SWEAT OF THE SUN, TEARS OF THE MOON

Gold funerary mask from La Tolita, Ecuador.
With almond shaped eyes and recessed pupils. Probably dates from about 200 A.D.
Museo Casa de la Cultura, Guayaquil, Ecuador
Metals in Pre-Columbian Latin America

- Metals were highly appreciated by Pre-Columbian cultures. Gold and silver were considered of divine origin.
- Color, shine and sound were main reasons to prefer this materials for ornaments and sacred artifacts.
- Copper and bronze were later used to produce tools and weapons but never replaced the use of stone and obsidian.
Stages in the evolution of Pre-Iron Metallurgy

Four stages are recognized, Patterson 1971.

I. Native Metals were hammered and annealed. Gold, copper and silver were the first metals used because they were obtained in native state.

II. Reduction, smelting, melting and casting was achieved using oxide ores.

III. Use of alloys such as bronze

IV. Smelting of sulfide ores

Iron and steel production was never achieved in pre-Columbian LA
Times of Metallurgical development in the world

Euro Asiatic:
7800 B.C. TO 1200 B.C.
Stages 1, 2, 3, and 4

Great Lakes: 4500 B.C. to 1000 A.D.
Stage 1

Latin America: 600 B.C. to 1500 A.D.
Stages 1, 2, 3, and 4?

The three areas of independent formative metallurgical development and their likely sources of ore.
Geology and the use of ores, Stage 1

The use of minerals depends on the availability and the technology.

• Native metals were the first used, concentrated at surface in the zone of leaching.

• Placer concentration by erosive processes. The metal is pure enough to be used but not very abundant.
Geology and the use of ores, Stage 2

- Oxides and Carbonates: concentrated in the Oxidation Zone, sometimes exposed or mined without much difficulty. Smelting is a simple reduction process.

Cuprite + Carbon monoxide = copper + CO_2
CuO + CO = Cu + CO_2
Stage 3, use of alloys: Bronze

- Alloy: a substance that is a mixture of two or more metals, or of a metal with a nonmetallic material.
- Bronze: is an alloy of copper, tin, arsenic, phosphorus, and small amounts of other elements.
- Bronzes are harder than brasses (copper and zinc).
- Most bronzes are produced by melting the copper and adding the desired amounts of arsenic, tin, phosphorous and other substances.
- Most of Pre-Columbian cultures were in the Bronze Age at the time of conquest. It is worth note that the use of metals was not widespread and stone artifacts and weapons were used extensively.
Geology and the use of ores

Stage 4

- Sulfides formula: $\text{Metal}_x \, \text{S}_x$
- Sulfides: The zone below the water table is the sulfide zone.
- Sulfide zone deposits have a high metal content but are harder to mine: deeper and below the water table. It requires pumping or draining the water, and proper ventilation.

- Smelting of sulfide ores involves two stages:
  1. Roasting: elimination of sulfur by oxidation
     $2\text{CuS} + 2\text{O}_2 = 2\text{SO}_2 + 2\text{CuO}$
  2. Reduction by carbon monoxide
     $\text{CuO} + \text{CO} = \text{Cu} + \text{CO}_2$
• Plate tectonics as a very useful model
  
  • Magmas related to subduction zone form the mineralization.
Gold

- Metallic chemical element, one of the transition elements, chemical symbol Au.
- In jewelry, its purity is expressed in 24ths, or karats: 24-karat is pure, 12-karat is 50% gold, etc.
- 24 K Pure; melting point: 1945°F, 1063 °C; Specific Gravity 19.32 (measure of weight per volume compared to water)
- Gold is widely distributed in all igneous rocks, usually pure but in low concentrations; its recovery from ores and deposits has been a major preoccupation since ancient times.
- The world's gold supply has seen three great leaps, with Christopher Columbus's arrival in the Americas in 1492, with discoveries in California and Australia (1850-75), and discoveries in Alaska, Yukon and South Africa (1890-1915).
- Pure gold is too soft for prolonged handling; it is usually used in alloys with silver, copper, and other metals.
This indestructible metal is completely recyclable and virtually immune to the effects of air, water, and oxygen. These properties include:

RESISTANCE TO CORROSION
Gold is the most non-reactive of all metals. It is benign in all natural and industrial environments. Gold never reacts with oxygen (one of the most active elements), which means it will not rust or tarnish.

DUCTILITY AND MALLEABILITY
Gold is the most ductile of all metals, allowing it to be drawn out into tiny wires or threads without breaking.
Platinum

- Metallic chemical element, chemical symbol Pt, atomic number 78.
- A very heavy (specific gravity 21.4), silvery-white precious metal, it is soft and ductile, with a high melting point (3,216°F, or 1,769°C) and good resistance to corrosion and chemical attack.
- Platinum is usually found as alloys of 80-90% purity in placer deposits, or more rarely combined with arsenic or sulfur.
Placer deposits = river deposits

Sedimentary Concentration Mechanisms:

Sedimentary processes involve transport and deposition:

- Sand and gravel from old river channels, glacial deposits, deltas.
- Placer deposits concentrated weathering-resistant and heavy minerals (gold, silver, diamond, garnet etc.)

Gold nugget, California (2 cm)  Placer diamonds, Namibia (3 cm across)
Placer Deposits

- Most placer gold occurs as grains the size of silt particles, the “gold-dust” of miners.
- Sometimes, the gold placer is larger and is called a nugget.
- Many heavy, durable minerals other than gold also form placers (platinum, copper, tinstone, diamond, ruby, and sapphire).
Pre-Columbian Mining Technologies

- Placer Mining
- Hard Rock Mining
Placer Mining in Pre-Columbian times

- Panning: early records indicate that gold and platinum were obtained by this process.

- Riffles – stone or wood structures constructed across a stream, collecting the nuggets and grains carried by the water.
Hard Rock Mining in Pre-Columbian times

Extraction of native metals from veins in hard igneous rocks: silver, gold, copper.

- Silver mines in Mexico: Pachuca, Hidalgo, Tepic, Taxco.
- Andes native metal mines at Porca (silver), and La Paz (gold).

Actual artisan mining in Bolivia
Mining in Pre-Columbian times: ore extraction

Extraction, usually by splitting the rock by fire and rock hammers, scraping the ores with horns or bones and carrying it out in sacks of hide.

Spanish reports (Garcilaso de la Vega) mention Inca mines with depths of 20 to 60 feet and a maximum of 240 feet.

The Inca state controlled the mines and exploited them with a form of forced labor called mita later adopted and enforced by the Spaniards.

Ores were mined for copper, tin, silver, gold and lead.
Copper mining in Mesoamerica

Copper ore sources exploited during 1300 to 1521 A.D.

Hosler, Dorothy 1988
Pre-Columbian Andean Mines, North area

From Lechtman, Heather, 1991
The Production of Copper-Arsenic Alloys in the Central Andes: Highland Ores and Coastal Smelters.
Metal working techniques

- Hammering and annealing
- Smelting: Huayrachinas
- Melting and casting
- Bronze production
- Sintering
**Techniques: Hammering and annealing**

**Hammering** involves only the shaping of the metal without melting. Gold is especially appropriate for using this technique. One ounce of gold can be hammered into a 100 square-foot sheet, and also can be drawn into a wire five miles long.

**Annealing** is a process in which glass, metals, and other materials are treated to render them less brittle and more workable. Annealing consists of heating the material and then cooling it very slowly and uniformly. Annealing increases ductility and lessens the possibility of a failure by relieving internal strains. The process is also called hot working.

Black stone matrix used to make gold ornaments

From Bergsoe, 1937
Techniques

Vessel shaping by hammering

A. First step in shaping a vessel like the one shown in Fig. 39 is to sink the center of a thin sheet of gold in a concavity in the end of a log.

B. Here the metal has been placed over a piece of hardwood, and the first round or "course" of hammering has begun to raise the sides of the vessel.

C. Still in position on the form, the metal is being stretched toward the mouth by hammering.

D. Continued hammering displaces the metal toward the front, where the face will be shaped in high relief.

E. Now on a new form, which would be called a snarling iron today, the bulge or "boss" for the face is being knocked out by repercussion with a springy anvil. The lefthand arrow shows where the form is struck. The righthand arrow indicates the force of repercussion.

F. A wedge is now placed behind a carved wood pattern, and the craftsman has begun to narrow the neck of the vessel at the arrow.

G. The final step: flattening the base of the beaker by hammering over a flat anvil.

Fig. 38. Reconstruction by Dudley T. Easby, Jr., of steps followed in hammering out an effigy beaker like the one shown in Fig. 39. Drawings by Elizabeth K. Easby
Smelting in Pre-Columbian times

Oxidized ores were the most used. In order to produce pure copper, Cu, from copper carbonate, CuCO₃ the atmosphere must be ‘reducing’. That is, be high in carbon monoxide, CO.

Charcoal will burn to carbon monoxide, with sufficient air. This gives CO + CuCO₃ = 2CO₂ + Cu.

The use of huairas was only by the Incas.
Huayrachinas

From Mary Van Buren

It is charged from the top, with alternating layers of charcoal and ore. The molten metal flows out the bottom.
Melting and casting

Once the metal is purified it may be turned into something useful.

From Emmerich, 1965
Both Aztecs and Incas were using this technique.
**Bronze**

- Bronze: is an alloy of copper, tin, arsenic, phosphorus, and small amounts of other elements.
- Bronzes are harder than brasses (copper and zinc), but much softer than iron.
- Most bronzes are produced by melting the copper and adding the desired amounts of arsenic, tin, phosphorous and other substances.

![Figure 23. Curves illustrating the principal ways of hardening metal. The cold-worked arsenic bronzes and tin bronzes were reduced in thickness by 50%. They are somewhat harder than steels that have been heated and allowed to cool naturally. Quenched steels become dramatically harder than either of the bronzes. In relation to air-cooled steels, tin bronzes are only slightly harder than arsenic bronzes (after Smith 1967: fig. 39).](image-url)
Pre-Columbian Bronzes

- Arsenic Bronzes: were produced in the Andes by 850 AD. Arsenic-bearing copper ores are very common in the region. The smelting of those ores produced naturally enriched arsenic bronzes. Batan Grande in Central Peru was a production center of this alloy with 24 furnaces uncovered so far.

- Tin bronzes: first appeared at 1000 AD in south Peru. Both bronzes were produced at the same time to use their different properties. The establishment of the Inca Empire at AD 1500 spread the use of this bronze from Chile to north Ecuador and west Mexico.

- Aztecs were producing bronzes about 1200 AD.

Diagram and photograph of a well preserved furnace, Shimada, Izumi, 1981. The Batan Grande-La Leche

Fig. 6. Distribution of furnaces and inverted urns with charcoal contents in excavation area 4, sector III. Cerro de los Cementerios.
Platinum-Gold Sintering

- Platinum has a very high melting point 1770 degrees Celsius, it was only reached by the technology of the industrial revolution.
- Materials from La Tolita (Ecuador) are made of gold and an alloy of gold and platinum. It was achieved not by melting the metals but by sintering (pressure and heat) applied to fine grains of platinum and gold to form a coherent mass without melting it.
- Sintering was a technique unknown in Europe at that time.

From Bergsoe, 1937
Chronology of metallurgy in the Andes

- 1500-200 B.C. Earliest metals were native copper and gold.
- AD 200-1000 Alloys: copper arsenic bronze.
- AD 850 copper-tin bronze in Southern Peru.
- Copper silver AD 1000
- AD 1500 copper-tin bronze spreads to all Inca Empire.
• About AD 650 Mesoamericans acquire the first metal objects through trade with Ecuador and Colombia via maritime route. Trade of clam shells (*Spondilus*) was very active. The Incas used it for ritual practices, it only lives in warm waters, off Ecuador or areas north of it. This trade led to the adaptation of metal working techniques in Mesoamerica.
Mesoamerica area: Metallurgy

- **Metallurgy Initial Period**
  AD 800 – AD 1200 similar techniques to Ecuador and Colombia

- **Metallurgy Second Period**
  of West Mexican metallurgy (A.D. 1200-1300 to the Spanish invasion) new techniques from these same regional metallurgies were developed, in addition to technical components from the metallurgy of Peru.

- Bronzes with high percentages of tin and arsenic (10 - 12%) to achieve golden and silvery colors.
Pre Colombian Mesoamerica

metallurgy

Plate 1: Period I copper bells from West Mexico cast using the lost-wax method. From the collections of the Regional Museum of Guadalajara, Guadalajara, Jalisco, Mexico.

Plate 2 (right): Period I copper bell from West Mexico cast using the lost-wax method. From the collections of the Regional Museum of Guadalajara, Guadalajara, Jalisco, Mexico.

Plate 3: Period I copper axe from West Mexico. From the collections of the Regional Museum of Guadalajara, Guadalajara, Jalisco, Mexico.

Plate 4 (right): Longitudinal sample from blade tip of a Period I copper axe. Elongated and compressed grains reveal heavy cold work and the extreme tip shows deformation from use (mag. 50x).