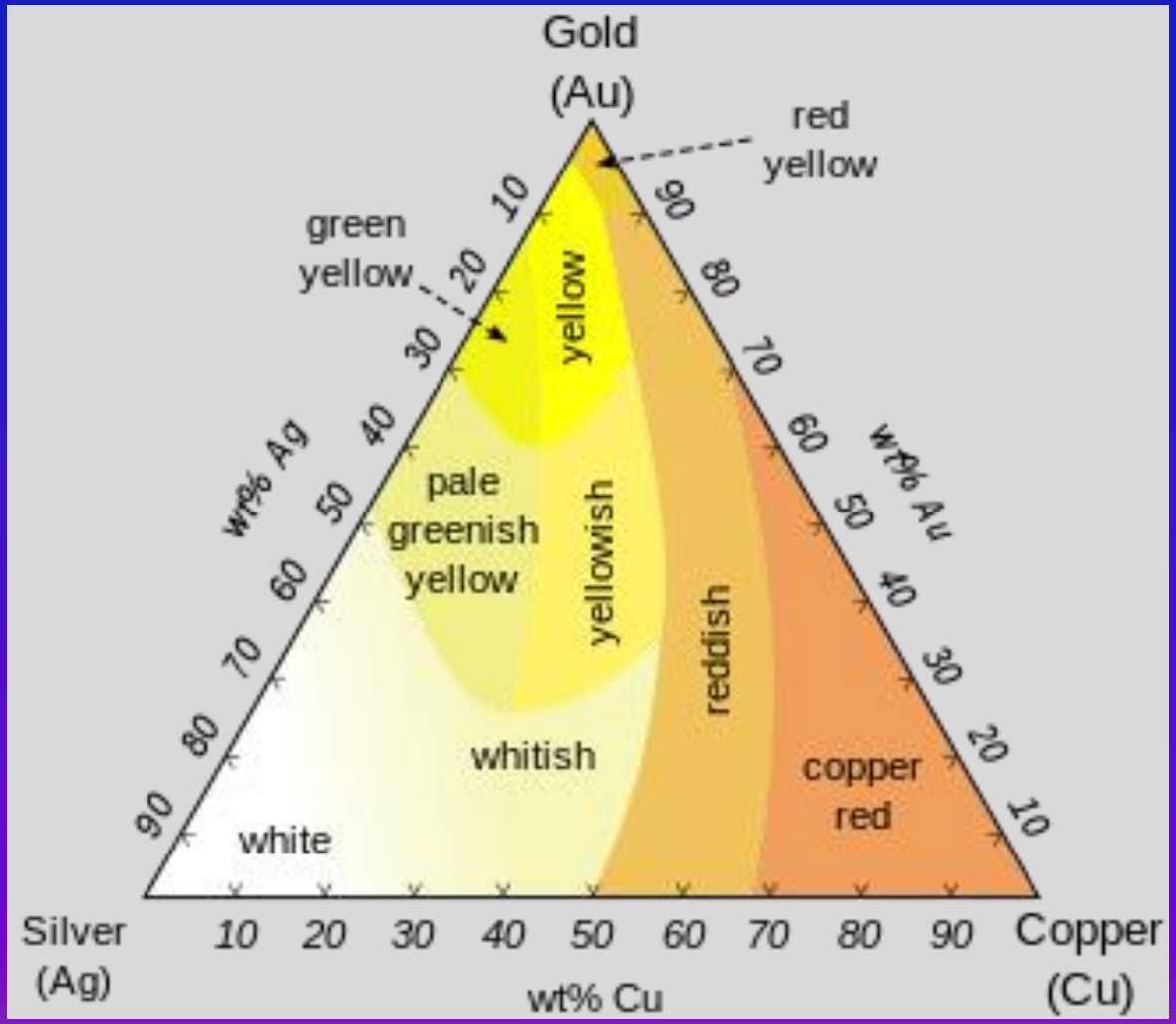
Alloys of iron: Steel, stainless steel, cast iron, tool steel

Cast iron: iron + silicon

Stainless steel: carbon steel + chromium, nickel, molybdenum

High strength-to-weight: Alloys of aluminum, titanium, magnesium

Alloys for Different Colors of Gold



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Noble Metals

Gold, silver, platinum, palladium, rhodium, iridium, osmium, rhutenium

Precious metals: Rare

Do not oxidize

Uses: Investment, art, jewelry, medicine, dentistry

GOLD (Au = Aurum)

A Gold Nugget

GOLD

5000 BC. - **Sumer civilization** used gold for jewelry

4600 BC - **Oldest thesaurus of gold** – Lake Varna, Bulgaria

2800 BC - Egypt **first miners of gold** in Nubia – gold for international trade

610 BC - Coinage in Lydia (Asia Minor)

1091 CE - China – First to introduce **gold coins**

Roman empire 25 BC - 106 CE: Hispania and Dacia (Rosia Montana, Romania)

Gold History (cont'd)

Middle Ages: Gold for coinage and jewelry

Alchemists trying to make gold

European colonization of Americas: Gold shipped to Spain

Legends of El Dorado cities filled with gold

Western Europe fairytales: Bro. Grimm's

Rumpelstiltskin (hay ⇨ gold) and

Jack and the beanstalk (hen ⇨ golden eggs)

Uses: Royal crowns, temples, statues, decorative, rings, valuables

Top prizes: Olympics, Nobel Prize

Gold Sites

Gold as flakes or micro particles or nuggets. Usually found in

Ores - mixed with silver or other metals or minerals

Earthquakes ⇨ gold, water, and silica through faults

Oceans and seas contain gold = 15,000 tonnes (?)

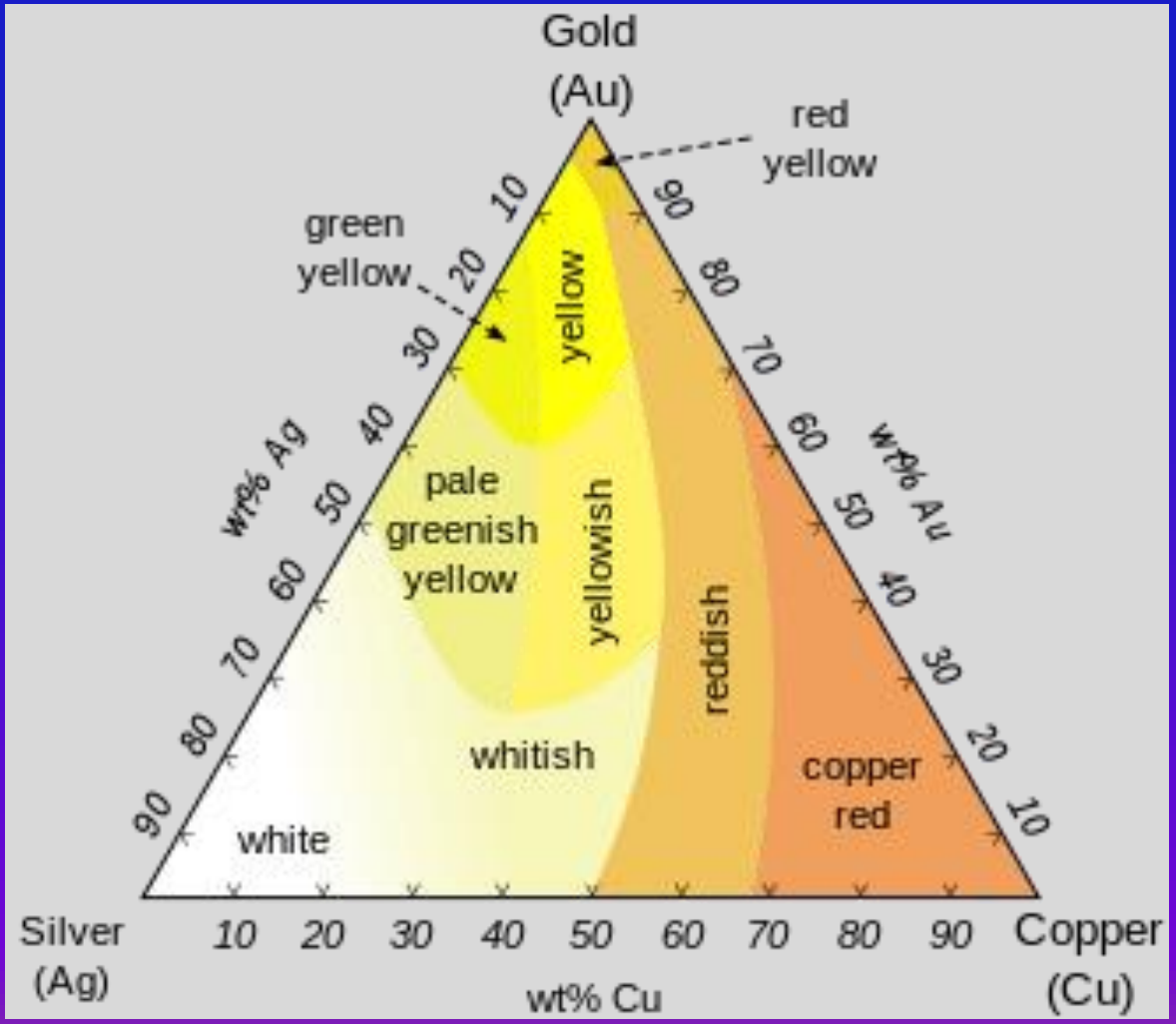
Gold-mining: China, Australia, USA, Russia, Peru, South Africa

- Witwatersand basin in South Africa had the **richest deposits** ⇨ 1886 Gold Rush
- **Boer War** (1899-1902) - Rights of Boer miners and gold in Transvaal and Orange states
- **Gold rushes -** 19th cent. - N. Carolina, California, Colorado, Klondike

Relative size of an 860 kg block of gold ore and the 30 g of gold extracted

Gold malleability – A 5 mm (1/5”) nugget may be expanded by hammering into a 0.5 m^2 (~ 5 sq ft) foil

Different Colors of Gold



Gold Production

Gold Economics

Precious metals measured in troy ounces

One **troy ounce** = 1.09714 regular (avoirdupois) ounces =

31.1034768 g

Karat indicates the gold purity **24 k = pure gold** (0.995)

For many years money had to be backed by gold

1930 - **Gold Standard Act** established gold as international trade standard (USA Dollar = 25 8/10 grains of 90% gold)

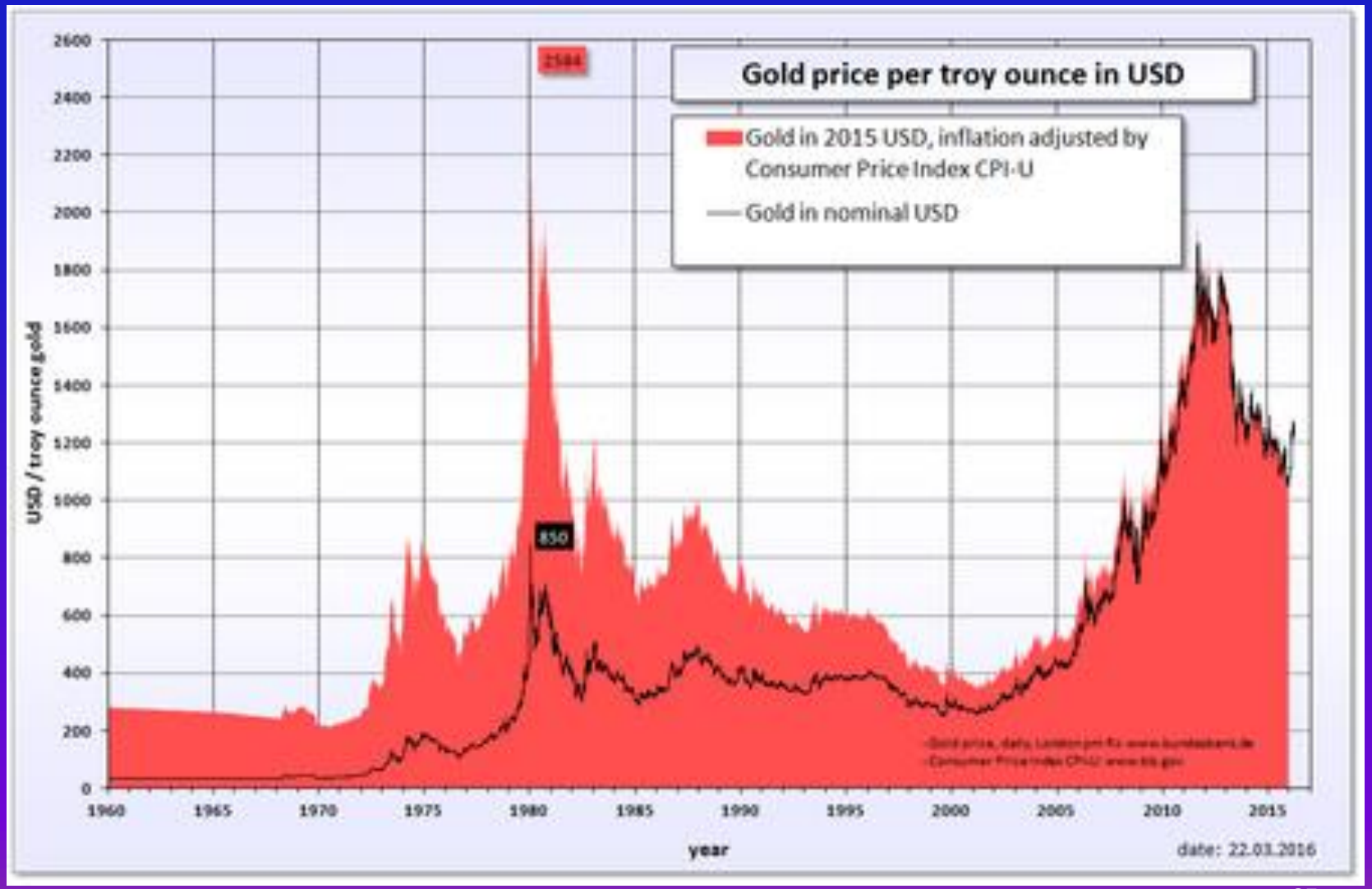
1944 – **Bretton Woods Conference**: **USA major influence**

US dollar = International Standard. No more gold standard

Price fluctuated. Since 1975 gold price depends on free market

Inflation and bear or instable markets increase its price.

Gold price per troy ounce - 1940-2015



Mycenaean Gold Earing – 1600 BC

Mask of Agamemnon – 1600 BC

National Archeological Museum, Athens

Funerary Mask of Tutankhamun c.1325 BC

Gold bullion

The Largest Gold Bar – 250 kg
Toi Museum, Japan

More About Gold

Toxicity: Gold salts are toxic to liver, kidneys, skin (Chrysiasis)

Drinks: *Danziger Goldwasser* - flakes of gold are inert

Medicine: Much used in the past for treatment of tuberculosis– ineffective

Some gold salts have been used in the treatment of rheumatoid arthritis

Symbolism: "Gold standard", "golden rule", "golden age", "golden years"

Wedding rings – **eternal vows**

SILVER (Ag = Argentum)

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Native Silver

SILVER - History

4000 BC - Separated from lead. One of the 7 metals of antiquity.

1500 BC – Egypt – Silver more expensive than gold

700 BC – Kingdom of Lydia (Asia Minor) **coins** of silver alloy with gold (*"electrum"*)

Silver sources: Phoenicians - Spain, Greeks - Laurium, Romans - Sardinia

Silver in the money of many nations in Europe, China, India, Japan

Pound sterling of UK (£) = **Sterling silver**

In many languages the word "silver" = money

19th cent. - Much silver mined in Americas

1947 - Most coins made of cupro-nickel

1970 - Last circulating silver coin (US half-dollar)

Silver - Uses

More abundant than gold. 94%-pure = “0.940 fine” **sterling silver** (0.925)

Old use: currency, ornamental, silverware, jewelry, coins and medals

Modern use: Solar panels, photo film, X-ray film, jewelry, (plated with a coat of .999-fine Ag), tableware, silverware. Antiseptic (silver nitrate)

Best electrical conductivity

Silver compounds - Silver + oxygen + hydrogen sulfide = **silver sulfide (tarnish)** + H_2O

WW2 - Electromagnets for enriching uranium - Manhattan Project

Silver in Technology

Solar energy - Photovoltaic panels

2015 - 100,000,000 oz. used in solar energy

Air Conditioning - Mirror-like panels on buildings

Electrical conductivity - Highest of all metals

Water purification - Eliminates the need for chlorine

Dentistry - Alloy with mercury for dental fillings

Telescopic mirrors - for thermal or infrared telescopes

Windows - “Sputtering” silver is applied to glass ⇨

high-performance insulated glazing.

High-quality musical instruments – Best flutes

Silver production

Silver bowl, Persia, 6th century BC

Silver 1000 troy ounce (~31 Kg) Bullion Bar

Silver Solar Panels

Canada's Maple Leaf 1 troy ounce Silver Bullion Coin

PLATINUM (Pt)

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PLATINUM

16 cent. - Spaniards found it in Mexico but thought that it was impurity of gold and discarded it.

Spanish "*platina*" = "little silver"

1748 – Antonio de Ulloa discovered platinum in Colombia

Rare element – major precious metal

Dense (heavy), malleable, ductile, highly unreactive

Mined in South Africa ⇨ 80% of world production

Alloy with palladium, rhodium, iridium, osmium, and ruthenium

PLATINUM

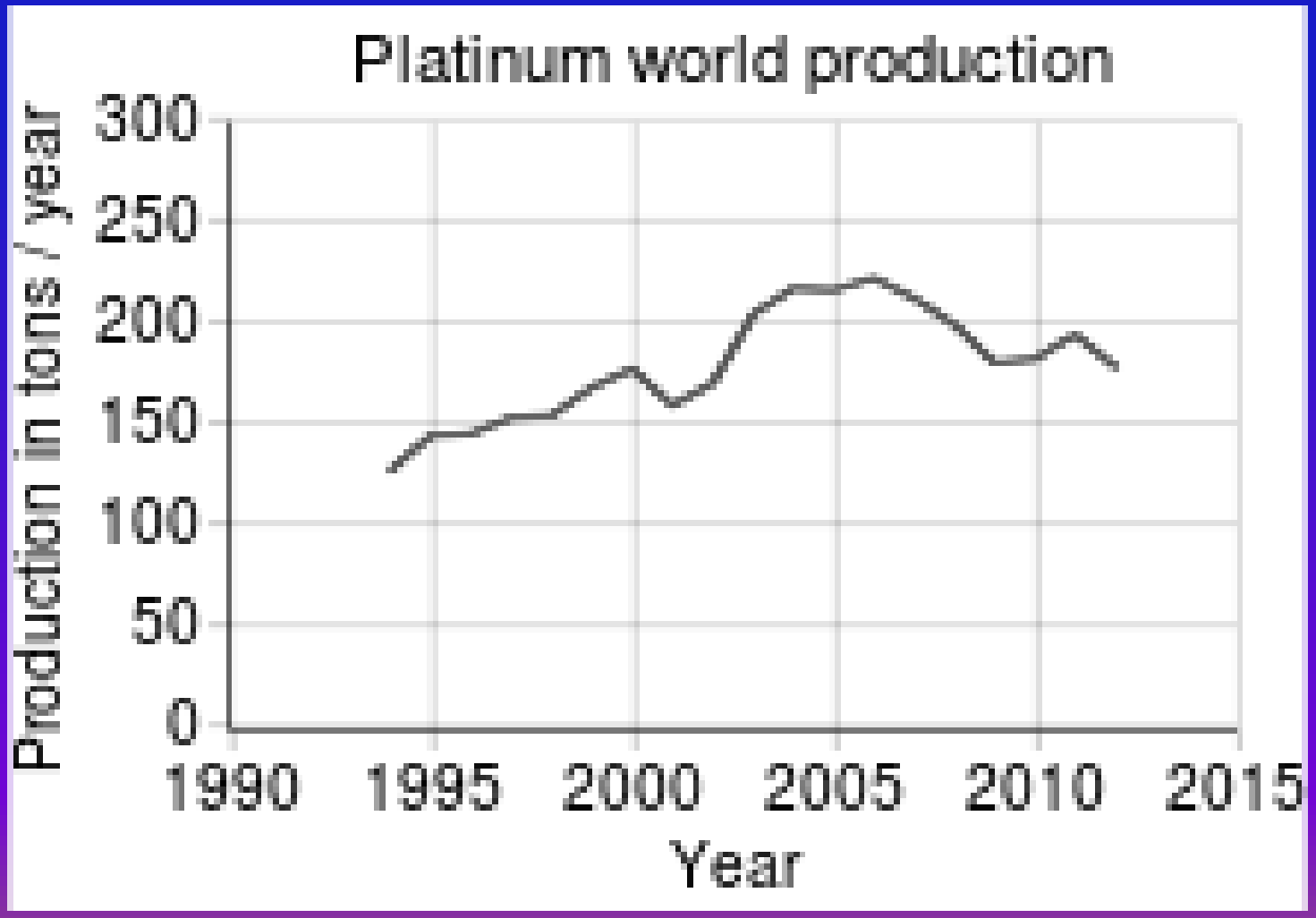
Uses: Jewelry

Catalyst for auto and industrial plant emissions

Organic chemicals

Cancer medications

Platinum World Production



1,000 Cubic Centimeters of 99.9% Pure Platinum, Worth About US $696,000 at 29 June 2016 Price

COPPER (Cu = Cuprum)

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COPPER

Discovered ~ 9,000 BC in 99.9% pure form

Found by serendipity - “Some stones” being fired

melted and new objects could be cast

Replaced stone tools: crude knives and sickles ⇨

The **“Chalcolithic Age” or “Copper Age”**

4000 - 1000 BC – “Old Copper Complex” of the

Western Lakes - copper 99% pure

Old use: Spearpoints, tools, decorative objects

2700-1200 BC - The Minoan Civilization

A Minoan copper ingot

The Snake Priestess

Native Copper

Timeline of Copper

5,000 BC - World oldest copper smelting - Rudnic Mt. (Serbia)

3800 BC - Copper mines in Sinai peninsula

3000 BC - Ores of copper in Cyprus and in Cornwall -

Phoenicians bring copper to Judea for the Temple of Solomon (~1000 BC)

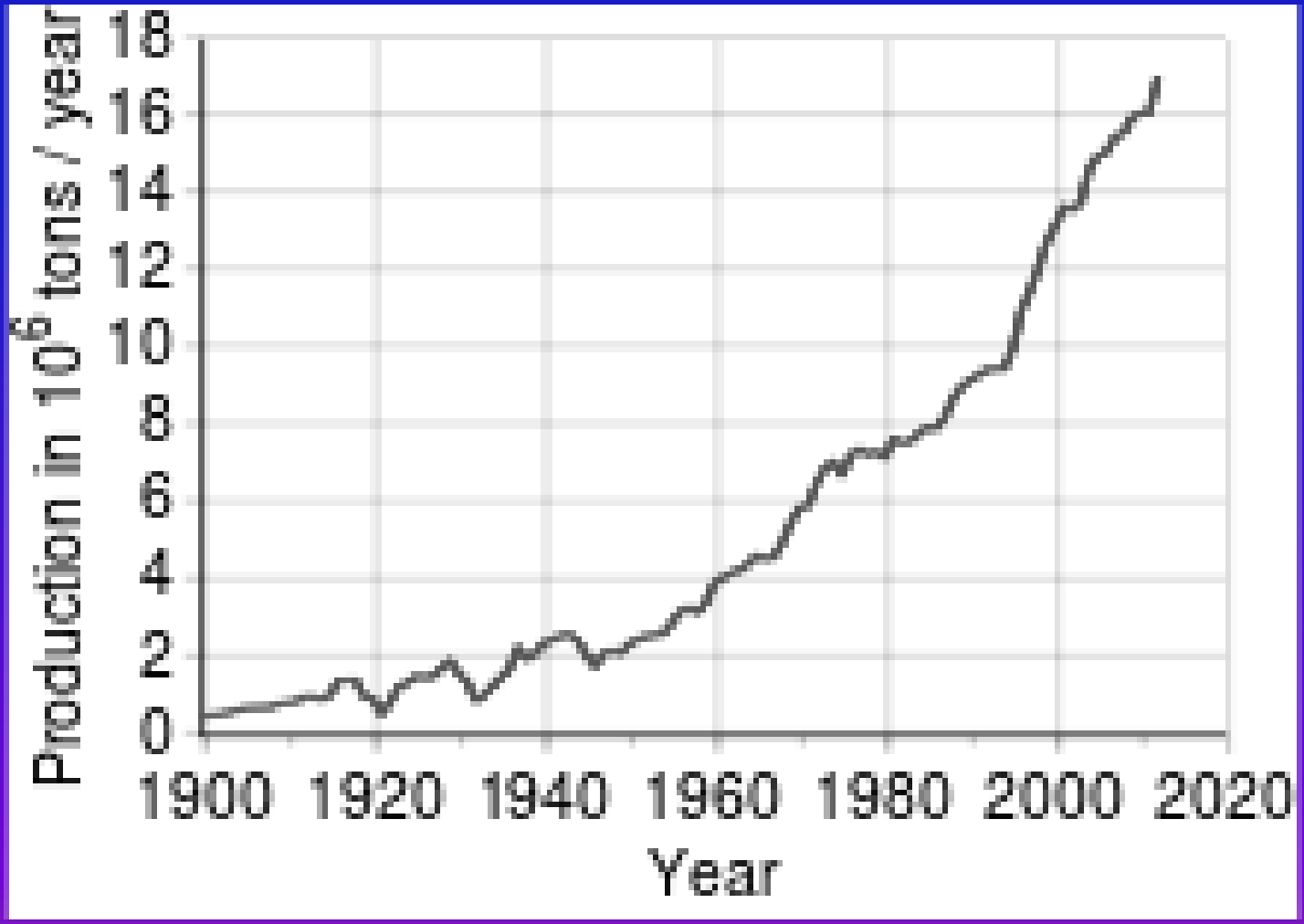
2800 BC - Ores of **copper and tin** ⇨ harder metal ⇨ **Bronze Age**

2800 BC - Sinai ⇨ Sumer ⇨ Anatolia ⇨ Europe ⇨ Indus valley

2500 BC ⇨ China (Shang dynasty) - 1500 BC

2750 BC - Copper water pipes in a temple in Egypt

World Production of Copper



Old and New Copper

ROYAL OBSERVATORY – EDINBURGH, SCOTLAND
COPPER OF 1894 AND OF 2010

LEAD (Pb = Plumbum)

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Lead nuggets

LEAD

Great availability (16 ppm). Found in ore ***(galena)***

Mined since 7000 – 6500 BC

Ancient civilizations - Various uses: Cosmetics, currency, contraception

Mined in China 1000 BC

Rome great producer of water pipes. Lead intoxication (?) ***(saturnism)***

16th cent. CE - Important for the **Gutenberg printing press**

Gun bullets

Whitened face ⇨ **Lead poisoning** ⇨ Lead teeth ⇨ Lead intox.

1621 - Lead mining in Virginia

1841 - Lead mining in Australia

Lead Uses

Production increased 31%

Primary by extraction & by recycling

Lead-acid batteries – Environmental hazards:

Vernon, CA

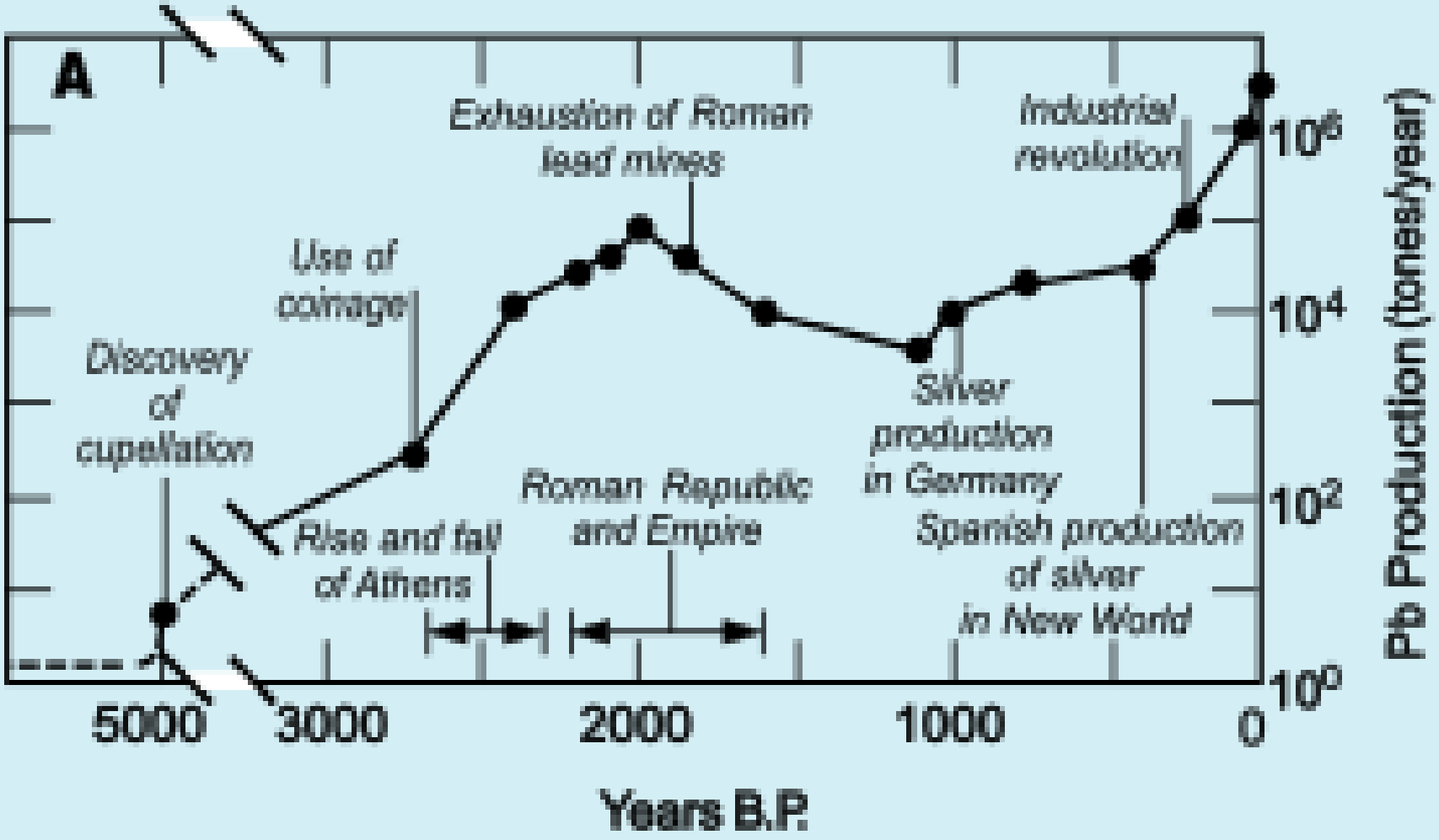
Alloys of copper + lead

Construction industry

Shielding from radiation – Radiation therapy rooms

Ballast keel of sailboats

Lead production



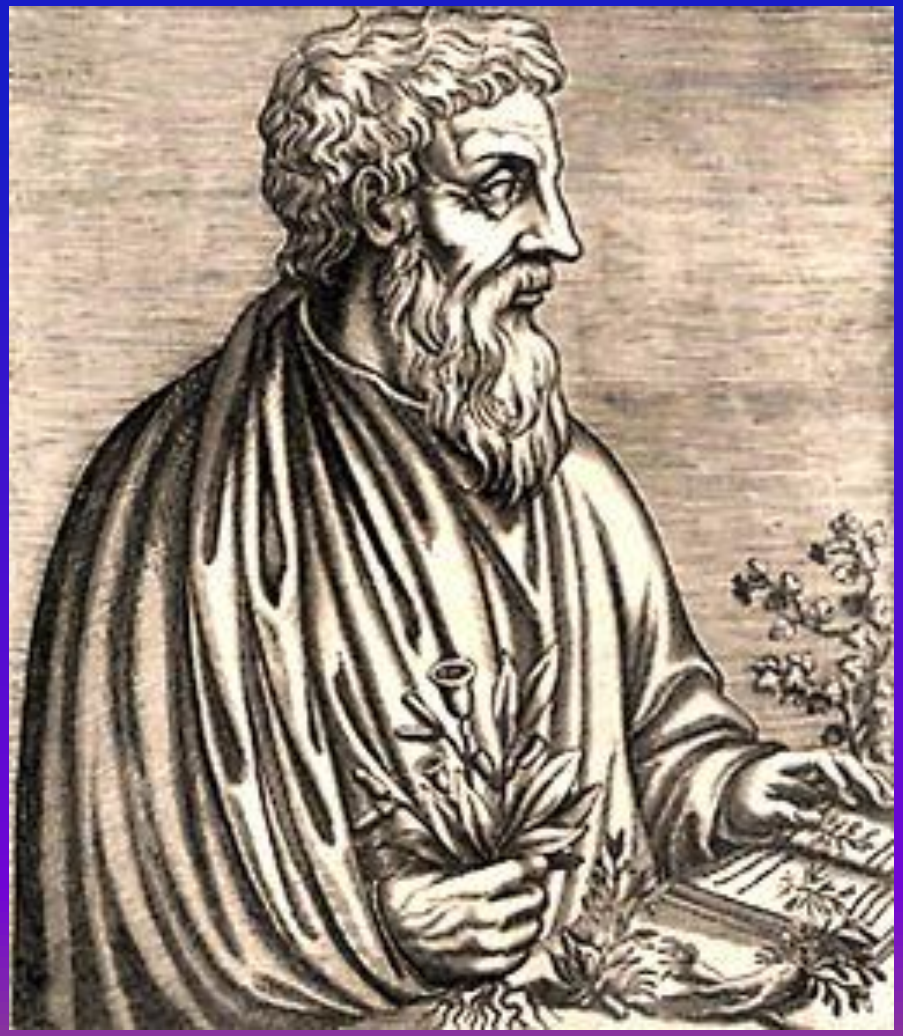
Water lead pipes
Emperor Vespasian Villa - Rome

Multicolor Lead-glaze Paint
Tang Dynasty 8th Cent. CE

Elizabeth I of England
White Powdering of Face and her Cause of Death

Lead Blocks Used for Radiation Protection

Dioscorides (Greek physician) noted lead's effects on the mind (1st Cent. CE)



LEAD POISONING

Lead poisoning by air, dust, water, food

Brain is the most sensitive

10% of cases -intellectual disability

Memory problems, anemia, sterility

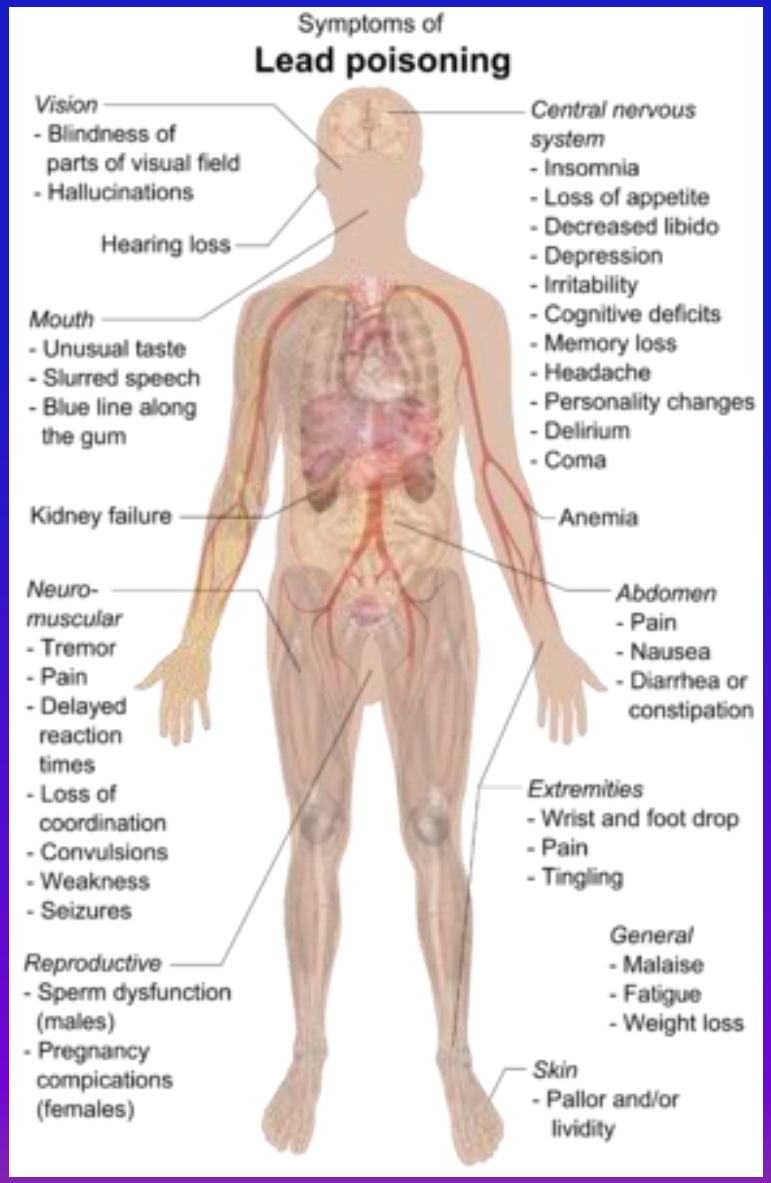
Various multi-system symptoms

Children more affected (by ingestion of paint)

Diagnosis: Gums colored blue and anemia

Treatment: Chelating agents

Symptoms of Lead Poisoning



General

Central nervous system

Vision

Neuro-muscular

Intestinal

Kidney failure

Anemia

Reproductive

Skin

Testing kit for lead detection
The swab turns red in lead presence

The Timeline of Flint Water Crisis

Feb. 2015 - Oct. 2015 - **high levels of lead: 104 ppb (threshold is 15 ppb) = HHS - Violation of the Safe Water Drinking Act**

Oct. 2, 2015 - State officials publicly announce **high lead content in drinking water of Flint**

Dec. 14, 2015 - Flint Mayor Karen Weaver: State of emergency

Jan. 16, 2016 - President Obama: Emergency Declaration

Apr. 20, 2016 - Michigan AG: charges against DEQ employees

June 2, 2016 - DEQ Chief Deputy Director Jim Sygo: *"Flint water crisis 'was overplayed'"*

June 2016 - Gov. Snyder: Apologies to citizens: $28 Mil. for medical supplies; $30 Mil. for water bills; + $165 Mil. for water pipes replacement

Prof. Mard Edward from Virginia Tech:

“Authorities' actions expose a new level of arrogance and uncaring that I have never encountered”

The Story of *Exide Technologies*

Manufacturing and Recycling of Automotive and Industrial Batteries – USA, Pacific Rim, Europe, and Australia

Vernon, CA - 2015

Exide Technologies
Batteries Recycling Plant, Vernon, CA

JOSE GOMEZ at his home in the 1100 block of South Hicks Avenue in East L.A., which is being tested for lead contamination. Crews sample soil from about 15 locations on each property and analyze them for lead.

'SOMETHING IN THE SOIL'

Brain-damaging lead levels near Vernon battery plant were as much as 100 times above health limits

LA TIMES MARCH 11, 2015

Exide Technologies
Batteries Recycling Plant, Vernon, CA

LA TIMES MARCH 11, 2015

Lead Economics, Health, and Politics

Industrial Revolution – Increased demand for plumbing, painting, and gasoline additive

Lead paint – Children lead intoxication

Lead more dangerous if **fumes are inhaled**

19th Cent. – **Lead causes mental disorders**

Lead causes blindness

1921 – Tetraethyl lead added to gasoline to avoid "knocking". Phased out

1930-2000 – Enormous US and European legislation on high lead blood levels ↓ to 2% of population

TIN (Sn = Stannum)

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Known Tin Deposits Exploited in Ancient Times

TIN

- **First alloy to make bronze**
- Discovered ~3000 BC - **Copper + tin was**
  - **harder ⇨ Bronze Age**
- Found as **Cassiterite** mineral in river banks
- Soft, malleable, ductile
- Melts at low temp. 232°C (450°F)
- Not easily oxidized in air, not toxic ⇨ food packaging in tin cans

TIN ORES

Yunnan province - China

Malaysia peninsula

Peru

Devon, Cornwall – England

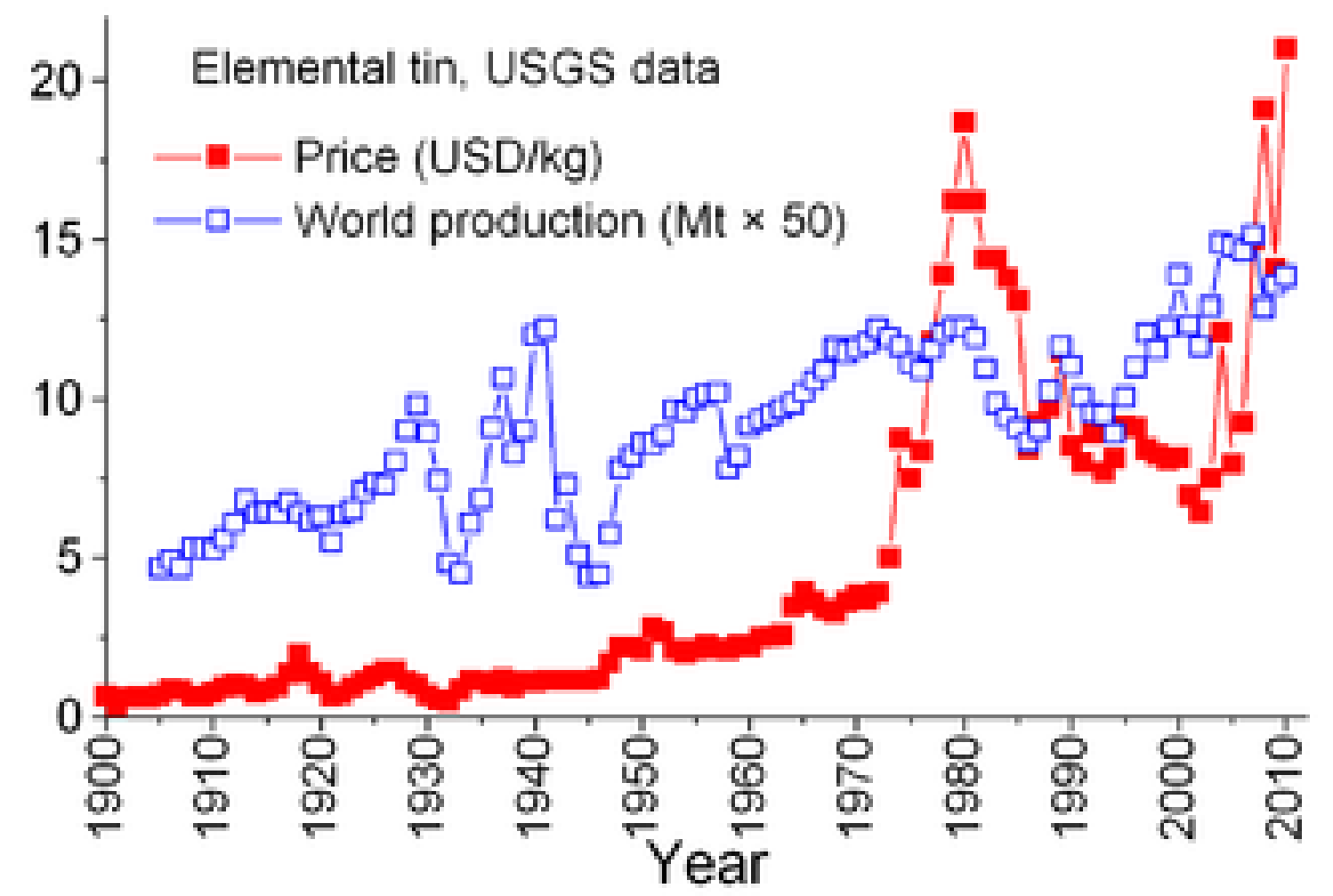
Brittany – France

Central Europe – Erzgebirge

Spain and Portugal

Central Africa

World Production and Price of Tin



COPPER ALLOYS: Bronze, Brass, Pewter

BRONZE

Bronze Age Timeline

The Bronze Age started 3,500 - 3,000 BC (after the copper age called the "**chalcolithic period**")

Casting of metal ⇨ **Metallurgy is born**

- Mesopotamia c. 4500 BC
- Egypt c. 3500 BC
- China c. 2800 BC
- Central America c. 600 CE
- West Africa c. 900 CE

BRONZE

Italian: *bronza* (bell) ⇨ French: *bronze*

Bronze is an **alloy of copper + 12% tin**

Various alloys ⇨ hardening the copper

Sumer, India, China and Japan - 4000 BC

Followed by the Iron Age (~1300 BC)

- Harder than iron; does not rust
- Iron easier to find and process but requires higher temps.
- Disruption in tin supply (?)

The Bronze Age of China (2000 – 771 BC)

Started under the Shan dynasty - Henan province

Imported technology or invented locally (?)

Bronze artifacts: Utilitarian, rituals, tools, weapons

Taotie motifs (animal-like masks)

Jade carving

Irrigation

Bronze Uses

Tools, weapons, armor, building materials

more durable than copper

Sculptures, bronze statues

Works of high art

Musical instruments: Bells, cymbals, stringed instruments: bass, piano, harpsichord, guitar

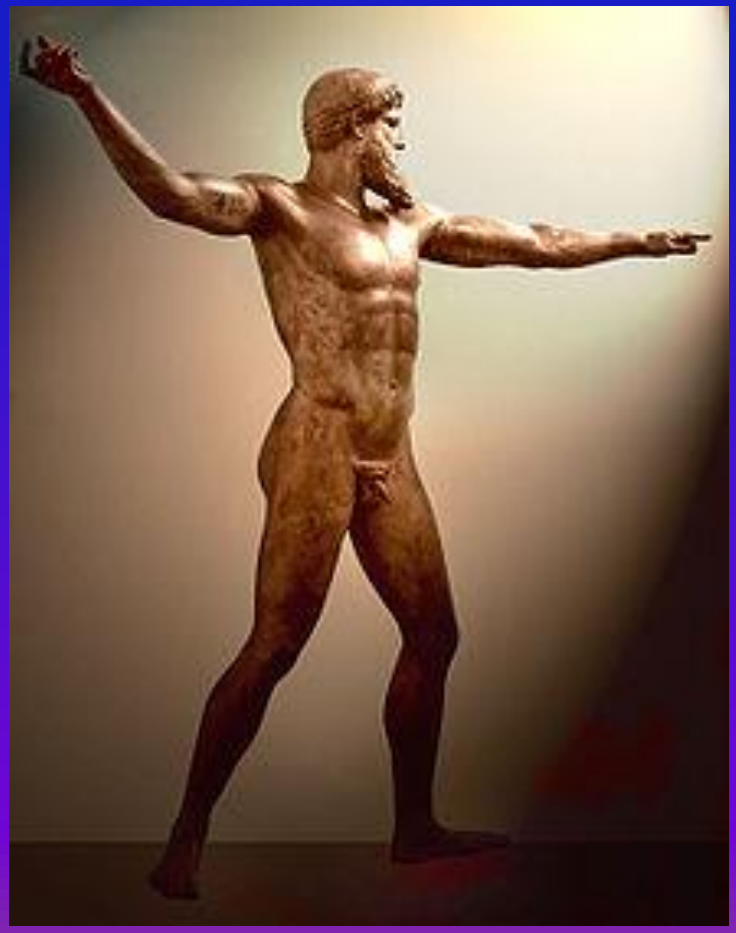
Coins and medals

Chinese Bronze Age – Shan dynasty 2500-1800 BC

Mycaenean Civilization Swords and Cups (1600 – 1100 BC)

Hittites – Masters of Metal Work in the Bronze Era (1600 – 1100 BC)

Bronze Sculptures
The Artemision Bronze c. 460 BC
The National Archeological Museum of Athens



Roman cuirass, Grenoble, France

Bronze relief
Wawel Cathedral, Krakow, Poland

Modern Bronze Statues
Degas' Dancers)

BRASS

BRASS

Alloy of copper + zinc (zinc identified only in 1746)

Several alloys in use

Bright gold-like appearance

Higher malleability than copper or zinc alone

Low melting point

Easy to cast

Antimicrobial (?)

90% is recycled

Brass Uses

Roman empire: Coinage

Medieval Europe: Religious objects

Metal of choice for musical instruments: **“the bass section”** (trombone, tuba, trumpet, cornet, horn)

Decorative objects

Household items

Brass – 7th Cent. Persian Ewer

Baptismal Font – St. Bartholomew's Church Liège, Belgium, 12th Cent.

Brass Cracking by Ammonia

PEWTER

PEWTER

Malleable **alloy. 85-99% tin** + **copper + antimony + bismuth**

Low melting point 170-230°C (338-446°F)

Used in the Near East, c.1450 BC in Egypt

Many household vessels in the Middle Age, **mugs**

Replaced by porcelain, pottery, and glass

Tin + 15% lead - household items - less used today

Pewter vessels

END OF LECTURE # 4