

# HIS 2129



Technology, Society and  
Environment since 1800  
(Winter 2014)



# Launching A Revolution

- The modern North American landscape is in great part the result not only of European settlement and technological activity, but also of a form of ecological imperialism not always deliberate or even noticed at the time.
- In addition to new animal and plant species, Europeans brought new diseases to North America and caused a demographic collapse that may have affected the global climate
- European colonialism also enriched Europe and may have driven the first Industrial Revolution, characterized by a shift in energy sources and advances in metallurgy

Bones,  
stones, and  
DNA...

# The Broad Sweep of the Human Story

Scraps of folk  
tales, phoneme  
evolution?

## 50,000 years BP — Invading Asia

*Homo Sapiens* leaves Africa with language, stone tools, fire, boat building skills, and maybe rock art  
Modern humans overrun Europe and Australia

*Cave art:* from  
30,000 to 15,000  
years ago

## 15,000 years BP — Invading America

*Homo Sapiens* tames the wolf and begins the long crossing to North America

Coming out of the last ice age, humans settle down and master useful plants

## 10,000 years BP — Farming

*Homo Sapiens* tames the cat and develops agriculture

Ötzi: ca. 5,300 BP

*History begins:* written records and ruined cities reveal more and more of the past, along with the other resources of the modern investigator

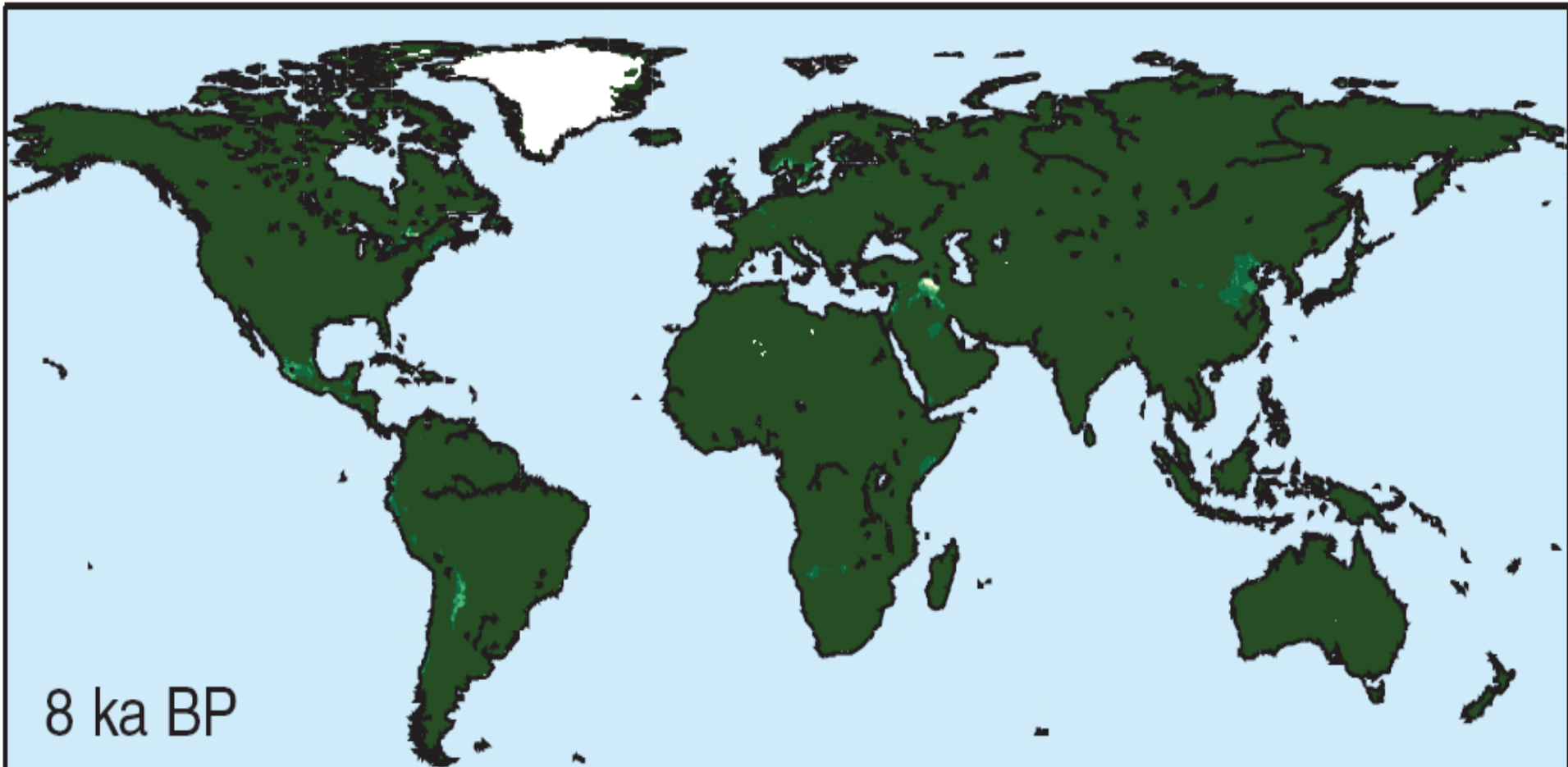
## 5,000 years BP

The oldest named people and places

# The KK model of land use change

(version 10 from 2010, with the deepest green used for the largest amount of natural vegetation cover in each gridcell)

The central assumption of the Kaplan-Krumhardt model is that humans use land more intensively as population increases and land grows scarcer.



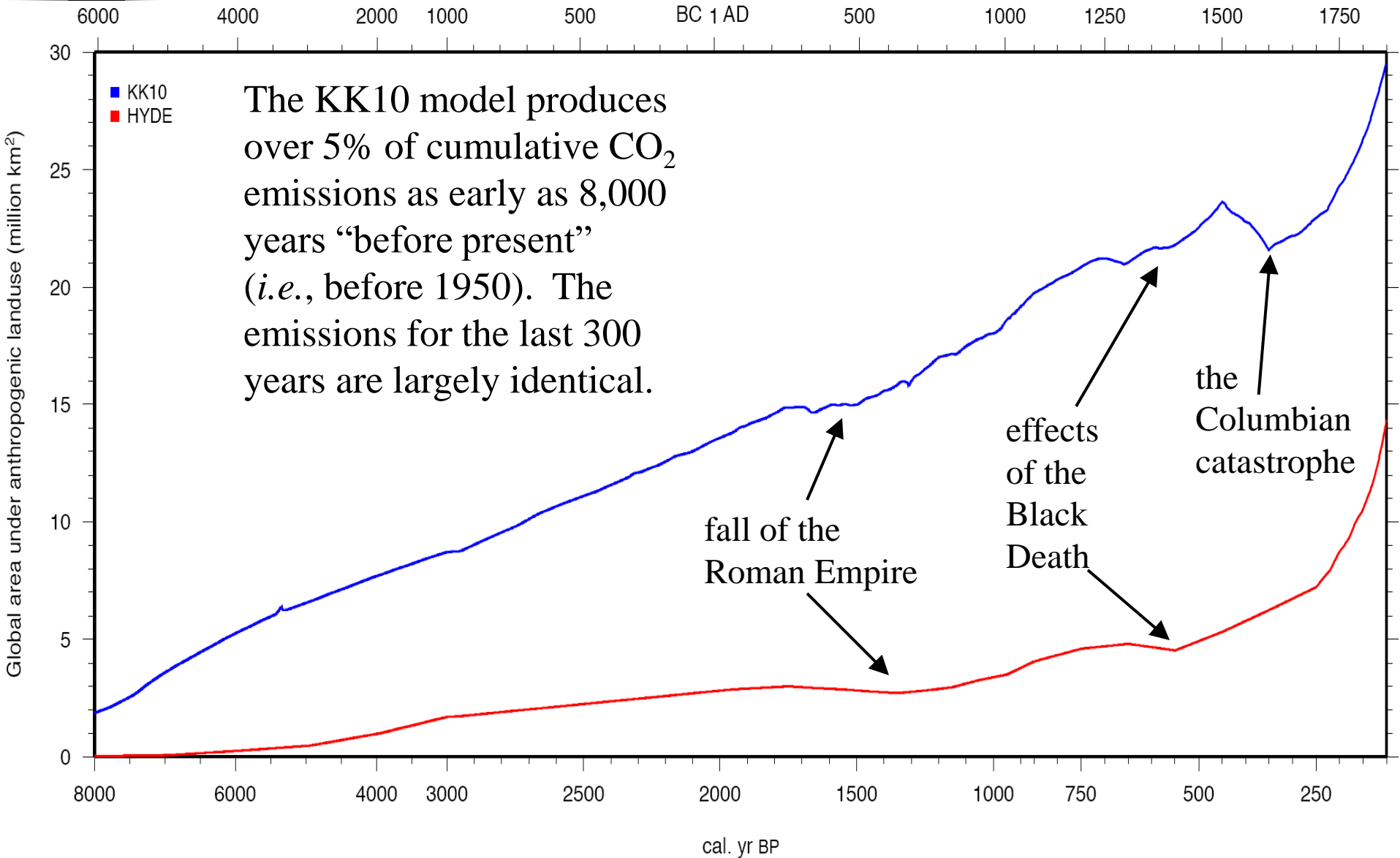
# The HYDE model of land use change

(version 3.1 from 2010, with the deepest green used for the largest amount of natural vegetation cover in each gridcell, using the values for crops and pasture)

The Historical Database of the Global Environment assumes a nearly direct relationship between population and the area of agricultural land in use.



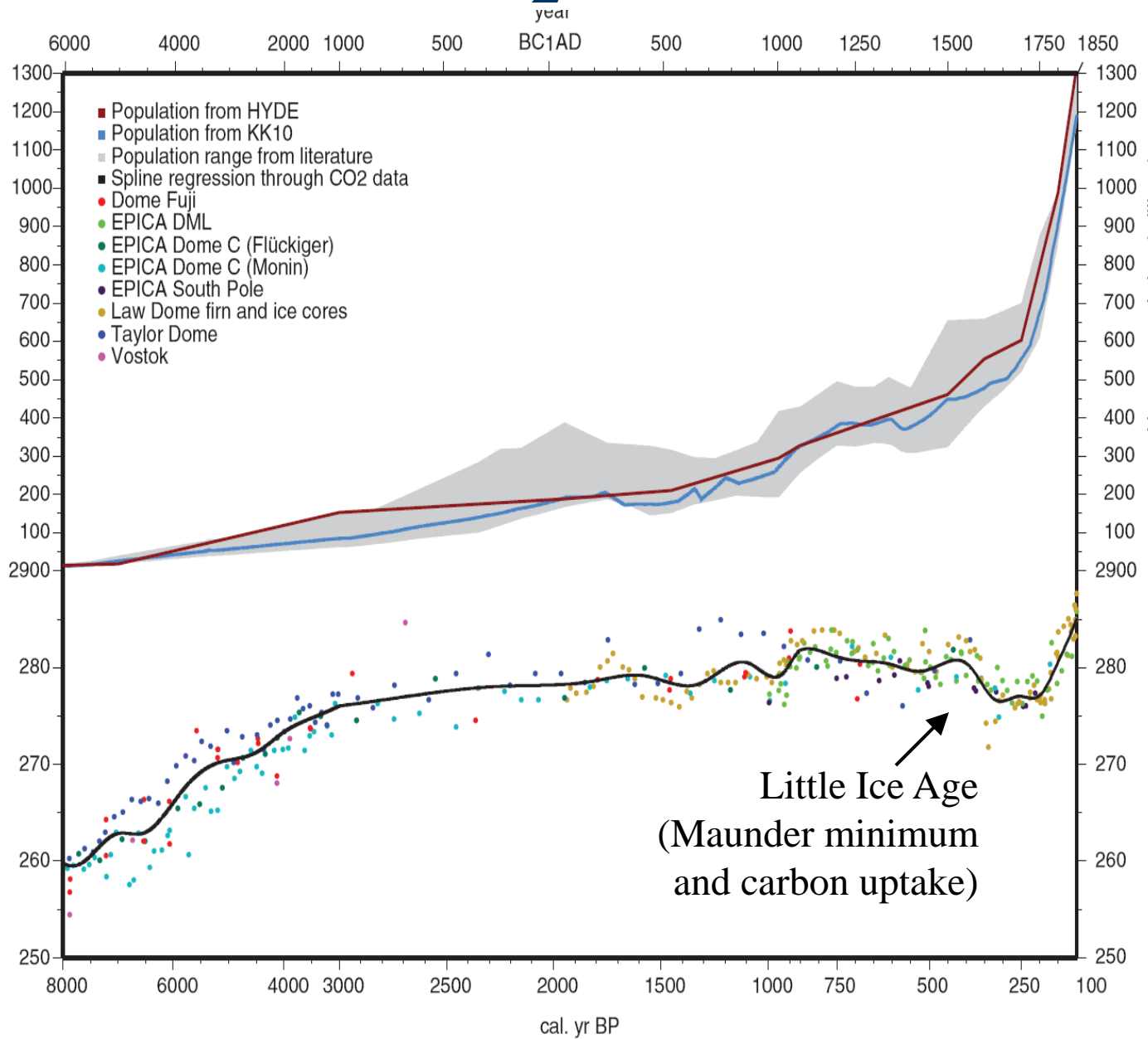
# Hypotheses as to land use change



# Population and CO<sub>2</sub> concentrations

J. O. Kaplan et al., "Holocene carbon emissions as a result of anthropogenic land cover change", *The Holocene* (2010): 1-17.

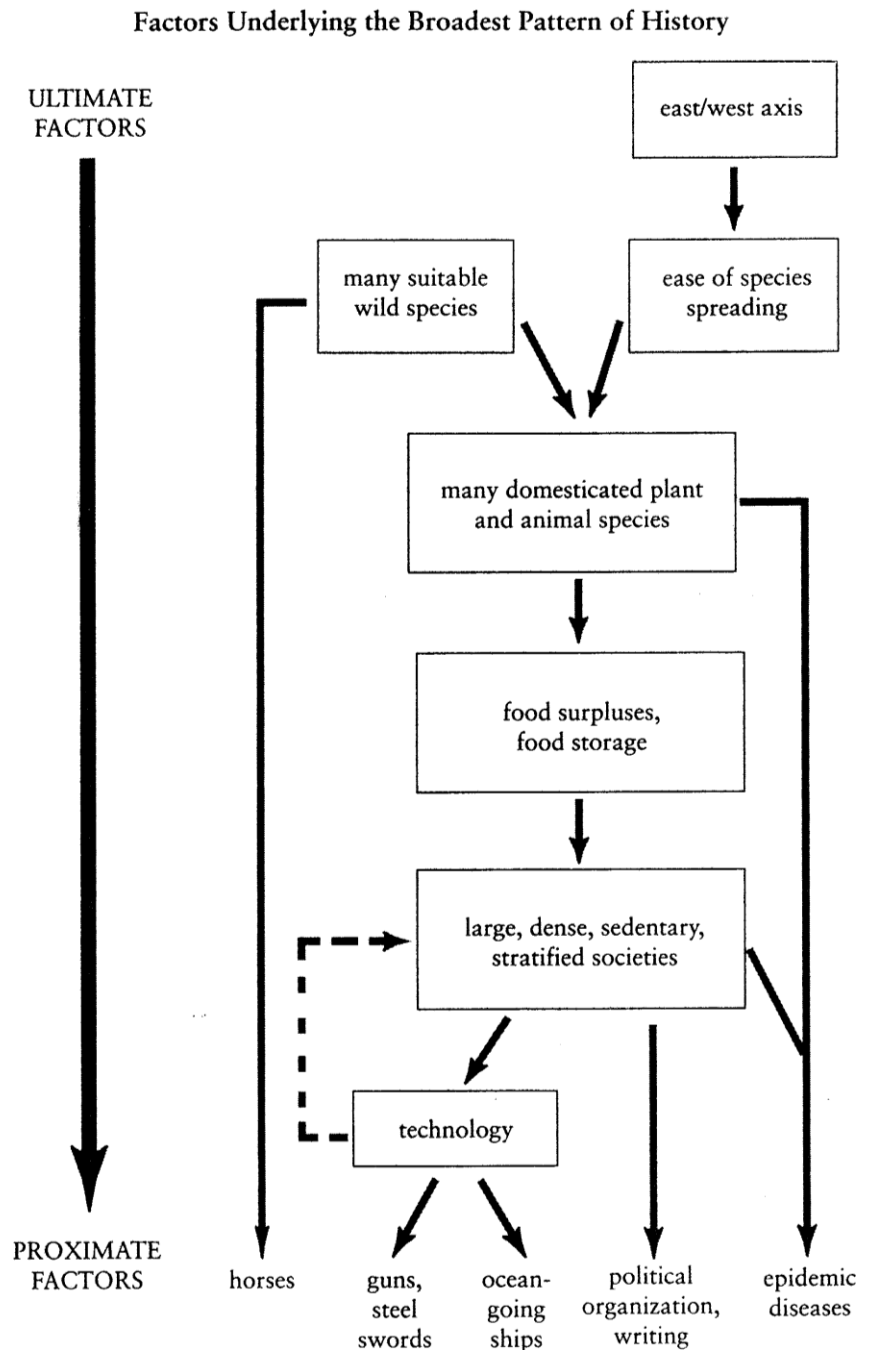
Population in millions and CO<sub>2</sub> concentrations in ppm; grey area shows the range of different population estimates.



A third of the rise of CO<sub>2</sub> around 8,000 years BP may be attributable to the clearing of forests by early farmers.

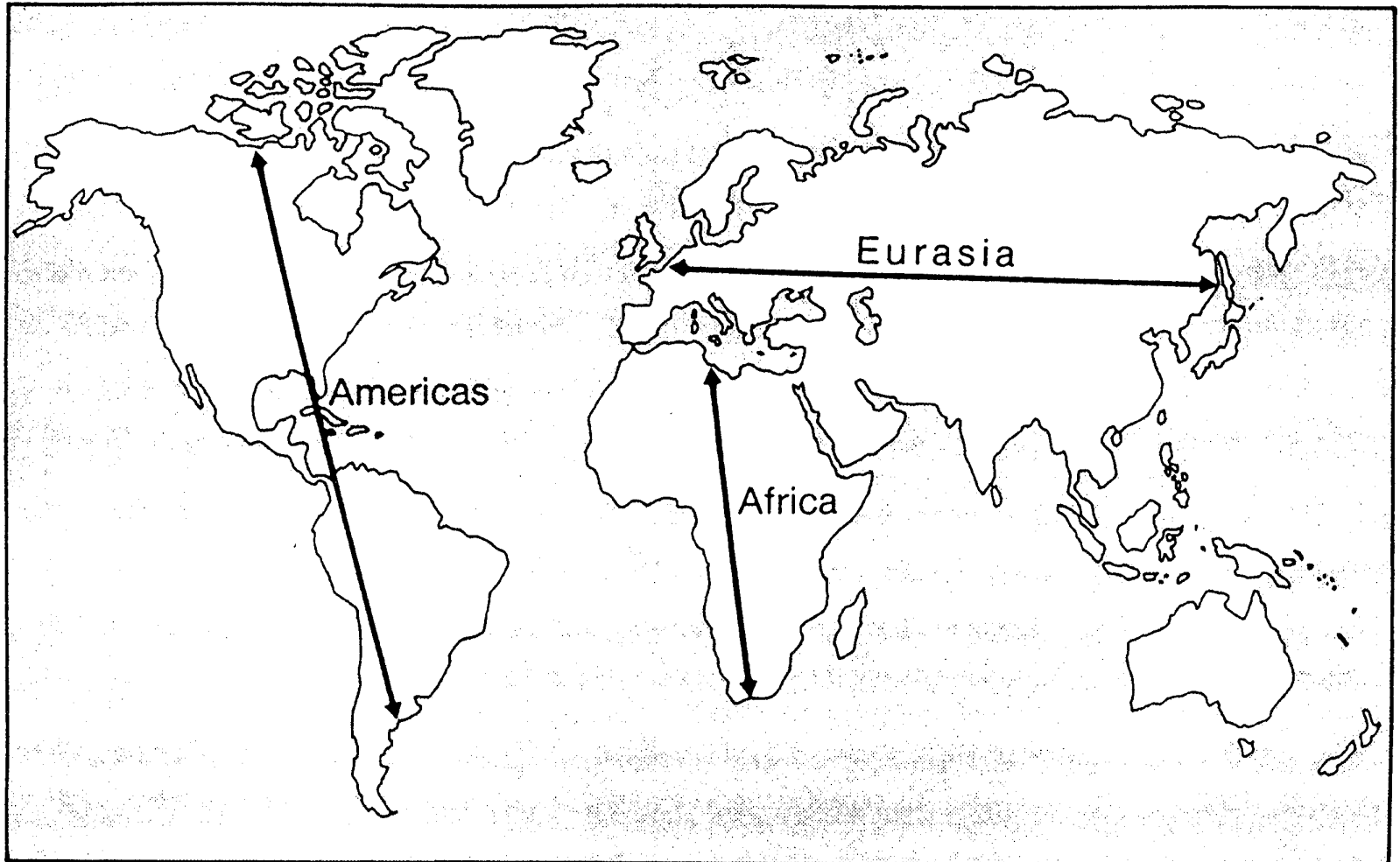
# Historical Patterns: A Synthesis (1)

Born in 1937, Jared Diamond is a professor of geography (UCLA) whose theory of history is outlined in such books as *Guns, Germs, and Steel* (1997) and *Collapse* (2005).



# Historical Patterns: A Synthesis

## (2)



*Figure 10.1. Major axes of the continents.*

# Domesticating Animal Species (1)

- Many animal species have been tamed or used by humans, including insects, birds, and mammals including canines, felines, and rodents
- But the ones massing more than 50 kg have proven most useful



# Domesticating Animal Species (2)

- Historically, humans domesticated 14 such species, though 9 were of only regional interest: the Arabian and Bactrian camels, the llama and alpaca, the donkey, the gaur, the Himalayan yak, the banteng, the Scandinavian reindeer, and the water buffalo



Alpaca

(Photo by Paul Grant, 2001, QEI)



Llama

(Photo by Christian Lauzon, 2002, QEI)

# The Eurasian Advantage (1)

- However, the 5 most useful species — the goat, the sheep, the pig, the cow, the horse — had one thing in common
- Their ancestors all came from Eurasia (bezoar goat, mouflon sheep, wild boar, aurochs, wild horse) or North Africa (aurochs, wild boar)



Sheep

(Photo by Jeanne Lehoux,  
2001, QEI)



Wild boars

(Photo by Paul Grant,  
2001, QEI)

# The Eurasian Advantage (2)

- This was partly the result of raw statistics: Eurasia had the most candidate species (72), followed by Sub-Saharan Africa (51), while all of the Americas were far behind (24) and Australia had only one
- And it seems also to have been a matter of luck



# The adoption of the horse by Native Americans

Archives Canada



Possibly posed or even staged, this picture illustrates the use of the horse by Blackfoot Plains Indians.

# The Eurasian Advantage (3)

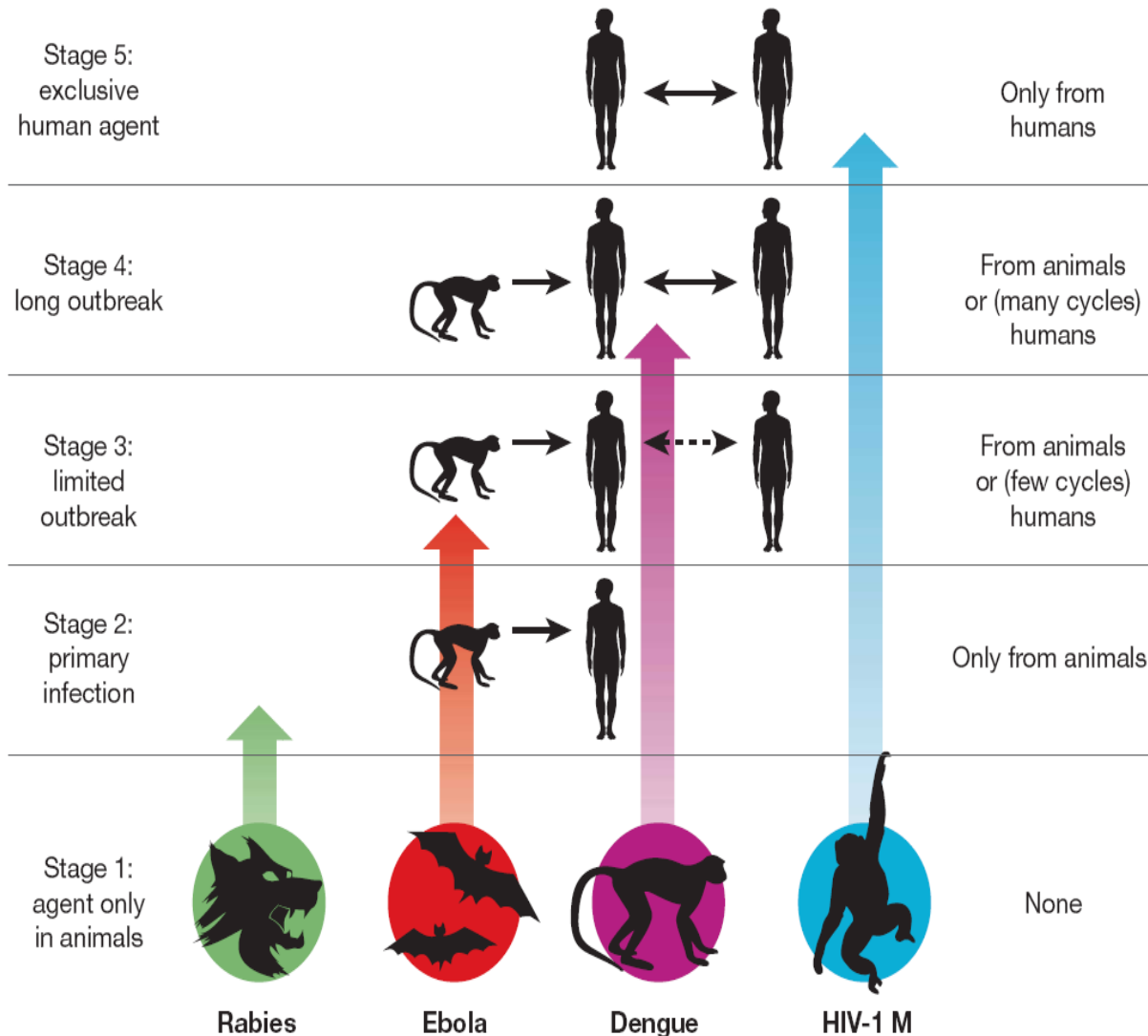
- The many contacts between humans and domesticated animals in the Old World favoured the swapping of diseases, and the built-up of resistance among human populations

Animals → Humans	
<i>Animal sources</i>	<i>Disease</i>
Chimpanzees	AIDS
Apes	Hepatitis B
Wild birds, pigs	Influenza A
African primates	Yellow fever
Rodents	Plague
Old World primates	Dengue fever
Asian macaques	Vivax malaria
Wild and domestic ruminants	East and West African sleeping sicknesses

Humans → Animals	
<i>Disease</i>	<i>Animal victims</i>
Tuberculosis	Cattle
Measles	Mountain gorillas
Poliomyelitis	Chimpanzees
Yellow fever	South American monkeys

# The Eurasian Advantage (4)

## ■ Not all diseases are equally worrisome



Some diseases can be transferred from animals to humans, but not between humans. They may be lethal (rabies), but they will never give rise to an epidemic or a pandemic. But if they evolve so as to spread from human to human without weakening or petering out, they may pose a truly fearsome threat.

# Farming, Counting, and Writing

- Meat doesn't keep, but grain can be stored
- In early villages, counters would have been used to keep track of grain, livestock, etc.
- As cities grew and new products multiplied (bread, oil, perfume, rope, furniture, etc.), more complex tokens were needed for accounting
- The final stage uses sealed clay balls with counters inside and markings outside





# Industrial Revolution: Outline

- Before the Industrial Revolution
- Causes and Factors
- Power technologies
  - — Waterpower: A short history
  - — Wind power
  - — Steam power: Early history
- The metallurgy of iron
  - — Cast iron
  - — Wrought iron



# The Industrial Revolution: Beginnings

- Lewis Mumford's classic *Technics and Civilization* broke up human history by sources of energy
- For most of recorded history, civilizations depended on muscle, wind, and water for power; the Industrial Revolution adopted steam as a new source of power
- Before the Industrial Revolution, there was, in England, an agricultural revolution, characterized by the adoption of new crops, the development of new animal breeds, the use of new tools, the opening of new lands, the move to enclosed fields, and a general interest for a more rational, even scientific pursuit of farming
- This led to more food production and a sharp increase in the population



# An Agricultural Revolution (of sorts)

- Between 1500 and 1850, yields doubled in Western Europe due to improved crop rotation (use of legumes to replenish the soil's nitrogen content) and intensive manuring
- In the best Dutch and English cases, wheat harvests tripled over the same period, but did not support 3 times as many people because part of the crops were diverted to animals
- Still, a typical Dutch farm could support 3-4 people per hectare, providing a diet rich in meat and dairy products; in South China, the carrying capacity might reach 7 people per hectare, though the diet might be more monotonous



# The Industrial Revolution: Causes and Factors (1)

- In the history of technology, the deciding factors of the Industrial Revolution in England remain debated
  - Increasing agricultural production in England brought about a population shift from the countryside to cities
  - The new urban population made up a low-cost labour force as well as a new market
  - However, England was also at the heart of a growing colonial empire; by 1763, it included colonies in North America, holdings in the Caribbean, and trade access to India; in spite of setbacks, this was a growing market
  - Governance, in modern terms, is often neglected, but England, in 1750, already enjoyed the rule of law, a stable limited democracy, and sufficient respect for property rights, including an established patent system



# The Industrial Revolution: Causes and Factors (2)

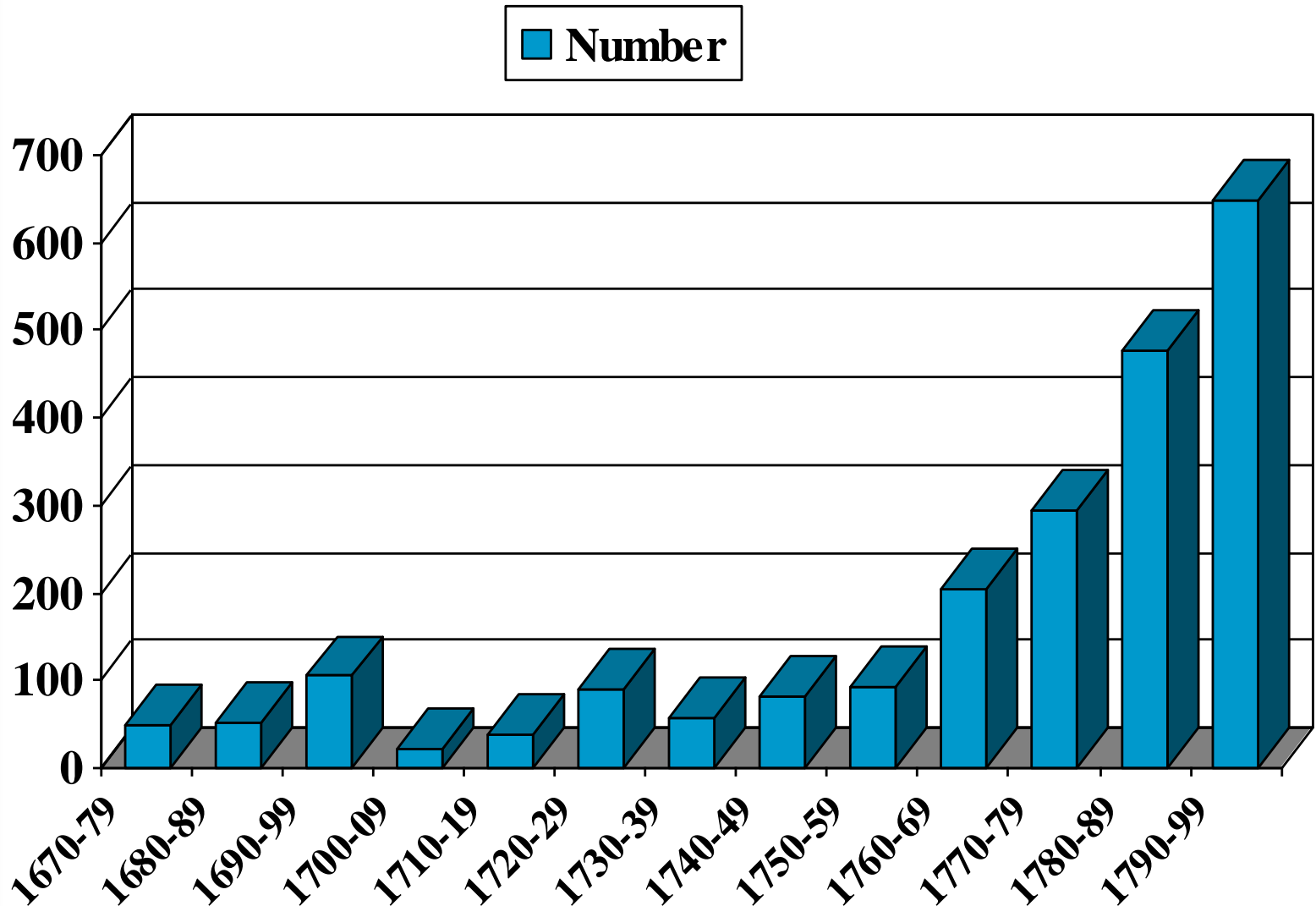
- England's advantages included a compact territory well-served by roads and canals
- This inland network supplemented Great Britain's key advantage as an island dotted with ports easily reached and linked by sea
- While this favoured the development of commerce, Great Britain was also generously endowed with coal and iron reserves; though the specific types of coal and iron ore proved to be important, few pre-industrial countries were in a similar position



# The Industrial Revolution: Causes and Factors (3)

- Increasing levels of literacy create at the very least the *possibility* of learning about new scientific and technological advances
- Between 1686-1690 and 1786-1790, literacy in France rose from **29%** to **47%** for men, and from **14%** to **27%** for women
- In England, literacy was estimated at **45%** for men and **25%** for women around 1714, but it rose to **60%** and **40%** respectively during the second half of the century
- In New England, from 1660 to 1760, literacy rose from **61%** to **84%** for men and from **31%** to **46%** for women
- The increasing engagement with science and technology is also reflected in patenting rates

# English Patents, to the end of the 18th century





# The Industrial Revolution: Features

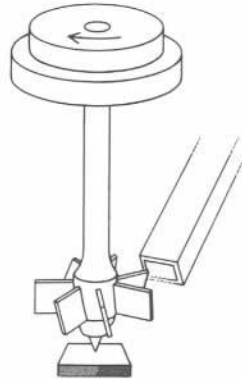
- Economically, the Industrial Revolution is defined by a change in growth rates
- While yearly growth rates before 1780 rarely exceeded 0.5-0.6%, growth was then sustained for decades at an average rate over 2%
- Population increased, but only at about 1.25%, so that, by 1850, per capita income had been multiplied by 2.5
- As the economy turned capitalist, the workforce was increasingly salaried in the employ of owners
- Technologically, the Industrial Revolution will be defined here by (a) new power technologies, (b) new metallurgical processes, and (c) mechanization in manufacturing



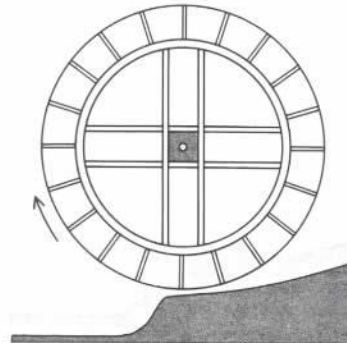
# The Power of Water

- Before discovering and applying the power of steam, the Industrial Revolution relied on waterpower
- Waterwheels went back to Antiquity, but 18th-century scientists strove to increase their efficiency
- In France, members of the Royal Academy of the Sciences like Antoine Parent (1666-1716) and Henri Pitot (1695-1771) were in the forefront of this effort
- In England, an engineer, John Smeaton (1724-1792), conducted the most systematic study of waterwheels; he later analysed the Newcomen steam engine
- As a result, it was clearly established that overshot vertical wheels produced the most power

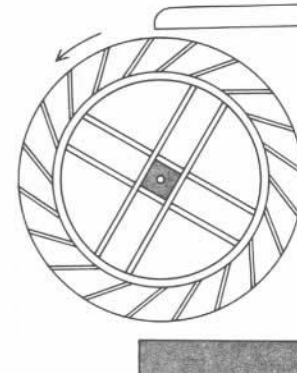
# Old-Time Waterwheels: The Three Contenders



1) The Horizontal (Norse) wheel: Perhaps not the oldest though the matter has been argued back and forth, but the simplest mechanically: the wheel turns the millstone directly.



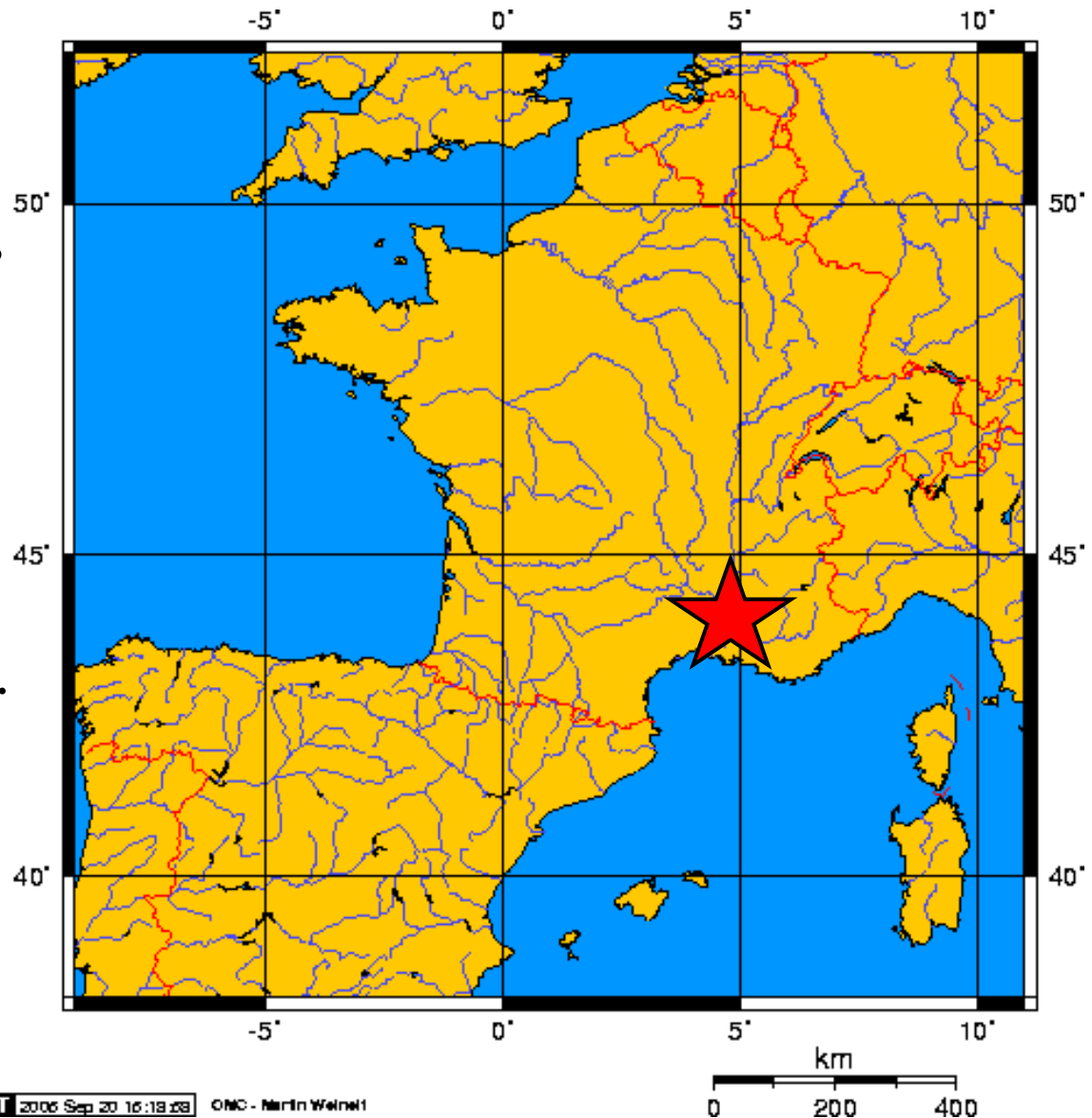
2) The Undershot Vertical wheel: The oldest recorded waterwheel, set down by Roman architect Vitruvius shortly before the Common Era (1st century BC), though possibly going back to the 2nd or 3rd century.



3) The Overshot Vertical wheel: Also known to the Romans (Barbegal, France), it is the most powerful as it takes advantage of both momentum and gravity. Like the undershot wheel, the rotary motion must be shifted through a right angle to power the millstone.

# Arles (France)

In the part of southern France known as Provence, the small city of Arles is best known as the one-time residence of the famous painter Vincent Van Gogh...





*Le Café de la nuit*, Vincent Van Gogh, 1888



*Le Café la nuit*, Arles, 2005

But Van Gogh's Arles was once upon a time a Gallo-Roman city, Arelatum...

And the flour it used to make  
bread came from right here



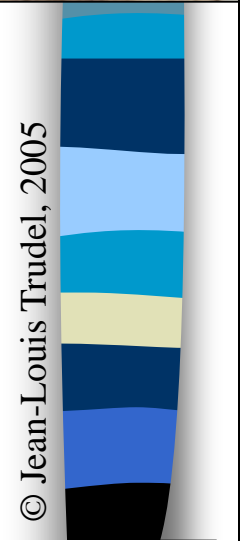
© Jean-Louis Trudel, 2005



# The Barbegal Mills (1)

← Today

About 1800 years ago ↓



# The Barbegal Mills (2)



This modern reconstruction in an Arles museum shows clearly how water brought by an aqueduct powered a series of overshot waterwheels set on both sides of the mill-houses, taking full advantage of the local topography.

Close-up of a reconstructed waterwheel →



# The Barbegal Aqueducts

The original aqueduct, built to supply Arles with drinking water.

The second aqueduct, paralleling the first, built to supply the mills with water.



# A Medieval Innovation: Windpower

Though built in 1815, this most famous of French windmills resembles its predecessors using the late medieval “tower mill” design.

Fontvieille, France (© Jean-Louis Trudel, 2005)



# Windmills in Western Europe

- Windmills reached Europe in the 12<sup>th</sup> century; the basic design (post mill) remained the same for centuries thereafter

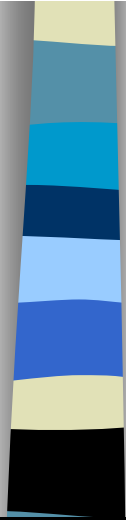
Windmill in Bergues (France)  
photographed on August 29, 1917  
by Paul Castelnau →



Medieval graffiti in the English  
church of Sawbridgeworth

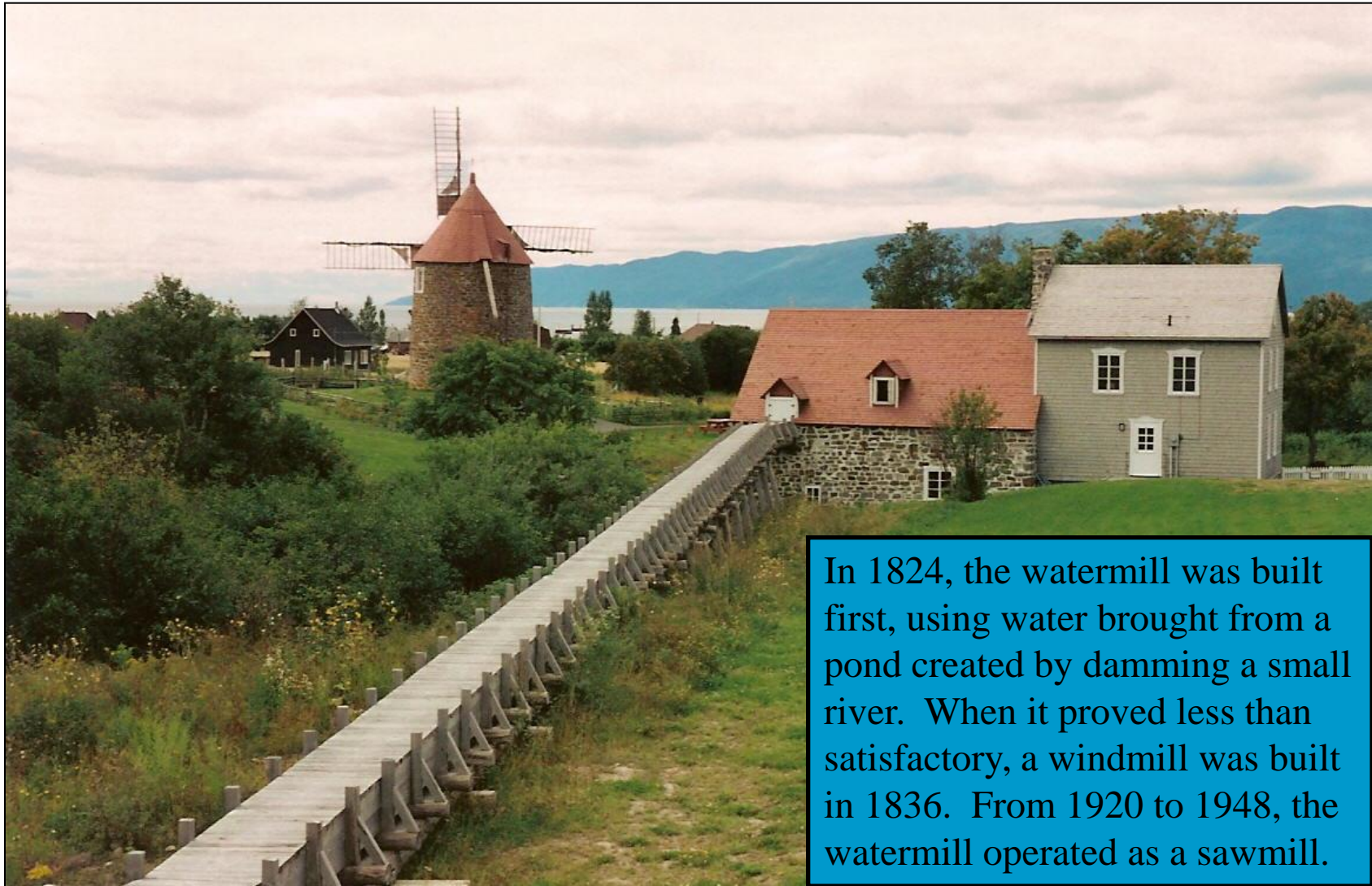


# Windmills in Ialutorovsk (Russia), *c.* 1910



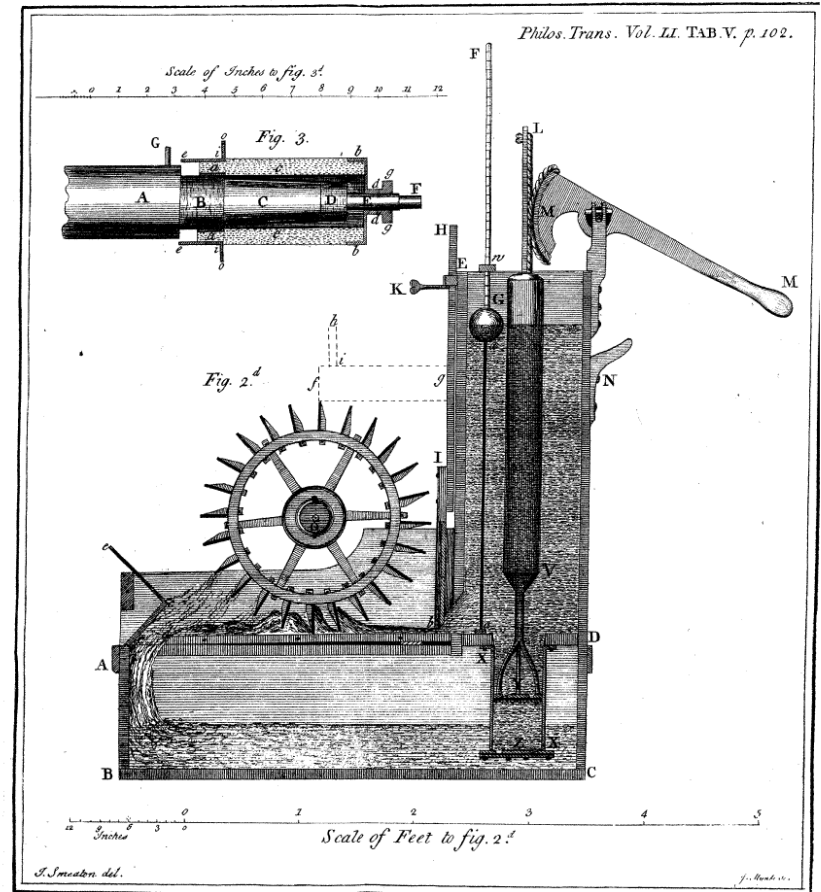
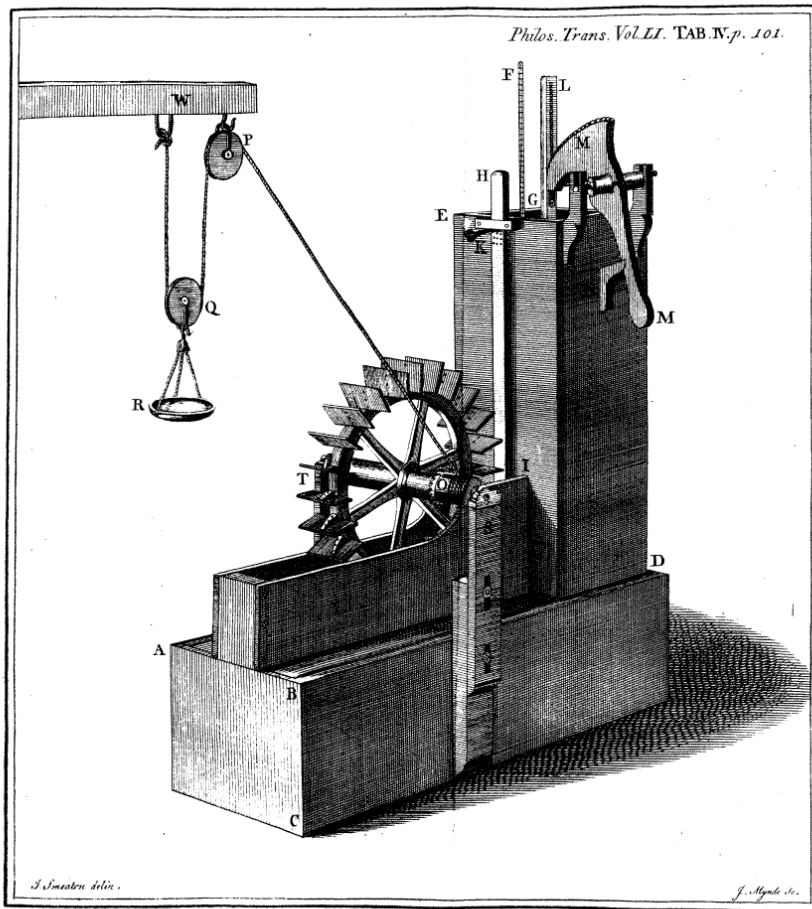
Picture produced from plates taken by Sergei M. Prokudin-Gorskii (1863-1944) through three colour filters. His pictures of pre-WWI Russia were taken between 1907 and 1915, and exhibited in road shows.

# Windmill and Watermill (Isle aux Coudres, Canada)



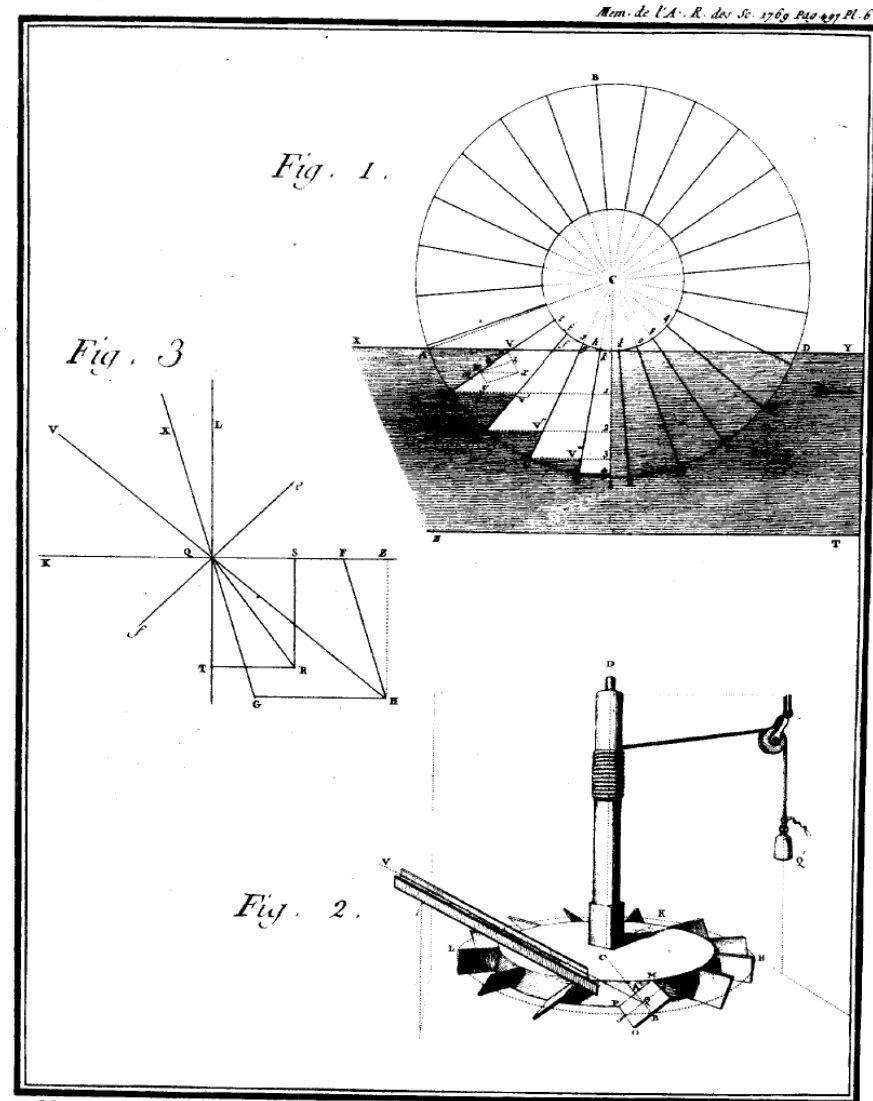
In 1824, the watermill was built first, using water brought from a pond created by damming a small river. When it proved less than satisfactory, a windmill was built in 1836. From 1920 to 1948, the watermill operated as a sawmill.

# Smeaton's Experimental Apparatus (2 views, 1759)



# The French Academicians

- In France, members of the Royal Academy of Sciences also studied waterwheels to model their workings
- In 1769, Charles Bossut attempted to improve on the mathematical treatment of his peers, such as Henri Pitot
- His experimental apparatus (right) was simpler than Smeaton's

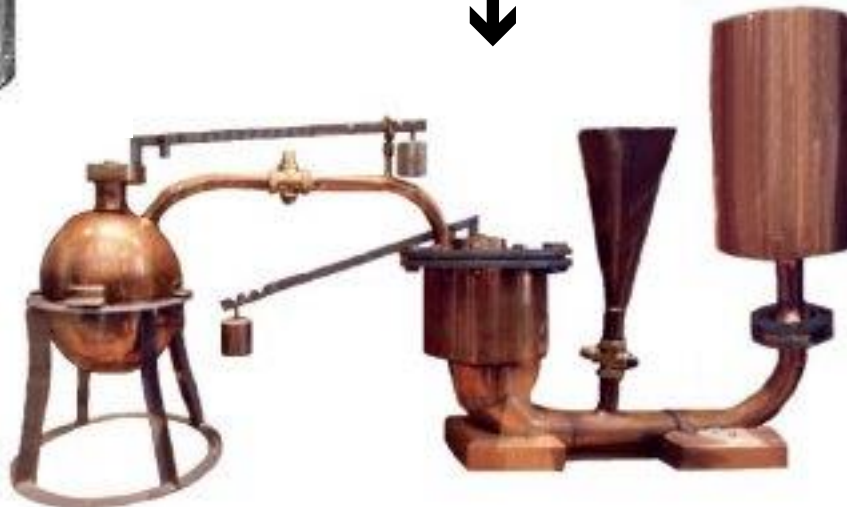


# Steam: Papin and Savery

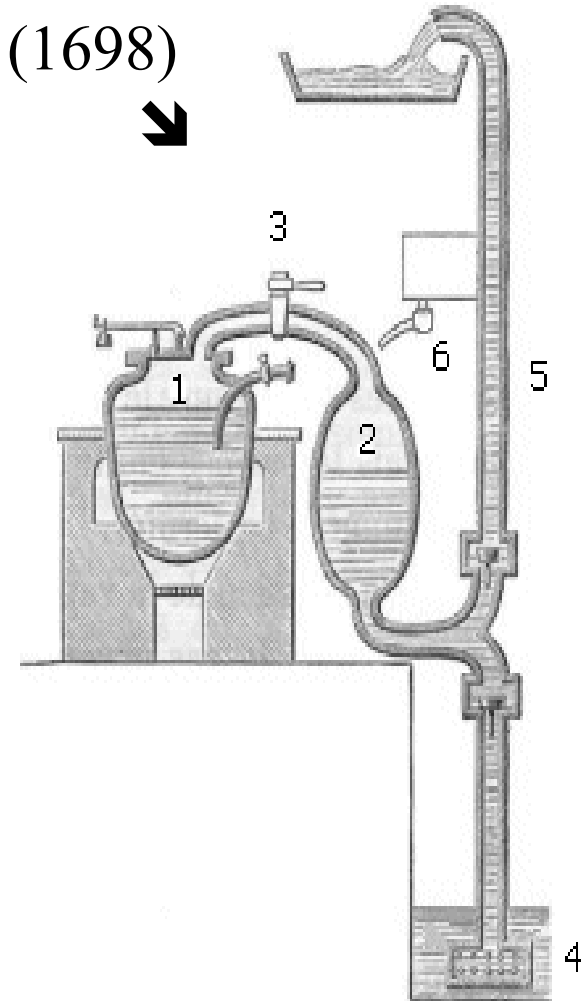


↙ Papin's Cylinder (1690)  
(from the *Acta Eruditorum*)

Papin's Pump (1698-1707)



Savery's Pump (1698)  
(patented)

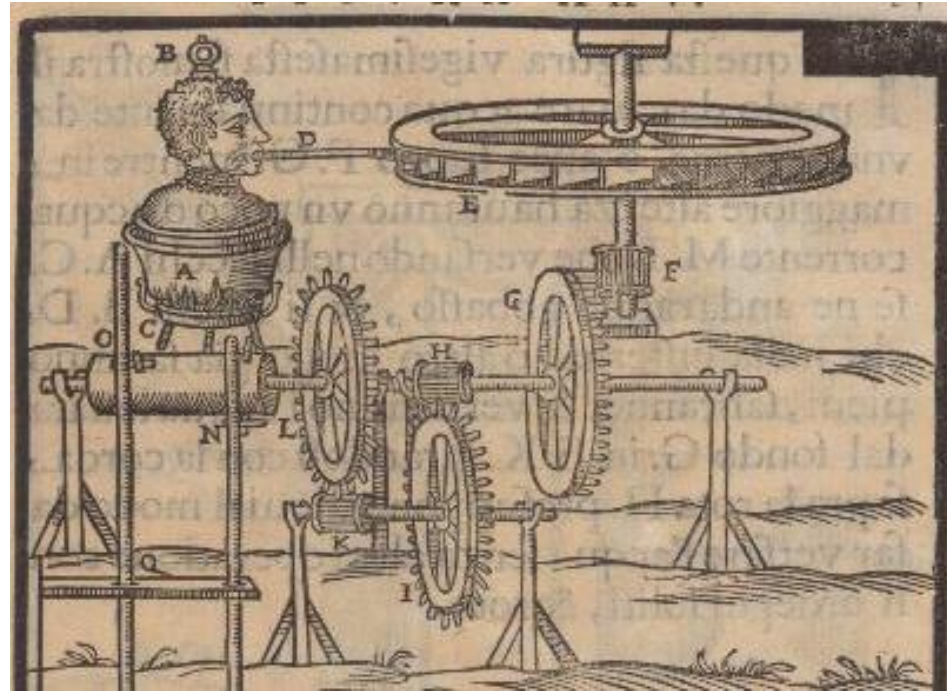


# The evolution of the steam engine

## Denis Papin (1)

- Denis Papin (1647-1713?) was a wandering scientist in a troubled age; a fellow of the Royal Society in London by 1680, he also worked in Paris and Venice
- As a Protestant, he was forced to leave France by the rescinding of the Edict of Nantes in 1685

**1629:** Early design for a steam turbine (from Giovanni Branca's *Le Machine*)





# The evolution of the steam engine

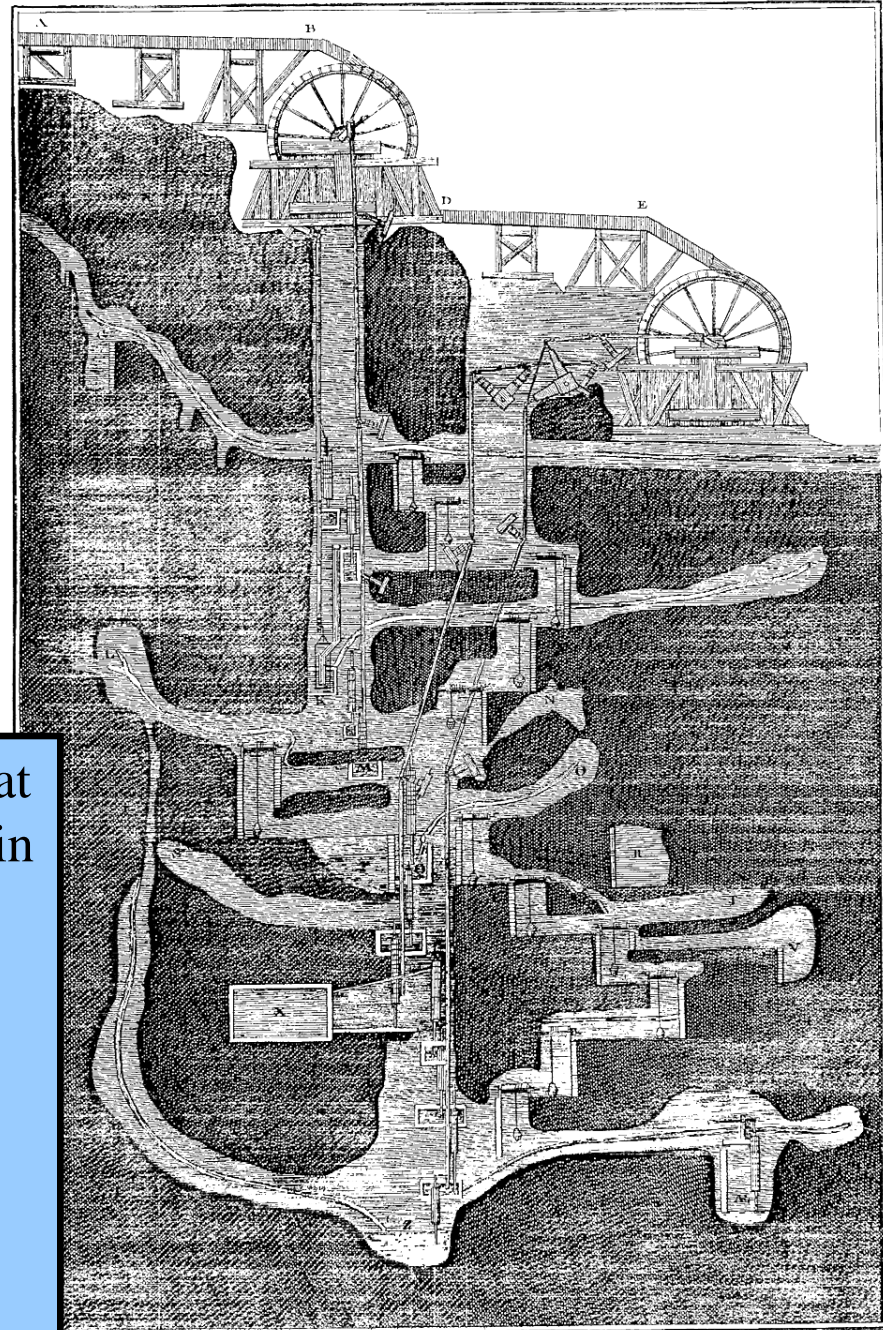
## Denis Papin (2)

- After curating experiments for the Royal Society, he left for Germany, where he entered the service of the prince of Hesse-Cassel
- Extending experiments made in France by Christiaan Huygens and himself, he studied the action of steam (expansion, condensation) on a piston in a cylinder (1690)
- In Germany, he designed a steam pump (1698-1707)
- He left for England with the idea of paddlewheel boat driven by the power of steam, but nobody was interested and he died in poverty, ignored by all

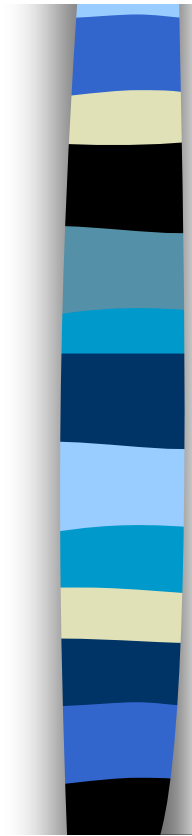
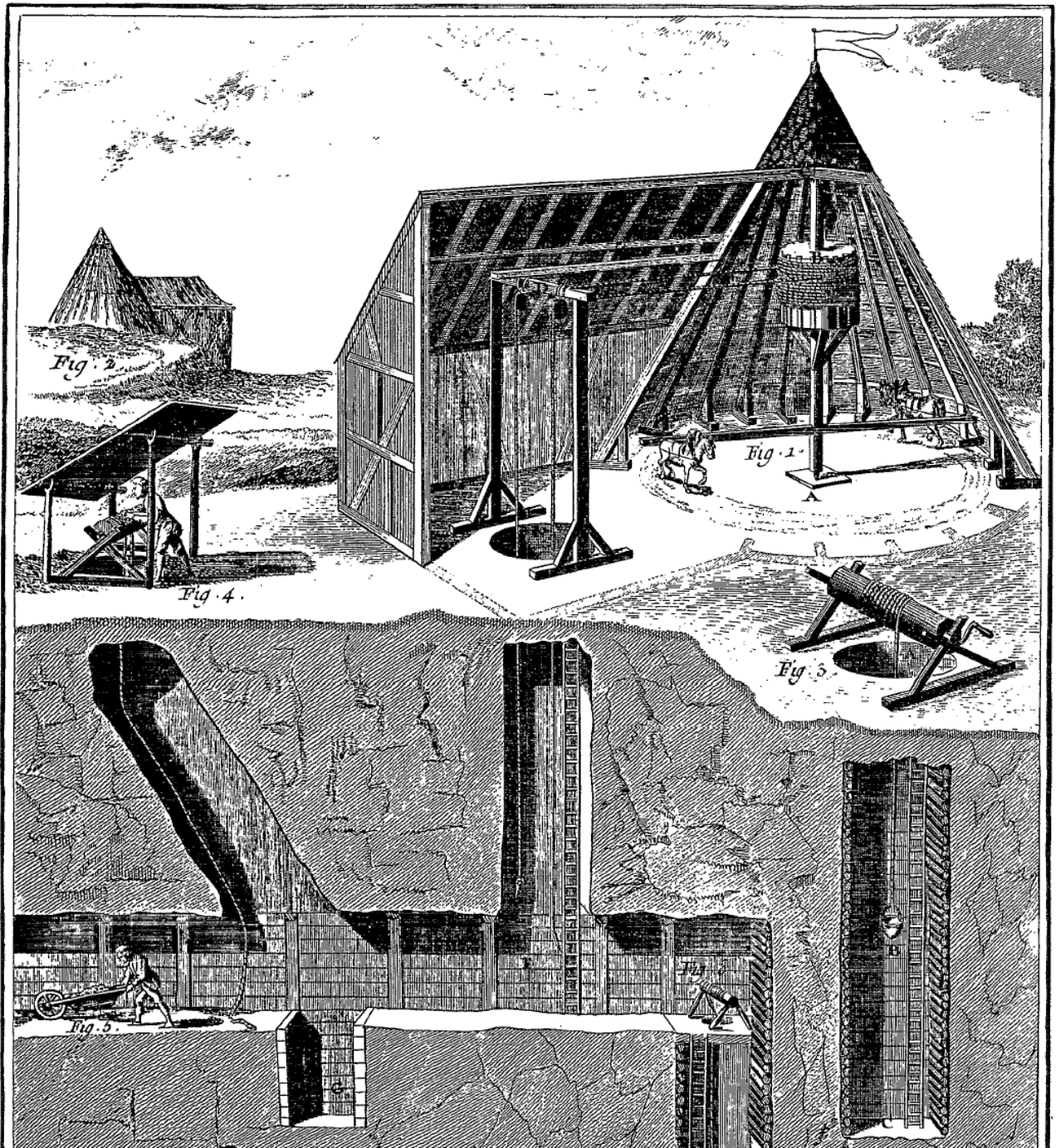
# Pumping Water out of Mines

- This engraving from the French *Encyclopédie* (1751-1780) shows a system of water-driven suction pumps

**Environmental impact:** Studies suggest that removal of both water and mineral deposits in mines results in earthquakes that may reach magnitudes of 5.6 or more, as in the case of the 1989 Newcastle (Australia) earthquake arguably triggered by 200 years of coal mining nearby. Large dams and drilling for shale gas and oil accompanied by fracking can also generate minor earthquakes.



# Horse-Driven Lifting (or Pumping)

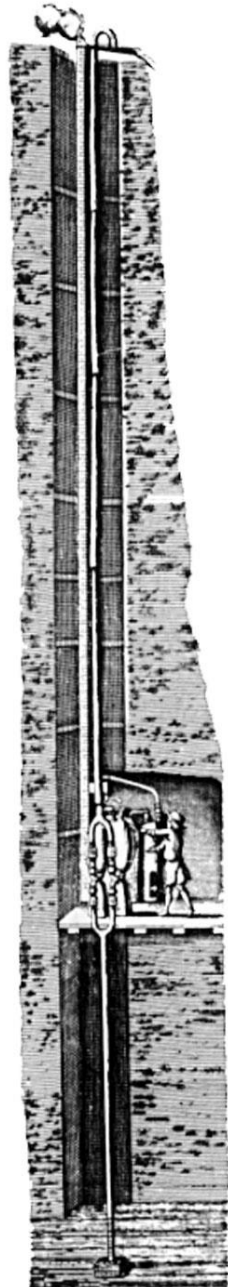


# The evolution of the steam engine: Thomas Savery (1)

- Thomas Savery (1650?-1715) was a British businessman and entrepreneur
- After trying to sell a paddlewheel boat to the Royal Navy, he designed a steam pump of his own, perhaps as a ship pump though he soon realized it could be mainly of use in mines

**1702:**

Figure from Thomas Savery's  
*The Miners Friend; or, An  
Engine to Raise Water by Fire*



The  
Engine  
Working in a  
Mine



# The evolution of the steam engine

## Thomas Savery (2)

- He had it patented in 1698, got an Act of Parliament in 1699 to extend the patent's term, and advertised it heavily in 1702... but it only served in a few wealthy aristocrats' gardens and never in mines
- On the other hand, the wording of Savery's patent was broad enough to let him claim the rights to a much more efficient invention...



# The evolution of the steam engine

## Thomas Newcomen (1)

- Thomas Newcomen (1663-1729) was an ironmonger concerned with the problems of coal mines flooded by water
- In 1712, he completed a machine that combined some traits of Papin's cylinder and of existing pumps with a fortuitous discovery (the rapid condensation of steam by water injection)



# The evolution of the steam engine

## Thomas Newcomen (2)

- Atmospheric pressure did most of the work
- Steam simply filled the space below the piston before condensation
- The balance beam transferred linear motion
- The Newcomen machine proved useful enough to spread to Europe (Venice in 1717-1718, Liège in 1720, Cassel in 1721-1722, the Danube basin in 1722-1723, France in 1726 and 1732, Sweden in 1728, etc.)

# Newcomen's (Atmospheric) Steam Engine

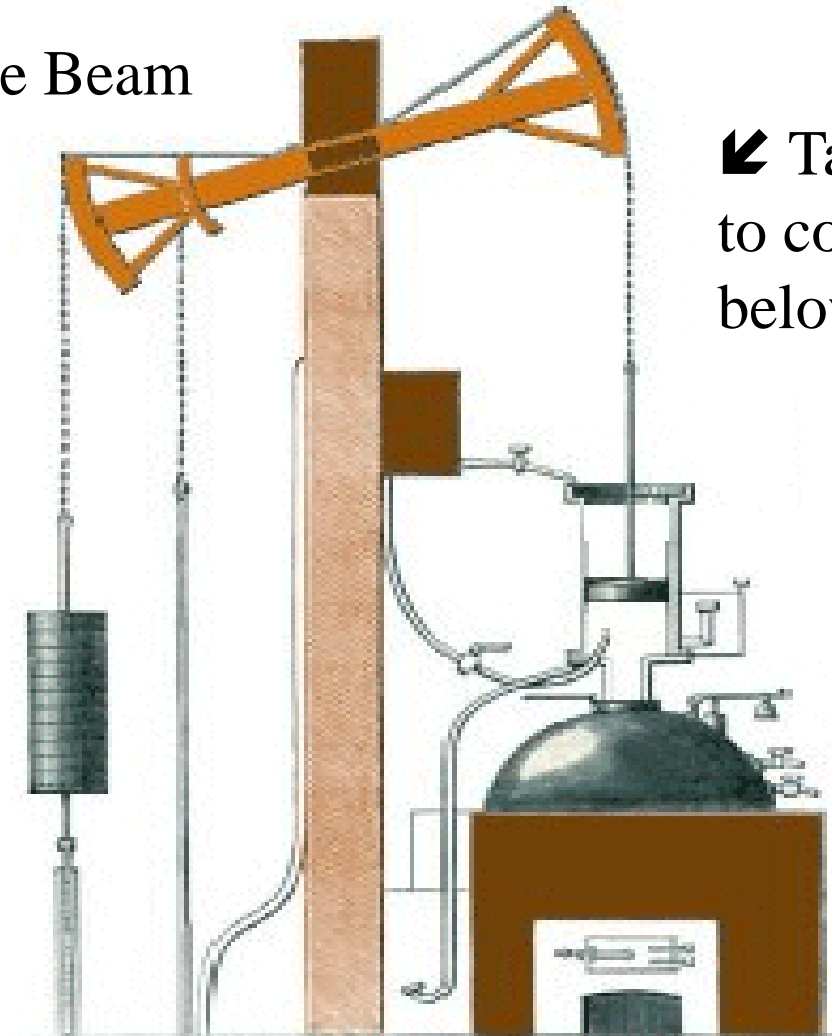
Balance Beam

↙ Tank with cold water to condense the steam below the piston

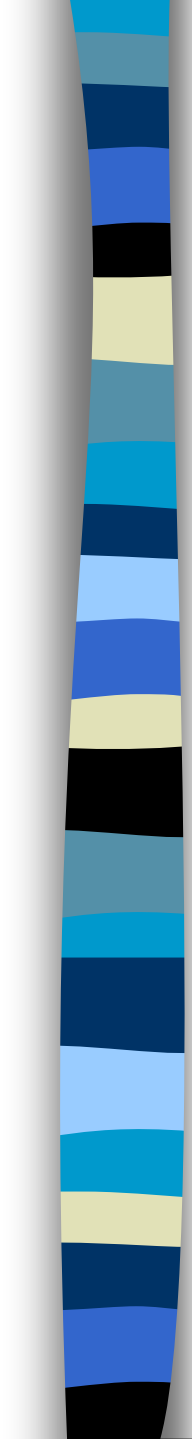
Piston

← (Safety Valve)  
Boiler

Furnace



Counterweight →



# Cast iron, wrought iron, and steel

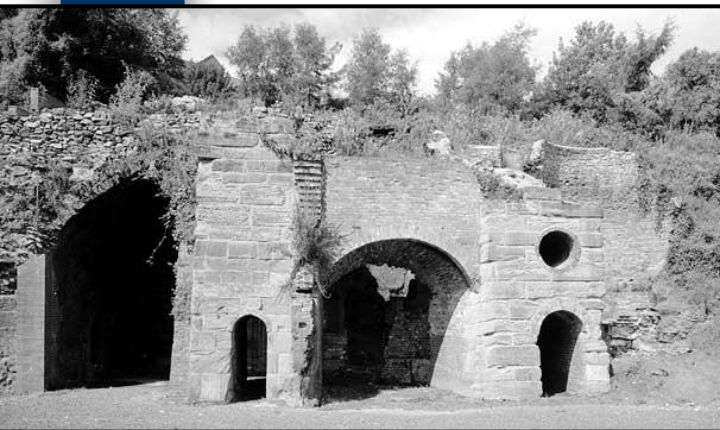
## (1)

- Until the mid-18th century, iron was the most useful of all metals, but refining it into usable form was a long and exhausting process
- The most primitive method involved heating the raw ore just enough to melt it so that it wouldn't absorb much carbon and smiths could beat out the other impurities (*slag*) from the pasty mass of metal (known as a *bloom*)
- This produced malleable *wrought iron* or *bar iron* (low carbon content, resilient, elastic) that could be used for tools or other implements in villages remote from larger installations

# Cast iron, wrought iron, and steel

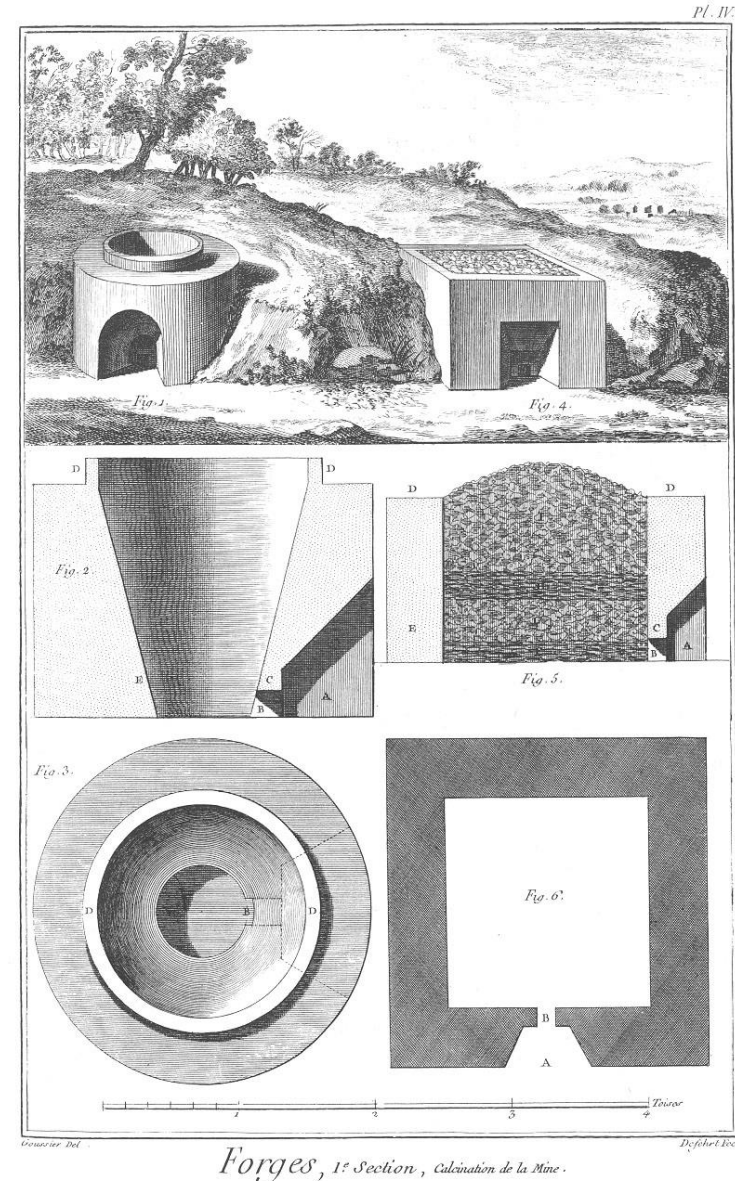
## (2)

- Larger iron-making concerns used a *furnace*, up to 10 m high, into which the workers tipped iron ore, charcoal, and limestone (flux): it produced either a bloom of just melted iron, or molten cast iron
- Primitive furnaces were built in pits or hillside



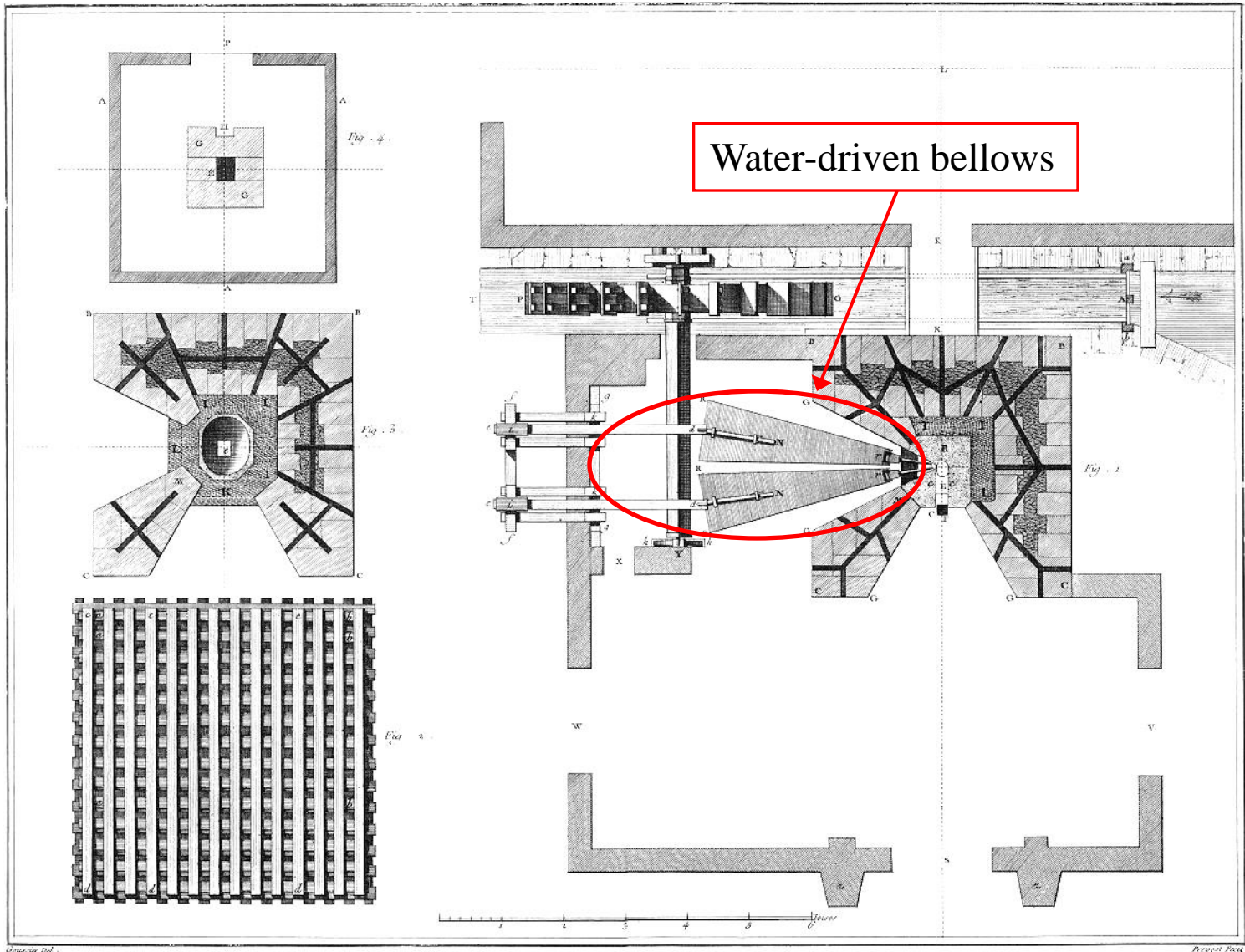
← The Bedlam Furnace in Ironbridge, Shropshire, used by Abraham Darby to build the Iron Bridge

Furnaces from the →  
18th-c. *Encyclopédie*



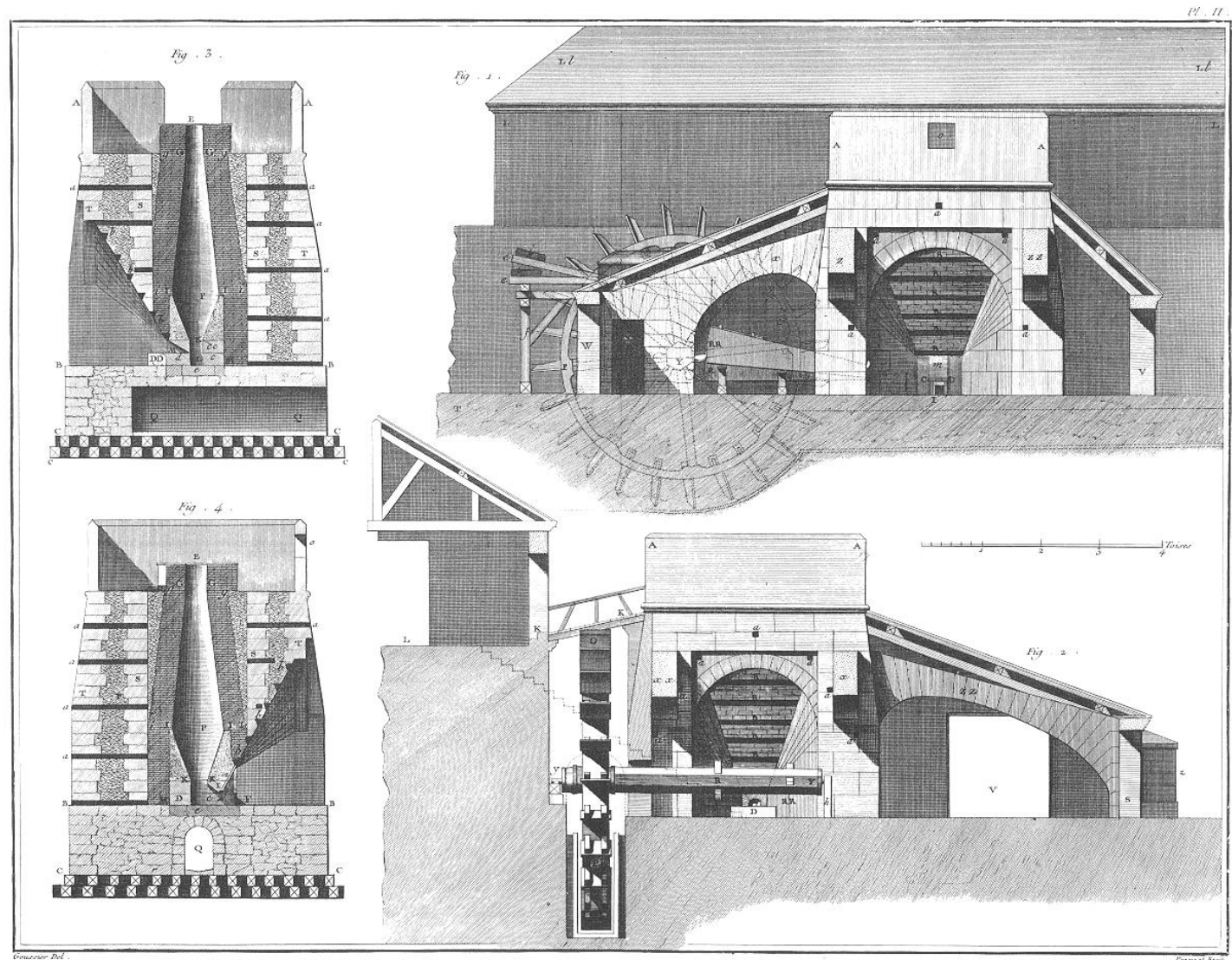
# Plan of a Blast Furnace (18<sup>th</sup> c.)

The next step  
up in scale for  
iron-making...



Forges, 2<sup>e</sup> Station, Fourneau à fer, Plan Général et Particulier d'un Fourneau.

# Eighteenth-Century Blast Furnace



Forges, 2<sup>e</sup> Section, Fourneau à Fer, Elevations et Coupes d'un Fourneau.



# Cast iron, wrought iron, and steel

## (3)

- What came out of the blast furnace was *slag* (consisting of lighter, liquid impurities) and *cast iron* (also known as *pig iron*), a mix of iron, carbon (up to 4%), and various impurities; it could be poured into a mould, either immediately or after heating it a second time
- Cast iron (high carbon content, low melting point) was hard but brittle



# Cast iron, wrought iron, and steel

## (4)

- To convert cast iron into a form suitable for use in tools, the carbon content needed to be reduced and the metal recrystallized; this was done in the 18th century by reheating the pig iron (to oxidize the carbon and produce bloom iron) and pounding out the slag with large tilt hammers driven by waterwheels
- The final product was *wrought iron* bars that could be turned into tools, weapons, and other products requiring the specific toughness of wrought iron

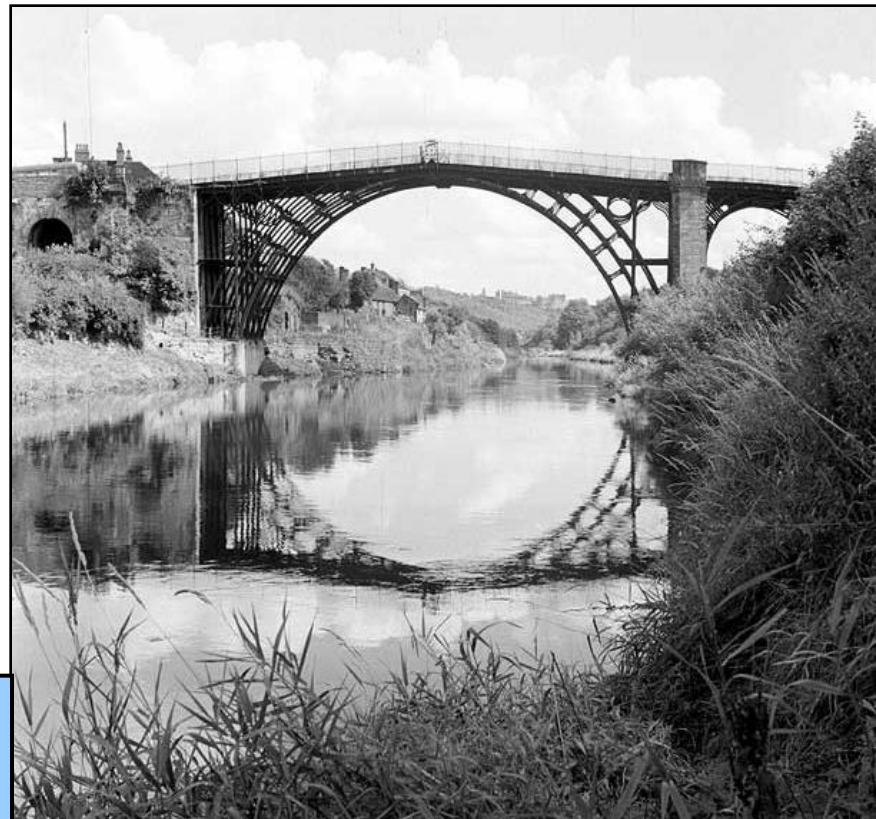


# Cast iron, wrought iron, and steel (5)

- *Wrought iron* could be reheated in the presence of charcoal (pulverized in some cases) in order to gain a surface enrichment in carbon and become *cementation* (or *blister*) *steel*; the “blisters” formed on the surface of the original wrought iron bars contained the best steel
- Cementation steel, once worked by a smith to give it more homogeneity, combined the advantages of cast iron (hardness) and wrought iron (springiness)
- By 1740, an English clockmaker, Benjamin Huntsman, perfected the melting of cementation steel in crucibles; though the process only yielded 30 kg at a time, *crucible steel* was the ultimate in quality and could be used in clocks or medical instruments

# Improvements in Iron-Making (1)

- As early as the 1740s, the Darby family produced *cast iron* using coal cooked into *coke*, cheaper and harder than charcoal (initial breakthrough in 1709), which meant that more coke could be piled into a larger furnace without it being crushed like the more fragile charcoal, producing more heat and making it possible to process more ore at one go



The Darby Iron Bridge over the River Severn in Shropshire, erected in 1778  
(English Heritage)

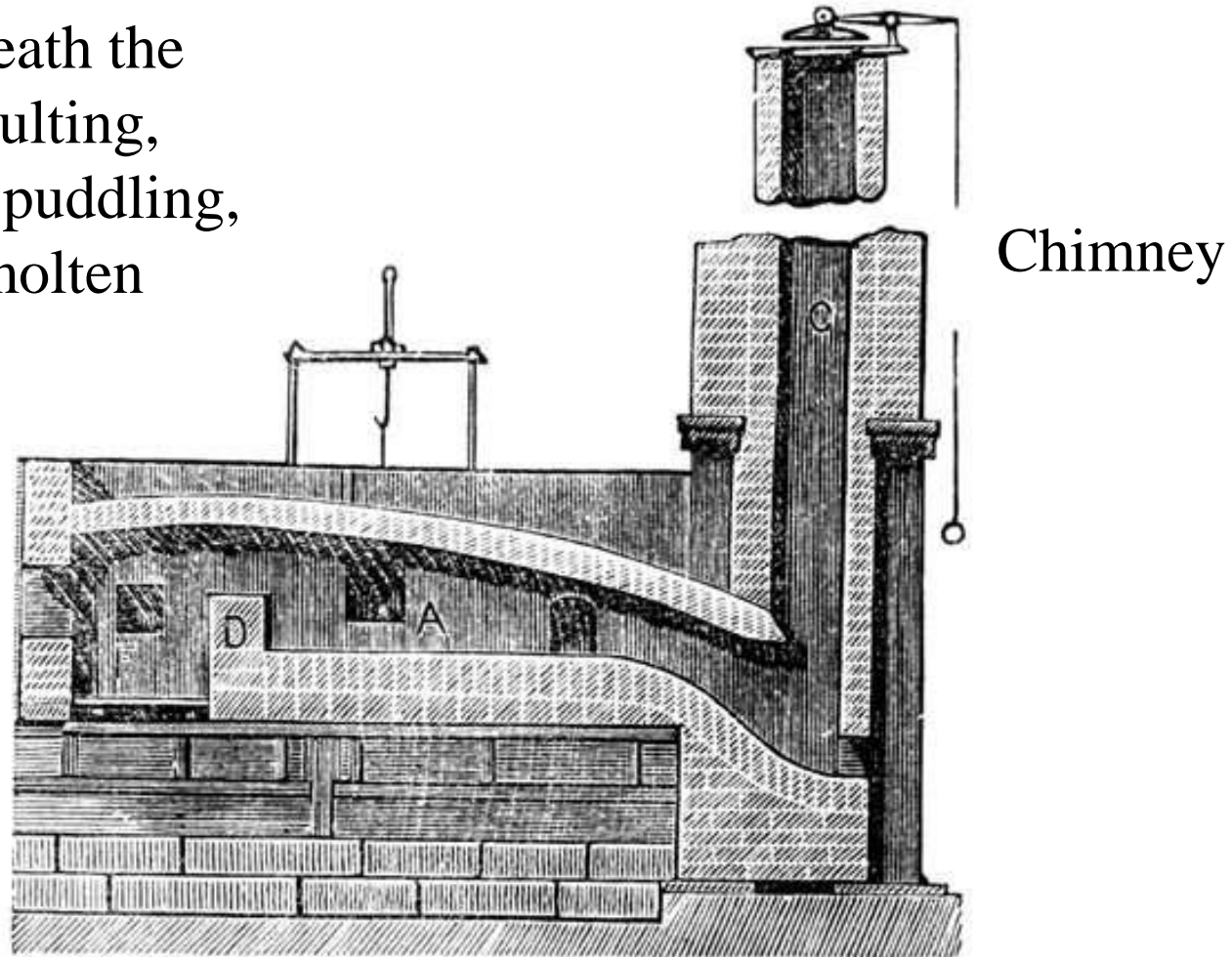
# Making Wrought Iron Cheap

## Reverberatory Furnace (Henry Cort, 1783)

A Ore bed, beneath the reverberation vaulting, and window for puddling, *i.e.* stirring the molten cast iron in the presence of  $O_2$

Hearth →

(The low wall, D, separates the sulphur- and phosphorus-rich fuel from the iron.)





# Improvements in Iron-Making (2)

- In 1783, Henry Cort developed the puddling of pig iron in a *reverberatory furnace* in order to turn out in mass quantities a cheaper form of *wrought iron* without any need for (costly) charcoal
- The wrought iron taken from the puddling furnace was then forged with a “shingling hammer” and turned into sheets or bars by a rolling mill

# Final Summation

- By 1800, there has been a metallurgical revolution in the production of pig iron and wrought iron

From: Rainer Fremdling, "Foreign Trade-Transfer-Adaptation", Groningen Growth and Development Centre, 2002

## *Primary wrought iron industry*

Stage of Production	Process		Product
	traditional	modern	
First Stage	<b>Smelting in the blast furnace</b>		pig iron
	with charcoal	with coke	
Second Stage	<b>Refining</b>		wrought iron
	in a hearth with charcoal	in a puddling furnace with coal	
	<b>Shaping</b>		bar iron (rails)
	by the hammer	by a rolling mill	