

SCHOOL LAUNCH • GEOGRAPHY K-12

GEOGRAPHY AND COMMERCE: SEA LANES, STRAITS AND TRADE ROUTES

A high-school semester course in the geography of trade, built on the journeys that made it: Zhang Qian's mission west, the camel caravans of Samarkand, the monsoon dhows of Kilwa, Zheng He's treasure fleets, the Manila galleons, the silver mountain of Potosí and Malcom McLean's first container ship, each one mapped, measured and worked with real numbers in a map notebook.

First edition

"And hath made of one blood all nations of men for to dwell on all the face of the earth, and hath determined the times before appointed, and the bounds of their habitation;" (Acts 17:26, KJV)

COURSE GUIDE

This is a one-semester, college-preparatory course in economic geography for students in grades 10–12. It asks two plain questions: why is most of the world's trade carried by sea, and why does so much of it pass through a few narrow straits? In five units of five lessons the student follows the Silk Road and the caravan trade, sails the Indian Ocean on the monsoon, studies the great straits of the world one by one, learns where the great resources lie, and reads today's trade map with the tools of economic geography. Every lesson has three worked examples, a practice set of 12 problems with answers, a picture study and a hands-on project. Each unit ends with a 100-point test, and there is a midterm after Unit 3 and a final at the end of the course.

Trade was built by people, one journey at a time, and the course is built around those journeys. Each lesson begins with **the story** (Zhang Qian setting out from the Han court about 138 BC, a caravan resting at Dunhuang, Zheng He's fleets leaving China between 1405 and 1433, the first galleon crossing from Acapulco to Manila, the Dutch East India Company chartered in 1602, McLean's *Ideal X* sailing from Newark in 1956), then **the geography**: the winds, coasts, passes, rivers and narrows that made the journey possible or hard. Then comes **the economics**, taught neutrally as tools to use: transport cost, cost per mile and per ton, choke points and alternatives, and David Ricardo's comparative advantage (1817) with a worked example. Contested questions are presented fairly, with the facts dated.

One thread runs through the whole course: **technology overcoming geography**. The camel made the desert crossable; the dhow and the monsoon made the Indian Ocean a highway; the galleon tied Asia to the Americas; the clipper, the steamship, the canal and the container ship each made distant trade cheaper; and pipelines and air cargo move what ships cannot. Lessons that carry the thread most directly are marked ✪. Yet the map still matters: a strait 2 miles wide or a canal lock still decides where the world's goods can go, and students learn to see why.

The course is written from a Christian view of the world. God made the earth and set the seas, mountains and winds in their places, and Scripture speaks plainly about trade: Solomon's "navy of Tharshish" (1 Kings 10:22), the merchants of Tyre in Ezekiel 27, and the command of honest dealing, "A false balance is abomination to the LORD: but a just weight is his delight" (Proverbs 11:1). The series verse frames the whole study of lands and peoples: "And hath made of one blood all nations of men for to dwell on all the face of the earth, and hath determined the times before appointed, and the bounds of their habitation;" (Acts 17:26). History is told candidly: the real achievements of merchants and navigators are given their due, and real wrongs, such as forced labor at Potosí, the violence of the spice wars and the slave trade, are named plainly and judged by the standards of truth.

WHO IT IS FOR

Written for students in grades 10–12 who are comfortable with basic algebra, ratios, percentages and reading a graph. No economics background is required; every term is defined when it first appears. It works well after the School Launch Grade 8 geography year or the high-school course Geography and History: Why Borders Fall Where They Do, but neither is required. Students work fairly independently, reading the lesson, working the examples and checking the practice sets against the answers; a parent or mentor discusses the essay questions, looks over the map notebook each week and grades the unit tests. No special materials are needed beyond a good atlas, a calculator and a notebook; optional books and resources are listed in each unit.

HOW TO USE THIS COURSE

The weekly rhythm. Each lesson takes three sessions of about 50 minutes. Session 1: the warm-up, the video, the story and the core ideas. Session 2: the worked examples, the picture study and the map notebook. Session 3: the practice set, checked against the answers, and the project. At five sessions a week the 25 lessons fill about 17 weeks, roughly one and a half lessons a week. Each unit ends with a test day, the midterm comes after Unit 3, and the final comes at the end; each exam has a review day before it.

The ⚙ thread is the whole course. Lessons marked ⚙ carry the story of technology overcoming geography most directly, from the monsoon dhow and the Manila galleon to the canal, the container and the pipeline. Do not skip them; they tie each unit together. In every lesson, ask the same question: what did this cost to move, and what made it cheaper?

The map notebook. Use one bound notebook, ideally with graph-paper pages, for the whole semester. Each unit adds at least one hand-drawn map: the overland routes, the Indian Ocean trade world, the world's sea lanes and choke points, the world's resources and the flows of modern trade. Draw from the atlas, label carefully, add a scale bar and a north arrow, and color with a key. By the end the notebook is a personal atlas of world commerce.

Worked examples and practice. Each lesson has three worked examples: a cost-per-mile comparison, a sailing-time estimate, a choke-point calculation, a comparative-advantage table. Cover the solution, try it yourself, then compare line by line. The practice set has 12 problems, from map reading and short answers to calculations and one short essay. Mark your work against the answers the same day and correct every miss in the notebook.

Unit tests and unit projects. Each unit test is worth 100 points and has 12–16 problems mixing map work, calculations, short answers and one essay. Each unit also has a larger project: a cost-per-mile model of camel and ship, a monsoon-calendar sailing game, a choke-point risk table, a resource-to-product chain and, as the final project, a map tracing the journey of one product to your home. Calculators are allowed on tests; atlases are not, so study from your own maps.

How it fits the series. This is Course B of the School Launch high-school geography electives and builds on the K–8 Geography years, especially Grade 8's rivers, ports and

straits. It pairs naturally with Course C, Technology Overcoming Geography, and the School Launch Engineering courses (ships, locks, canals and containers), and with the Business courses, where supply, cost and trade appear from the merchant's side of the counter.

SCOPE AND SEQUENCE

Unit 1: The Silk Road and the Caravan Trade (Weeks 1–3)

From Zhang Qian's mission west to the oasis cities and the Mongol peace: what moved overland across Asia, why the caravan was so costly, and why the sea route finally won.

Unit 2: The Spice Routes and the Monsoon (Weeks 4–6)

Sailing with the seasons across the Indian Ocean: the dhow and the Swahili coast, Zheng He's treasure fleets, the Dutch in the Spice Islands and the silver galleons between Acapulco and Manila.

Unit 3: The Great Straits (Weeks 7–10)

The narrow doors of the world's sea lanes, one by one: Malacca, Hormuz and Bab-el-Mandeb, Gibraltar and the Bosphorus, the canals of Suez and Panama, and Dover and the Danish straits, with traffic, width, depth and alternatives. The midterm follows this unit.

Unit 4: Resources and Where They Lie (Weeks 11–13)

The goods that built trade and where God placed them: salt, silver and gold, coal and iron, oil and gas, and the grain, copper and rare earths of the modern world, with how each one moves.

Unit 5: The Modern Trade Map (Weeks 14–17)

Comparative advantage, the container revolution, the great ports and hubs, and what flies, floats and flows, ending with the final project and the final exam.

MATERIALS

- **A good world atlas:** Any recent physical and political atlas with thematic maps of resources and trade. A used copy is fine; a free online atlas works if a print copy is not at hand.
- **Map notebook:** One bound notebook, ideally with graph-paper pages, used for maps, worked examples and corrections all semester.
- **Outline maps:** Blank world and regional outline maps (Asia, the Indian Ocean, Europe), printed free from many sources, for practice before drawing in the notebook.
- **Colored pencils, fine pens and a ruler:** For routes, keys, scale bars and labels. A ruler with metric and inch marks helps with map distances.
- **String or a strip of paper:** For measuring curved routes on the atlas and the globe and converting them with the map scale.

- **A globe:** Helpful for great-circle routes and for seeing why ships and planes do not follow straight lines on a flat map. An inexpensive one is enough.
- **Scientific calculator:** For cost-per-mile models, sailing times, percentages and comparative-advantage tables. A phone calculator works.
- **Internet access:** For the lesson videos and for NASA Earth Observatory satellite images of the straits and ports. A spreadsheet program is optional but useful for the unit projects.
- **A King James Bible:** For the Scripture passages in the lessons.

GRADING

Grades come from the practice sets, the map notebook, the five unit projects, the five unit tests, the midterm and the final. A calculation earns full credit when the setup, the numbers with their units and the answer are all shown. A map earns full credit when it is accurate, neatly labeled, and has a title, a key, a scale bar and a north arrow. An essay earns full credit when it answers the question with specific places, dates and evidence.

- Practice sets (completed and corrected): 15%
- Map notebook (accuracy, labels, completeness): 10%
- Unit projects: 15%
- Unit tests: 30%
- Midterm exam: 15%
- Final exam: 15%

A 90–100, B 80–89, C 70–79, D 60–69, F below 60.

- Practice sets are graded for completion and correction, not first-try accuracy: a problem done, checked and correctly reworked earns full credit.
- On tests, give partial credit for a correct setup even if the arithmetic slips. A missing unit or a misplaced strait costs a point; an answer with no work earns at most half credit.
- Unit projects are graded on accuracy, clear reasoning and neat presentation. The final project, the product-journey map, should name every leg of the journey, the mode of transport and at least one choke point or port along the way.
- For a high-school transcript this course is one-half credit of social studies (geography or economics). Keep the map notebook, projects and tests as the record of the semester.

A NOTE TO PARENTS

This course is meant to show your student that the world's commerce is not random. Goods move where the winds, coasts, rivers and straits allow, and every great advance in trade, from the camel to the container ship, has been an attempt to make the map cheaper to cross. Your part is simple: look over the map notebook each week, check that practice sets are corrected, talk through the essay questions and grade the unit tests with the answer keys

provided. Ask your student to explain one map to you each week; teaching it back is the best review there is.

Some lessons touch matters that are in the news, such as oil straits, canals, ports and the minerals of modern devices. These are presented factually, with figures rounded and dated (as of 2026), and with no partisan claims. Economic ideas such as comparative advantage are taught as tools for understanding, with their strengths and limits, so your student can weigh them. History is told candidly, with real achievements and real wrongs alike, judged by the standards of truth rather than modern slogans.

A word about time. This course is written from a Christian view of creation (Genesis 1:1) and the Flood (Genesis 6-9). It gives no ages of the earth or its rocks in millions of years. Deep-time names such as “Ice Age” are taught as museum words, vocabulary a student will meet on museum signs and in textbooks, so your student can read any sign or book with understanding. Where a long age comes up, for example in where oil, coal or salt deposits lie, a “Thinking About Time” box separates what is measured from what is assumed, and explains how Christians who read Genesis as history understand it. Recorded history, with dates from written sources, is given normally. We begin where Scripture begins: “In the beginning God created the heaven and the earth” (Genesis 1:1).

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Unit 1: The Silk Road and the Caravan Trade

- 1.1 Silk and the Han Dynasty
- 1.2 Oasis Cities
- 1.3 What Moved on the Road
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- 1.5 Why the Road Declined

Unit 2: The Spice Routes and the Monsoon

- 2.1 The Monsoon Winds
- 2.2 The Dhow and the Swahili Coast
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- 2.5 Manila Galleons

Unit 3: The Great Straits

- 3.1 Malacca: The Busiest Strait in the World
- 3.2 Hormuz and Bab-el-Mandeb: The Oil Straits
- 3.3 Gibraltar and the Bosphorus: Doors to the Mediterranean and the Black Sea
- 3.4 Suez and Panama: Canals as Man-Made Straits
- 3.5 Dover and the Danish Straits: Northern Europe's Sea Doors

Unit 4: Resources and Where They Lie

- 4.1 Salt
- 4.2 Silver and Gold
- 4.3 Coal and Iron
- 4.4 Oil and Gas
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Unit 5: The Modern Trade Map

- 5.1 Comparative Advantage: Ricardo's Wine and Cloth
- 5.2 The Container Revolution: Malcom McLean and the Cost of Shipping
- 5.3 Ports and Hubs: Shanghai, Singapore, Rotterdam and Los Angeles-Long Beach
- 5.4 Air Cargo and Pipelines: What Flies, What Floats and What Flows
- 5.5 Final Project: Trace the Journey of One Product to Your Home

★ quarter path · ⚙ technology overcoming geography

THE SILK ROAD AND THE CARAVAN TRADE

Why does trade go where it goes? For most of history, the answer was written in mountains, deserts and water. This unit follows the oldest great trade route between the far ends of the Old World: the web of caravan roads that ran from China through the oases of Central Asia to Persia and the Mediterranean, which a German geographer in 1877 named the **Silk Road**. You will ride west with Zhang Qian, the Han envoy who was held captive by the Xiongnu for ten years; walk the strings of oases around the Taklamakan to Dunhuang, Kashgar and Samarkand; open the sealed Library Cave at Mogao; follow silk, horses, glass, paper, the gospel and the plague along the roads; see how the Mongol conquests, at a terrible price, made the roads safe for a century; and learn why, after Vasco da Gama reached India in 1498, the long way around by sea became the cheap way.

This is a course in economic geography, so you will work with real numbers: distances from latitude and longitude, caravan days, water loads, the value density of goods, the cost of tolls, the speed of a relay, a great-circle distance across Asia, and finally a full cost model comparing the camel and the ship. Along the way you will meet a principle that will run through the whole semester: **goods move by the cheapest road that is safe enough, and the cost of the road decides which goods can travel at all.**

The Bible teaches that God “hath made of one blood all nations of men for to dwell on all the face of the earth, and hath determined the times before appointed, and the bounds of their habitation” (Acts 17:26). The same mountains and deserts that divided the peoples of Asia also channeled where they would meet, and along those roads traveled not only silk but the Scriptures, carried by the monks of the Church of the East to China by AD 635. The merchants of the road also remind us of the plain command that runs through this course: “A false balance is abomination to the LORD: but a just weight is his delight” (Proverbs 11:1).

BEFORE YOU BEGIN

- Can read latitude and longitude on a map or globe and convert between kilometers and miles
- Can work with percentages, ratios, powers (such as 0.9^8) and simple rates (distance = speed $\times$ time) with a calculator
- Can use the cosine function on a calculator (for the length of a degree of longitude and the great-circle formula in Lesson 1.4)
- Knows in outline the empires of Rome, Han China and Persia and the rise of Islam

MASTERY CHECKLIST

- I can tell the story of Zhang Qian’s mission and explain how it opened the Han road to the west through the Hexi Corridor.
- I can explain how an oasis works and why Dunhuang, Kashgar and Samarkand became great crossroads.

- I can explain value density and why the Silk Road carried silk, horses, glass, paper, faiths and disease but not grain.
- I can describe the Mongol peace honestly, with both its conquests and the yam, the paiza and the travelers it made possible.
- I can build a cost model comparing camel and ship and explain why the sea route became cheaper after 1498.
- I can draw the overland routes on a map with their oases, mountains, deserts and main cities from Chang'an to the Mediterranean.

OPTIONAL BOOKS AND RESOURCES

- **International Dunhuang Programme (British Library and partners)** (<https://idp.bl.uk/>): Free. Photographs of manuscripts, paintings and objects from Dunhuang and other Silk Road sites, including the Diamond Sutra of 868 (Lessons 1.2 and 1.3). Best browsed with a parent.
- **UNESCO World Heritage: Mogao Caves** (<https://whc.unesco.org/en/list/440>): Free. A short description, map and photographs of the Mogao Caves near Dunhuang, the unit's picture study site.
- **Project Gutenberg (free primary sources)** (<https://www.gutenberg.org/>): Free. Search for Henry Yule's translation of *The Book of Ser Marco Polo* (Lesson 1.4) and Adam Smith's *The Wealth of Nations* (1776), Book I, Chapter 3, for his comparison of wagon and ship (Lesson 1.5). A parent may choose the passages.

1.1 SILK AND THE HAN DYNASTY

OBJECTIVES

- Tell the story of Zhang Qian's mission west (about 138-126 BC) from Sima Qian's record, and explain why Emperor Wu sent him.
- Explain why silk was so valuable, how it was made, and why a light, costly good was the kind of thing that could pay its way across Asia.
- Trace the overland routes on a map from Chang'an through the Hexi Corridor and around the Taklamakan, and estimate distances and caravan travel times.

Warm-up. Gather three things of about the same size: a silk or satin scarf or tie (or a smooth polyester one if you have no silk), a cotton handkerchief and a wool sock. Weigh each on a kitchen scale, then squeeze each into your fist. Which packs smallest for its weight? Now suppose each one had to be carried on your back for a thousand miles, and you could sell only what you carried. Write one sentence naming which you would carry, and why.

Watch. *The Silk Road Network - UNESCO World Heritage Site* (World Heritage Journey, 4:35). <https://www.youtube.com/watch?v=bU8cmkShC-s>

With On the map: take a short tour of Xi'an, the old Han capital Chang'an where Zhang Qian's journey began, and look for the city walls and other Silk Road landmarks.

Note: Captions were not available to check; preview it first. This is a travel tour of Xi'an and the Silk Road World Heritage sites, so it does not tell Zhang Qian's story or show how silk is made.

Backup video. *Did Ancient Rome and China Know About Each Other? (Short Animated Documentary)* (History Matters, 3:13). <https://www.youtube.com/watch?v=5e8Yde6qXrI>

With the big idea: watch how Han China and Rome traded silk across Asia but almost never met, and notice the middlemen who stood between them. Note: Captions were not available to check; preview it first. History Matters is usually clean, but its narrator sometimes makes a light joke.

KEY TERMS

sericulture

The raising of silkworms (the caterpillars of the moth *Bombyx mori*) on mulberry leaves and the unwinding of their cocoons into silk thread.

Xiongnu

A confederation of horse-riding nomads on the steppe north of China, the Han dynasty's great rival in the 200s and 100s BC.

Hexi Corridor

A narrow strip of oases, about 1,000 km (600 miles) long, between the Qilian Mountains and the Gobi, which forms China's gateway to the west (also called the Gansu Corridor).

envoy

A messenger sent by a ruler to speak for him to a foreign people or king.

relay trade

Trade in which goods pass from merchant to merchant and market to market, so that few traders ever travel the whole route.

Silk Road

A modern name (German *Seidenstraße*, coined by Ferdinand von Richthofen in 1877) for the web of overland trade routes between China and the Mediterranean.

CORE IDEAS

The story. In about 138 BC a young palace officer named Zhang Qian (jahng chyen) rode out of the Han capital, Chang'an, near today's Xi'an, with a party of more than a hundred men. His master was Emperor Wu of Han (reigned 141–87 BC), and his errand was dangerous. North and west of China roamed the **Xiongnu**, a confederation of horse-riding nomads who raided the frontier and had forced the Han court to pay them yearly gifts of silk, grain and wine. Captured Xiongnu told the emperor that their people had once crushed a nation called the Yuezhi, killed its king and made his skull into a drinking cup, and that the Yuezhi had fled far to the west. Emperor Wu wanted to find them and make an alliance to strike the Xiongnu from both sides. To reach them, his envoy had to cross Xiongnu country. His guide was a Xiongnu-born servant named Ganfu.

The journey. The Xiongnu caught them almost at once. Zhang Qian was held for more than ten years. He was given a Xiongnu wife and had a son, but the historian tells us he kept the emblem of his office as the emperor's envoy. At last he slipped away west, across the edge of the Tarim Basin and over the mountains to Dayuan, a land of walled towns and fine horses in the Ferghana Valley. Dayuan sent him on to Kangju, in the Sogdian country around Samarkand, and from there he reached the Yuezhi. They had conquered Daxia (Bactria, in today's northern Afghanistan), found the land rich and peaceful, and had no wish to go back east for revenge. After about a year, Zhang Qian turned home by the southern edge of the Tarim Basin, was captured by the Xiongnu a second time, and escaped in 126 BC during a quarrel over the Xiongnu throne. He reached Chang'an about twelve years after he had left, with his wife and the faithful Ganfu. Of more than a hundred men, two came home. The mission failed at its purpose and succeeded beyond anything the emperor had imagined.

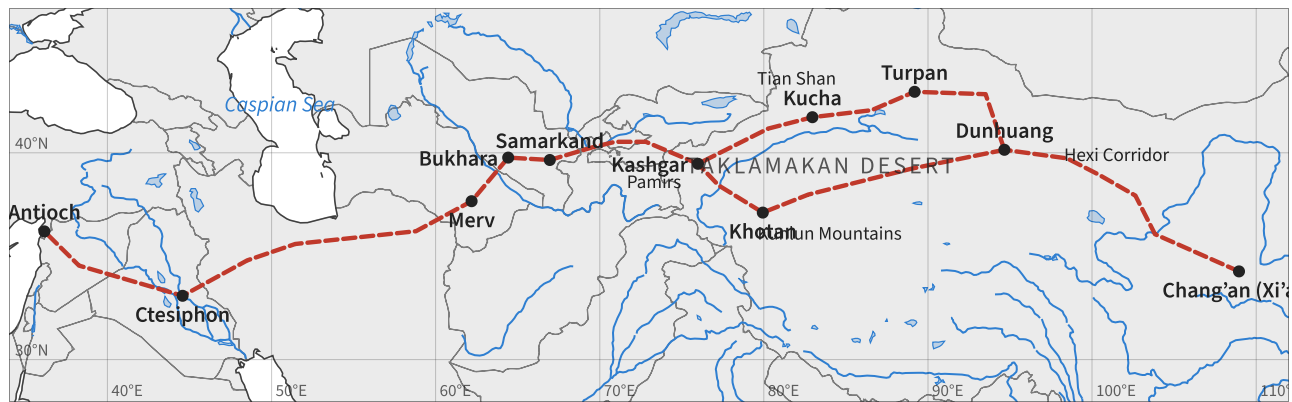
How they figured it out. Zhang Qian's report survives because Sima Qian, the Grand Historian of the Han court, wrote it into his *Shiji* (Records of the Grand Historian), finished about 90 BC, in the chapter on Dayuan. It is one of the first descriptions of Central Asia written by an eyewitness. Zhang Qian described Ferghana's great horses, which were said to sweat blood; its grapes, which people made into wine; and alfalfa grown as horse feed. He described Anxi (Parthia, in Persia), with hundreds of walled towns, merchants who traveled by cart and by boat, silver coins stamped with the king's face, and writing set down sideways on strips of leather. Most surprising of all, in the markets of Bactria he had seen bamboo

canes and cloth made in Shu (Sichuan, in western China). The Bactrians said their merchants bought them in Shendu (India). Chinese goods were already traveling west by roads the Han court knew nothing about.

What the emperor did. Emperor Wu acted on the report with both diplomacy and war. His generals Wei Qing and Huo Qubing pushed the Xiongnu back, and in 121 BC Huo Qubing drove them out of the Hexi Corridor, and by about 111 BC the Han had founded four frontier commanderies there: Wuwei, Zhangye, Jiuquan and Dunhuang. Walls and beacon towers were pushed west to the Jade Gate (Yumen Pass) and the Yang Pass beyond Dunhuang. Han embassies loaded with silk went west year after year. When Dayuan refused to sell its best horses, the emperor sent the general Li Guangli to take them. This War of the Heavenly Horses (104–101 BC) brought back about 3,000 horses, but only a fraction of the soldiers came home. Grapes and alfalfa were planted near the imperial palaces. Ambition, cruelty and courage are all in this story, and Sima Qian, who wrote in the emperor's own lifetime, did not hide the cost.

The big idea. Why silk? Silk comes from the cocoon of a caterpillar that eats mulberry leaves. Each cocoon is spun from one continuous filament, often close to a kilometer (more than half a mile) long. Workers soak the cocoons in hot water, find the ends, and reel several filaments together into thread. A few thousand cocoons make one pound of silk, so every bolt holds months of careful labor. The finished cloth is light, strong, smooth and takes dye brilliantly. For the Han, bolts of silk served as money: soldiers were paid in it, taxes were collected in it, and it was the gift of choice to foreign rulers. Far to the west, Romans called the Chinese the *Seres*, the silk people. Writers such as Pliny the Elder believed the Seres combed silk off the leaves of trees, and about AD 77 Pliny complained that India, the Seres and Arabia drained 100 million sesterces a year from the empire. That is the economic key to the whole unit: **only goods of high value for their weight** could pay for the months of travel across Asia. Silk was the perfect cargo.

On the map. China is ringed by natural walls: the Pacific on the east, the Gobi and the steppe on the north, the Tibetan Plateau and the Himalaya on the southwest. The one easy door to the west is the **Hexi Corridor**, a strip of oases fed by snowmelt from the Qilian Mountains, with desert on its other side. At Dunhuang the road meets the **Tarim Basin**, a great bowl holding the Taklamakan Desert and ringed by the Tian Shan to the north, the Kunlun to the south and the Pamirs to the west. Caravans did not cross the sand; they skirted it by a northern chain of oases (Turpan, Kucha, Aksu) or a southern chain (Miran, Khotan, Yarkand), and the two roads met again at Kashgar. Beyond the Pamirs lay Ferghana, Samarkand, Bukhara and Merv, then Persia and the Mediterranean, roughly 6,500 km (4,000 miles) from Chang'an. It was never one road, and almost no one traveled all of it. Goods moved by **relay trade**, from Chinese to Sogdian to Parthian to Syrian hands, gaining a markup at every market. The German geographer Ferdinand von Richthofen gave the whole web its famous name, the Silk Road, in 1877. The mountains and deserts that seem to wall the nations apart also channeled where they would meet; as Paul told the Athenians, God "hath determined the times before appointed, and the bounds of their habitation."



The overland routes. From Dunhuang the roads split around the Taklamakan and meet again at Kashgar before climbing over the Pamirs.

PICTURE STUDY



Zhang Qian Taking Leave of Emperor Wu (Mogao Cave 323), Unknown Buddhist painters of Dunhuang, Early Tang dynasty, about AD 618–712 · Wall painting in mineral pigments on plaster · Mogao Caves, Cave 323 (north wall), near Dunhuang, Gansu, China

More than seven hundred years after Zhang Qian's journey, Buddhist painters at the Mogao Caves near Dunhuang painted his departure on the wall of Cave 323. The emperor sits on horseback under a canopy with his courtiers, and Zhang Qian kneels before him with a tablet in his hands. In other scenes on the same wall the little party rides off across the hills toward a walled city in the far west.

The painting is a lesson in how stories change. In the mural, Emperor Wu sends Zhang Qian west to learn the names of two golden statues, as if they were images of the Buddha. Sima Qian's history says nothing of the kind: Zhang Qian went to find allies against the Xiongnu. Later Buddhists, living on the road their faith had traveled, retold the famous journey as part

of their own story. A historian learns to love such pictures and also to check them against the oldest written sources.

Look closely

- Find the emperor. How has the painter shown that he is the most important person in the scene?
- Find Zhang Qian. What is he holding, and what does his posture say about his relation to the emperor?
- Look for the riders setting out. How has the painter shown distance and a long journey in a small space?
- Look at the colors that remain. Which have faded, and which still look strong after some thirteen centuries in a desert cave?

Talk about it

1. The mural gives a different reason for the mission than Sima Qian does. Which source should a historian trust more, and why?
2. Why might the people of Dunhuang, a frontier oasis, have cared so much about the man who first opened the road to the west?
3. What does the dry desert climate of Dunhuang have to do with why these paintings survived?

PROJECT: STRING-AND-SCALE MAP OF ZHANG QIAN'S JOURNEY

You will draw a large map of the routes from Chang'an to Bactria, mark Zhang Qian's journey out and back, and measure it with a piece of string against your map's scale bar. Then you will turn distance into days of travel, the way a caravan master would.

You will need

- A large sheet of paper or poster board, at least 60 × 45 cm (24 × 18 in)
- An atlas or printed map of Central Asia and western China (or the figure in this lesson)
- Pencil, fine black pen, colored pencils (blue for rivers, brown for mountains, yellow for deserts, red for routes)
- A piece of thin string about 1 m long, a ruler and a calculator

Steps

1. Lightly draw a grid on your sheet from 60° E to 112° E and from 30° N to 46° N, with a line every 4 degrees. Label the lines.
2. Using the atlas or the figure, plot these places by latitude and longitude: Chang'an (34.3° N, 108.9° E), Wuwei (37.9° N, 102.6° E), Dunhuang (40.1° N, 94.7° E), Turpan (43.0° N, 89.2° E), Kucha (41.7° N, 83.0° E), Kashgar (39.5° N, 76.0° E), Khotan (37.1° N, 79.9° E), Kokand in the Ferghana Valley (40.5° N, 70.9° E), Samarkand (39.7° N, 67.0° E) and Balkh in Bactria (36.8° N, 66.9° E).

3. Shade the Taklamakan Desert yellow and draw the Tian Shan, Kunlun, Qilian and Pamir mountains in brown. Label the Hexi Corridor.
4. Draw a scale bar. At about 40° N, one degree of latitude is about 111 km, so measure the distance between two of your latitude lines and mark that length as 444 km (4 degrees).
5. In red, draw Zhang Qian's probable route out: Chang'an, the Hexi Corridor, the northern edge of the Tarim Basin, Kashgar, Ferghana, Samarkand, Balkh. In a second color draw his route home along the southern edge, through Khotan.
6. Lay the string along each route, following the bends. Mark the string, straighten it along your scale bar, and record each distance in km and miles (1 km = 0.621 miles).
7. Make a table: leg, distance, days at 30 km (19 miles) a day. Add up the total marching days out and back, and compare them with the twelve years the mission actually took.
8. Write a paragraph: What, besides distance, made the journey take so long?

Tips

- A degree of longitude shrinks as you go north. At 40° N it is only about 85 km, so use latitude lines, not longitude lines, for your scale bar.
- String measurements on a hand-drawn map will be rough. Round to the nearest 50 km; caravan masters did not know their distances any better.

Check your work

- My map has a grid, a scale bar and at least ten correctly placed places.
- I measured both routes and turned distances into days in a neat table.
- My paragraph names at least three reasons, besides distance, why the mission took twelve years.

MAP NOTEBOOK

1. Draw the life cycle of the silkworm in four panels (egg, caterpillar on a mulberry leaf, cocoon, moth) and label where the silk comes from.
2. Sketch China's "natural walls" as a simple diagram: the Pacific, the Gobi and steppe, the Tibetan Plateau and Himalaya, and the Taklamakan, with the Hexi Corridor drawn as the one open door.
3. Make a two-column chart from Zhang Qian's report: "What he saw" and "Why it mattered to Emperor Wu." List at least five items.

From history. In AD 97 the Han general Ban Chao, who had restored Chinese power in the Tarim Basin, sent an officer named Gan Ying to reach Da Qin, the Roman Empire. Gan Ying traveled through Parthia to the shore of a great sea, probably the Persian Gulf. There Parthian sailors told him the crossing could take months or even two years with a fair wind, and that men far from home grew homesick and died. He turned back. Many historians think the Parthians, who grew rich as middlemen in the silk trade, had good reason not to help China and Rome meet face to face.

WORKED EXAMPLES

Example 1. Estimate the straight-line distance from Chang'an (34.3° N, 108.9° E) to Dunhuang (40.1° N, 94.7° E). Use 111 km per degree of latitude and $111 \times \cos(\text{average latitude})$ km per degree of longitude. Then compare it with the road distance of about 1,700 km.

(Use the map or drawing "Find Chang'an and Dunhuang at the east end of the routes." shown earlier in this lesson.)

1. North-south difference: $40.1^\circ - 34.3^\circ = 5.8^\circ$. Distance = $5.8 \times 111 = 644$ km.
2. East-west difference: $108.9^\circ - 94.7^\circ = 14.2^\circ$. Average latitude = $(34.3 + 40.1) \div 2 = 37.2^\circ$, and $\cos 37.2^\circ \approx 0.797$. Distance = $14.2 \times 111 \times 0.797 \approx 1,256$ km.
3. Treat the two as sides of a right triangle (fine for a region this size): $\sqrt{(644^2 + 1,256^2)} = \sqrt{(414,736 + 1,577,536)} = \sqrt{1,992,272} \approx 1,411$ km.
4. In miles: $1,411 \times 0.621 \approx 877$ miles. Ratio of road to straight line: $1,700 \div 1,411 \approx 1.2$.

Answer: About 1,410 km (about 880 miles) in a straight line. The road is about 1.2 times longer, because it bends northwest to follow the oases of the Hexi Corridor instead of crossing mountains and desert.

Example 2. A Han caravan sets out from Chang'an for Kashgar by the northern route. Approximate road distances: Chang'an to Dunhuang 1,700 km; Dunhuang to Turpan (by Hami) 700 km; Turpan to Kucha 600 km; Kucha to Kashgar 750 km. Loaded camels average 30 km a day, and the caravan rests one day after every five days of marching. How long does the trip take?

1. Total distance: $1,700 + 700 + 600 + 750 = 3,750$ km ($3,750 \times 0.621 \approx 2,330$ miles).
2. Marching days: $3,750 \div 30 = 125$ days.
3. Rest days: one per five marching days, so $125 \div 5 = 25$ rest days.
4. Total: $125 + 25 = 150$ days, or about 5 months.

Answer: About 150 days, roughly five months, to cover about 3,750 km (2,330 miles), and Kashgar is barely more than halfway to the Mediterranean. This is why few merchants traveled the whole road.

Example 3. About AD 77 Pliny the Elder wrote that India, the Seres (China) and Arabia took 100 million sesterces a year from the Roman Empire. A Roman legionary in this period was paid 900 sesterces a year, and a legion had about 5,000 men. How many soldiers' yearly pay does Pliny's figure equal? About how many legions is that?

1. Soldiers: $100,000,000 \div 900 \approx 111,111$ soldier-years of pay.
2. Legions: $111,111 \div 5,000 \approx 22$ legions.
3. Caution: Pliny gave one round figure for three regions together, and he was complaining, not auditing. The number shows how large the eastern trade seemed to a Roman, not an exact account.

Answer: About 111,000 soldiers' yearly pay, roughly the pay of 22 legions. Even as a rough complaint, it shows that the trade in silks, spices and pearls moved a great deal of Roman silver east.

PRACTICE

1. **EASY** Who sent Zhang Qian west, about when did he leave, and what was the purpose of his mission?
2. **EASY** Who gave the routes the name "Silk Road," in what language, and in what year?
3. **EASY** Name the narrow strip of oases that is China's gateway to the west, the mountains that water it, and the two passes at its western end.
4. **EASY** Convert 6,500 km, the rough length of the routes from Chang'an to the Mediterranean, to miles.
5. **MEDIUM** Zhang Qian left about 138 BC and returned in 126 BC. How many years was he gone? Explain why you subtract this way with BC dates.
6. **MEDIUM** A caravan travels from Dunhuang to Kashgar by the northern route: 700 km to Turpan, 600 km to Kucha and 750 km to Kashgar. At 30 km a day with no rest days, how many days of marching is that? Give the distance in miles too.
7. **MEDIUM** Dunhuang lies at about 40.1° N , 94.7° E and Kashgar at about 39.5° N , 76.0° E . At 40° N one degree of longitude is about 85 km. Estimate the straight-line distance between them in km and miles.
(Use the map or drawing "Use this map for Problem 7." shown earlier in this lesson.)
8. **MEDIUM** The War of the Heavenly Horses began in 104 BC. How many years was that after Zhang Qian's return? What did Zhang Qian's report have to do with it?
9. **HARD** Four Roman sesterces made one denarius, and a legionary was paid 225 denarii a year. Convert Pliny's 100 million sesterces to denarii and then to soldier-years of pay.
10. **HARD** Use the map. Name the city where the northern and southern routes around the Taklamakan meet, the mountain range north of the northern route, and the range south of the southern route. Why did caravans not cross the middle of the basin?
(Use the map or drawing "Use this map for Problem 10." shown earlier in this lesson.)
11. **HARD** In a relay trade, a bolt of silk is bought in Dunhuang for 10 silver coins. It changes hands at four more markets, and at each one the seller charges 50 percent more than

he paid. What is its price at the fifth sale, and how many times the original price is that?

12. **CHALLENGE** Write a paragraph explaining how geography shaped Emperor Wu's policy toward the west. Use at least three place names and the words corridor, oasis and steppe.

COMMON MISTAKES

- Picturing the Silk Road as one paved highway traveled end to end by the same merchants. It was a web of routes, and goods usually passed through many hands.
- Thinking Zhang Qian went west to open trade. He went to find a military ally; trade followed from what he learned.
- Measuring east-west distances with 111 km per degree of longitude at Silk Road latitudes. Near 40° N a degree of longitude is only about 85 km.

Make it a game · The Envoy's Escape. Draw a track of 20 squares from Chang'an to Bactria and back, through the Hexi Corridor, the Xiongnu lands, Ferghana and Sogdiana. Each player is an envoy with a token and an "emblem of office" card. Roll a die to move. Squares 4 and 16 are Xiongnu camps: land there and you are captured; you escape only by rolling a 6, but each turn held you may answer a question from this lesson to roll twice. A player who lands on Ferghana gains a "heavenly horse" and moves two extra squares each turn on the way home. The first envoy to return to Chang'an with the emblem wins, and must then make a one-minute report to the "emperor" naming three things seen in the west.

Scripture. "And hath made of one blood all nations of men for to dwell on all the face of the earth, and hath determined the times before appointed, and the bounds of their habitation;" (Acts 17:26, KJV)

Paul spoke these words in Athens, a city that knew of silk only as a luxury from the far edge of the world. Every people on the Silk Road, Han and Xiongnu, Sogdian and Parthian, came from one blood. The same mountains and deserts that set the bounds of their habitation also decided where they would meet and trade.

Practice answers

1. Emperor Wu of Han sent him about 138 BC to find the Yuezhi and make an alliance with them against the Xiongnu.
2. The German geographer Ferdinand von Richthofen, as *Seidenstraße*, in 1877.
3. The Hexi (Gansu) Corridor, watered by snowmelt from the Qilian Mountains; the Jade Gate (Yumen Pass) and the Yang Pass beyond Dunhuang.
4. $6,500 \times 0.621 \approx 4,040$ miles, about 4,000 miles.
5. $138 - 126 = 12$ years. BC years count down toward the birth of Christ, so the later date is the smaller number and you subtract the smaller from the larger.
6. $700 + 600 + 750 = 2,050$ km (about 1,270 miles). $2,050 \div 30 \approx 68.3$, so 69 days of marching.

7. The latitudes are nearly the same, so use the longitude difference: $94.7 - 76.0 = 18.7^\circ$; $18.7 \times 85 \approx 1,590$ km (about 990 miles).
8. $126 - 104 = 22$ years later. Zhang Qian had reported Ferghana's great "blood-sweating" horses, and when Dayuan refused to sell its best horses, Emperor Wu sent an army to take them.
9. $100,000,000 \div 4 = 25,000,000$ denarii. $25,000,000 \div 225 \approx 111,111$ soldier-years, the same answer as using 900 sesterces a year.
10. Kashgar; the Tian Shan to the north; the Kunlun to the south. The middle of the basin is the Taklamakan, a sea of shifting sand with no water, while the oases lie along its edges where rivers come down from the mountains.
11. $10 \times 1.5^4 = 10 \times 5.0625 \approx 50.6$ coins, about five times the starting price. Each markup paid for a merchant's travel, animals, tolls, risk and profit.
12. Answers will vary. A strong answer: China's only easy road west ran through the Hexi Corridor, a narrow chain of oases between the Qilian Mountains and the desert, and the Xiongnu of the steppe could cut it. So Emperor Wu drove the Xiongnu out of the corridor, founded commanderies at places such as Wuwei and Dunhuang, and pushed walls and beacon towers to the Jade Gate. Beyond Dunhuang, the routes had to follow the oases around the Taklamakan to Kashgar and over the Pamirs to Ferghana, so control of a few oasis towns and passes meant control of the whole road.

1.2 OASIS CITIES

OBJECTIVES

- Explain how an oasis works: snowmelt rivers, gravel fans, groundwater, springs and the karez, and why oases lie in strings along the foot of mountains.
- Describe Dunhuang, Kashgar and Samarkand: where each lies, what made it a crossroads, and what survives from its past, including the Library Cave at Mogao.
- Compare the northern and southern routes around the Taklamakan by distance, water and safety, and plan a caravan's water needs across a dry stage.

Warm-up. Pour a cup of water slowly onto one end of a baking pan filled with a thin layer of sand or soil, tilted on a book. Watch where the water goes. Does it run all the way across the pan, or soak in? Where does the sand stay damp longest? Write one sentence: if you were a farmer in a desert, where in this pan would you plant?

Watch. *Episode XV: The Guardians of Dunhuang* (Justin Jacobs, 13:01).

<https://www.youtube.com/watch?v=0q1uRJs9L4>

After the story: listen to how Wang Yuanlu found the hidden Library Cave at Mogao and how he dealt with the scholars and explorers, like Aurel Stein, who came for the scrolls.

Note: Captions were not available to check; preview it first. It is a university historian's lecture about Buddhist cave scrolls and may touch on the debate over whether foreign explorers had the right to take them.

KEY TERMS

oasis

A fertile place in a desert where water reaches the surface or near it, from springs, rivers or wells.

alluvial fan

A fan-shaped spread of gravel and sand laid down where a mountain stream leaves its valley and slows; water often sinks into it and reappears as springs at its lower edge.

karez

An underground channel that carries groundwater by gravity from the foot of the mountains to an oasis, dug with a line of vertical shafts (called a qanat in Persia).

caravanserai

A walled inn on a trade route with a courtyard for animals and rooms for merchants and their goods.

Sogdians

An Iranian people of the region around Samarkand and Bukhara who were the leading long-distance merchants of the Silk Road from about AD 300 to 800.

entrepôt

A trading city where goods are brought in, stored, sold and sent on to other markets.

CORE IDEAS

The story. In the summer of 1900, a Daoist priest named Wang Yuanlu was clearing drifted sand out of the cave temples at Mogao, about 25 km (15 miles) southeast of Dunhuang, where he had made himself caretaker. In the passage of one cave his workmen noticed a crack in the painted wall. Behind it was a small, sealed room, packed from floor to ceiling with bundles of paper scrolls, silk paintings and printed sheets. It had been walled up around the year 1000, and no one knows for certain why. Today it is called the **Library Cave** (Cave 17). It held tens of thousands of documents in Chinese, Tibetan, Sanskrit, Khotanese, Sogdian, Old Uyghur and other languages: Buddhist scriptures, contracts, letters, school exercises, a calendar, Christian texts of the Church of the East, even a Hebrew prayer. In 1907 the Hungarian-born British archaeologist Aurel Stein persuaded Wang to sell him thousands of manuscripts for a modest donation to the temple, and in 1908 the French scholar Paul Pelliot took thousands more. In 1910 the Chinese government sent most of the rest to Beijing. Stein and Pelliot believed they were rescuing the scrolls for scholarship; many Chinese have regarded the removals as a great loss. Both views are part of the story. The documents are now divided among London, Paris, Beijing, St. Petersburg and other cities, and much of the collection has been photographed and placed online by the International Dunhuang Programme.

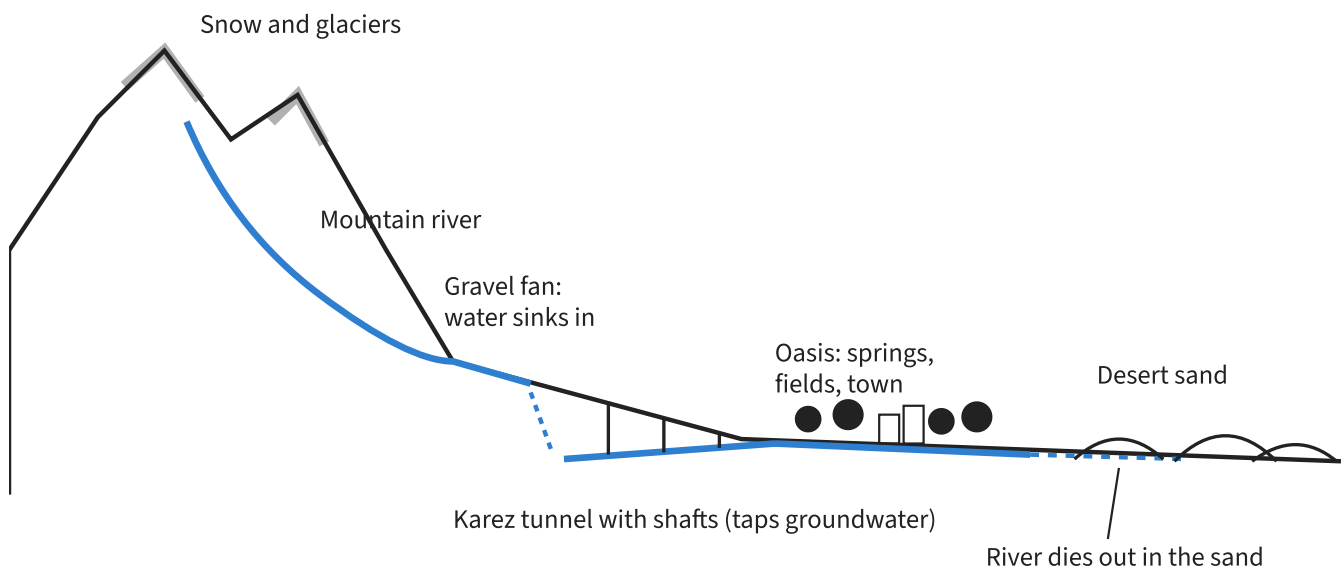
How an oasis works. Why did a desert town keep such treasures? Because the Silk Road was a road of **oases**, and the oases were where wealth, faith and learning gathered. The Tarim Basin and the lands west of it get very little rain, but the mountains around them catch snow. Each spring the snow and glaciers melt and feed rivers that rush down to the foot of the range. There each river spreads its load of gravel into an **alluvial fan**, and much of its water sinks into the loose stones. Lower down, where the gravel gives way to finer soil, the groundwater rises again in springs. That band of springs, fields and orchards along the foot of the mountains is the oasis. Below it, the rivers wither into the sand. At Turpan, where the Turpan Depression sinks to about 150 m (about 500 ft) below sea level, farmers dug the **karez**: gently sloping tunnels that run for kilometers under the gravel, with a line of shafts from the surface, to bring groundwater out by gravity without losing it to the burning sun. The same technique, called the qanat, was used across Persia. Because oases form wherever mountain water meets the plain, they lie in **strings**, and the caravan roads simply ran from one to the next, a day or several days apart.

Dunhuang: the gate. Dunhuang sits where the Hexi Corridor ends and the desert begins, fed by the Dang River coming down from the mountains. Just west of it stood the Jade Gate and the Yang Pass, the last Chinese frontier posts. Every caravan going west took on water, food and fresh animals there, and every caravan coming east stopped to rest, pray and pay. Merchants and pilgrims gave thanks for safe journeys by paying for new cave shrines. According to an inscription of AD 698, a monk named Lezun began the first cave at Mogao in 366. Over the next thousand years nearly five hundred decorated caves were cut into a cliff about 1.6 km (1 mile) long. In the 780s Dunhuang fell to the Tibetan Empire, which held it until a local leader, Zhang Yichao, drove them out in 848; the caves record both rulers.

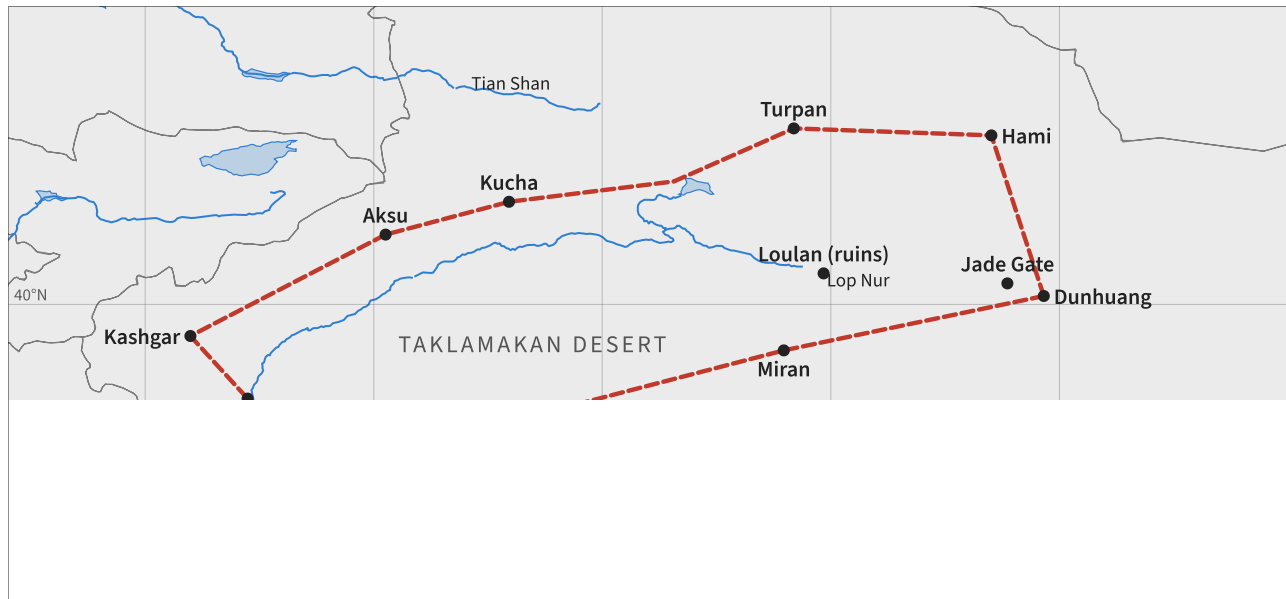
Kashgar: the knot. At the far western end of the Tarim Basin, the northern and southern routes meet at **Kashgar**, on an oasis fed by rivers from the Pamirs and Tian Shan. From here, passes climb west over the mountains toward Ferghana and Samarkand, and south toward Afghanistan and India. Any caravan crossing between the Tarim and the lands beyond had to pass through or near Kashgar, so it became a great market town where camels were swapped for mountain ponies and yaks, and goods changed hands for the climb ahead. Under the Karakhanid rulers in the 900s the town became Muslim, and it has been a center of Turkic and Islamic learning ever since; its Id Kah Mosque dates in its first form from 1442.

Samarkand: the merchant city. West of the Pamirs, the Zeravshan River waters the rich valley of **Samarkand**, the Maracanda that Alexander the Great captured in 329 BC. Its people, the **Sogdians**, became the master merchants of Asia, with colonies in Dunhuang, Chang'an and along the steppe. In 1907 Stein found a mailbag of Sogdian letters in a ruined watchtower near Dunhuang, written about AD 313 by merchants far from home; one is from a woman named Miwnay, abandoned in Dunhuang by her husband and left in poverty. In 1220 Genghis Khan's army took Samarkand and killed or carried off much of its people. It rose again as the capital of Timur (Tamerlane) after 1370, and his grandson Ulugh Beg built a great observatory there in the 1420s.

The big idea. Oasis cities were **entrepôts**: they lived by serving the traffic between them, with caravanserais, markets, money changers, guides, translators and temples. They were also small and exposed, islands in a sea of sand and steppe. A city that controlled water could tax trade, and an empire that controlled a string of oases controlled the road. That is why the Han, the Tang, the Tibetans, the Uyghurs, the Arabs and the Mongols fought over places that look like dots on a map. Geography made these cities rich, and geography made them prizes.



How an oasis works. Snowmelt sinks into the gravel fan and comes up again in springs and karez tunnels at the oasis, below which the desert begins.



The oasis strings of the Tarim Basin. Each dot is a town where mountain water meets the plain.

PICTURE STUDY



Merchants Meeting Robbers (Mogao Cave 45), Unknown Buddhist painters of Dunhuang, High Tang dynasty, 700s AD · Wall painting in mineral pigments on plaster · Mogao Caves, Cave 45 (south wall), near Dunhuang, Gansu, China

The walls of the Mogao Caves were painted mostly to teach Buddhist scripture, but the painters filled the scenes with the life they saw around them in Dunhuang. This scene illustrates a chapter of the Lotus Sutra, which promises that merchants who call on the bodhisattva Guanyin will be saved from robbers. The merchants are shown as *hu*, the Chinese word for western foreigners: men with full beards, long noses and pointed caps, very likely Sogdians, the great traders of the road.

Look past the religious lesson and you see the real dangers of the caravan trade. Robbers waited in the narrow mountain passes, where caravans could not spread out or run. Merchants traveled together for safety, paid for guards when they could, and gave gifts to the temples when they came home alive.

Look closely

- Count the merchants and the robbers. Who is armed, and how can you tell who has the upper hand?
- Find the pack animals. What kinds of animals are they, and what are they carrying?
- Look at the merchants' faces, beards and hats. How did the painter show that they came from far away?
- Look at the setting. Why would a robber choose a mountain pass rather than open desert?

Talk about it

1. What does this painting tell us about the risks of the Silk Road that a list of trade goods would not?
2. Why would merchants pay for paintings like this in a temple at Dunhuang?
3. How might a strong government that kept the roads safe change the price of silk in the far west?

PROJECT: OASIS IN A TRAY

You will build a working model of a desert basin: mountains, a snowmelt river, a gravel fan, an oasis and the desert beyond. Then you will dig a model karez and see whether it brings water to the surface where the river alone does not.

You will need

- A large shallow plastic storage tub or a disposable aluminum roasting pan
- Modeling clay or a few stones and a plastic bag for the mountains
- Aquarium gravel or small pebbles (about 2 cups), coarse sand and fine sand or garden soil
- Ice cubes for snow and glaciers, a cup of water, food coloring
- A drinking straw cut in half lengthwise or a length of clear aquarium tubing, toothpicks for shafts
- Small twigs or moss for oasis trees, and a ruler

Steps

1. Build a mountain range of clay at one end of the tub, about 10 cm (4 in) high, wrapped in plastic so it does not soak up water. Make a valley in its face.
2. Below the valley, spread gravel in a fan shape. Below the fan, spread coarse sand, and then fine sand or soil to the far end. Slope everything gently down away from the mountains.

3. Put four or five ice cubes on the mountain tops and add a few drops of blue food coloring to them. Let them melt and watch the river.
4. Record where the colored water runs on the surface, where it disappears into the gravel, and where (if anywhere) the sand becomes wet again downslope. Mark these places with toothpicks.
5. Plant twigs or moss where the sand stays damp. That is your oasis.
6. Now build a karez: lay the half-straw or tubing in a shallow trench sloping gently from the lower part of the gravel fan to the oasis, cover it with sand, and push toothpicks down along its line to mark the shafts. Melt more ice and compare where water appears.
7. Measure the length of your river on the surface, your fan, and your oasis. Draw a cross-section of your tray and label it like the diagram in this lesson.

Tips

- Pour slowly. A real snowmelt river rises gradually over weeks, not in one splash.
- If no water reappears below the fan, add a layer of clay or soil under the sand to act as the solid ground beneath it, so water spreads sideways instead of soaking straight down.

Check your work

- My model has mountains, a gravel fan, an oasis and a desert, and I recorded where the water went.
- I can explain why the river sank into the gravel and where the water came back.
- I can explain how a karez carries groundwater to fields without losing it to the sun.

MAP NOTEBOOK

1. Copy the oasis cross-section and add a caravan arriving at the town and a caravanserai with its courtyard.
2. Draw a simple map of the Tarim Basin with its three mountain walls and the two strings of oases, and color the routes red.
3. Make a “city card” for Dunhuang, Kashgar and Samarkand: river or water source, neighbors on the road, main faith in different centuries, and one thing that survives today.

From history. In the 1070s a scholar from the Kashgar region, Mahmud al-Kashgari, wrote in Baghdad the *Dīwān Lughāt al-Turk*, a dictionary of the Turkic languages written in Arabic for the Arab-speaking caliphate. In it he drew a round map of the world as the Turks knew it, centered on his homeland near Lake Issyk-Kul, with the cities of the Silk Road arranged around it and China at the edge. It is one of the earliest maps drawn from the point of view of Central Asia itself.

WORKED EXAMPLES

Example 1. A caravan of 100 camels and 25 men must cross a waterless stretch of 120 km (75 miles) between two oases. It travels 30 km a day. Each man needs about 5 liters of water a day, and the camels can go without drinking for this long. A camel carries about 200 kg, and 1 liter of water weighs about 1 kg. How much water must the caravan carry for the men, and how many camel loads is that?

1. Days to cross: $120 \div 30 = 4$ days.
2. Water for the men: $25 \times 5 \text{ L} \times 4 \text{ days} = 500 \text{ L}$, which weighs about 500 kg.
3. Add a safety margin of one extra day, since a sandstorm can stop a caravan: $25 \times 5 \times 5 = 625 \text{ L}$.
4. Camel loads: $625 \div 200 \approx 3.1$, so 4 camels must carry water (plus the weight of the waterskins).

Answer: About 500 L for four days, or 625 L with a one-day margin: about 3 to 4 camel loads out of 100. A short dry stage costs little cargo space; a long one, such as the old road across the Lop Desert, cost far more and was far more dangerous.

Example 2. The Turpan Depression reaches about 154 m below sea level at Aydingkol Lake. Bogda Peak in the Tian Shan, about 156 km away, rises to about 5,445 m. What is the total relief between them, and what is the average drop per kilometer? Give the relief in feet too (1 m = 3.28 ft).

1. Relief: $5,445 - (-154) = 5,445 + 154 = 5,599 \text{ m}$, about 5.6 km.
2. In feet: $5,599 \times 3.28 \approx 18,360 \text{ ft}$.
3. Average drop: $5,599 \text{ m} \div 156 \text{ km} \approx 36 \text{ m per km}$ (about 190 ft per mile).

Answer: About 5,600 m (18,400 ft) of relief, an average fall of about 36 m per km. That steep fall is what drives the snowmelt down to the oasis and lets a karez tunnel run downhill all the way to the fields.

Example 3. Use the road distances in this lesson. Northern route from Dunhuang to Kashgar: 700 km to Turpan, 600 km to Kucha, 750 km to Kashgar. Southern route: 550 km to Miran, 600 km to Niya, 300 km to Khotan, 300 km to Yarkand, 200 km to Kashgar. Which is shorter, by how much, and why might a caravan still choose the longer route?

(Use the map or drawing “Trace both routes from Dunhuang to Kashgar.” shown earlier in this lesson.)

1. Northern total: $700 + 600 + 750 = 2,050$ km (about 1,270 miles).
2. Southern total: $550 + 600 + 300 + 300 + 200 = 1,950$ km (about 1,210 miles).
3. Difference: $2,050 - 1,950 = 100$ km, about 3 or 4 days at 30 km a day.
4. Compare the conditions: the southern stages between Miran and Niya are long and dry, with oases shrinking as rivers from the Kunlun change course; the northern route has larger, richer oases fed by the Tian Shan and more towns for supplies and protection.

Answer: The southern route is about 100 km (60 miles) shorter. A caravan might still take the northern route because its oases are bigger and closer together, water and food are easier to find, and its towns offer more markets and protection. Distance is only one cost of a road.

PRACTICE

1. **EASY** Where does the water of a Silk Road oasis come from? Answer in one or two sentences.
2. **EASY** Who found the Library Cave, in what year, and about when had it been sealed?
3. **EASY** Name the two scholars who took large collections from the Library Cave, with their years and nationalities.
4. **EASY** Which people of the Samarkand region were the leading long-distance merchants of the Silk Road from about AD 300 to 800?
5. **MEDIUM** Mogao’s first cave was begun in AD 366 and the Library Cave was sealed about AD 1000. How many years apart are these events? About how old was the Library Cave’s seal when Wang found it?
6. **MEDIUM** Explain why oases lie in “strings” along the foot of mountain ranges, and what that meant for where roads ran.
7. **MEDIUM** A caravan of 40 men must cross a dry stage of 150 km at 25 km a day. Each man needs 5 L a day. How much water should they carry, with one extra day for safety? How many 200 kg camel loads is that?
8. **MEDIUM** Use the map. List the oases of the northern route from east to west, and of the southern route from east to west. Where do the two meet?
(Use the map or drawing “Use this map for Problem 8.” shown earlier in this lesson.)
9. **HARD** A karez runs 3 km from its mother well to the oasis and drops 1 m in every 1,000 m. How far does the water drop over the whole tunnel? If shafts are dug every 30 m, about how many shafts are there?

10. **HARD** Kashgar is at about 39.5° N, 76.0° E and Samarkand at about 39.7° N, 67.0° E. At this latitude one degree of longitude is about 85 km. Estimate the straight-line distance. Why is the caravan road between them much longer?
11. **HARD** Give two reasons why so many documents and paintings survived at Dunhuang when similar things decayed elsewhere.
12. **CHALLENGE** Write a paragraph comparing Dunhuang, Kashgar and Samarkand as crossroads. For each, name what it sat between and why caravans had to stop there.

COMMON MISTAKES

- Thinking oases are scattered at random in the desert. Most lie where mountain water reaches the plain, in lines along the foot of the ranges.
- Assuming the shortest route was always the one used. Water, food, towns and safety mattered as much as distance.
- Treating the Library Cave documents as only Buddhist or only Chinese. They are in many languages and include Christian, Jewish, Manichaean and everyday business documents.

Make it a game · Oasis Hopping. Lay out ten index cards in a line as the oases from Dunhuang to Kashgar, and write a distance in days on each gap (1 to 4 days). Each player starts with 12 water tokens (beans or coins). On each turn, roll a die: 1 is a sandstorm (lose a day of water and stay put), 2-5 means move on to the next oasis, paying one water token per day of the gap, and 6 means you find a spring (gain 2 tokens). At each oasis you may refill to 12 tokens, but only by answering a question from this lesson correctly. Run out of water between oases and you must go back one oasis. First to Kashgar wins.

Scripture. “A false balance is abomination to the LORD: but a just weight is his delight.” (Proverbs 11:1, KJV)

Every oasis market ran on scales: silk weighed against silver, tea against horses, spices against coin. Among the Dunhuang papers are contracts and loan agreements that show how much merchants depended on honest dealing far from any court. The Lord who made the deserts and the springs also cares whether the weights in the market are true.

Practice answers

1. Mostly from snow and glaciers in the surrounding mountains; their meltwater runs down in rivers and through the ground and comes up in springs or is brought out by wells and karez at the foot of the mountains.
2. The Daoist priest Wang Yuanlu in 1900; it had been sealed around AD 1000.
3. Aurel Stein, a Hungarian-born British archaeologist, in 1907, and Paul Pelliot, a French scholar, in 1908.
4. The Sogdians.
5. $1000 - 366 = 634$ years. $1900 - 1000 =$ about 900 years.
6. Oases form where mountain rivers and groundwater reach the plain, which happens all along the foot of a range, so they line up along it. Caravans had to go from water to water, so the

roads followed the same lines, one oasis to the next.

7. $150 \div 25 = 6$ days, plus 1 = 7 days. $40 \times 5 \times 7 = 1,400$ L (about 1,400 kg). $1,400 \div 200 = 7$ camel loads.
8. Northern: Dunhuang, Hami, Turpan, Kucha, Aksu, Kashgar. Southern: Dunhuang, Miran, Niya, Khotan, Yarkand, Kashgar. They meet at Kashgar.
9. Drop: $3,000 \text{ m} \times (1 \div 1,000) = 3 \text{ m}$. Shafts: $3,000 \div 30 = 100$ shafts (about 100, depending on whether you count both ends).
10. $76.0 - 67.0 = 9.0^\circ$; $9.0 \times 85 \approx 765 \text{ km}$ (about 475 miles). The road is longer because it must climb around and over the Pamirs and the Alay ranges by passes and follow the valleys through Ferghana.
11. Any two: the desert air is extremely dry, so paper, silk and paint did not rot; the Library Cave was sealed and forgotten for about nine centuries; the caves are cut into rock, protected from sun and rain; the remote site escaped many wars and the rebuilding of cities.
12. Answers will vary. A strong answer: Dunhuang sat between the Hexi Corridor and the Tarim Basin, at the last Chinese frontier, so caravans stopped to supply before the desert or to rest after it. Kashgar sat at the western end of the Tarim where the northern and southern routes met below the passes over the Pamirs and Tian Shan, so goods were swapped and animals changed for the mountains. Samarkand sat in the rich Zeravshan valley between the mountains and the plains of Persia and the steppe, and its Sogdian merchants ran trade in every direction. Each lived by water and by its place on the road.

1.3 WHAT MOVED ON THE ROAD

OBJECTIVES

- Name the main goods that moved east and west on the Silk Road (silk, horses, glass, jade, paper and more) and explain why high value for low weight decided what was worth carrying.
- Explain how techniques (sericulture, papermaking), faiths (Buddhism, the Church of the East, Manichaeism, Islam) and diseases (the Black Death) also traveled the routes.
- Calculate how transport cost changes the price of cheap and costly goods, and estimate how fast a technique or a disease spread across Eurasia.

Warm-up. Collect five things from the kitchen: a bag of rice or flour, a jar of a costly spice (such as saffron, vanilla or whole nutmeg), a sugar bowl, a tea bag and a can of beans. Look up or guess the price of each and weigh each on a kitchen scale. Rank them from highest to lowest price per gram. Which would you carry across a desert on your back to sell? Which would never be worth it?

Watch. *How did the Black Death affect Africa and Asia? (Short Animated Documentary)* (History Matters, 3:12). <https://www.youtube.com/watch?v=tnBQtH7G0hI>
After the story: watch how the Black Death traveled along the trade routes into Asia and Africa, not only Europe, and think about how the same roads carried both goods and disease.

Note: Captions were not available to check; preview it first. The video covers a plague that killed huge numbers of people, and the channel's style includes light jokes, such as calling the plague's name a 'stage name.'

Backup video. *The Silk Road / BBC Select* (BBC Select, 2:18).

<https://www.youtube.com/watch?v=1UU1UAa1ckY>

With the big idea: use this short clip as a quick picture of how long the Silk Road was, the lands it crossed, and how goods and ideas traveled along it. Note: Captions were not available to check; preview it first. This is a 2-minute trailer for a BBC series, so it gives an overview and ends by pointing to the full series. It probably does not tell the story of the monks bringing silkworms to Justinian.

KEY TERMS

value density

How much a good is worth for each unit of its weight (for example, silver coins per kilogram). Goods with high value density can bear high transport costs.

diffusion

The spread of a good, idea, technique, faith or disease from the place it began to other places.

technology transfer

The passing of a skill or invention, such as papermaking or silk-raising, from one people to another.

Church of the East

The Christian church of Persia and Mesopotamia, often called “Nestorian,” whose monks and merchants carried the gospel across Central Asia to China by AD 635.

Black Death

The great epidemic of plague, caused by the bacterium *Yersinia pestis*, that swept Asia, the Middle East and Europe in the 1340s.

CORE IDEAS

The story. In about AD 552, the Byzantine historian Procopius tells us, some monks came to the emperor Justinian in Constantinople. They had lived for a long time in a land beyond India where silk was made, and they had learned the secret: silk was spun by worms. Justinian had good reason to listen. Every thread of silk worn in his court came from the east through Persia, the empire’s great enemy, which taxed it heavily and sometimes cut it off. The monks went back and returned with silkworm eggs smuggled out. Later writers say the eggs were hidden in hollow canes. Hatched in warm manure and fed on mulberry leaves, the worms founded a silk industry that made the Byzantine Empire famous for its silks for centuries. A good that had moved west for six hundred years was now followed by the *knowledge* of how to make it. That is the theme of this lesson: the Silk Road carried things, but it also carried skills, ideas, faiths and, at last, death.

The big idea: what was worth carrying. A camel carries about 200 kg (440 lb). Every day on the road costs the same whether that load is worth a little or a great deal: the camel must be fed, the driver paid, the tolls met at every oasis. So merchants carried goods with high **value density**, worth a great deal for their weight. Silk was the classic case, along with fine cotton, spices, musk, gems, coral and precious metals. Grain, timber and iron, which are heavy and cheap, almost never traveled far overland; their price would have been eaten up by the cost of carrying them. Horses were the great exception, because they carried themselves. The Han and Tang needed tens of thousands of good horses for their cavalry, and the steppe and Ferghana bred them. Chinese records complain that in the 700s the Uyghurs charged forty bolts of silk for a single horse, and not always a good one. From the west also came glass. Roman and Persian glass, clear and brightly colored, was a rare luxury in China, and cut-glass bowls of Persian style are still kept in the Shōsōin, the imperial treasure house of the 700s at Nara in Japan, at the far eastern end of the trade. Jade from the rivers of Khotan went east to China; silver and gold went both ways.

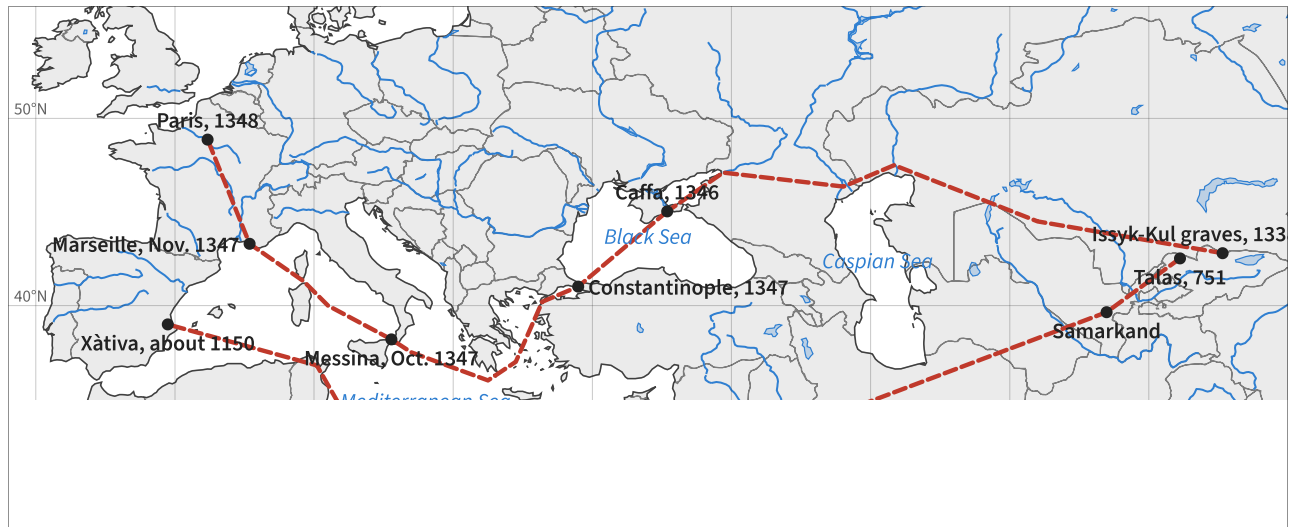
How they figured it out: paper. Paper was an invention, and inventions travel more slowly than goods. In AD 105 the court official Cai Lun reported to the Han emperor an improved paper made from bark, hemp, rags and old fishnets. For six centuries paper stayed mostly in the Chinese world. In 751 an Arab Abbasid army defeated a Tang army at the Talas River, in today’s Kazakhstan and Kyrgyzstan, and an old tradition says that Chinese prisoners taught papermaking in Samarkand. Historians debate that story, but by 794 there was paper-

making in Baghdad, and Arabic learning, with its translations of Greek science and its account books, ran on paper. From Baghdad the craft spread to Cairo and across North Africa, and by about 1150 there was a paper mill at Xàtiva in Muslim Spain. Within a few centuries paper would carry Gutenberg's printed Bibles. The world's oldest dated printed book, a Buddhist scripture printed in 868, was found at Dunhuang (see the picture study).

Faith on the road. The road carried preachers and pilgrims as surely as it carried silk. Buddhism came from India over the passes and through the oases. The monk Kumarajiva, born in the oasis kingdom of Kucha, was brought to Chang'an in 401 and translated scriptures into Chinese that are still read today. The pilgrim Xuanzang walked from Chang'an to India and back between 629 and 645 to collect Buddhist texts, traveling through Turpan, Kucha, Samarkand and Khotan. Christians came too. Monks of the **Church of the East** spread the gospel from Persia along the merchant roads, and in 635 a monk named Alopen reached Chang'an, where the Tang emperor Taizong allowed churches to be built. A stone monument erected in 781 tells the story in Chinese and Syriac. Manichaeism, a Persian religion, became the state faith of the Uyghur rulers in 763, and after the 700s Islam spread steadily through Central Asia by trade, conquest and preaching, until by the Mongol age it was the faith of most of the western half of the road.

Plague. The road also carried disease, which needs no merchant's decision to travel. Gravestones of the Church of the East near Lake Issyk-Kul, in today's Kyrgyzstan, record deaths from "pestilence" in 1338 and 1339, and in 2022 scientists reported finding the DNA of the plague bacterium, *Yersinia pestis*, in graves there. In 1346 the plague struck the Mongol army of the Golden Horde besieging Caffa, a Genoese trading port in Crimea. The notary Gabriele de' Mussis wrote that the Mongols hurled their dead into the town. Whether or not that is exactly how it entered, Genoese ships carried the sickness to Constantinople in 1347 and to Messina in Sicily that October, and from there it spread over Europe. Between 1347 and 1351 Europe lost perhaps a third to a half of its people.

On the map. Put it together and the Silk Road looks less like a road for luxuries and more like a great artery joining the far ends of the Old World. Most of what moved on it was light: thread, cloth, paper, seeds, recipes, a sermon, a germ. That is the deep reason the overland routes mattered so much more to history than their small tonnage would suggest.



Two things that traveled the routes: paper moved west over four centuries, plague in less than ten years.

PICTURE STUDY



Frontispiece of the Diamond Sutra, Unknown Chinese woodblock carvers; printed for Wang Jie, AD 868 · Woodblock print on paper, part of a scroll about 5 m (16 ft) long · British Library, London (found in the Library Cave at Mogao, Dunhuang)

This picture is the opening of the oldest dated printed book in the world. It was found in 1907 among the scrolls of the Library Cave at Dunhuang and brought to London by Aurel Stein. At the end of the scroll a short note says that it was made by a man named Wang Jie for free distribution, on behalf of his two parents, on a day that matches 11 May 868. The text is the Diamond Sutra, a Buddhist scripture in the Chinese translation of Kumarajiva of Kucha.

Look at what this one object contains: paper, a Chinese invention; a faith that came from India over the Silk Road; a translation made by a man from a Tarim oasis; and the technique

of printing from carved wooden blocks, almost six centuries before Gutenberg. The dry air of Dunhuang kept it whole.

Look closely

- Find the Buddha at the center. How has the carver made him the most important figure?
- Find the old man kneeling on the mat in the lower left. He is the disciple Subhuti, who asks the questions in the text. What is he doing?
- Look at the fine lines of faces, robes and canopy. Remember that every line was cut into wood with a knife, in reverse. What does this tell you about the skill of the carver?
- Look for lions or guardians at the base of the picture. Why might a printed book open with a picture at all?

Talk about it

1. Name four different things that had to travel or be invented before this book could exist.
2. The note says the book was made “for free distribution.” Why does printing make free distribution possible in a way hand-copying does not?
3. What does a book printed in China in 868 tell us about the common idea that printing began in Europe?

PROJECT: WOULD IT PAY ITS WAY? A VALUE-DENSITY LAB

You will weigh and price real goods, compute their value per kilogram, and then test which of them could bear the cost of a 3,000 km caravan journey. You will finish with a ranked chart, like the mental list every Silk Road merchant carried in his head.

You will need

- A kitchen scale that reads in grams
- Eight goods from home or a store receipt: for example rice, flour, sugar, tea, coffee beans, a costly spice (saffron, vanilla beans or whole nutmeg), a small piece of silver jewelry or a silver coin (look up its weight and today’s silver price), and a silk scarf or tie (look up a price online)
- Calculator, ruler and graph paper

Steps

1. For each good, record its weight in grams and its price in dollars. Convert to price per kilogram: $\text{price} \div \text{grams} \times 1,000$.
2. Rank the goods from highest to lowest value per kilogram. Make a bar chart on graph paper. If the bars are too different in length, use a scale that doubles each time (1, 2, 4, 8, 16 dollars and so on).
3. Now model the caravan. Suppose carrying 1 kg for 3,000 km costs \$5 in today’s money (feed, drivers, tolls and losses). For each good, compute the cost of carrying it as a

percentage of its value: $5 \div (\text{value per kg}) \times 100$.

4. Draw a line across your chart: any good whose carrying cost is more than 50 percent of its value is “not worth the trip.” Which goods are above the line?
5. Add one more row for a good that weighs nothing: an idea (a recipe, a hymn, a method of making paper). What does the model say about it?
6. Write a paragraph: Which of your goods would have traveled the Silk Road, and why do historians say the road carried luxuries and ideas rather than daily bread?

Tips

- Use prices from the same store or day so they can be compared fairly.
- The \$5 cost is a model number chosen to show the idea; Lesson 1.5 builds a fuller model with real comparisons.

Check your work

- I recorded weight, price and value per kilogram for at least eight goods.
- I calculated carrying cost as a percentage of value for each.
- My paragraph explains value density and connects it to silk, horses, glass and paper.

MAP NOTEBOOK

1. Make a two-way arrow chart titled “East to West, West to East.” List at least six goods, two techniques and three faiths that moved each way.
2. Draw the Diamond Sutra scroll unrolled, with the picture at the start and the date note at the end, and label it with four things that had to travel the road for it to exist.
3. On a small outline map, trace the plague from Issyk-Kul to Caffa to Messina with dates, and color the sea part blue and the land part brown.

From history. The monument of 781 that tells of Alopen’s coming is called the Xi’an Stele or Nestorian Stele. It is a slab of black limestone nearly 3 m (about 9 ft) tall, headed with a cross, carved with nearly 1,800 Chinese characters and lines of Syriac. It praises the “luminous religion,” summarizes the gospel and lists the names of many clergy. After the Church of the East declined in China, the stele was buried and forgotten. It was dug up near Xi’an around 1625, and Jesuit missionaries, who had come to China themselves, were astonished to find that Christians had reached China nearly a thousand years before them. It stands today in the Forest of Stone Steles Museum in Xi’an.

WORKED EXAMPLES

Example 1. Model: carrying one 200 kg camel load 3,000 km costs 300 silver coins (feed, driver, tolls and losses). A load of wheat is worth 20 coins where it is bought; a load of silk is worth 20,000 coins. For each, what is the carrying cost as a percentage of the starting value, and what is the lowest price that covers costs at the far end?

1. Wheat: $300 \div 20 \times 100 = 1,500$ percent. The wheat must sell for at least $20 + 300 = 320$ coins, sixteen times its starting price.
2. Silk: $300 \div 20,000 \times 100 = 1.5$ percent. The silk must sell for at least $20,000 + 300 = 20,300$ coins.
3. Value per kilogram: wheat $20 \div 200 = 0.1$ coin/kg; silk $20,000 \div 200 = 100$ coins/kg, a thousand times more.

Answer: Carrying wheat adds 1,500 percent to its price; carrying silk adds 1.5 percent. No one far away would pay sixteen times the price for ordinary wheat, but buyers would happily pay a little more for silk. These are model numbers, but the principle is real: overland trade selected for high value density.

Example 2. Plague killed people near Lake Issyk-Kul in 1338-1339 and reached Caffa in 1346, a straight-line distance of about 3,200 km. From Messina (October 1347) it reached Marseille by ship by November 1347, about 1,000 km by sea. Estimate the speed of each spread in km per day, and compare them.

(Use the map or drawing "Compare the long land path of the plague with its short sea path." shown earlier in this lesson.)

1. Overland: about 1338 to 1346 is about 8 years, or $8 \times 365 = 2,920$ days. Speed $\approx 3,200 \div 2,920 \approx 1.1$ km per day (about 0.7 miles per day).
2. By sea: October to November is about one month, say 30 days. Speed $\approx 1,000 \div 30 \approx 33$ km per day (about 21 miles per day).
3. Ratio: $33 \div 1.1 \approx 30$.

Answer: Overland the plague moved roughly 1 km a day; by ship about 33 km a day, some thirty times faster. These are rough estimates (we do not know the exact path or dates across the steppe), but they show how ships, with their crews, rats and fleas carried quickly from port to port, speeded the disease once it reached the sea.

Example 3. Papermaking reached Samarkand by about 751 and Baghdad by 794, a straight-line distance of about 2,100 km. From Baghdad it reached Xàtiva in Spain by about 1150, about 4,100 km. Find the average spread in km per year for each stage and suggest why the second stage was slower.

1. Stage 1: $794 - 751 = 43$ years. $2,100 \div 43 \approx 49$ km per year.
2. Stage 2: $1150 - 794 = 356$ years. $4,100 \div 356 \approx 12$ km per year.
3. Reason: Baghdad was a capital full of scholars and clerks who needed cheap writing material at once. Farther west, papyrus from Egypt and parchment from animal skins were already in use, so there was less pressure to change, and skilled papermakers moved only where mills could be built near clean water and rags.

Answer: About 49 km (30 miles) a year from Samarkand to Baghdad, but only about 12 km (7 miles) a year from Baghdad to Spain. A technique spreads as fast as people want it and can build it, not simply as fast as a caravan can walk.

PRACTICE

1. **EASY** List three goods that traveled mainly east to west on the Silk Road and three that traveled mainly west to east.
2. **EASY** What did the monks bring to Justinian about AD 552, and why did it matter?
3. **EASY** Who reported improved papermaking to the Han emperor, and in what year?
4. **EASY** Who was Alopen, and when did he reach Chang'an?
5. **MEDIUM** Explain in two or three sentences why horses could be traded over long distances even though they are large and heavy.
6. **MEDIUM** Model: carrying a 200 kg load 2,000 km costs 200 coins. A load of iron bars is worth 100 coins and a load of glassware 5,000 coins. Find the carrying cost of each as a percentage of its value.
7. **MEDIUM** The Diamond Sutra was printed in 868. Gutenberg printed his Bible about 1455. How many years earlier was the Diamond Sutra?
8. **MEDIUM** Use the map. Name the port where the plague entered the Mediterranean world in 1346 and the sea it lies on, and the Sicilian port it reached in October 1347.
(Use the map or drawing "Use this map for Problem 8." shown earlier in this lesson.)
9. **HARD** Xuanzang left Chang'an in 629 and returned in 645. If his total journey was about 16,000 km (a rough estimate), what was his average distance per year and per day? Why is the daily figure so much lower than a caravan's 30 km a day?
10. **HARD** If Europe had about 75 million people in 1346 and lost between one third and one half of them by 1351, how many people died, in round numbers?
11. **HARD** Name four faiths that traveled along the Silk Road and one person or monument connected with each.
12. **CHALLENGE** Write a paragraph arguing that the most important things carried on the Silk Road weighed almost nothing. Use at least three examples from this lesson.

COMMON MISTAKES

- Thinking the Silk Road carried bulk goods such as grain. Overland costs were far too high; bulk goods went short distances or by water.
- Assuming that because a good traveled, the knowledge of making it traveled too. Rome wore silk for six centuries without knowing how it was made.
- Telling the story of Talas and papermaking as certain fact. It is an old tradition; what is certain is that paper was made in Samarkand and Baghdad soon after.

Make it a game · Caravan Cargo Auction. Make twelve cargo cards, each with a good, its weight in camel loads and its value (for example: silk, 1 load, 100 coins; wheat, 1 load, 1 coin; horses, walks itself, 40 coins; glass, 1 load, 60 coins; iron, 1 load, 3 coins; jade, 1 load, 80 coins; paper, 1 load, 30 coins; a sermon, 0 loads, priceless). Each player is a caravan master with 5 camels. Each camel load costs 10 coins to carry to the far market. Players take turns choosing cards until their camels are full, then add up value minus carrying cost. Highest profit wins. Then discuss which cards no one picked, and why the “priceless” cards traveled anyway.

Scripture. “How beautiful upon the mountains are the feet of him that bringeth good tidings, that publisheth peace; that bringeth good tidings of good, that publisheth salvation; that saith unto Zion, Thy God reigneth!” (Isaiah 52:7, KJV)

The monks of the Church of the East walked the same mountain passes as the silk merchants, carrying a message that weighed nothing at all. Their journey reminds us that the roads God allows men to build for trade can also carry the good news.

Practice answers

1. East to west (any three): silk, paper, fine porcelain in later centuries, tea in later centuries, rhubarb, lacquer. West to east (any three): horses, glass, silver and gold, wool and carpets, grapes and alfalfa seeds, jade from Khotan to China.
2. Silkworm eggs smuggled from the east. They let the Byzantine Empire raise its own silk instead of buying it through Persia, its enemy.
3. Cai Lun, in AD 105.
4. A monk of the Church of the East who brought the Christian gospel to China; he reached Chang'an in 635.
5. Horses walk, so they carry themselves instead of being loaded on other animals, and they can graze along the way. Their value to Chinese armies was very high, so they were worth the long journey from the steppe and Ferghana.
6. Iron: $200 \div 100 \times 100 = 200$ percent. Glassware: $200 \div 5,000 \times 100 = 4$ percent.
7. $1455 - 868 = 587$ years, almost six centuries earlier.
8. Caffa, on the Black Sea in Crimea; Messina in Sicily.
9. $645 - 629 = 16$ years. $16,000 \div 16 = 1,000$ km per year; $1,000 \div 365 \approx 2.7$ km per day. He spent years studying in India (especially at Nalanda) and waited out winters and seasons; travelers did not move every day.

10. One third: $75 \div 3 = 25$ million. One half: $75 \div 2 = 37.5$ million. Between about 25 and 38 million people.
11. Buddhism: Kumarajiva or Xuanzang or the Diamond Sutra. Christianity (Church of the East): Alopen or the stele of 781. Manichaeism: the Uyghur rulers, who made it their state faith in 763. Islam: the Karakhanids of Kashgar, or the Abbasid victory at Talas in 751 (other correct pairings accepted).
12. Answers will vary. A strong answer: the total tonnage of the caravan trade was small, but the things it carried changed the world because they could be copied or could multiply. Silkworm eggs smuggled to Justinian founded a whole industry; the knowledge of papermaking reached Baghdad and Spain and later carried printed Bibles; the gospel carried by Alopen and the Buddhist texts translated by Kumarajiva shaped the faith of millions; and the plague, a microscopic passenger, killed perhaps a third or more of Europe. Weight determined what merchants carried for profit, but ideas, skills, faith and disease moved without regard to weight.

1.4 THE MONGOL PEACE

OBJECTIVES

- Explain how the Mongol conquests of the 1200s, with their great destruction, united most of the overland routes under one power and made long-distance travel safer for about a century.
- Describe the tools of the Mongol peace: the yam relay stations, the paiza safe-conduct tablet, merchant partnerships and religious toleration, and name the travelers who used the roads (Rubruck, the Polos, Rabban Bar Sauma).
- Calculate the effect of many tolls versus one, the speed of a relay system, and a great-circle distance across Eurasia.

Warm-up. Set up a short relay in a hallway or yard: mark a 20 m (about 65 ft) course. Time one person carrying a book from start to finish and back twice (80 m). Then time four people passing the book along at 20 m stations for the same 80 m. Which was faster, and why? Write one sentence guessing how a ruler could use this idea to send messages across a continent.

Watch. *Ten Minute History - Genghis Khan and the Mongol Empire (Short Documentary)* (History Matters, 9:59). <https://www.youtube.com/watch?v=CUQhuC31ieI>
With the big idea: watch how Genghis Khan united the steppe tribes and built the largest connected land empire in history, and see how Kublai Khan later ruled it.
Note: Captions were not available to check; preview it first. The video describes the Mongol wars and their conquests, which were very violent.

Backup video. *7th May 1253: William of Rubruck sets out on his journey into the Mongol Empire* (HistoryPod, 2:29). <https://www.youtube.com/watch?v=JfW4iB2BBX0>
After the story: follow the friar William of Rubruck from Constantinople to Möngke Khan's court at Karakorum, and notice how far a traveler could safely go across Mongol lands.
Note: Captions were not available to check; preview it first. Also check that the narration sounds like a real person, since this is a short daily-history channel.

KEY TERMS

Pax Mongolica

“The Mongol Peace”: the period of roughly the mid-1200s to the mid-1300s when Mongol rule over most of Asia made overland travel and trade unusually safe.

yam

The Mongol network of relay stations along the main roads, with fresh horses, food and lodging for official messengers and travelers carrying a pass.

paiza

A tablet of gold, silver or wood carried by Mongol officials and envoys as a passport and order, entitling the bearer to protection and to horses and supplies at the stations.

ortoq

A merchant partnership in which Mongol nobles invested money with merchants, often Muslim or Uyghur, who traded on their behalf and shared the profits.

khanate

A realm ruled by a khan. After 1260 the Mongol Empire divided into four: the Yuan in China, the Chagatai Khanate in Central Asia, the Ilkhanate in Persia and the Golden Horde on the western steppe.

steppe

The great belt of grassland that stretches across Eurasia from Hungary to Manchuria, open country where horses can travel easily.

CORE IDEAS

The story. In 1218 a caravan of about 450 merchants, sent by Genghis Khan with silver, furs and goods, arrived at Otrar, a frontier town of the Khwarazmian Empire on the Syr Darya. Genghis, who had united the Mongol tribes and been proclaimed khan in 1206, wanted trade with the rich Muslim lands of Central Asia and Persia, and he sent word that he wished for peace and commerce. The governor of Otrar, Inalchuq, accused the merchants of spying, seized their goods and had them killed. Genghis sent envoys to Shah Muhammad II to demand that the governor be punished. The shah had one envoy put to death and sent the others back humiliated. It was one of the most costly decisions in history.

The cost. In 1219 the Mongol armies came west. Otrar fell after a long siege. In 1220 Bukhara and Samarkand were taken, and in 1221 Urgench, Merv and Nishapur. The Mongols spared cities that surrendered at once and destroyed many that resisted. At Merv and Nishapur they massacred whole populations, sparing chiefly craftsmen, who were marched east to work for their new masters. The numbers in the medieval chronicles are surely exaggerated, but the destruction was real, and parts of Khwarazm and Persia took generations to recover. Over the next decades Genghis's sons and grandsons conquered northern China, Korea, the Russian principalities, Persia and, in 1279, southern China. Baghdad was sacked in 1258. The peace this lesson describes was built on conquest and terror, and an honest account must say so plainly.

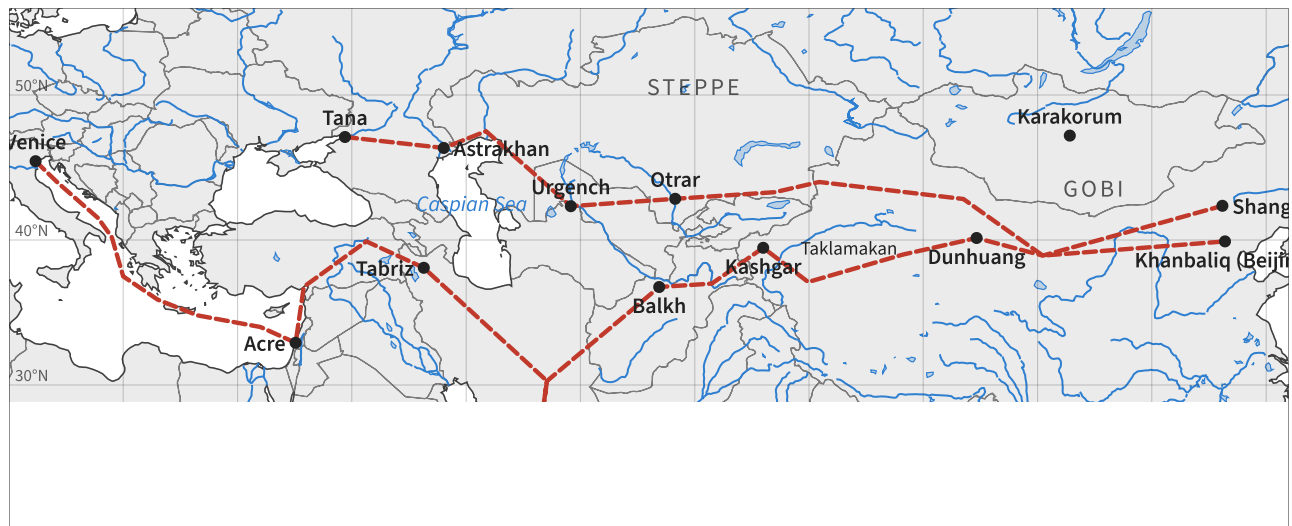
How it worked. Yet once the conquests were made, the Mongols ruled an empire that stretched from Korea to the Black Sea and the Russian lands, and they wanted its roads open. Genghis's son Ögedei, who ruled from 1229 to 1241, organized the **yam**, a system of relay stations along the main roads, each supplied with horses, fodder and food. An official messenger could change horses at every station and cover a great distance in a day. Envoys and favored merchants carried a **paiza**, a tablet of gold, silver or wood inscribed with the khan's order, which commanded every official to protect the bearer and supply him. Mongol princes invested in **ortoq** partnerships with Muslim and Uyghur merchants. Tolls along the road were collected by one authority instead of a dozen rival princes, and robbers faced

Mongol justice. In Karakorum, the capital built under Ögedei, and later in Khanbaliq (Beijing), merchants and envoys from every corner of the Old World met.

The travelers. For the first time, Europeans could cross all of Asia and come back. The Franciscan friar William of Rubruck, sent by King Louis IX of France, reached the court of the Great Khan Möngke in 1253–1254. At Karakorum he found a French goldsmith from Paris, Guillaume Boucher, and a woman from Metz, both captured in Hungary, and in 1254 he took part in a public debate before the khan's officials with Muslims and Buddhists. The Venetian merchants Niccolò and Maffeo Polo, with Niccolò's son Marco, left in 1271 and reached the court of Khubilai Khan in about 1275; Marco did not return until 1295. Travel went the other way too: Rabban Bar Sauma, a monk of the Church of the East born near Khanbaliq, reached Rome and Paris in 1287–1288 (see the history note). About 1340 the Florentine merchant Francesco Pegolotti wrote a handbook for traders in which he said that the road from Tana, on the Sea of Azov, to China was perfectly safe by day and by night, according to the merchants who had used it.

The big idea. Trade costs are not only the cost of moving goods. They are also the costs of **danger** (robbery, war, seizure) and of **tolls** and bribes at every border. When one power controls a whole route, those costs fall sharply, even if the distance and the deserts are unchanged. That is why trade flourished under the Han and Tang when they held the Tarim, and why it flourished even more under the Mongols, who held nearly everything from the Pacific to the Black Sea. Goods, scholars and techniques moved freely: Chinese doctors and astronomers worked in Persia, the Persian historian Rashid al-Din wrote a history of the whole known world, and the Yuan government printed paper money, which amazed Marco Polo.

On the map. The Mongol peace opened a northern road, across the **steppe**, alongside the old oasis routes. Pegolotti's route ran from Tana on the Sea of Azov to Astrakhan on the Volga, across the steppe to Urgench near the Aral Sea and Otrar on the Syr Darya, past the Tian Shan to Ganzhou in the Hexi Corridor, and on to Khanbaliq. But the empire did not stay whole. After 1260 it split into four khanates that often fought each other, and in the 1340s the plague followed the same roads. The peace lasted roughly a century, long enough to change the map of the world in the minds of Europeans, who now knew that a great and rich land lay at the far end of Asia.



Roads of the Mongol peace. The steppe route (Pegolotti) ran north of the old oasis routes that Marco Polo followed.

PICTURE STUDY



Khubilai Khan Hunting, Liu Guandao, 1280 · Hanging scroll, ink and color on silk · National Palace Museum, Taipei

Liu Guandao was a court painter in the service of Khubilai Khan, the grandson of Genghis who ruled China as the first emperor of the Yuan dynasty. He signed and dated this great silk scroll in 1280, the year after the Mongols completed the conquest of southern China. Khubilai, heavy and splendid in a white ermine coat, rides at the center beside a woman usually identified as his empress, Chabi. Around them are hunters of many peoples, with a falcon, a hunting cat riding on a horse's back, and an archer aiming at geese.

Look up to the top of the painting and you will find a small caravan of camels crossing the desert hills. The painter, perhaps without meaning to make a point, has put the whole

Mongol peace in one picture: the khan and his court in the foreground, a mixed company of many nations around him, and the trade of Asia moving quietly behind.

Look closely

- Find Khubilai Khan. How has the painter shown his power and wealth?
- Look at the faces and clothes of the attendants. How many different peoples do you think are shown?
- Find the hunting animals: the falcon, the hunting cat and the dogs. What do they tell you about the life of the Mongol nobility?
- Find the camel caravan in the background. Which direction is it moving, and why might the painter include it?

Talk about it

1. A Chinese painter painted this for a Mongol conqueror of China. What might Liu Guandao have felt, and what does the painting show of how he chose to portray his ruler?
2. How does the mixture of peoples in the hunting party reflect the empire the Mongols ruled?
3. Why would a painting made for the khan include a camel caravan at all?

PROJECT: THE YAM RELAY AND THE PAIZA

You will make a paiza, the Mongol pass that opened every station on the road, and run a relay on a measured course to see why relay stations made messages so much faster than a single rider. Then you will scale your results up to the size of Asia.

You will need

- Thin cardboard, aluminum foil, a pencil or dull stylus and string (for the paiza)
- A tape measure (at least 30 m or 100 ft) and chalk or cones
- A stopwatch or phone timer
- At least four runners (family or friends) and a “message” (a folded paper in a small pouch)
- Notebook and calculator

Steps

1. Make a paiza: cut a cardboard rectangle about 8 × 25 cm (3 × 10 in), round the top, cover it with foil, punch a hole for a string, and press an inscription into the foil with a dull pencil. Real paiza bore an order in the Mongol script commanding that the bearer be obeyed and helped. Write your own short order in English.
2. Measure a straight course and mark stations every 25 m (about 82 ft), with four stages in all (100 m).
3. Trial 1: one runner carries the message all 100 m, then back, then out again, then back (400 m in all). Record the total time and each 100 m split. Note whether the runner

slows down.

4. Trial 2: put a fresh runner at each station. Run the same 400 m as a relay, passing the message and showing the paiza at each handoff. Record the time.
5. Compute the average speed for each trial in meters per second and km per hour ($\text{m/s} \times 3.6 = \text{km/h}$).
6. Scale up: if your relay keeps its average speed for 24 hours, how far would the message go? Now compare a yam rider who covers 40 km in 2 hours per stage with a 10-minute change of horses (see Worked Example 1).
7. Write a paragraph: What did the yam need to work (horses, fodder, keepers, discipline, the khan's authority), and what happens to the system if the empire breaks apart?

Tips

- Run on a safe, flat path away from traffic, and let runners warm up first.
- Practice the handoff once before timing it; the Mongols drilled their station keepers too.

Check your work

- I made a paiza with an inscribed order.
- I recorded times for both trials and calculated speeds correctly.
- My paragraph explains why fresh horses and stations made the yam fast, and what it depended on.

MAP NOTEBOOK

1. Draw the four khanates after 1260 on an outline map of Asia and label each with its capital (Khanbaliq, Almaliq, Tabriz, Sarai).
2. Sketch a yam station: a walled yard, stables, a well, the station keeper, and a rider arriving with a paiza on a cord around his neck.
3. Make a timeline from 1206 to 1368 with Genghis proclaimed khan, the Otrar caravan, the fall of Samarkand, the sack of Baghdad, Rubruck at Karakorum, the Polos' journey, Bar Sauma in Rome, Pegolotti's handbook, the plague at Caffa and the fall of the Yuan.

From history. Rabban Bar Sauma was a monk of the Church of the East born near Khanbaliq. He set out about 1275 on pilgrimage for Jerusalem, which war prevented him from reaching. In 1287 the Mongol ruler of Persia, Arghun, sent him west as an envoy to seek an alliance with the Christian kings against the Mamluks of Egypt. He saw Hagia Sophia in Constantinople, met King Philip IV of France in Paris and King Edward I of England in Gascony, and in 1288 received Holy Communion from Pope Nicholas IV in Rome. His travel account, written in Syriac, survives. He traveled from China to Europe in the very years when Marco Polo, who had gone the other way, was serving Khubilai Khan in China.

WORKED EXAMPLES

Example 1. Model of the yam: stations are 40 km (25 miles) apart. A rider covers each stage in 2 hours and spends 10 minutes changing horses at each station. If relays of riders keep the message moving day and night, how far does it travel in 24 hours? How many times faster is that than a caravan at 30 km a day?

1. Time per stage: $2 \text{ h} + 10 \text{ min} = 130 \text{ minutes}$.
2. Stages in 24 hours: $24 \times 60 = 1,440 \text{ minutes}$; $1,440 \div 130 \approx 11.1 \text{ stages}$.
3. Distance: $11.1 \times 40 \approx 443 \text{ km}$ (about 275 miles).
4. Comparison: $443 \div 30 \approx 15$.

Answer: About 440 km (275 miles) a day, roughly 15 times faster than a caravan. The numbers are a model, but they show why the khan's orders could cross his empire in weeks while goods took months.

Example 2. Model of tolls: before the Mongol conquests, a caravan crosses the lands of 8 different rulers, and each takes 10 percent of the value of the cargo. Under the Mongols, it pays one tax of 5 percent. A cargo is worth 1,000 silver coins at the start. How much value is left at the end in each case?

1. Before: each toll leaves 90 percent of what remains. After 8 tolls: $1,000 \times 0.9^8$.
2. $0.9^2 = 0.81$; $0.9^4 = 0.81^2 = 0.6561$; $0.9^8 = 0.6561^2 \approx 0.4305$. So about 430 coins remain; 570 coins are lost to tolls.
3. After: $1,000 \times 0.95 = 950 \text{ coins remain}$; 50 coins paid.

Answer: About 430 coins remain under eight rulers, but 950 under one. In this model, unified rule cuts the toll burden from 57 percent to 5 percent, more than ten times less, without moving a single mountain. Real tolls varied greatly, but this is the logic of the Mongol peace.

Example 3. Find the great-circle (shortest) distance from Venice (45.4° N, 12.3° E) to Khanbaliq, today's Beijing (39.9° N, 116.4° E). Use $\cos c = \sin \varphi_1 \sin \varphi_2 + \cos \varphi_1 \cos \varphi_2 \cos \Delta\lambda$, where φ is latitude, $\Delta\lambda$ the difference in longitude, and each degree of c is 111.2 km. Then compare with the time the Polos took: about three and a half years from 1271 to about 1275.

(Use the map or drawing "Compare Marco Polo's winding route with the straight-line distance." shown earlier in this lesson.)

1. $\Delta\lambda = 116.4^\circ - 12.3^\circ = 104.1^\circ$.
2. $\sin 45.4^\circ \approx 0.712$, $\sin 39.9^\circ \approx 0.641$; product ≈ 0.457 .
3. $\cos 45.4^\circ \approx 0.702$, $\cos 39.9^\circ \approx 0.767$, $\cos 104.1^\circ \approx -0.244$; product $\approx 0.702 \times 0.767 \times (-0.244) \approx -0.131$.
4. $\cos c \approx 0.457 - 0.131 = 0.326$, so $c \approx 71.0^\circ$.
5. Distance $\approx 71.0 \times 111.2 \approx 7,900$ km (about 4,900 miles).
6. Time: 3.5 years $\approx 1,280$ days. Average straight-line progress $\approx 7,900 \div 1,280 \approx 6$ km (about 4 miles) a day.

Answer: About 7,900 km (4,900 miles) by the great circle. The Polos averaged only about 6 km a day of straight-line progress, because their real route wandered by sea to Acre, south to Hormuz and back, over the Pamirs and around the Taklamakan, and because they stopped for months at a time.

PRACTICE

1. **EASY** What happened at Otrar in 1218, and what followed?
2. **EASY** Define yam and paiza.
3. **EASY** Name the four khanates the Mongol Empire divided into after 1260 and the region each ruled.
4. **EASY** Who was William of Rubruck, who sent him, and where did he go?
5. **MEDIUM** Marco Polo left Venice in 1271 and returned in 1295. How many years was he gone? If he reached Khubilai's court about 1275, how many years did he spend in the Mongol lands and on the way home?
6. **MEDIUM** Model: a caravan crosses 6 rulers' lands, each taking 10 percent of the cargo's value. Starting value: 500 coins. How much remains? ($0.9^6 \approx 0.531$)
7. **MEDIUM** A yam rider covers stages of 30 km in 1.5 hours with 10 minutes to change horses. How far can relays carry a message in 24 hours?
8. **MEDIUM** Use the map. List, from west to east, the main places on Pegolotti's steppe route from Tana to Khanbaliq.
(Use the map or drawing "Use this map for Problem 8." shown earlier in this lesson.)
9. **HARD** Explain why a road can become cheaper to use even though its distance, mountains and deserts do not change. Use the words danger and tolls.

10. **HARD** Karakorum lies at about 47.2° N, 102.8° E and Khanbaliq at about 39.9° N, 116.4° E. Estimate the distance between them with the flat method: 111 km per degree of latitude, and $111 \times \cos(\text{average latitude})$ km per degree of longitude. ($\cos 43.6^\circ \approx 0.724$)
11. **HARD** Give two reasons the Mongol peace ended in the 1300s.
12. **CHALLENGE** Some historians praise the Mongol peace for opening Eurasia to trade; others emphasize the millions who died in the conquests. Write a paragraph that weighs both truthfully.

COMMON MISTAKES

- Speaking of the Mongol peace as if it were gentle. It was imposed by conquest and kept by fear; the safety of the roads came after massacres.
- Thinking the Mongol Empire stayed one state. After 1260 it was four khanates that often warred with one another.
- Using the flat-map method for very long distances. Across 100 degrees of longitude, the earth's curve matters, and a great-circle calculation is needed.

Make it a game • Paiza Pass. Draw a road of 12 stations across a large paper from Tana to Khanbaliq. Half the players are merchants and one player is the khan, who holds three paiza cards. Each merchant starts with 100 coins. Round 1, “before the Mongols”: at every third station a different prince demands 10 percent of your coins. Round 2, “the Mongol peace”: a merchant who answers a question from this lesson correctly receives a paiza from the khan and pays only one 5 percent tax for the whole road; merchants without a paiza roll a die at each station and lose 10 coins to robbers on a 1. Compare everyone's coins at the end of each round.

Scripture. “I exhort therefore, that, first of all, supplications, prayers, intercessions, and giving of thanks, be made for all men; For kings, and for all that are in authority; that we may lead a quiet and peaceable life in all godliness and honesty.” (1 Timothy 2:1-2, KJV)

Paul wrote under Roman rule, which also kept the roads open by force. Order and safe roads are real goods that let ordinary people work, trade and worship, which is why Christians pray for rulers. But order is not the same as justice, and the Mongol peace shows how much evil can come before a peace is made.

Practice answers

1. The governor, Inalchug, seized and killed a caravan of about 450 merchants sent by Genghis Khan; when the shah killed and humiliated Genghis's envoys, the Mongols invaded Khwarazm (1219-1221) and destroyed Otrar, Bukhara, Samarkand, Merv, Nishapur and other cities.
2. The yam was the Mongol network of relay stations with fresh horses and supplies along the main roads. A paiza was a tablet carried as a passport and order, entitling the bearer to protection and supplies at the stations.
3. The Yuan (China and Mongolia), the Chagatai Khanate (Central Asia), the Ilkhanate (Persia and Iraq) and the Golden Horde (the western steppe and the Russian lands).

4. A Franciscan friar sent by King Louis IX of France, who traveled to the court of the Great Khan Möngke and to Karakorum in 1253-1254.
5. $1295 - 1271 = 24$ years. $1295 - 1275 =$ about 20 years.
6. $500 \times 0.531 \approx 266$ coins remain; about 234 coins (47 percent) go to tolls.
7. Each stage takes 100 minutes. $1,440 \div 100 = 14.4$ stages. $14.4 \times 30 = 432$ km (about 270 miles).
8. Tana, Astrakhan, Urgench, Otrar, Ganzhou (in the Hexi Corridor), Khanbaliq.
9. The cost of trade includes more than moving goods: merchants must also pay for danger (guards, losses to robbers, seizure in war) and for tolls and bribes at each border. When one power controls the whole road and punishes robbers, danger falls, and when one authority collects one tax instead of many princes each taking a share, tolls fall. So the same road becomes cheaper to use.
10. North-south: $7.3^\circ \times 111 \approx 810$ km. East-west: $13.6^\circ \times 111 \times 0.724 \approx 1,093$ km. Distance $\approx \sqrt{(810^2 + 1,093^2)} = \sqrt{(656,100 + 1,194,649)} \approx \sqrt{1,850,749} \approx 1,360$ km (about 845 miles).
11. Any two: the empire split into rival khanates after 1260 that fought one another; the plague of the 1340s killed huge numbers along the routes and in the cities they served; the Yuan dynasty in China collapsed in 1368; other khanates broke into feuding parts, so the roads were no longer under one protector.
12. Answers will vary. A strong answer states both sides plainly: the conquests brought massacres at cities such as Merv and Nishapur, the destruction of irrigation and towns, and the deportation of craftsmen, and medieval people rightly saw them as a catastrophe. Afterward, Mongol rule did make the roads safer, cut tolls, carried messengers by the yam, welcomed merchants and allowed many faiths, so that travelers like Rubruck, the Polos and Bar Sauma crossed Asia and knowledge moved between China, Persia and Europe. A wise judgment admits that the peace was real and that its price was terrible, and does not let either fact cancel the other.

1.5 WHY THE ROAD DECLINED

OBJECTIVES

- Explain the causes of the decline of the overland trade after the 1300s: the breakup of the Mongol realms, the plague, the fall of the Yuan, new empires and tolls, and above all the cheaper sea route opened by Vasco da Gama in 1498.
- Build and use a cost model comparing camel caravans with ships in labor, animals, time and cost per tonne-kilometer, and check it against Adam Smith's real comparison of wagon and ship (1776).
- Describe how overland trade survived in new forms (the Kyakhta tea caravans, railways, today's China-Europe freight trains) while the sea carries most of the world's trade.

Warm-up. Put five heavy books in a cardboard box and drag it 2 m across a carpet or floor, noticing how hard you must pull. Now float a plastic container in a sink or tub, put two or three cans of food in it, and tow it across the water with one finger on a string. Write one sentence comparing the effort, and one sentence guessing what this means for moving cargo across a continent.

Watch. *8th July 1497: Vasco da Gama sets sail from Portugal on the first known voyage to India from Europe* (HistoryPod, 2:26). <https://www.youtube.com/watch?v=2sgmkRoXe4w>
After the story: trace Vasco da Gama's route around the Cape of Good Hope to Calicut on a map, and notice why a sea route to India let Portugal bypass the overland traders.
Note: Captions were not available to check; preview it first. The video mentions that da Gama's dealings with some East African rulers were hostile. The video describes four ships with about 170 men; the lesson mentions the three ships that anchored off Calicut.

Backup video. *What's Happening with China-Europe Rail Transport?* (Railways Explained, 12:33). <https://www.youtube.com/watch?v=Dsx-KbaAICY>
As review: see how freight trains still carry goods between China and Europe today, and listen for why most cargo still goes by sea because ships are cheaper. Note: Captions were not available to check; preview it first. It probably mentions current geopolitics (for example, routes changing because of the war in Ukraine) and asks viewers to become channel members, and it gives trade figures in euros.

KEY TERMS

transport cost

Everything it costs to move goods from where they are made to where they are sold: labor, animals or fuel, the vehicle, tolls, time, losses and risk.

tonne-kilometer

A measure of freight work: one metric tonne (1,000 kg) moved one kilometer. Cost per tonne-kilometer lets us compare camels, wagons, ships and trains fairly. (One tonne-km is about 0.68 ton-miles.)

economies of scale

The fall in cost per unit as size grows; a ship ten times larger needs far less than ten times the crew.

middleman

A trader who buys from one merchant and sells to another, taking a profit or toll along the way.

Cape Route

The sea route from Europe around the Cape of Good Hope at the southern tip of Africa to India and the East, first sailed by Vasco da Gama in 1497-1498.

CORE IDEAS

The story. On 20 May 1498 three Portuguese ships under Vasco da Gama anchored off Calicut, on the Malabar Coast of India. They had sailed from Lisbon in July 1497, swung far out into the Atlantic, rounded the Cape of Good Hope, crept up the coast of East Africa, and at Malindi taken on a pilot who guided them across the Arabian Sea with the monsoon. When a North African merchant in Calicut asked the first Portuguese ashore what had brought them so far, the reply, according to the journal of the voyage, was that they had come in search of Christians and spices. The voyage was hard and costly. Da Gama lost many of his men, mostly to scurvy, and the ships returned to Lisbon in 1499 with a modest cargo of pepper and other spices. But that cargo had come all the way from India to Europe *without passing through a single middleman's hands*: no Arab ship, no Egyptian customs house, no Venetian merchant. Europe now had a door to Asia that no caravan city controlled.

Why the road was already weakening. The overland routes did not die in a day. After 1260 the Mongol Empire split into rival khanates. The plague of the 1340s killed huge numbers of people along the routes and in the cities they served. In 1368 the Mongol Yuan dynasty fell in China, and the new Ming emperors faced north against the steppe and in time rebuilt the Great Wall. Timur (Tamerlane), who ruled from Samarkand from 1370 until his death in 1405, adorned his capital but wrecked Baghdad, Delhi and other cities in his campaigns. In 1453 the Ottoman Turks took Constantinople, and in 1475 they took Caffa from the Genoese. Older textbooks said the Turks “closed” the road to Asia. It is more accurate to say that the eastern trade now passed through powerful Muslim states, the Mamluks of Egypt, the Ottomans and later the Safavids of Persia, who taxed it heavily, while Venice held the European end. Every hand that touched the pepper raised its price. The Portuguese wanted to go around them all.

How it worked: the cost of a camel and the cost of a ship. The deeper reason was the arithmetic of transport, which this unit has been building toward. A camel carries about 200 kg (440 lb) and walks about 30 km (19 miles) a day; a driver can manage only a string of about five. Every camel must eat, every driver must be paid, and every oasis takes its toll. A merchant ship of the 1500s could carry a hundred tonnes or more, and its crew did not grow

in proportion to its size, so the cost of labor for each tonne fell as ships grew: an **economy of scale** that caravans could never match. Water holds a ship up, so the wind does nearly all the work of moving it. In 1776 the Scottish economist Adam Smith gave a real comparison from his own country. A broad-wheeled wagon with two men and eight horses took about six weeks to carry about four tons from London to Edinburgh and back. In about the same time a ship with six or eight men, sailing between London and Leith, the port of Edinburgh, often carried two hundred tons. To match one ship, Smith reckoned, would take fifty wagons, a hundred men and four hundred horses. That is why, he argued, the first great civilizations and markets grew up along coasts and navigable rivers.

Technology overcoming geography. The ship did not cross the mountains and deserts of Asia; it went around them. The Cape Route from Lisbon to India is far longer than the caravan roads from the Levant to the East, but distance was no longer the deciding cost. The carrack and later the galleon, with their stern rudders, mixed sails and deep holds, together with the compass, better charts and knowledge of the ocean winds and monsoons, made the long way around the cheap way around. Within a few decades the Portuguese held Goa (1510), Malacca (1511) and Hormuz (1515), and spices began to reach Europe by sea in large amounts. In the next century the Dutch and English followed (Unit 2). As a share of Eurasian trade, the caravan routes shrank.

What survived. Yet the overland trade adapted rather than vanished. Persian silk still went west by caravan to Aleppo and Bursa in the 1500s and 1600s, and the grand madrasas of Samarkand's Registan were built between 1417 and 1660 on wealth that included trade. After the Treaty of Kyakhta in 1727, Russian and Chinese merchants carried tea by camel across Mongolia to the border town of Kyakhta for nearly two centuries. Then railways arrived: the Russian Trans-Caspian Railway reached Samarkand in 1888. Today, as of 2026, freight trains run between China and Europe across Kazakhstan and Russia, and China's Belt and Road Initiative, announced in 2013, has funded railways, roads and ports across Central Asia and beyond. Trains are faster than ships and cheaper than aircraft, so they carry goods that are valuable and in a hurry, such as electronics and car parts. But ships still carry roughly 80 percent of world trade by volume. The lesson the caravan merchants learned the hard way still holds: **water is the cheapest road**, and the goods that go overland are, as always, the ones that can pay for the trip.

Moving 100 tonnes from China to the Mediterranean (model)

Camel caravan
4,000 km, 133 days
500 camels, 100 men



13,300

Ship
6,000 km, 40 days
25 men, no animals



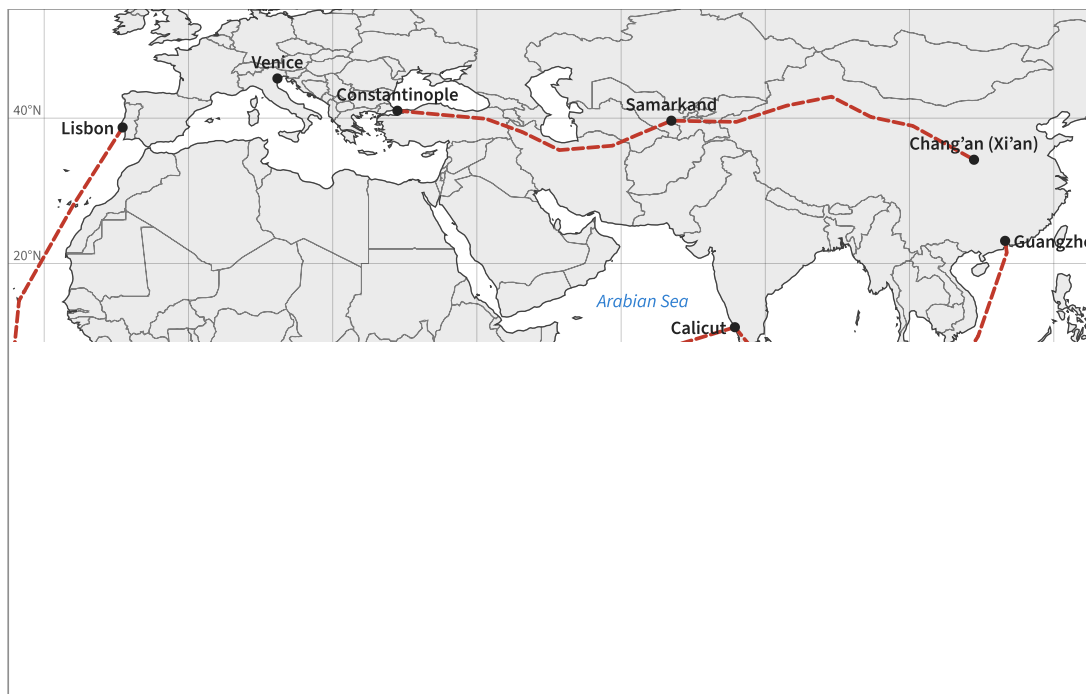
1,000

Man-days of labor (bar length to scale)

Adam Smith, 1776: London to Edinburgh and back, about six weeks

50 wagons + 100 men + 400 horses (200 tons) = 1 ship + 6 to 8 men (200 tons)

Camel and ship. The top bars are this lesson's model; the bottom line is Adam Smith's real comparison of 1776.



The long way around. The Cape Route is much longer than the overland roads, but by the 1500s it was cheaper per tonne.

PICTURE STUDY



Tilla-Kari Madrasa seen from the Ulugh Beg Madrasa, Registan, Samarkand, Sergei Mikhailovich Prokudin-Gorsky, Between 1905 and 1915 · Color photograph made from three glass-plate negatives (red, green and blue filters), digital color composite · Prokudin-Gorsky Collection, Library of Congress, Washington, D.C.

Sergei Prokudin-Gorsky was a Russian chemist and photographer who, with the support of Tsar Nicholas II, set out to photograph the whole Russian Empire in color. He took three pictures of each scene in quick succession through red, green and blue filters; projected together, they made a color image decades before color film was common. He traveled to Central Asia, then ruled by Russia, and photographed Samarkand. The Library of Congress bought his glass plates in 1948 and has made color composites of them.

The Registan, Samarkand's great square, is framed by three madrasas, or religious colleges: that of Ulugh Beg (1417-1420), the Sher-Dor (1619-1636) and the Tilya-Kori (1646-1660). The later two were built long after da Gama's voyage, which shows that Samarkand was still rich in the 1600s. In Prokudin-Gorsky's photographs the buildings are cracked and some domes have fallen; the railway had reached the city in 1888. The pictures catch the old caravan city at the moment the modern world arrived.

Look closely

- Look at the size of the arches compared with the doors at ground level. What does the scale tell you about the wealth that built them?
- Look for damage: cracks, missing tiles, broken tower tops and bare brick. What might have caused it?
- Find the small shop with the awning in the lower left. What does it tell you about how the old square was being used in Prokudin-Gorsky's day?
- Look at the colors. Where do you see the blue tilework that Samarkand is famous for?

Talk about it

1. Two of these madrasas were built after the sea route to India opened. What does that tell you about the claim that the Silk Road “died” in 1498?
2. Why might the coming of the railway have changed Samarkand more than the coming of Portuguese ships?
3. Why is a photograph from about 1911 a useful source for a lesson about the 1400s and 1500s, and what are its limits?

PROJECT: CAMEL AND SHIP: A COST-PER-MILE MODEL

This is the unit project. First you will measure, with a rubber band, how much less force it takes to move a load on water than on land. Then you will build a cost model on paper or in a spreadsheet for moving 100 tonnes of goods from China to the Mediterranean by camel caravan and by ship, and find the cost per tonne-kilometer and per ton-mile of each.

You will need

- A shoebox and a plastic food container of about the same size, and 6–8 cans of food as cargo
- Several identical rubber bands, a paper clip, string and a ruler (or a small spring scale if you have one)
- A bathtub or large sink with a few inches of water, and a smooth floor or carpet
- Graph paper or a spreadsheet program, and a calculator

Steps

1. Force test: tie the string to a rubber band and the rubber band to the loaded shoebox. Pull the box slowly and steadily across the floor and have a helper measure how far the rubber band stretches. Repeat three times and average.
2. Put the same cans in the floating container, attach the same rubber band and tow it slowly and steadily across the water. Measure the stretch again. Compare: how many times more force did the land haul need? Note that faster towing on water needs more force, which is why ships have a best speed.
3. Now build the model. Write the inputs in a table: camel load 200 kg; caravan speed 30 km a day; 1 driver for every 5 camels; overland distance 4,000 km. Ship: 100 tonnes of cargo; crew 25; average 150 km a day including stops; sea distance 6,000 km (the sea route is longer).
4. Compute for the caravan: number of camels, number of drivers, days on the road, man-days and camel-days (follow Worked Example 2).
5. Compute the same for the ship: days at sea and man-days.
6. Add costs: 1 coin per man-day, 1 coin per camel-day for feed and keep, 20 coins per day for the ship itself (wear, repairs and the owner’s capital), and a toll of 5 percent of cargo value at each of 6 oasis cities for the caravan, on a cargo worth 50,000 coins. Compute total cost, cost per tonne and cost per tonne-km for each (follow Worked Example 3).

7. Convert the cost per tonne-km to cost per ton-mile (multiply by 1.46, because one ton-mile is $0.907 \text{ tonne} \times 1.609 \text{ km} = 1.46 \text{ tonne-km}$).
8. Change one input at a time (camel load, ship speed, ship crew, number of tolls, risk of shipwreck) and record how the answer changes. Which input matters most?
9. Make a bar chart of total cost for each mode, and write a one-page report: "Why the sea route won."

Tips

- Keep units on every number (kg, tonnes, km, days). Most mistakes in models are unit mistakes.
- Your model is a simplification. Say in your report which numbers are well documented (a camel's load, Adam Smith's wagons and ships) and which are assumptions (the coin costs).

Check your work

- I measured and compared the force to move a load on land and on water.
- My model shows camels, drivers, days, man-days and total cost for both modes, with units.
- I calculated cost per tonne-km and per ton-mile correctly.
- I tested at least three changes to the inputs and explained which matters most.

MAP NOTEBOOK

1. Copy the land-and-sea map and color the overland route brown and the Cape Route blue. Mark Lisbon, the Cape of Good Hope, Malindi, Calicut, Constantinople and Samarkand.
2. Draw Adam Smith's comparison as a picture: one ship with 6–8 sailors on one side of the page, and on the other side 50 wagons, 100 men and 400 horses drawn as tally marks or tiny icons.
3. Make a cause-and-effect chain from 1260 to 1500 showing at least five reasons the overland trade declined, with arrows.

From history. After the Treaty of Kyakhta in 1727, the border town of Kyakhta, south of Lake Baikal, became the chief legal meeting place for Russian and Chinese merchants. Tea from China was carried by camel across the Gobi and Mongolia, traded at Kyakhta for furs and cloth, and then carried thousands of kilometers across Siberia to Moscow. Russians came to prize this "caravan tea," and some believed the long journey in cold dry air improved its flavor. The trade lasted until the Suez Canal (1869) made the sea route to Russian ports cheaper and the Trans-Siberian Railway carried tea by rail, and so the last great caravan trade of Asia gave way to ships and trains.

WORKED EXAMPLES

Example 1. Adam Smith (1776): a wagon with 2 men and 8 horses carries about 4 tons from London to Edinburgh and back in about six weeks; in the same time a ship with 6 to 8 men carries about 200 tons. How many wagons, men and horses match one ship? How many tons are carried per man in each case (use 7 men for the ship)?

(Use the map or drawing “Adam Smith’s comparison is shown in the bottom line of the figure.” shown earlier in this lesson.)

1. Wagons needed: $200 \div 4 = 50$ wagons.
2. Men: $50 \times 2 = 100$ men. Horses: $50 \times 8 = 400$ horses.
3. Tons per man, wagon: $4 \div 2 = 2$ tons. Ship: $200 \div 7 \approx 29$ tons.
4. Ratio: $29 \div 2 \approx 14$.

Answer: 50 wagons, 100 men and 400 horses, which is exactly Smith’s own figure. Each sailor moves about 14 times as much cargo as each wagoner, and the ship needs no horses to feed at all.

Example 2. Model: move 100 tonnes from China to the Mediterranean. Overland: 4,000 km at 30 km a day; each camel carries 200 kg; 1 driver per 5 camels. By sea: 6,000 km at an average of 150 km a day in one ship with a crew of 25. Find the camels, drivers, days, man-days and camel-days for the caravan, and the days and man-days for the ship.

1. Camels: $100,000 \text{ kg} \div 200 \text{ kg} = 500$ camels. Drivers: $500 \div 5 = 100$ men.
2. Caravan days: $4,000 \div 30 \approx 133$ days. Man-days: $100 \times 133 = 13,300$. Camel-days: $500 \times 133 = 66,500$.
3. Ship days: $6,000 \div 150 = 40$ days. Man-days: $25 \times 40 = 1,000$.
4. Ratio of man-days: $13,300 \div 1,000 \approx 13$.

Answer: The caravan needs 500 camels, 100 drivers, about 133 days, 13,300 man-days and 66,500 camel-days. The ship needs 40 days and 1,000 man-days, about one-thirteenth of the labor, and no animals, even though its route is 50 percent longer.

Example 3. Continue the model. Costs: 1 coin per man-day; 1 coin per camel-day; 20 coins per day for the ship itself. The cargo is worth 50,000 coins, and the caravan pays a 5 percent toll at each of 6 oasis cities (on the cargo's starting value, to keep it simple). Find total cost and cost per tonne-km for each mode, using each mode's own distance.

(Use the map or drawing "The labor bars come from Worked Example 2." shown earlier in this lesson.)

1. Caravan running cost: $13,300 + 66,500 = 79,800$ coins.
2. Caravan tolls: $6 \times 5\% \times 50,000 = 6 \times 2,500 = 15,000$ coins. Total: $79,800 + 15,000 = 94,800$ coins.
3. Caravan cost per tonne-km: $94,800 \div (100 \text{ tonnes} \times 4,000 \text{ km}) = 94,800 \div 400,000 \approx 0.24$ coin.
4. Ship cost: crew $1,000 + \text{ship } 20 \times 40 = 800$, total 1,800 coins.
5. Ship cost per tonne-km: $1,800 \div (100 \times 6,000) = 1,800 \div 600,000 = 0.003$ coin.
6. Cost per tonne delivered: caravan $94,800 \div 100 = 948$ coins; ship $1,800 \div 100 = 18$ coins.

Answer: Caravan: about 94,800 coins, 0.24 coin per tonne-km, 948 coins per tonne delivered. Ship: 1,800 coins, 0.003 coin per tonne-km, 18 coins per tonne. In this model the ship is about 50 times cheaper per tonne delivered ($948 \div 18 \approx 53$). Even if you add large costs for the risk of shipwreck, the sea wins easily. This is a model, not a record, but historians' estimates point the same way.

PRACTICE

1. **EASY** When and where did Vasco da Gama reach India, and why did his voyage threaten the caravan cities and Venice?
2. **EASY** List four events between 1260 and 1475 that weakened the overland trade.
3. **EASY** Define economies of scale and give a shipping example.
4. **EASY** About what share of world trade by volume do ships carry today (as of 2026)?
5. **MEDIUM** How many 200 kg camel loads are there in 300 tonnes of cargo? With 1 driver per 5 camels, how many drivers?
6. **MEDIUM** A ship with a crew of 30 carries 300 tonnes 8,000 km at 160 km a day. How many days and man-days? How many tonnes per crewman?
7. **MEDIUM** Convert 0.24 coin per tonne-km to coins per ton-mile (1 ton-mile = 1.46 tonne-km).
8. **MEDIUM** Use the map. Name the ocean da Gama sailed after rounding the Cape of Good Hope, the African port where he took on a pilot, and the Indian port he reached.
(Use the map or drawing "Use this map for Problem 8." shown earlier in this lesson.)
9. **HARD** In the model of Worked Example 3, suppose 1 ship in 10 is lost at sea with its whole cargo worth 50,000 coins. Add the expected loss per voyage (one-tenth of the cargo's value) to the ship's cost. What is the new cost per tonne shipped (divide by the full 100 tonnes), and is the ship still cheaper than the caravan's 948 coins per tonne?

10. **HARD** Older textbooks said the Ottomans “closed” the Silk Road in 1453. Explain in two or three sentences why historians now describe it differently.
11. **HARD** The Treaty of Kyakhta was signed in 1727, and the Trans-Caspian Railway reached Samarkand in 1888. How many years after da Gama reached Calicut was each? What do these dates show about the end of the overland trade?
12. **CHALLENGE** Today freight trains run from China to Europe in a fraction of a ship’s time but at a higher cost per tonne. Using the idea of value density from Lesson 1.3, write a paragraph explaining which goods go by train and which by ship, and connect your answer to the Silk Road.

COMMON MISTAKES

- Saying the Silk Road ended suddenly in 1453 or 1498. It declined in share over centuries and survived in new forms, including the tea caravans and the railways.
- Comparing only distances. The Cape Route was much longer, but cost per tonne-kilometer, not distance, decided which route merchants used.
- Forgetting the costs hidden in a caravan: animal feed, many drivers, tolls at every oasis, and goods lost to robbers.

Make it a game · Camel or Carrack?. Make cards for ten cargoes, each with a weight in tonnes, a value and an urgency (for example: 50 tonnes of pepper, 20,000 coins, not urgent; 1 tonne of silk, 10,000 coins, urgent; a letter from the khan, weight 0, very urgent; 100 tonnes of grain, 1,000 coins, not urgent). Use the costs from this lesson’s model: 0.24 coin per tonne-km by caravan over 4,000 km, and 0.003 coin per tonne-km by ship over 6,000 km, but the ship takes three months longer. Players take turns drawing a cargo and choosing camel, carrack or “do not ship,” and must give the reason. The group scores each choice; the best-reasoned shipper after ten cards wins.

Scripture. “Go to now, ye that say, To day or to morrow we will go into such a city, and continue there a year, and buy and sell, and get gain: Whereas ye know not what shall be on the morrow. For what is your life? It is even a vapour, that appeareth for a little time, and then vanisheth away.” (James 4:13-14, KJV)

James wrote to people who knew the merchant’s life of travel, markets and profit. The caravan cities that had grown rich for centuries could not foresee that ships sailing around Africa would change their fortunes. Planning is wise, but James reminds merchants and nations alike to hold their plans humbly before God.

Practice answers

1. At Calicut, on 20 May 1498. He brought spices from India to Europe by sea without passing through any Arab, Egyptian, Ottoman or Venetian middlemen, so their tolls and profits could be bypassed.
2. Any four: the split of the Mongol Empire into rival khanates after 1260; the plague of the 1340s; the fall of the Yuan dynasty in 1368; Timur’s destructive campaigns (1370–1405); the Ottoman capture of Constantinople in 1453; the Ottoman capture of Caffa in 1475.

3. The fall in cost per unit as size grows. A ship that carries ten times as much cargo does not need ten times the crew, so the labor cost per tonne falls.
4. Roughly 80 percent.
5. $300,000 \div 200 = 1,500$ camels; $1,500 \div 5 = 300$ drivers.
6. $8,000 \div 160 = 50$ days; $30 \times 50 = 1,500$ man-days; $300 \div 30 = 10$ tonnes per crewman.
7. $0.24 \times 1.46 \approx 0.35$ coin per ton-mile.
8. The Indian Ocean; Malindi; Calicut.
9. Expected loss: $50,000 \div 10 = 5,000$ coins. New cost: $1,800 + 5,000 = 6,800$ coins, or $6,800 \div 100 = 68$ coins per tonne. Still far cheaper than 948, about 14 times cheaper.
10. Trade with the East continued through Ottoman, Mamluk and Persian lands after 1453; Persian silk, for example, still went west to Aleppo and Bursa. What changed was that powerful states controlled and taxed the routes, raising prices, which gave the Portuguese a strong reason to find a sea route that bypassed them.
11. $1727 - 1498 = 229$ years; $1888 - 1498 = 390$ years. They show that overland trade continued for centuries after the sea route opened, in new forms such as the tea caravans, and that railways later revived overland transport.
12. Answers will vary. A strong answer: goods worth a lot for their weight, or needed in a hurry, such as electronics, car parts and fashion goods, can pay the higher cost per tonne of the train because transport is a small share of their value and time saved has value. Heavy, cheap goods such as ore, grain, coal and most containers of ordinary goods go by ship, which is far cheaper per tonne-kilometer. This is the same rule that governed the Silk Road: caravans carried silk, spices and silver, not grain, and once the sea route opened, the bulk of trade went by water.

UNIT 1 TEST

Answer every question. Show your work for all calculations, with units, and write complete sentences for explanations. Use 111 km per degree of latitude, 1 km = 0.621 miles, and the facts from this unit. The test is worth 100 points.

1. (6 pts) Who sent Zhang Qian west, about when did he leave, what was the purpose of his mission, and did it succeed?
2. (6 pts) Give three reasons silk was an ideal good for long-distance overland trade, and state what Pliny the Elder complained of about AD 77.
3. (6 pts) Name the corridor that is China's gateway to the west, the desert in the Tarim Basin, and the three mountain ranges that ring the basin on the north, south and west. Where do the northern and southern routes meet?
4. (8 pts) A caravan must travel 3,000 km. It averages 25 km on each marching day and rests one day after every six marching days. How many marching days, rest days and total days does the trip take? Give the distance in miles.
5. (6 pts) Explain how an oasis at the foot of a mountain range gets its water. Use the terms snowmelt, alluvial fan and karez.
6. (8 pts) A caravan of 30 men must cross a waterless stage of 200 km at 25 km a day. Each man needs 5 liters of water a day, and they want one extra day of water for safety. How many liters must they carry, and how many 200 kg camel loads is that (1 L $\approx$ 1 kg)?
7. (6 pts) What was the Library Cave at Mogao? Who found it and when, who took large parts of its collection, and why do people judge those removals differently?
8. (8 pts) Bukhara lies at about 39.8° N, 64.4° E and Kashgar at about 39.5° N, 76.0° E. At this latitude one degree of longitude is about 85 km. Estimate the straight-line distance in km and miles, and explain why the caravan road is longer.
9. (6 pts) Model: carrying a 200 kg camel load across Asia costs 400 coins. A load of rice is worth 50 coins at the start, and a load of silk 25,000 coins. Find the carrying cost of each as a percentage of its starting value, and explain what this shows.
10. (8 pts) Trace the spread of papermaking from China to Spain with at least four places and dates, and name one Christian and one Buddhist who traveled the Silk Road, with what each did.
11. (6 pts) Trace the path of the Black Death from Central Asia to western Europe, with places and dates, and explain why it moved faster once it reached the sea.
12. (8 pts) Model: a cargo worth 2,000 coins crosses the lands of 5 rulers, each taking 10 percent of its remaining value. Under the Mongols it pays one tax of 4 percent instead. How much value is left in each case? ($0.9^5 \approx 0.590$) What does this show about why trade grew under the Mongols?
13. (8 pts) Describe the Mongol peace in a paragraph: how it began, two tools that made the roads safe, two travelers who used them, and why an honest account must include its cost.
14. (10 pts) (a) Adam Smith wrote that one ship with 6 to 8 men could carry as much between London and Edinburgh as how many wagons, men and horses, if one wagon

with 2 men and 8 horses carries 4 tons and the ship 200 tons? (b) Model: 60 tonnes must move 3,000 km overland by camels carrying 200 kg each at 30 km a day, with 1 driver per 5 camels; or 4,500 km by sea at 150 km a day in a ship with a crew of 20. Find the man-days for each. (c) In two or three sentences, explain why the overland trade declined after 1498 and how it survived.

UNIT PROJECT: CAMEL AND SHIP: MAPPING AND COSTING THE SILK ROAD

Draw a large map (at least 60×45 cm, or 24×18 in) of the overland routes from Chang'an to the Mediterranean with a latitude-longitude grid and a scale bar. Show the Hexi Corridor, the Taklamakan with its northern and southern oasis routes, the Tian Shan, Kunlun and Pamirs, and at least twelve cities, including Dunhuang, Kashgar, Samarkand, Bukhara and Merv. Add the Mongol steppe route and, in a different color, da Gama's Cape Route to Calicut. Mark at least six goods, faiths or techniques with small symbols showing which way they traveled.

Beside the map, present your camel-and-ship cost model from Lesson 1.5: your rubber-band force test, your input table, your calculations of camels, drivers, days, man-days and cost per tonne-km and per ton-mile, at least three changed-input trials, and a one-page report titled "Why the Sea Route Won," which also explains what kinds of goods still traveled overland and why.

- **Geographic accuracy:** Routes, cities, mountains, deserts and seas are placed correctly on the grid; the scale bar is correct; labels are clear.
- **Quantitative model:** The cost model is complete, with units on every number; calculations of loads, days, labor and cost per tonne-km are correct; input changes are tested and explained.
- **Historical reasoning:** The report explains value density, the role of safety and tolls, the causes of decline and the survival of overland trade, using at least four dated examples from the unit, judged fairly and without exaggeration.
- **Craft and clarity:** Map and report are neat, well organized and easy to read, with a title, key and sources noted.

Answer key

1. Emperor Wu of Han sent him about 138 BC to find the Yuezhi and make an alliance against the Xiongnu. The alliance failed (the Yuezhi, settled in Bactria, did not want war), but his report on Ferghana, Sogdiana, Bactria, Parthia and India opened the Han road to the west and led to embassies, trade and the Han advance through the Hexi Corridor.
2. Silk was light and compact for its value, durable, beautiful and hard to make (each bolt held months of labor), and only China knew how to make it, so it fetched high prices far away. Pliny complained that India, the Seres (China) and Arabia took 100 million sesterces a year from the Roman Empire.
3. The Hexi (Gansu) Corridor; the Taklamakan Desert; the Tian Shan (north), the Kunlun (south) and the Pamirs (west). The routes meet at Kashgar.
4. Marching days: $3,000 \div 25 = 120$. Rest days: $120 \div 6 = 20$, but the last of these would fall after arrival, so 19 are taken on the road. Total: 139 days (accept 140 if the final rest is

counted), about four and a half months. Distance: $3,000 \times 0.621 \approx 1,860$ miles.

5. Snowmelt from the mountains runs down in rivers; where they leave the mountains they spread gravel in an alluvial fan, and much of the water sinks into it. Lower down, the groundwater rises again in springs, and farmers dig karez, gently sloping underground tunnels with shafts, to bring groundwater out by gravity without losing it to the sun. The fields and town grow where this water reaches the surface.
6. $200 \div 25 = 8$ days, plus 1 = 9 days. $30 \times 5 \times 9 = 1,350$ L (about 1,350 kg). $1,350 \div 200 = 6.75$, so 7 camel loads.
7. A small chamber (Cave 17) sealed around AD 1000 and packed with tens of thousands of manuscripts, paintings and printed texts in many languages. The Daoist priest Wang Yuanlu found it in 1900; Aurel Stein took thousands of documents in 1907 and Paul Pelliot in 1908. Stein and Pelliot believed they were rescuing them for scholarship, while many Chinese regard their removal as a great loss of national heritage.
8. The latitudes are almost the same, so use the longitude difference: $76.0 - 64.4 = 11.6^\circ$; $11.6 \times 85 \approx 986$ km, about 990 km (about 610 miles). The road is longer because it follows the Zeravshan valley through Samarkand and the Ferghana Valley and must cross the Pamir and Alay mountains by passes.
9. Rice: $400 \div 50 \times 100 = 800$ percent. Silk: $400 \div 25,000 \times 100 = 1.6$ percent. Overland transport was so costly that only goods of high value density, worth a great deal for their weight, could pay their way; cheap bulk goods could not travel far by caravan.
10. Paper: improved papermaking reported by Cai Lun in China in 105; Samarkand by about 751 (by tradition after the Battle of Talas); Baghdad by 794; then Cairo and North Africa; Xàtiva in Spain by about 1150. Christian: Alopen, a monk of the Church of the East, who reached Chang'an in 635 and was allowed to build churches. Buddhist: Kumarajiva of Kucha, who translated scriptures in Chang'an after 401, or Xuanzang, who walked to India and back (629–645) to bring Buddhist texts.
11. Graves near Lake Issyk-Kul record plague deaths in 1338–1339; it struck the Mongol army besieging Caffa in Crimea in 1346; Genoese ships carried it to Constantinople in 1347 and to Messina in Sicily in October 1347, then to Marseille (November 1347) and on to Paris and the rest of Europe in 1348. Ships moved much faster than caravans and carried infected people, rats and fleas quickly from port to port.
12. Five rulers: $2,000 \times 0.590 = 1,180$ coins left (820 lost). One tax: $2,000 \times 0.96 = 1,920$ coins left (80 paid). Unified rule cut the cost of tolls and danger even though the distance and terrain were unchanged, so more goods could pay their way.
13. Answers will vary. A strong answer: after the Otrar massacre of Genghis Khan's merchants in 1218, the Mongols conquered Khwarazm (1219–1221) and went on to rule from Korea to the Black Sea. They made the roads safe with the yam relay stations, the paiza safe-conduct tablet, a single authority collecting tolls, and ortoq merchant partnerships. William of Rubruck reached Karakorum in 1253–1254; the Polos traveled 1271–1295; Rabban Bar Sauma went from China to Rome and Paris in 1287–1288. The peace was built on conquest and massacre, as at Merv and Nishapur, so an honest account names that cost alongside its real benefits.
14. (a) $200 \div 4 = 50$ wagons, 100 men and 400 horses. (b) Camels: $60,000 \div 200 = 300$; drivers 60; days $3,000 \div 30 = 100$; man-days $60 \times 100 = 6,000$. Ship: $4,500 \div 150 = 30$ days; $20 \times 30 = 600$ man-days, one-tenth as many. (c) After da Gama reached Calicut in 1498, spices and other goods could reach Europe by sea at far lower cost per tonne and without the tolls of Mamluk, Ottoman and Venetian middlemen, while the overland routes had already been weakened by the breakup of the Mongol khanates, the plague and the fall of the Yuan.

Overland trade survived in new forms, such as Persian silk caravans to Aleppo and Bursa, the Kyakhta tea caravans after 1727 and later railways, but its share of trade shrank.

THE SPICE ROUTES AND THE MONSOON

In Unit 1 you followed the camel across Asia. Now you go down to the sea, where for most of history the cheapest road in the world was found. The Indian Ocean has a gift no other ocean has in the same measure: a wind that reverses with the seasons. God set the great continent of Asia across the ocean's northern side, and because land and sea heat and cool at different rates, the monsoon blows toward Asia in summer and away from it in winter. The Preacher saw such circuits long ago: "the wind returneth again according to his circuits" (Ecclesiastes 1:6). Merchants who learned the calendar of the winds could cross thousands of kilometers of open sea and come home within a year, and for well over a thousand years the Indian Ocean was the busiest long-distance trading sea on earth. Ezekiel 27 describes the merchants of Sheba and Raamah coming to Tyre with the chief of all spices; the trade you study here is the same ancient trade, carried on across a wider world.

You will sail with Roman merchants from the Red Sea to India, ride a sewn dhow with Ibn Battuta to Kilwa in 1331, follow Zheng He's treasure fleets from China to Africa (1405–1433), watch Jacob van Neck's ships come home to Amsterdam in 1599 in Hendrick Vroom's painting, and cross the Pacific with Andrés de Urdaneta on the first eastward return in 1565. In every lesson you will ask the questions of a commercial geographer: **Where do the goods come from? What does the route cost in distance, time and risk? What season must you sail in? Who controls the narrow places?**

The history will be told honestly. You will give real achievements their due: the seamanship of Arab, Indian, Swahili, Malay and Chinese sailors, the organization of the Dutch East India Company, and the courage of Urdaneta's crew. You will also name the wrongs plainly: the slave markets of the Swahili coast and Zanzibar, the conquest of the Banda Islands in 1621, and the forced labor behind the galleons. The project for the unit is a monsoon-calendar sailing game on a map of the Indian Ocean trade world.

BEFORE YOU BEGIN

- Can compute speed, distance and time and convert between kilometers, miles and knots
- Can read latitude and longitude and estimate distances using about 111 km per degree of latitude
- Can locate Africa, Arabia, India, Southeast Asia, China and the Pacific Ocean on a world map
- Knows the overland Silk Road and why caravan trade was costly (Unit 1)

MASTERY CHECKLIST

- I can explain why the monsoon reverses with the seasons and build a sailing calendar for the Indian Ocean.

- I can describe the sewn-plank dhow and its lateen sail and explain why Kilwa grew rich as the gateway to Sofala's gold.
- I can tell the story of Zheng He's seven voyages, weigh the evidence on the size of his ships, and explain why the voyages ended.
- I can locate the clove islands and the Banda Islands and explain how the VOC built its monopoly, both its achievements and its wrongs.
- I can explain how Urdaneta used the wheel of North Pacific winds and currents and why silver flowed from the Americas to China.
- I can compare great-circle and parallel distances and calculate voyage times, speeds and cargo weights.

OPTIONAL BOOKS AND RESOURCES

- **Rijksmuseum, Amsterdam (online collection)** (<https://www.rijksmuseum.nl/en>): Free. Search the collection for Hendrick Cornelisz Vroom's *The Return to Amsterdam of the Second Expedition to the East Indies* (1599) and for VOC ship models, maps and paintings. High-resolution images can be zoomed to study the ships (Lesson 2.4).
- **Library of Congress, Geography and Map Division** (<https://www.loc.gov/maps/>): Free. Search for historic maps of the Indian Ocean, the East Indies, the Philippines and the Pacific to compare with the maps in this unit and to use in the portfolio.
- **Internet Archive** (<https://archive.org/>): Free. Search for Wilfred H. Schoff's 1912 English translation of *The Periplus of the Erythraean Sea*, a public-domain edition of the first-century merchant's guide used in Lesson 2.1. A parent may choose short passages on the ports and sailing seasons.

2.1 THE MONSOON WINDS

OBJECTIVES

- Explain in physical-geography terms why the winds of the Indian Ocean reverse with the seasons, and name the months of the southwest and northeast monsoons.
- Describe how merchants from Roman Egypt to medieval Arabia, India and East Africa built a sailing calendar around the monsoon, using the Periplus, Strabo and Pliny as sources.
- Calculate sailing speeds and times for real monsoon crossings, compare a voyage with the wind to one against it, and find latitude with a kamal.

Warm-up. Fill one cup with sand or soil and another with water, and set both in a sunny window (or under a desk lamp) for fifteen minutes. Feel the top of each. Which warmed faster? Now imagine the sand cup is the whole continent of Asia and the water cup is the Indian Ocean. In which direction would you expect the air near the ground to flow on a hot summer afternoon: from sea to land, or land to sea? Write your guess and keep it for the end of the lesson.

Watch. *The Gospel Arrives in India: Apostle Thomas - "Ends of the Earth"* (Drive Thru History with Dave Stotts, 3:46). <https://www.youtube.com/watch?v=YYPkoj4mh8c>
After the story: learn how, by tradition, the Apostle Thomas reached India's southwest coast along the same monsoon sea route Roman traders used, and look for Christian history that remains there today.

Note: Captions were not available to check; preview it first. Drive Thru History is a trusted Christian channel, but this clip is about the Gospel reaching India, not about how the monsoon winds work, and the description includes a TV airing promo. Thomas's voyage to India comes from church tradition; the lesson's dated evidence for the sea trade comes from Strabo.

KEY TERMS

monsoon

A seasonal reversal of the prevailing wind over a large region. The word comes from the Arabic *mawsim*, "season," through the Portuguese *monção*. In the northern Indian Ocean the wind blows from the southwest in summer and from the northeast in winter.

southwest monsoon

The summer monsoon, about June to September: strong, moist winds from the southwest that bring heavy rain to India's west coast and rough seas to the Arabian Sea.

northeast monsoon

The winter monsoon, about November to March: drier, steadier winds from the northeast that carry ships from India toward Arabia and East Africa.

Periplus of the Erythraean Sea

A Greek merchant's guide written in the first century AD, listing the ports, goods and sailing seasons of the Red Sea, Arabia, East Africa and India.

kamal

A simple navigation tool of Arab and Indian sailors: a small wooden card on a knotted cord, used to measure the height of the Pole Star above the horizon and so to find latitude.

knot

A speed of one nautical mile (1.852 km, about 1.15 miles) per hour.

CORE IDEAS

The story. About 25 BC the Greek geographer Strabo traveled up the Nile with Aelius Gallus, the Roman governor of Egypt. Strabo had read older writers who said that in the days of the Ptolemies hardly twenty ships a year dared the long voyage to India. Now, he wrote, he learned that as many as 120 ships a year were sailing to India from Myos Hormos, a Roman port on the Red Sea coast of Egypt. Something had changed. Greek and Roman merchants had learned what Arab and Indian sailors had long known: that the winds of the Indian Ocean keep a calendar. A Greek handbook of the next century, the *Periplus of the Erythraean Sea*, credits a pilot named Hippalus with discovering how to cross the open sea directly to India instead of creeping along the coasts. Whoever first learned it, the secret was simple and powerful. In summer the wind blows steadily toward India; in winter it blows steadily back. A captain who knew the months could cross more than 3,000 km (about 1,900 miles) of open water and come home within a year.

How it works. Land heats and cools faster than water, as your warm-up showed. In the northern summer the great landmass of Asia grows hot. Warm air rises over India and the lands to the north, pressure near the ground falls, and moist air flows in from the cooler ocean. The southeast trade winds south of the equator cross the line and, turned by the earth's rotation, arrive as the **southwest monsoon**, roughly June to September. These winds are strong, wet and stormy; they bring the rains that water India's fields, and they make the Malabar Coast a dangerous lee shore. In winter the process runs backward. Asia cools, cold heavy air spreads outward from the interior, and from about November to March the **northeast monsoon** blows dry and steady across the Arabian Sea and the Bay of Bengal. Between the two lie calmer, changeable weeks in spring and autumn. The Creator set these circuits in the world, and the Preacher noticed them long ago: the wind "returneth again according to his circuits" (Ecclesiastes 1:6).

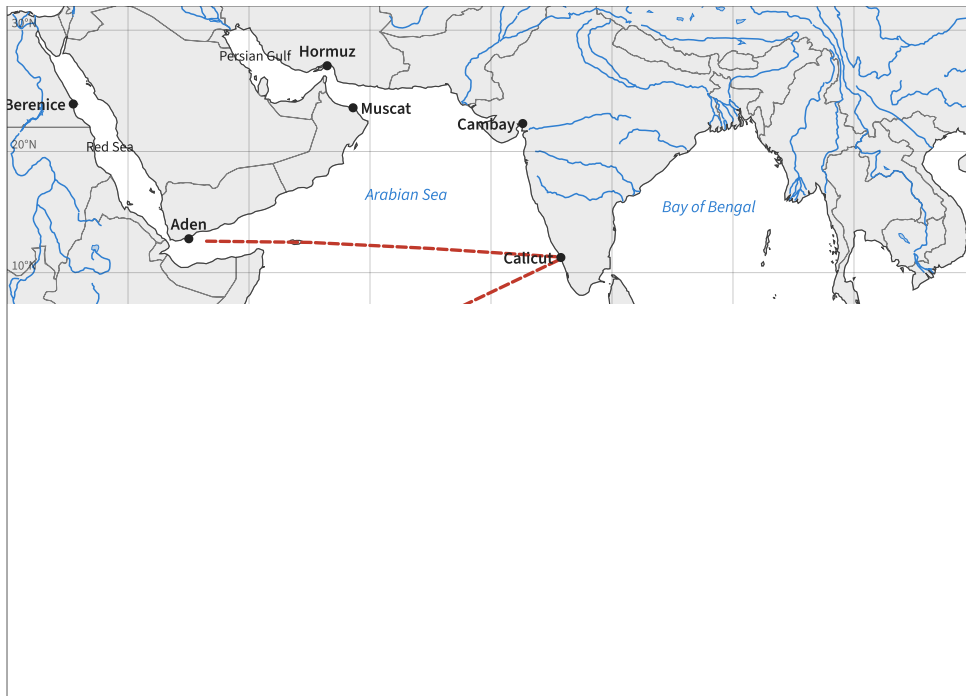
The sailing calendar. Every port around the ocean lived by these winds. The Roman writer Pliny the Elder, about AD 77, gave the schedule for ships from Egypt: leave the Red Sea port of Berenice at midsummer, reach Ocelis near the mouth of the Red Sea in about thirty days, then run before the wind about forty days to Muziris on the Malabar Coast of India, and start home in December or January. Arab and Gujarati merchants did the same in the other direction, sailing from India to Arabia and Africa on the winter monsoon and returning with the summer winds. Because the strongest summer gales closed the harbors of India's west coast for weeks, captains learned to sail early or late in the season, and a ship that missed its wind might wait half a year in a foreign port. That waiting built cities. Merchants rented

warehouses, married local wives, learned languages and built mosques, temples and later churches in one another's towns. Pliny complained that India drained at least fifty million sesterces a year from the Roman Empire in exchange for pepper, cottons, gems and other goods.

Technology overcoming geography. The monsoon itself was a kind of free engine, but sailors needed tools to use it. They needed hulls that could survive weeks on open water and sails that could hold a steady wind on the quarter. They needed to know where they were. Arab and Indian pilots used the **kamal**, a small card on a knotted cord. Holding the knot in the teeth and the card at arm's length, a pilot lined up the lower edge with the horizon and the upper edge with the Pole Star; the knot that fit told him his latitude, and the cord could be knotted for the latitudes of favorite ports. He could then sail north or south to the right latitude and run east or west along it to landfall. Fifteenth-century pilots such as Ahmad ibn Majid of Julfar wrote long guides to stars, coasts and seasons. With such knowledge the open ocean, which looked like a barrier, became a highway with a timetable.

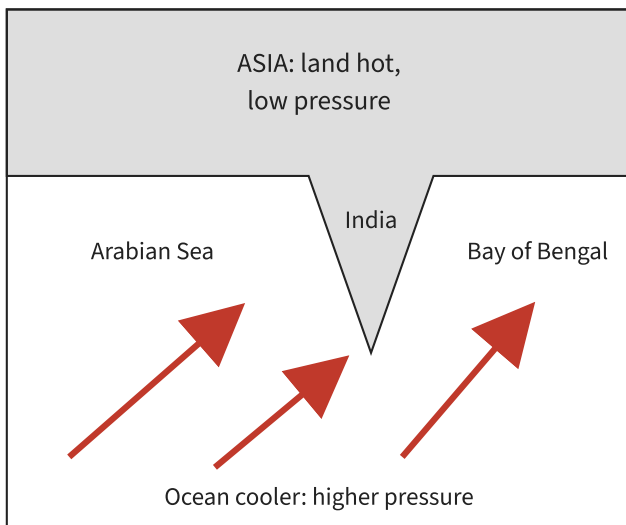
On the map. Look at the map of the Indian Ocean trade world (Figure hb-indian-ocean). The ocean is closed on the north by Asia, which is why the monsoon is so strong here: no other ocean has a huge continent sitting across its northern side. Notice the great ports at the edges: Aden at the mouth of the Red Sea, Hormuz at the mouth of the Persian Gulf, Cambay and Calicut in India, Galle in Ceylon, Malacca on its strait, and Mogadishu, Mombasa, Kilwa and Sofala in East Africa. Each sat where ships met the wind, the land or a narrow passage. Notice too how far south Sofala lies. The monsoon weakens toward the south, so ships from Arabia could rarely reach Sofala and return in a single season, a fact you will meet again in Lesson 2.2.

The big idea. Geography does not only set barriers; it also offers gifts. The monsoon made the Indian Ocean the busiest long-distance sea route in the world for well over a thousand years before Europeans arrived, linking Africa, Arabia, Persia, India, Southeast Asia and China. When Vasco da Gama reached India in 1498, he did not discover this world; he entered it, sailing with a pilot hired at Malindi and with the monsoon behind him. The lesson for a geographer is that every trade route has a *season* as well as a *path*. Ask of any route not only where it goes, but when it can be sailed and what it costs to wait.

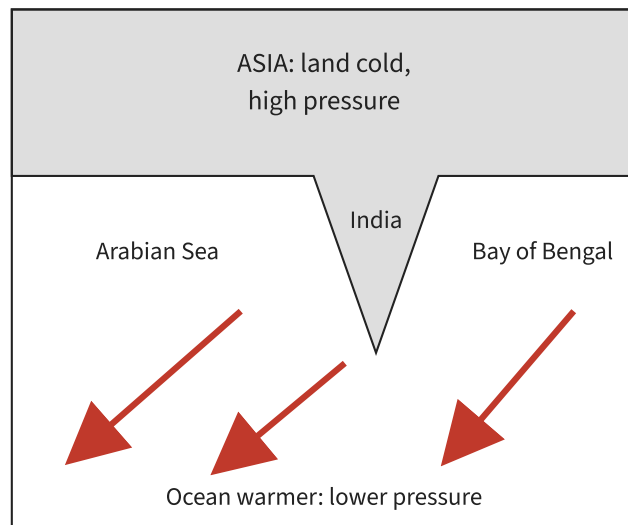


The Indian Ocean trade world: ports and monsoon routes.

Summer (about June–September)



Winter (about November–March)



Why the monsoon reverses: summer and winter.

PICTURE STUDY

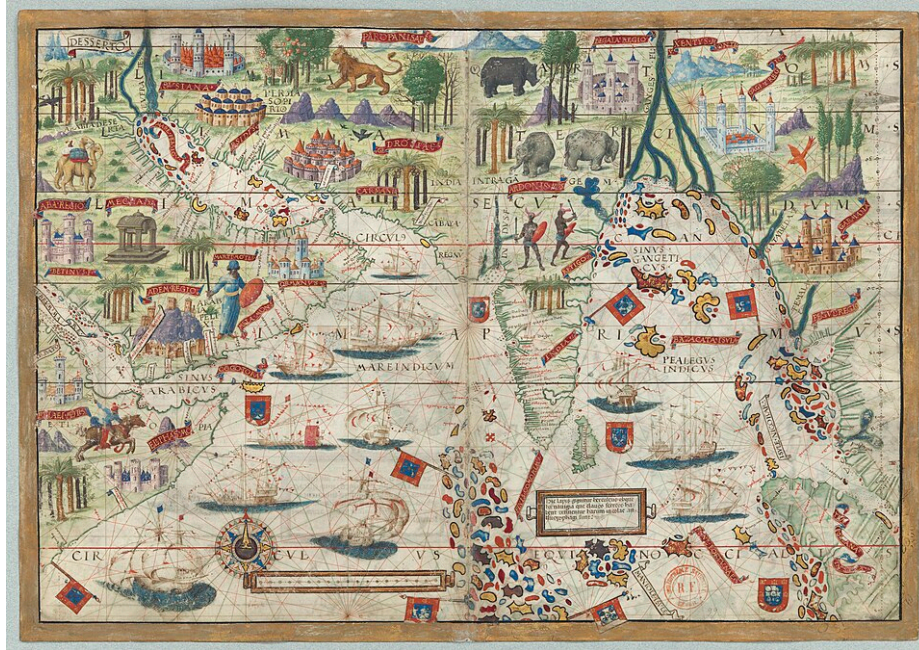


Chart of the Indian Ocean, from the Miller Atlas, Lopo Homem, Pedro Reinel and Jorge Reinel (cartographers); illuminations attributed to Ant3nio de Holanda, about 1519 · Ink, color and gold on vellum ·
Bibliothèque nationale de France, Paris

The Miller Atlas is a set of Portuguese charts made about 1519, about twenty years after Vasco da Gama reached India. It was probably meant as a splendid gift, and it is one of the most beautiful map books ever made. Its sheet of the Indian Ocean stretches from Arabia to the Bay of Bengal and the Malay Peninsula, with India and Ceylon in the middle, filled with ships, towns and people.

Look closely at the ships. The painter did not show only Portuguese vessels. He also painted the ships of the people who had sailed these waters for centuries, with different hulls and sails. The chart is a picture of a busy, crowded ocean that Europeans had only just joined.

Look closely

- Find the straight lines that cross the sea from compass roses. These are rhumb lines, used by pilots to steer a steady course.
- Find at least three ships. Compare their sails and hulls. Which look European, and which do not?
- Find the triangle of India and the island of Ceylon (Sri Lanka) to its south. How accurate does the shape look to you?
- Look at the pictures on the land. What did the mapmakers think a viewer in Portugal would want to know about India?

Talk about it

1. What does the chart tell you about who was already sailing the Indian Ocean when the Portuguese arrived?
2. Why would a beautiful chart like this be more useful as a gift or a statement of power than as a working chart on a ship?
3. If you could add one thing to this chart to help a pilot, what would it be? (Hint: think about seasons.)

PROJECT: THE MONSOON-CALENDAR SAILING GAME

You will design and play a board game in which merchant ships can only sail with the wind of the month. Players carry goods among the ports of the Indian Ocean, and the calendar decides when each voyage is possible. By the end you will feel why merchants planned a whole year around the monsoon and why missing the wind could cost a fortune. This game becomes part of the unit portfolio, so build it to last.

You will need

- A large sheet of poster board or the back of a cereal box flattened out
- A printed or traced outline map of the Indian Ocean (from Mozambique to the Malay Peninsula)
- Twelve index cards for the month deck, and twenty smaller cards for goods
- Small tokens for ships (buttons, coins or bottle caps) and one six-sided die
- Colored pencils, a ruler and a pencil

Steps

1. Draw or glue the map on the board. Mark eight ports: Aden, Hormuz, Cambay, Calicut, Galle, Malacca, Mombasa and Kilwa. Join them with sailing lanes, and divide each lane into spaces of about 500 km (310 miles) each, using the map scale.
2. Make the month deck: one card for each month. On each card write the wind. June–September: “Southwest monsoon: sail only toward the northeast or east; Malabar ports closed in June and July.” November–March: “Northeast monsoon: sail only toward the southwest or west.” April, May and October: “Changing winds: move only half speed in any direction.”
3. Make goods cards with real cargoes and their home ports: pepper (Calicut), cotton cloth (Cambay), horses (Hormuz), gold (Kilwa), ivory (Mombasa), cinnamon (Galle), porcelain (Malacca), frankincense (Aden). Give each a value of 1 to 3 at home and double that value at any port across the ocean.
4. Each player starts at a different port with one ship and two goods cards. Each turn, turn over the next month card. A player may move up to 3 spaces if the lane runs with the wind, or stay in port. Sailing against the monsoon is not allowed.
5. Add risk: in June and July, a ship at sea in the Arabian Sea rolls the die; on a 1 or 2 it loses one cargo in a storm.
6. Trading: in a port, a player may exchange goods with the market (draw a new local good) or with another player by agreement.

7. Play two full years (24 month cards). The player with the highest total value of goods wins.
8. After playing, write a paragraph: Which route paid best? When did you have to wait in port, and what did waiting cost you?

Tips

- Keep a ship's log as you play: month, port, wind, move and cargo. It is your evidence for the paragraph.
- Real winds are not perfectly regular. If you want a harder game, let the first and last month of each monsoon be "uncertain": roll the die, and on a 1 the wind has not yet changed.

Check your work

- My map shows the eight ports correctly placed, with lanes divided to scale.
- My month deck gives the correct monsoon for each month.
- I can explain from my log why timing mattered as much as distance.

MAP NOTEBOOK

1. Draw two small maps of the northern Indian Ocean side by side, labeled "July" and "January," and draw the prevailing wind arrows on each.
2. Make a circular calendar of the twelve months. Color the southwest monsoon months one color and the northeast monsoon months another, and mark the best months to sail from Arabia to India and from India to Africa.
3. Sketch a kamal: a small card on a cord with knots. Label the horizon line, the Pole Star and the knot in the teeth.

From history. A popular story says that the Arab navigator Ahmad ibn Majid guided Vasco da Gama from Malindi to India in 1498. Ibn Majid was real and famous; his guide to navigation, written about 1490, is one of the great works of Arabic seamanship. But Portuguese accounts do not name da Gama's pilot, and the story connecting the two appears in later sources. Most historians think the pilot hired at Malindi was a Gujarati or another Muslim sailor of the region. The honest answer is that we do not know his name, only that he knew the monsoon and the way to Calicut.

WORKED EXAMPLES

Example 1. Pliny says a ship from Ocelis, near the mouth of the Red Sea, reached Muziris in India in about 40 days. The open-sea distance is about 3,600 km (about 2,240 miles). Find the average speed in km per day, km per hour and knots.

1. Per day: $3,600 \text{ km} \div 40 \text{ days} = 90 \text{ km per day}$ (about 56 miles per day).
2. Per hour, sailing day and night: $90 \text{ km} \div 24 \text{ h} = 3.75 \text{ km/h}$.
3. In knots: $3.75 \text{ km/h} \div 1.852 \text{ km per nautical mile} \approx 2.0 \text{ knots}$.
4. Check: 2 knots is a slow walking pace, but kept up day and night for six weeks it carries a ship across an ocean.

Answer: About 90 km (56 miles) a day, or 3.75 km/h, about 2 knots.

Example 2. In 1498 Vasco da Gama left Malindi on April 24 and sighted India about 23 days later, a distance of about 4,250 km (2,650 miles), with the monsoon winds behind him. Coming back late in 1498, he left the Indian coast in early October before the northeast monsoon had settled in, and the crossing to Africa took about 90 days. Compare the average speeds.

1. Outward: $4,250 \text{ km} \div 23 \text{ days} \approx 185 \text{ km per day}$ (about 115 miles per day).
2. Return (taking the distance as about the same): $4,250 \text{ km} \div 90 \text{ days} \approx 47 \text{ km per day}$ (about 29 miles per day).
3. Ratio: $185 \div 47 \approx 3.9$.
4. Interpretation: the same ships, crews and distance, but the wrong season made the voyage about four times slower. On the long return many of his men died of scurvy.

Answer: About 185 km a day outward and about 47 km a day back; sailing with the season was about four times faster.

Example 3. An Arab pilot's kamal is marked in *isba* (fingers). One isba is $1/224$ of a full circle. After correcting for the Pole Star's small circle around the true pole, he measures the star's height as 7 isba. What is his latitude, and which Indian port lies at about that latitude? How far north or south is one isba on the earth's surface?

1. One isba = $360^\circ \div 224 \approx 1.607^\circ$.
2. Height of the pole = $7 \times 1.607^\circ \approx 11.25^\circ$. The height of the celestial pole above the horizon equals the observer's latitude, so he is near 11.25° N.
3. Calicut lies at about 11.25° N, so he is on the latitude of Calicut and can run east until he sights the coast.
4. One degree of latitude is about 111 km, so one isba $\approx 1.607 \times 111 \approx 178$ km (about 111 miles).

Answer: About 11.25° N, the latitude of Calicut. One isba of star height corresponds to about 178 km (111 miles) north or south.

PRACTICE

1. **EASY** What does the word "monsoon" originally mean, and from what language does it come?
2. **EASY** Give the direction and the approximate months of the summer and winter monsoons over the Arabian Sea.
3. **EASY** According to Strabo, about how many ships a year sailed to India from Myos Hormos in his day, about 25 BC?
4. **EASY** What does a kamal measure, and what does that measurement tell a navigator?
5. **MEDIUM** Explain in two or three sentences why the wind over the Arabian Sea blows toward India in summer.
6. **MEDIUM** Aden to Calicut is about 3,350 km (2,080 miles). How many days would a ship need at an average of 4 knots, sailing day and night?
7. **MEDIUM** Use the map. Name the port at the mouth of the Persian Gulf and the port at the mouth of the Red Sea. Why would both be valuable to whoever controlled them?
(Use the map or drawing "The Indian Ocean trade world." shown earlier in this lesson.)
8. **MEDIUM** A merchant in Calicut wants to send pepper to Aden and get his ship back the same year. In which months should it leave Calicut, and in which months should it come back?
9. **HARD** A pilot measures the Pole Star at 14 isba. Find his latitude in degrees and name a port near that latitude on the map (choose from Aden, Calicut, Cambay, Hormuz).
10. **HARD** Muscat to Calicut is about 2,300 km (1,430 miles). A ship makes 6 knots with the monsoon behind it and 1.5 knots working against light, changeable winds. How many days does each crossing take?
11. **HARD** Pliny says a Roman ship left Berenice at midsummer, spent about 30 days reaching Ocelis and about 40 days crossing to Muziris, and left India for home in

December. About how many weeks did it spend in India? (Take midsummer as June 24 and the start of the return as December 15.)

12. **CHALLENGE** In a paragraph, explain why the Indian Ocean became a great trading sea long before the Atlantic, using at least three geographic facts from the lesson.

COMMON MISTAKES

- Thinking the monsoon is only “the rainy season.” The word first meant the season of the wind; the rains of India are one result of the summer wind.
- Assuming sailors could cross whenever they liked if they were brave enough. Against the monsoon, crossings were slow, dangerous or impossible, so timing was everything.
- Believing Europeans discovered the Indian Ocean route. Arab, Persian, Indian, Malay, Chinese and African sailors had used it for many centuries before da Gama.

Make it a game • Which Wind?. One player calls out a month and a voyage, such as “February, Calicut to Mombasa” or “July, Cambay to Kilwa.” The other has five seconds to answer “Sail!” or “Wait!” and name the wind (southwest, northeast or changing). A correct answer with the right wind scores 2 points; a correct answer without the wind scores 1. Switch roles after ten calls. Bonus round: name the month in which a ship should leave to arrive in a given port before the wind turns.

Scripture. “The wind goeth toward the south, and turneth about unto the north; it whirleth about continually, and the wind returneth again according to his circuits.” (Ecclesiastes 1:6, KJV)

The monsoon is one of the clearest examples in the world of the circuits Solomon describes. God made a world of order, and merchants who studied that order and planned by it were rewarded.

Practice answers

1. It comes from the Arabic *mawsim*, “season” (through Portuguese *monção*).
2. Summer: from the southwest, about June to September. Winter: from the northeast, about November to March.
3. As many as 120 a year.
4. It measures the height of the Pole Star above the horizon, which (after a small correction) equals the observer’s latitude.
5. Land heats faster than water, so in summer the air over Asia and India becomes hot and rises, lowering the pressure near the ground. Cooler, moist air from the ocean flows in to replace it, and the earth’s rotation turns this flow into a wind from the southwest.
6. $4 \text{ knots} = 4 \times 1.852 = 7.41 \text{ km/h}$, or $7.41 \times 24 \approx 178 \text{ km a day}$. $3,350 \div 178 \approx 18.8$, about 19 days.
7. Hormuz (Persian Gulf) and Aden (Red Sea). Ships to and from those seas had to pass them, so a ruler could collect customs, supply ships and control the trade between the gulfs and the open ocean.

8. Leave on the northeast monsoon, about December to February, and return on the southwest monsoon, either early (about April-May) or late in the season (about August-September), avoiding the worst gales of June and July when the Malabar ports were closed.
9. $14 \times 1.607^\circ \approx 22.5^\circ \text{ N}$. Cambay (about 22.3° N) is closest.
10. 6 knots = 11.1 km/h = 267 km a day: $2,300 \div 267 \approx 8.6$ days. 1.5 knots = 2.78 km/h = 66.7 km a day: $2,300 \div 66.7 \approx 34.5$ days. The wrong season makes the trip about four times as long.
11. June 24 + 70 days $\approx$ September 2. From September 2 to December 15 is about 104 days, roughly 15 weeks in India, spent selling, buying pepper and waiting for the northeast monsoon.
12. Model answer: The Indian Ocean has a huge continent, Asia, across its northern side. Because land heats and cools faster than water, the winds reverse every season, blowing toward Asia in summer and away from it in winter. These predictable monsoons let sailors cross thousands of kilometers of open sea and return within a year, using simple tools like the kamal to hold a latitude. The ocean is also ringed by productive, populous lands with different goods (pepper, cottons, gold, ivory, horses, incense, porcelain), so trade paid well. The Atlantic has no such seasonal reversal over most of its width, and its shores were not linked by a single regular wind system, so long-distance trade there came later.

2.2 THE DHOW AND THE SWAHILI COAST

OBJECTIVES

- Describe the sewn-plank dhow and its lateen sail and explain how they suited monsoon trade.
- Locate the Swahili city-states of Mogadishu, Malindi, Mombasa, Zanzibar, Kilwa and Sofala and explain why Kilwa grew rich as the gateway to the gold of the interior.
- Tell the history of the coast honestly, from Ibn Battuta's visit in 1331 through the Portuguese and Omani eras to the Zanzibar slave market and its closing in 1873.

Warm-up. Take two craft sticks and lay them edge to edge. Try to join them without glue or tape, using only a needle and thread (or a twist tie poked through small holes). Sew them tightly, then bend the joined piece gently. Does it flex or snap? Write one sentence: why might a shipbuilder want a hull that can flex a little in heavy surf?

Video. Coming soon. The dhow, Kilwa Kisiwani, Fort Jesus at Mombasa and Stone Town, Zanzibar: search The History Guy, Drive Thru History with Dave Stotts and Smithsonian; Fall of Civilizations is flagged (use selectively); UNESCO and Geography Now are candidates (need vetting).

KEY TERMS

dhow

A general name for the traditional sailing ships of the western Indian Ocean, usually with one or two masts and lateen sails. Older dhows had hull planks sewn together with coconut-fiber cord.

lateen sail

A triangular sail hung from a long yard set at a slant to the mast. It can sail closer to the wind than a square sail, but the yard must be swung around the mast to change tack.

coir

Strong fiber from the husk of the coconut, twisted into cord and used to sew planks together and to make rope.

Swahili

The people and the language of the East African coast. The name comes from the Arabic *sawahil*, "coasts." Swahili is a Bantu language with many words borrowed from Arabic.

entrepôt

A port where goods from many places are gathered, stored, traded and shipped on again.

break-of-bulk point

A place where cargo must be moved from one kind of transport to another (or from one ship to another), which often makes it a natural site for a trading city.

CORE IDEAS

The story. In 1331 the Moroccan traveler Ibn Battuta boarded a ship at Aden and sailed south along the coast of Africa with the northeast monsoon. He stopped at Mogadishu, where he was entertained by the sultan, and at Mombasa, an island whose people he found pious and honest. Then he reached Kilwa, on a small island off the coast of what is now Tanzania, and called it one of the most beautiful and well-built towns in the world. Kilwa's sultan, al-Hasan ibn Sulaiman, was so generous that people called him the Father of Gifts. Ibn Battuta also recorded plainly that the sultan raided the peoples of the mainland and brought back plunder and captives. When the wind turned, the traveler sailed north again to Arabia. His short visit gives us a window into a rich, Muslim, seafaring civilization on the edge of Africa.

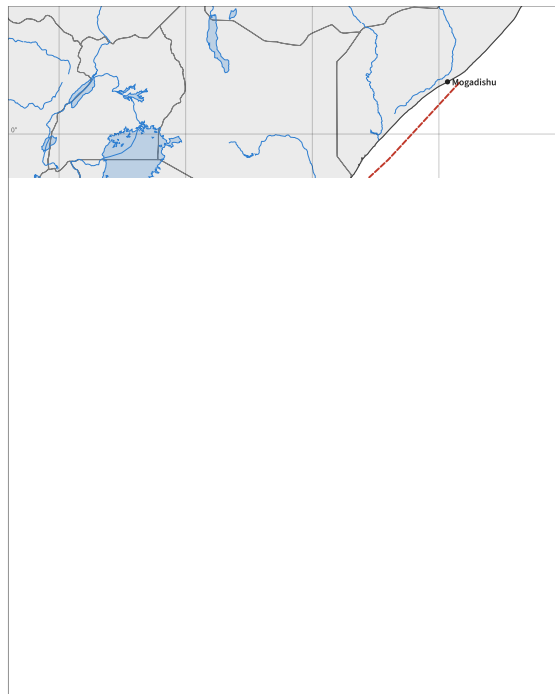
How it worked. The ships that carried Ibn Battuta were dhows. For many centuries the shipbuilders of Arabia, India and East Africa did not nail their hulls; they **sewed** the planks together with cord of **coir** from coconut husks, passed through holes along the edges and caulked with fiber and oil. A sewn hull flexed in the surf and could be beached and repaired with materials found on any tropical shore. The best timber was teak from India's Malabar Coast. A shipwreck found in 1998 near Belitung island in Indonesia, a sewn ship of Arab or Indian type from the ninth century, carried about 60,000 pieces of Chinese pottery, proof of how far such ships sailed. The dhow's **lateen sail** hung from a long slanting yard. It handled a steady monsoon wind on the beam or quarter very well, though changing tack meant swinging the great yard around the mast, so long voyages were planned to run with the wind for weeks at a time. Later dhows were built with iron nails, and many large ones copied the square stern of European ships, but the lateen sail and the monsoon calendar remained.

The Swahili coast. From Mogadishu in the north to Sofala in the south, a chain of trading towns grew up on islands and headlands: Lamu, Malindi, Mombasa, Pemba, Zanzibar, Kilwa and others. Their people spoke Swahili, a Bantu language rich in Arabic words, were mostly Muslim by the 1200s and 1300s, and built houses and mosques of coral stone and lime. They were brokers between two worlds. From the interior came gold, ivory, rhinoceros horn, timber, and enslaved captives; from across the sea came Indian cotton cloth, glass beads, Persian and Chinese ceramics and Chinese porcelain. Kilwa became the richest of the towns, with a great domed mosque and the huge palace of Husuni Kubwa, and it minted its own copper coins. Its wealth came from **gold** mined on the Zimbabwe plateau and brought down to the port of Sofala.

On the map. Look at the map of the Swahili coast (Figure hb-swahili-coast). Kilwa sits about 1,350 km (840 miles) north of Sofala. Why didn't Arabian ships simply sail to Sofala themselves? Because the monsoon weakens to the south. A dhow from Oman could ride the northeast monsoon to the northern Swahili ports and Kilwa, but going on to Sofala and back would usually make it miss the southwest wind home and lose a whole year. So Kilwa became a **break-of-bulk point**: its merchants carried gold and ivory up from Sofala in their own vessels and sold them to the ships from the north. Geography made Kilwa a middleman, and the middleman grew rich.

Conquest and change. In 1498 Vasco da Gama was received coldly at Mombasa and warmly at Malindi, whose ruler was Mombasa's rival. In 1505 a Portuguese fleet under Francisco de Almeida took Kilwa and sacked Mombasa, and Portugal tried to control the gold trade from forts on the coast. Kilwa never recovered its old greatness. At Mombasa the Portuguese built Fort Jesus in 1593-96. In 1696 an army from Oman laid siege to it, and after nearly three years the fort fell in December 1698. Over the next century and a half the sultans of Oman became masters of the coast, and about 1840 Sultan Said bin Sultan moved his capital to **Zanzibar**. There, and on nearby Pemba, Omani landowners planted cloves, and by the mid-1800s the islands grew most of the world's cloves. The plantations were worked by enslaved Africans, and Zanzibar's market sold many thousands of captives each year from the mainland to Arabia, Persia and the plantations of the islands. The explorer and missionary David Livingstone made the cruelty of the East African slave trade known in Britain, and in 1873 the British pressed Sultan Barghash to close the Zanzibar slave market. An Anglican cathedral, Christ Church, was later built on the very site of the market.

The big idea. The Swahili coast shows how a narrow strip of land can become a great trading civilization when it sits where wind, sea and a rich interior meet. It also shows that trade carries whatever people value, including human beings. A geographer studies both the achievement (seamanship, architecture, a language spoken today by many millions) and the wrongs, and names each truly.



The Swahili coast and the gold of Sofala.

PICTURE STUDY



Views of Aden, Mombasa (Mombaza), Kilwa (Quilwa) and Sofala (Cefala), from Civitates Orbis Terrarum, Georg Braun (editor) and Frans Hogenberg (engraver), 1572 · Copper engraving, often hand-colored, in a printed atlas of city views · Civitates Orbis Terrarum, volume 1 (Cologne, 1572), plate 53; this copy David Rumsey Map Collection

Civitates Orbis Terrarum (“Cities of the World”) was a great book of city views published in Cologne beginning in 1572. Its editor, Georg Braun, gathered pictures and descriptions of towns from across the known world, and Frans Hogenberg engraved them on copper plates. Among the towns of Asia and Africa he included Mombasa and Kilwa, the most famous ports of the Swahili coast.

Neither man ever saw East Africa. The pictures were made from Portuguese reports and drawings, so they show what Europeans had heard: stone houses, a harbor full of ships and the fortifications of the newcomers. Read them as evidence of how Europe imagined the coast, and compare them with what archaeologists have found.

Look closely

- Find the island or harbor setting. Why would an island be a safe place for a trading town?
- Look at the buildings. Which look like houses of the townspeople, and which look like forts or walls?
- Find the ships. Are they drawn as dhows or as European ships?
- Look for people, animals or trees. What did the engraver add to make the scene look “African” to a European reader?

Talk about it

1. What can a historian trust in a picture made by someone who never saw the place, and what should be checked against other sources?
2. Why would European readers in 1572 want pictures of Kilwa and Mombasa?
3. How does this view compare with Ibn Battuta's description of Kilwa in 1331?

PROJECT: SEW A MODEL DHOW HULL

You will build a small model dhow whose planks are sewn together, not nailed or glued, and rig it with a lateen sail. Then you will test it in a tub with a fan as the monsoon wind. You will learn with your own hands why a sewn hull flexes and why a lateen sail likes some winds better than others.

You will need

- Thin balsa or basswood strips about 3 mm (1/8 in) thick, or cardboard from a cereal box for a simpler model
- A large needle, a small hand drill or an awl (with adult help), and strong cotton string or jute twine
- A thin dowel or bamboo skewer for the mast and a longer one for the yard
- A triangle of cloth or paper for the sail
- Beeswax, petroleum jelly or candle wax for sealing the seams
- A tub or bathtub of water and a small electric fan

Steps

1. Draw a hull shape about 30 cm (12 in) long: a pointed bow, a pointed or square stern and a flat keel strip.
2. Cut a keel strip and two or three side planks for each side. Bend the planks gently (soak balsa in warm water for ten minutes first).
3. With adult help, make small holes about 1 cm apart along the edges of the planks and the keel.
4. Sew the planks to the keel and to each other with twine, pulling each stitch tight. Add two or three cross-pieces inside as frames.
5. Rub wax into all the seams to seal them, the way dhow builders used fiber and oil.
6. Step the mast a little forward of the middle. Tie the long yard to the mast at a slant, with the forward end low, and fasten the triangular sail along the yard.
7. Float the model. Test it with the fan behind it, beside it and ahead of it. Record which wind directions push it along best.
8. Write a short report: How did the sewn hull behave? Which wind directions suited the lateen sail? Why would a monsoon sailor plan to keep the same wind for weeks?

Tips

- A little leaking is normal in a sewn model, as it was in real sewn ships. Keep a small sponge handy as your bilge pump.

- Weight the bottom with a few coins or washers so the model does not tip in the fan's wind.

Check your work

- My hull is held together only by sewing, with sealed seams.
- My sail is a lateen: a triangle on a slanting yard.
- I tested and recorded at least three wind directions and explained the results.

MAP NOTEBOOK

1. Draw a side view of a dhow and label the hull, sewn seams, mast, yard, lateen sail and rudder.
2. Trace the East African coast from Mogadishu to Sofala and mark six Swahili towns. Draw an arrow showing gold coming down from the Zimbabwe plateau to Sofala.
3. Make a two-column table: "Goods from the interior" and "Goods from across the sea." List at least four in each column.

From history. In 1938–39 the Australian sailor and writer Alan Villiers sailed from Aden down to Zanzibar and then home to Kuwait in a large Kuwaiti dhow called a boom, commanded by a captain named Ali bin Nasr al-Nejdi. In his book *Sons of Sinbad* (1940) he described a world that still ran on the monsoon calendar: ships that left Kuwait in autumn, called at Aden and the Swahili ports in winter, loaded mangrove poles in the Rufiji delta and sailed home on the southwest monsoon. Within a generation engines and steel ships had replaced most of them.

WORKED EXAMPLES

Example 1. A dhow sails from Muscat to Zanzibar, about 3,950 km (2,450 miles), with the northeast monsoon behind it, averaging 5 knots day and night. How many days does the voyage take?

1. Convert the speed: $5 \text{ knots} \times 1.852 \text{ km/h per knot} = 9.26 \text{ km/h}$.
2. Per day: $9.26 \times 24 \approx 222 \text{ km a day}$ (about 138 miles).
3. Time: $3,950 \div 222 \approx 17.8 \text{ days}$.
4. Round sensibly: about 18 days of sailing, not counting stops along the coast.

Answer: About 18 days.

Example 2. An Omani merchant reaches Zanzibar on January 5 with the northeast monsoon. He must leave by April 15 to catch the early southwest monsoon home. How many days can he spend trading? If instead he goes on to Sofala and back (about 3,600 km round trip from Zanzibar, at 150 km a day along the coast) and needs 20 days in Sofala to trade, can he still leave Zanzibar by April 15?

1. Days in Zanzibar: January has 26 days left after the 5th, February 28, March 31 and April 15: $26 + 28 + 31 + 15 = 100$ days.
2. Sofala trip sailing time: $3,600 \div 150 = 24$ days, plus 20 days trading = 44 days.
3. $100 - 44 = 56$ days left over, so on these numbers it looks possible.
4. But the farther south he goes, the weaker and less reliable the monsoon becomes, and the coastal winds and currents south of Cape Delgado often run against a ship returning north. A delay of a few weeks would make him miss the wind and wait a whole year. That risk is why most northern merchants left the Sofala run to Kilwa's own ships.

Answer: He has 100 days in Zanzibar. On paper the Sofala trip fits (44 days), but the weak and uncertain southern winds made it a gamble with a year's delay as the penalty, so Kilwa's merchants handled the Sofala trade.

Example 3. Use the coordinates Kilwa (8.96° S, 39.51° E) and Sofala (20.15° S, 34.73° E). Estimate the straight-line distance between them, using 111 km per degree of latitude and about 108 km per degree of longitude at this latitude.

1. North-south difference: $20.15 - 8.96 = 11.19^\circ$; $11.19 \times 111 \approx 1,242$ km.
2. East-west difference: $39.51 - 34.73 = 4.78^\circ$; $4.78 \times 108 \approx 516$ km.
3. Straight-line distance: $\sqrt{(1,242^2 + 516^2)} = \sqrt{(1,542,564 + 266,256)} = \sqrt{1,808,820} \approx 1,345$ km.
4. In miles: $1,345 \div 1.609 \approx 836$ miles.

Answer: About 1,350 km (about 840 miles).

PRACTICE

1. **EASY** How were the planks of older dhows held together, and what material was used?
2. **EASY** Where does the name "Swahili" come from?
3. **EASY** Which Moroccan traveler visited Kilwa in 1331, and what did he think of it?
4. **EASY** Name four goods that came from the African interior to the Swahili ports and three goods that came from across the sea.
5. **MEDIUM** Use the map. List these towns in order from north to south: Kilwa, Malindi, Zanzibar, Mogadishu, Sofala, Mombasa.

(Use the map or drawing "The Swahili coast." shown earlier in this lesson.)

6. **MEDIUM** Mombasa (4.05° S) and Kilwa (8.96° S) lie at nearly the same longitude. Estimate the distance between them in km and miles.
7. **MEDIUM** Explain what a break-of-bulk point is and why Kilwa was one.
8. **MEDIUM** Give the dates of these events: Almeida takes Kilwa; Fort Jesus built; the fort falls to Oman; the Zanzibar slave market closed.
9. **HARD** A dhow averages 4 knots. How long does it take to sail from Mombasa to Zanzibar, about 240 km (150 miles)? If it leaves at dawn (6 a.m.), at about what time does it arrive?
10. **HARD** Why could a lateen-rigged dhow handle the monsoon well but find frequent changes of course difficult?
11. **HARD** The Belitung wreck, a ninth-century sewn ship, was found off Indonesia with about 60,000 pieces of Chinese pottery. What does this find tell historians about Indian Ocean trade?
12. **CHALLENGE** In a paragraph, explain how geography made Zanzibar the capital of the Omani sultans in the 1800s, and describe honestly the economy built there.

COMMON MISTAKES

- Thinking the Swahili towns were Arab colonies. They were African towns whose people spoke a Bantu language, though they traded with, married into and borrowed much from Arabia and Persia.
- Assuming the slave trade of East Africa was only a European business. Arab, Swahili and African traders ran the East African trade for centuries, and Britain later pressed for its end.
- Placing Sofala near Kilwa. Sofala lies about 1,350 km (840 miles) farther south, near modern Beira in Mozambique.

Make it a game • Middleman of Kilwa. Three players: a Sofala trader, a Kilwa merchant and an Arabian captain. Use beans as gold and slips of paper as Indian cloth. The Arabian captain may not go south of Kilwa (the monsoon will not let him get home). The Sofala trader may not go north of Kilwa. Only the Kilwa merchant can deal with both. Play five rounds of trading, with each player trying to end with the most value. Then discuss: why did Kilwa's position let it take a share of every trade? What happens to Kilwa if someone builds ships that can sail to Sofala and back regardless of the wind?

Scripture. "A false balance is abomination to the LORD: but a just weight is his delight." (Proverbs 11:1, KJV)

Every Swahili market had its scales for gold and ivory, and trust kept the trade alive across the sea. Honest weights are a matter of justice before God, in Kilwa as in Jerusalem.

Practice answers

1. They were sewn together with cord made of coir (coconut-husk fiber), not nailed.
2. From the Arabic *sawahil*, meaning "coasts."

3. Ibn Battuta. He called it one of the most beautiful and well-built towns in the world.
4. From the interior: gold, ivory, rhinoceros horn, timber and enslaved captives (any four). From overseas: Indian cotton cloth, glass beads, Persian and Chinese ceramics, Chinese porcelain (any three).
5. Mogadishu, Malindi, Mombasa, Zanzibar, Kilwa, Sofala.
6. $8.96 - 4.05 = 4.91^\circ$; $4.91 \times 111 \approx 545$ km; $545 \div 1.609 \approx 339$ miles.
7. It is a place where cargo must be shifted from one kind of transport or one ship to another. Kilwa was one because northern ships could reach it on the monsoon but could not easily go on to Sofala and return in one season, so gold and ivory were carried from Sofala to Kilwa in local ships and transferred there to the ships from Arabia and India.
8. 1505; 1593–96; December 1698 (after a siege begun in 1696); 1873.
9. 4 knots = 7.41 km/h. $240 \div 7.41 \approx 32.4$ hours. Leaving at 6 a.m., it arrives about 32 hours later, around 2 p.m. the next day.
10. The lateen sail works very well with a steady wind on the beam or quarter, which is what the monsoon provided for weeks at a time. But to change tack the crew had to swing the long, heavy yard around the mast, a slow and labor-intensive job, so the rig suited long straight runs better than constant tacking.
11. That ships of western Indian Ocean type (Arab or Indian sewn ships) were sailing all the way to China and back by the 800s, carrying bulk cargoes of manufactured goods, so the sea route linked the Middle East and China centuries before Europeans arrived.
12. Model answer: Zanzibar is an island close to the mainland, easy to defend, with a good harbor on the monsoon route from Oman. Ships from Arabia and India could reach it on the northeast monsoon and return on the southwest. It faced the mainland caravan routes to the interior, so ivory and captives could be brought to it. Its fertile soil and warm, wet climate suited cloves, and by the mid-1800s Zanzibar and Pemba grew most of the world's cloves. That wealth rested on slavery: the plantations were worked by enslaved Africans, and Zanzibar's market sold many thousands of captives a year until the British pressed Sultan Barghash to close it in 1873.

2.3 ZHENG HE'S TREASURE FLEETS

OBJECTIVES

- Tell the story of Zheng He and the seven Ming voyages (1405–1433), naming their main ports and the purposes the Yongle Emperor gave them.
- Explain how the fleets used the monsoon calendar and calculate voyage times and the scale of the fleets compared with European expeditions.
- Weigh the evidence on the size of the treasure ships and explain why the Ming court ended the voyages and what the decision meant for China's place in sea trade.

Warm-up. Measure the length of your house or apartment in paces, then estimate it in meters (one adult pace is about 0.75 m, or 2½ ft). A Ming history says the largest treasure ships were 44 *zhang* long, which would be well over 100 m (330 ft). How many of your houses, end to end, would that be? Write the number and one question you would want answered before believing it.

Watch. *Zheng He's Floating City: When China Dominated the Oceans* (Kings and Generals, 18:16). <https://www.youtube.com/watch?v=t-s1K56UgM0>

After the story: watch this animated documentary to see how big Zheng He's treasure ships were and to follow the fleet's routes across the Indian Ocean.

Note: Captions were not available to check; preview it first. The description shows a mobile-game sponsor (Perfect World Mobile), so expect an ad you can skip, and the animation shows battles with pirates and in Ceylon. Couldn't be checked without captions. Compare the number of ships and men and Zheng He's birth year with the lesson (62 great ships, about 27,800 men, born about 1371).

KEY TERMS

Ming dynasty

The Chinese dynasty that ruled from 1368 to 1644, founded after the fall of the Mongol Yuan dynasty.

Yongle Emperor

Zhu Di, third emperor of the Ming (reigned 1402–1424), who seized the throne from his nephew, moved the capital to Beijing and sent out the treasure fleets.

treasure ship (baochuan)

The largest ships of Zheng He's fleets, built at the Longjiang yards in Nanjing and filled with silks, porcelain and other gifts for foreign rulers.

tributary system

The Chinese practice of treating foreign rulers as vassals who sent "tribute" to the emperor and received rich gifts and trading rights in return.

zhang

A Chinese unit of length equal to 10 *chi* (Chinese feet). The Ming *chi* varied, so a *zhang* was roughly 3.1 m (about 10 ft), which makes the size of the ships hard to pin down.

haijin

“Sea ban”: Ming laws restricting private Chinese overseas trade and sea travel, enforced at different strengths from the 1370s to the 1560s.

CORE IDEAS

The story. In 1405, by order of the Yongle Emperor, a fleet of 62 great ships and many smaller support vessels gathered on the Yangtze near Nanjing and moved down to the coast of Fujian. On board were about 27,800 men: sailors, soldiers, officials, doctors, interpreters and astrologers. Its commander was a court eunuch named Zheng He. He had been born about 1371 into a Muslim family in Yunnan, in the far southwest of China; when Ming armies conquered Yunnan in the early 1380s, he was taken captive as a boy, castrated and placed in the household of the prince who later became the Yongle Emperor. He rose by his ability as a soldier and manager. Between 1405 and 1433 he led seven voyages across the South China Sea and the Indian Ocean, reaching Champa, Java, Sumatra, Malacca, Ceylon, Calicut, Hormuz, Aden and the coast of East Africa. Ships from the later voyages visited Mogadishu and Malindi, and a detachment of the seventh voyage reached Jiddah, the port for Mecca.

Why they sailed. The Yongle Emperor had taken the throne by civil war, and the voyages proclaimed his power and legitimacy to the world. They carried silks, porcelain and gifts to foreign rulers and invited them to send tribute missions to China; dozens of envoys came back with the fleets. They gathered luxuries for the court: pepper, gems, incense, rare woods and animals. They also fought when crossed. In 1407 the fleet defeated the pirate chief Chen Zuyi at Palembang and took him to Nanjing for execution, and in 1411 Zheng He captured the king of Kotte in Ceylon and carried him to China. In 1414 a giraffe arrived at the court, sent with an embassy from Bengal; officials hailed it as a *qilin*, a creature of good omen, and court painters recorded it. Behind the gifts lay a plain message: China was the center of the world, and other rulers were its tributaries.

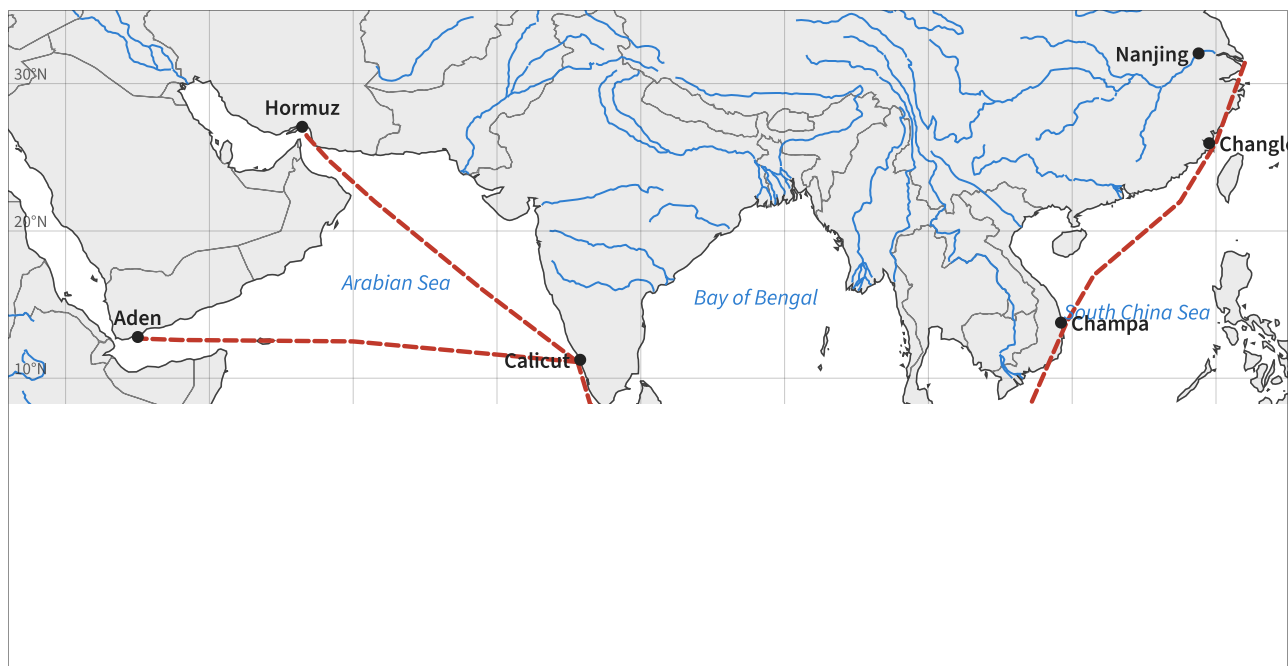
How it worked. The fleets were sailed by the monsoon, just like the dhows. They gathered on the Fujian coast in autumn and sailed in winter on the **northeast monsoon** to Champa, Java and the Strait of Malacca. At Malacca, whose ruler welcomed Ming protection against his neighbors, Zheng He kept a fortified depot where the fleet stored goods and waited for the wind to change. Squadrons then crossed the Bay of Bengal to Ceylon and Calicut, and later voyages went on to Hormuz, Aden and Africa. They came home on the **southwest monsoon** of summer. A full voyage took about two years. Chinese pilots steered by the magnetic compass, measured the height of stars above the horizon, and counted distances in *geng*, watches of sailing time. A chart traced from the voyages’ sailing directions was included in the military encyclopedia *Wubei Zhi* (completed 1621, printed 1628); it is known today as the Mao Kun map.

How big were the ships? The official *History of Ming*, compiled long afterward, says the largest treasure ships were 44 *zhang* long and 18 *zhang* wide. At about 3.1 m to a *zhang*, that is about 136 m (450 ft) long, longer than a football field. Many naval historians doubt

that a wooden ship of that size could have sailed well, and they estimate the largest ships at perhaps 60–75 m (200–250 ft), still several times the length of Columbus's *Santa María*, at about 18 m (60 ft). A huge rudder post, about 11 m (36 ft) long, dug up in 1957 at the site of the Nanjing shipyard, shows that some of the ships were very large indeed. The honest conclusion is that the fleets were the largest the world had yet seen, while the exact size of the biggest ship remains uncertain (Figure hb-ship-sizes).

On the map. Trace the routes on the map of the voyages (Figure hb-zheng-he). Notice that the fleet followed routes that Indian Ocean merchants had used for centuries, calling at the same great ports: Malacca, Calicut, Hormuz, Aden. Zheng He did not discover a new world; he showed the Ming flag in an old one. A trilingual stone he set up at Galle in Ceylon in 1409, carved in Chinese, Tamil and Persian, records gifts to the Buddha, to a Hindu god and to Allah, a sign of how many peoples and faiths met on these shores. The stone was found in 1911 and is now in the National Museum in Colombo.

The big idea. After the Yongle Emperor died in 1424, his successor stopped the voyages. The Xuande Emperor allowed one more, the seventh (1431–1433), and Zheng He died about 1433, probably on the return. Then the fleets ended. Court officials argued that they cost a fortune while the empire faced the Mongols on its northern frontier and was rebuilding the Grand Canal and the capital at Beijing. The sea ban on private trade remained law. Geography helps explain the choice: China's great dangers came over land from the north, and its food and wealth moved by river and canal, so the sea seemed a luxury. Within a century Portuguese ships were in the same ports. The treasure fleets show that great power at sea is a choice a nation must keep making, not a gift that lasts by itself.



The routes of Zheng He's seven voyages, 1405–1433.

Santa María, 1492: about 18 m (60 ft)



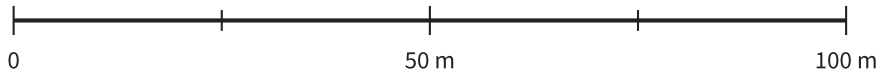
Modern estimates, largest treasure ships: about 60–75 m (200–250 ft)



History of Ming figure, 44 zhang: about 136 m (450 ft) at 3.1 m per zhang



football field, 100 yd (91 m)



How big were the treasure ships? Three lengths compared.

PICTURE STUDY



Tribute Giraffe with Attendant, After Shen Du (1357–1434), original 1414; this copy Ming dynasty, probably 16th century · Hanging scroll; ink and color on silk · Philadelphia Museum of Art

In 1414 an embassy from Bengal brought a giraffe to the Ming court in Nanjing; the animal had come to Bengal from East Africa. Officials declared it a *qilin*, a creature of good omen that was said to appear only under a wise and virtuous ruler. The court calligrapher and painter Shen Du painted the animal and wrote a poem of praise above it. His original is lost, but copies like this one preserve it.

The painting shows how the treasure fleets were understood at court: not mainly as trade, but as proof that the whole world honored the emperor. Another giraffe came from Malindi itself in 1415, and the fleets brought back zebras, ostriches and other animals for the imperial gardens.

Look closely

- Find the giraffe's long neck, spots and horns. How accurate is the painting, compared with a photograph of a giraffe?
- Find the attendant who leads it. What do his clothes and appearance suggest about where he came from?
- Look at the inscription above. Why would a painter put a poem on the picture itself?
- Notice the empty background. What does the painter want you to focus on?

Talk about it

1. Why would calling a giraffe a qilin be good politics for the Yongle Emperor?
2. What does this painting tell you about the purpose of the voyages, compared with the purpose of a merchant's dhow?
3. Can you think of a modern example in which a nation uses a rare gift or an exploit to show its greatness?

PROJECT: LAY OUT THE TREASURE SHIP

You will lay out the length and width of three ships full size on the ground: Columbus's Santa María, a treasure ship at a modern skeptic's estimate, and a treasure ship at the Ming history's figure. Standing inside the outlines is the best way to feel the scale of the debate.

You will need

- A long open space: a park, a school field, an empty parking lot or a long sidewalk
- A 30 m (100 ft) tape measure, or a string knotted every meter
- Sidewalk chalk, cones, or stakes and string
- A notebook and a calculator

Steps

1. Calculate the three sizes. Santa María: about 18 m long and 5.5 m wide. Skeptic's treasure ship: about 65 m long and 15 m wide. Ming history figure: 44 zhang by 18 zhang, at 3.1 m per zhang.
2. Mark a starting line. Measure and mark the length of the Santa María, then its width at the middle, and outline it with chalk or string.
3. Using the same starting line, mark the 65 m ship around it, then the Ming-history ship around both.
4. Walk the length of each. Count your paces and time your walk.
5. Stand at the bow of the largest outline and look back. Photograph or sketch the three outlines from one end.
6. Compute the deck area (length $\times$ width) of each ship as a rough rectangle, and the ratio of each to the Santa María.
7. Write a paragraph: Which estimate do you find more believable, and why? What evidence would settle the question?

Tips

- Real hulls are pointed at the ends, so a rectangle overstates the deck area. That is fine for comparing; just say so in your report.
- If space is short, use a scale of 1 m on paper to 1 cm and draw the three outlines on a long roll of paper instead.

Check your work

- I calculated all three ship sizes correctly in meters and feet.
- I laid out or drew the outlines to scale.
- I explained which estimate I find more believable, using evidence.

MAP NOTEBOOK

1. On an outline map from China to East Africa, trace the main route of the voyages and mark Nanjing, Malacca, Galle, Calicut, Hormuz, Aden and Malindi.
2. Draw a monsoon clock for the fleet: a circle of months, with arrows for “sail southwest” in winter and “sail home” in summer.
3. Make a timeline of the seven voyages from 1405 to 1433, adding the death of the Yongle Emperor (1424) and the arrival of the Portuguese at Malacca (1511).

From history. In 1431, before the last voyage, Zheng He and his officers set up inscriptions at Liujiagang near the mouth of the Yangtze and at Changle in Fujian, dedicated to Tianfei, a goddess sailors prayed to. They list the seven voyages and the countries reached, and say the fleets had visited more than thirty countries. These stones, together with the travel book of Ma Huan, a Muslim interpreter who sailed on three of the voyages, are among our best sources for what the fleets actually did.

WORKED EXAMPLES

Example 1. The Ming history gives the largest treasure ship as 44 zhang long. If 1 zhang = 3.1 m, how long is that in meters and feet? How many times longer is it than the Santa María (about 18 m)? Repeat the comparison for a modern estimate of 65 m.

1. Length: $44 \times 3.1 \text{ m} = 136.4 \text{ m}$. In feet: $136.4 \times 3.281 \approx 448 \text{ ft}$.
2. Compared with the Santa María: $136.4 \div 18 \approx 7.6$ times as long.
3. Modern estimate: $65 \div 18 \approx 3.6$ times as long.
4. Either way, the treasure ships were much larger than the ships Europeans sent into the Atlantic later in the century.

Answer: About 136 m (about 450 ft), about 7.6 times the length of the Santa María; at 65 m, about 3.6 times.

Example 2. A squadron sails from Changle to Malacca (about 3,500 km by the sailing route), then Malacca to Galle (about 2,500 km), then Galle to Calicut (about 760 km). At an average of 4 knots, sailing day and night, how many days of sailing is that? Why did the real outward voyage take many months?

1. Total distance: $3,500 + 2,500 + 760 = 6,760$ km (about 4,200 miles).
2. Speed: $4 \text{ knots} \times 1.852 = 7.41 \text{ km/h}$; per day $7.41 \times 24 \approx 178 \text{ km}$.
3. Sailing days: $6,760 \div 178 \approx 38$ days.
4. The real voyage was much longer because the fleet sailed only when the monsoon allowed, waited at Malacca and other ports for the wind to change, and stopped to trade, deliver gifts and take on water and food.

Answer: About 38 days of actual sailing; the months of waiting for the monsoon and calling at ports made the outward voyage last most of a year.

Example 3. The first voyage (1405) carried about 27,800 men in 62 large ships plus support vessels. Columbus's first voyage (1492) carried about 90 men in 3 ships, and da Gama's first voyage (1497) about 170 men in 4 ships. How many times more men did Zheng He command than Columbus and than da Gama? If all the men had been on the 62 large ships alone, how many would each have carried?

1. Compared with Columbus: $27,800 \div 90 \approx 309$ times.
2. Compared with da Gama: $27,800 \div 170 \approx 164$ times.
3. Men per large ship (if no support vessels): $27,800 \div 62 \approx 448$.
4. Because many men actually sailed on the support vessels, the real number per treasure ship was lower; this is an upper bound.

Answer: About 309 times as many men as Columbus and about 164 times as many as da Gama; at most about 450 men per large ship.

PRACTICE

1. **EASY** Give the dates of Zheng He's seven voyages and name the emperor who began them.
2. **EASY** Where was Zheng He born, and into what faith?
3. **EASY** Name five ports or regions the fleets visited.
4. **EASY** What animal arrived at the Ming court in 1414, and what did officials call it?
5. **MEDIUM** In which season did the fleets sail from China toward the Indian Ocean, and in which season did they return? Name the winds.
6. **MEDIUM** Use the map. Through which strait did the fleets pass between the South China Sea and the Indian Ocean, and which port beside it served as Zheng He's depot?
(Use the map or drawing "The voyages of Zheng He." shown earlier in this lesson.)

7. **MEDIUM** The Ming history gives the treasure ships a width of 18 zhang. At 3.1 m per zhang, how wide is that? What is the ratio of length (44 zhang) to width?
8. **MEDIUM** What languages are carved on the Galle inscription of 1409, and what does that tell us about the Indian Ocean world?
9. **HARD** A full voyage took about two years. If the fleet sailed about 20,000 km (12,400 miles) in all, what was its average progress per day over the whole voyage? Compare with a sailing speed of 178 km a day.
10. **HARD** Galle (6.0° N, 80.2° E) and Calicut (11.25° N, 75.8° E). Estimate the straight-line distance, using 111 km per degree of latitude and 110 km per degree of longitude at this latitude.
11. **HARD** Give three reasons the Ming court ended the voyages after 1433.
12. **CHALLENGE** A popular book published in 2002 claimed that Chinese fleets reached America in 1421. In a paragraph, explain how a historian should test such a claim, and why historians reject it.

COMMON MISTAKES

- Saying Zheng He “discovered” the lands he visited. He sailed to well-known ports on routes that Asian, Arab and African merchants had used for centuries.
- Repeating the largest ship size as a settled fact. The Ming history figure is real, but many historians think it is exaggerated; give the range and the reason.
- Thinking the voyages were mainly trading ventures for profit. They were state missions for prestige, tribute and luxuries, paid for by the treasury.

Make it a game · Admiral’s Orders. One player is the Yongle Emperor and gives sealed orders: a port, a cargo to deliver and a gift to bring back (for example, “Calicut: deliver silk; bring pepper”). The other player, as Zheng He, must plan the voyage on the map, naming the month to leave China, the wind, the waiting port and the month to come home. Score 1 point for each correct element. After three voyages, switch roles. Final round: the emperor dies and the new court votes on whether to send another fleet; each player argues one side for one minute.

Scripture. “And hath made of one blood all nations of men for to dwell on all the face of the earth, and hath determined the times before appointed, and the bounds of their habitation;” (Acts 17:26, KJV)

The Ming court saw the world as one center and many lesser tributaries. Scripture teaches a different picture: all nations come from one blood, and it is God, not any emperor, who appoints the times and bounds of the peoples.

Practice answers

1. 1405–1433; the Yongle Emperor (Zhu Di).
2. In Yunnan, in southwest China, into a Muslim family.

3. Any five of: Champa, Java, Palembang (Sumatra), Malacca, Ceylon (Galle), Calicut, Hormuz, Aden, Mogadishu, Malindi, Jiddah.
4. A giraffe; they called it a qilin, a creature of good omen.
5. They sailed out in winter on the northeast monsoon and came home in summer on the southwest monsoon.
6. The Strait of Malacca; the port of Malacca.
7. $18 \times 3.1 = 55.8$ m (about 183 ft). Ratio $44 : 18 \approx 2.4 : 1$, an unusually broad, beamy shape.
8. Chinese, Tamil and Persian. It shows that Chinese, South Indian and Persian-speaking (often Muslim) peoples all met and traded in the ports of Ceylon.
9. Two years ≈ 730 days. $20,000 \div 730 \approx 27$ km a day (about 17 miles). That is only about one-sixth of the actual sailing speed, because most of the time was spent in port waiting for the monsoon and doing the business of the voyage.
10. North-south: $5.25^\circ \times 111 \approx 583$ km. East-west: $4.4^\circ \times 110 \approx 484$ km. Distance $\approx \sqrt{(583^2 + 484^2)} \approx \sqrt{(339,889 + 234,256)} \approx \sqrt{574,145} \approx 758$ km (about 470 miles).
11. Any three: they were very expensive; the Yongle Emperor who backed them had died; Confucian officials distrusted the eunuchs who ran them and thought foreign luxuries wasteful; the empire's main danger was the Mongols on the northern land frontier; money was needed for the Grand Canal, the new capital at Beijing and the northern defenses; the sea ban on private trade reflected a policy of controlling contact with foreigners.
12. Model answer: A historian asks for evidence: records in Ming archives or the voyage inscriptions, archaeological finds (wrecks, Ming objects in datable American sites), and maps that can be shown to be genuine and early. The voyages' own inscriptions of 1431 list the countries visited and say nothing of any land across the Pacific. No Ming wrecks or settlements have been found in the Americas, and the maps offered as proof are later or misread. The claim depends on speculation and loose reading of evidence, so historians reject it, while fully honoring what the fleets really did.

2.4 THE SPICE ISLANDS

OBJECTIVES

- Locate the Moluccas and the Banda Islands, and explain why cloves, nutmeg and mace once grew only on a handful of small islands in eastern Indonesia.
- Explain how the Dutch East India Company (VOC, chartered 1602) raised capital, spread risk and built a monopoly of the fine spices, including the conquest of Banda in 1621.
- Calculate distances, bearings and the effect of the Brouwer route, and reason about risk, scarcity and price in the spice trade.

Warm-up. Set out whole cloves, a whole nutmeg and, if you have it, a blade of mace, along with ground cinnamon and black pepper. Smell each and grate a little of the nutmeg. Then read the labels on the jars: where were they grown? Write down a guess for how much one pound of nutmeg costs at the grocery store today, and then ask: why would people once have risked their lives to bring these home?

Video. Coming soon. The Spice Islands, the Banda Islands and the Dutch East India Company (VOC): search The History Guy, Smithsonian and the Rijksmuseum's own channel; Kings and Generals (HS) for the Dutch-Portuguese wars; Wendover Productions and Half as Interesting are candidates (need vetting).

KEY TERMS

Moluccas (Maluku)

The island group of eastern Indonesia between Sulawesi and New Guinea, called the Spice Islands. Cloves came from five small islands in the north (Ternate, Tidore, Moti, Makian and Bacan).

Banda Islands

A cluster of tiny volcanic islands in the Banda Sea, south of Seram, which until the 1700s were the world's only source of nutmeg and mace.

nutmeg and mace

Two spices from the same fruit of the nutmeg tree: nutmeg is the hard seed, and mace is the red, lacy covering (aril) around it.

VOC

Vereenigde Oostindische Compagnie, the United East India Company, chartered by the States General of the Dutch Republic on March 20, 1602, with a monopoly of Dutch trade east of the Cape of Good Hope.

joint-stock company

A business owned by many investors who buy shares. Each shares in the profits and losses in proportion to what he put in, so large, risky ventures can be paid for without ruining any one person.

monopoly

Control of the whole supply of a good by one seller, who can then restrict supply and raise the price.

CORE IDEAS

The story. In July 1599 four ships sailed up the IJ to Amsterdam, their decks crowded and their holds packed with pepper, cloves, nutmeg and mace. They were the first half of a fleet of eight under Jacob van Neck that had left the Netherlands in 1598, reached Java and sent ships on to the Moluccas and Banda. Bells rang, the city celebrated, and the investors made a profit of several hundred percent. The marine painter Hendrick Cornelisz Vroom painted the scene that same year: the returning ships firing their guns as a swarm of small boats crowds around them. Only two years earlier the first Dutch expedition to the East, under Cornelis de Houtman, had come home with barely a third of its men alive and little profit. The difference was knowledge: now the Dutch knew the way to the Spice Islands.

The geography of a monopoly. Why were cloves and nutmeg so precious? Because God had planted them, in the natural order of things, in one of the most remote corners of the world. Clove trees grew wild only on five small volcanic islands off the west coast of Halmahera: Ternate, Tidore, Moti, Makian and Bacan. Nutmeg trees grew only in the Banda Islands, a scatter of islets so small that the whole group would fit inside a modest American county. For centuries Malay, Javanese and Chinese traders carried the spices west to Java and Malacca; Indian and Arab merchants carried them on across the Indian Ocean on the monsoon; and Venetian merchants bought them in Alexandria and Beirut. Each hand added its cost and profit, so a spice cheap in Banda was costly in Europe. When the Portuguese seized Malacca in 1511 and reached Banda the next year, they were trying to cut out the middlemen. The Spanish arrived too: in 1522 the *Victoria*, the one ship of Magellan's fleet to return, reached Spain with a hold full of cloves from Tidore.

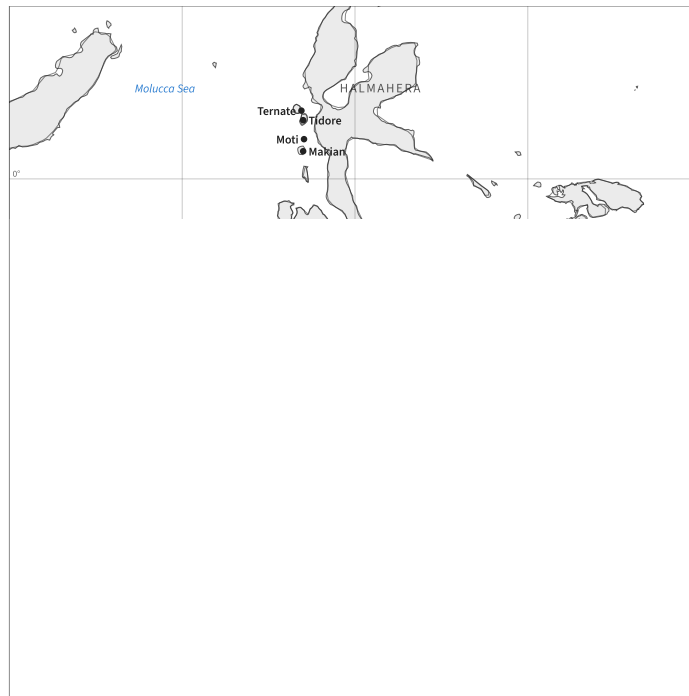
How it worked. The Dutch Republic's answer was a new kind of company. In 1602 the States General merged the rival Dutch trading firms into the **VOC** and gave it a monopoly of Dutch trade east of the Cape of Good Hope. It raised about 6.4 million guilders from more than a thousand investors, from rich merchants to servants, and its shares could be bought and sold in Amsterdam, which made it one of the first modern joint-stock companies. A voyage to the Indies might lose half its men and some of its ships; by pooling money across many voyages, the company spread the risk. The charter also let the VOC build forts, make treaties, keep soldiers and wage war, so it was both a business and a kind of state. In 1611 the VOC captain Hendrik Brouwer tried a new way to Java: instead of sailing north from the Cape along Africa and waiting on the monsoon, he ran east in the strong westerly winds near 40° S and then turned north to Java. The **Brouwer route** cut months off the voyage and was soon required of all company ships (Figure hb-brouwer-route).

Conquest of Banda. The Bandanese had sold nutmeg to all comers for centuries and did not intend to sell only to the Dutch, whatever treaties some of their leaders had signed. In 1621 the governor-general, Jan Pieterszoon Coen, who had founded Batavia (now Jakarta) two years before, invaded the islands with a large force. The Bandanese were killed in

fighting, executed, starved in the hills or shipped away as slaves; dozens of their leaders, the *orang kaya*, were put to death at Banda Neira. Of a population usually estimated at about 15,000, perhaps a thousand remained on the islands. The company divided the nutmeg groves into plantations, gave them to Dutch planters and brought in enslaved workers to tend them. Some in the Netherlands criticized Coen's methods even then. In the clove islands the VOC concentrated cultivation on Ambon and sent expeditions to cut down clove trees elsewhere so that it alone controlled the supply. In 1623 at Ambon, company officials tortured and executed ten English traders on a charge of plotting, a deed long remembered in England.

On the map. Find the Moluccas and Banda on the map of the Spice Islands (Figure hb-spice-islands). Notice how small the islands are and how far they lie from any great power: about 2,550 km (1,600 miles) from Batavia, and more than 20,000 km (12,400 miles) from Amsterdam by sea. Geography made the spices scarce; scarcity made them valuable; value drew fleets across half the world; and the smallness of the islands made a monopoly possible. The monopoly ended the same way it had begun, with geography: in 1770 a French official, Pierre Poivre, had clove and nutmeg seedlings smuggled out and planted on Mauritius, and in the next decades nutmeg and cloves spread to Zanzibar, Ceylon, Penang and the West Indies. Today the island of Grenada puts a nutmeg on its flag.

The big idea. The spice trade teaches three lessons of economic geography. First, scarcity is often geographic: what grows in only one place can command a high price far away. Second, distance and risk add cost at every step, and institutions such as the joint-stock company can lower that cost. Third, a monopoly built on force can be broken by the spread of the plant, the knowledge or the route that made it possible. The VOC lasted nearly two hundred years, sending nearly a million people to Asia on nearly five thousand voyages, until its charter lapsed in 1799. Its story joins great skill in shipping, finance and organization with grave wrongs done for profit.



The Spice Islands: the clove islands, Ambon and Banda.



The Brouwer route to Batavia, used by VOC ships from the 1610s.

PICTURE STUDY



The Return to Amsterdam of the Second Expedition to the East Indies, Hendrick Cornelisz Vroom, 1599 · Oil on canvas · Rijksmuseum, Amsterdam

Hendrick Cornelisz Vroom of Haarlem was one of the first Dutch painters to specialize in ships and the sea. In 1599 he painted the triumphant return of Jacob van Neck's ships from the East Indies, the voyage that proved the Dutch could reach the spice islands and come home rich. The painting was made in the same year as the event it shows, so it is almost a news picture.

Vroom took great care with the rigging, flags and hulls, and Dutch viewers could recognize each ship. Notice the mood: this is a celebration of a whole city, from the merchants who paid for the voyage to the boatmen who row out to greet it.

Look closely

- Find the large ships. How many can you count, and what are they doing to announce their arrival?
- Look at the small boats around them. Who seems to be in them, and why have they come out?
- Find the flags. What do they tell you about who owns the ships and where they come from?
- Look at the sky and water. How does Vroom make the scene feel joyful and busy?

Talk about it

1. Why would a voyage to the Indies be cause for celebration for a whole city, not just the investors?
2. This painting shows the return. What parts of the story does it leave out (the men who did not return, the people of the islands)?

3. How did this voyage help lead to the founding of the VOC three years later?

PROJECT: FROM BANDA TO AMSTERDAM: A SPICE PRICE CHAIN

You will build a price chain that follows one pound of nutmeg from a Banda grove to a Dutch kitchen, adding the cost and profit at each step. Then you will model a joint-stock company with dice to see why investors pooled their money. You will finish with a short report explaining why the spice was so expensive.

You will need

- A whole nutmeg, a grater and a kitchen scale if you have one
- Index cards or a long strip of paper for the price chain
- Two six-sided dice and a calculator
- Play money or counters

Steps

1. Make a card for each link in the old chain before the VOC: Banda grower, Javanese or Malay trader, Malacca market, Indian or Arab merchant, Red Sea or Persian Gulf caravan, Alexandria market, Venetian merchant, European shop.
2. Start with a price of 1 at Banda. At each link, roll a die and add that many tenths of the current price as cost and profit (a roll of 4 adds 40%). Write the new price on each card.
3. Find the final price and the ratio of the final price to the Banda price. Repeat three times and average.
4. Now model the VOC chain: Banda (company plantation), Batavia, company ship, Amsterdam auction, shop. Use the same dice rule. Compare the final prices of the two chains.
5. Joint-stock model: each player starts with 10 counters. A voyage “succeeds” if a die shows 3–6 and pays back three times the stake; on 1–2 the ship is lost. Player A puts all 10 counters on one voyage. Player B puts 2 counters on each of five voyages. Play ten rounds and record who is ruined and who prospers.
6. Weigh a whole nutmeg (or use 7 g as a typical value). How many nutmegs make a pound (454 g)?
7. Write a one-page report explaining, with your numbers, why nutmeg cost so much in Europe and how the VOC tried to capture the profit.

Tips

- These are model numbers, not historical prices. The point is to see how cost builds up link by link.
- Notice that the VOC chain is shorter, but the company also paid for forts, soldiers and ships lost at sea. A short chain is not automatically a cheap one.

Check your work

- My price chains are complete, with the price written at every link.
- I calculated and compared the ratio of final price to starting price for both chains.
- I can explain from my dice game why investors preferred to spread their money across many voyages.

MAP NOTEBOOK

1. Draw a nutmeg fruit cut open: label the husk, the red mace and the brown seed (nutmeg). Draw a clove beside it and label it as a dried flower bud.
2. Trace the Moluccas and mark the five clove islands, Ambon and the Banda Islands. Add a scale bar.
3. Draw a timeline from 1511 to 1799: Portuguese at Malacca (1511), Victoria returns (1522), van Neck returns (1599), VOC founded (1602), Brouwer route (1611), Batavia founded (1619), conquest of Banda (1621), Treaty of Breda (1667), seedlings to Mauritius (1770), VOC charter lapses (1799).

From history. The little nutmeg island of Run, about 3 km (2 miles) long, was claimed by the English, who held out there against the Dutch in the 1610s. At the end of the Second Anglo-Dutch War, the Treaty of Breda (1667) let each side keep what it held: the Dutch kept Run, and the English kept New Netherland, which they had captured in 1664 and renamed New York. At the time many thought the Dutch had the better bargain.

WORKED EXAMPLES

Example 1. Model risk: a voyage to the Indies has a 2-in-3 chance of returning, and a returning voyage pays back 3 times the money invested. Investor A puts 900 guilders into one voyage. Investor B puts 300 guilders into each of three voyages that succeed or fail independently. Find each investor's expected return and the chance that each loses everything.

1. Expected return for A: $(2/3) \times (3 \times 900) = (2/3) \times 2,700 = 1,800$ guilders. Chance of losing everything: $1/3$, about 33%.
2. Expected return for B: each voyage gives $(2/3) \times (3 \times 300) = 600$, and $3 \times 600 = 1,800$ guilders.
3. B loses everything only if all three voyages fail: $(1/3)^3 = 1/27$, about 3.7%.
4. The expected returns are the same, but spreading the money cuts the chance of ruin from about 1 in 3 to about 1 in 27. A joint-stock company that funds many voyages does this for all its investors at once.

Answer: Both expect 1,800 guilders, but A has a 1-in-3 chance of ruin and B only a 1-in-27 chance.

Example 2. The Brouwer route runs from the Cape of Good Hope (about 18.5° E) east along about 39° S to 100° E, then north to the Sunda Strait near 6° S, 105.8° E. Estimate the length of each leg and the whole route, using 111.2 km per degree of latitude and $111.2 \times \cos(\text{latitude})$ km per degree of longitude. At 6 knots, how many days is it?

(Use the map or drawing “The Brouwer route.” shown earlier in this lesson.)

1. East leg: $100 - 18.5 = 81.5^\circ$ of longitude. At 39° S one degree is $111.2 \times \cos 39^\circ \approx 111.2 \times 0.777 \approx 86.4$ km, so $81.5 \times 86.4 \approx 7,040$ km.
2. North leg: $39 - 6 = 33^\circ$ of latitude: $33 \times 111.2 \approx 3,670$ km north. It also runs 5.8° east; at the middle latitude (22.5° S) that is $5.8 \times 111.2 \times 0.924 \approx 596$ km. Length $\approx \sqrt{(3,670^2 + 596^2)} \approx 3,720$ km.
3. Total: $7,040 + 3,720 = 10,760$ km (about 6,690 miles).
4. 6 knots = 11.1 km/h = about 267 km a day. $10,760 \div 267 \approx 40$ days.

Answer: About 10,760 km (6,690 miles), roughly 40 days of sailing at 6 knots.

Example 3. Banda Neira is at 4.52° S, 129.90° E; Ternate is at 0.79° N, 127.38° E. Find the distance and the compass bearing from Banda Neira to Ternate.

(Use the map or drawing “The Spice Islands.” shown earlier in this lesson.)

1. North-south: from 4.52° S to 0.79° N is $4.52 + 0.79 = 5.31^\circ$ north; $5.31 \times 111.2 \approx 590$ km.
2. East-west: $129.90 - 127.38 = 2.52^\circ$ west; near the equator $1^\circ \approx 111$ km, so about 280 km west.
3. Distance: $\sqrt{(590^2 + 280^2)} = \sqrt{(348,100 + 78,400)} = \sqrt{426,500} \approx 653$ km (about 406 miles).
4. Bearing: the angle west of north is $\arctan(280 \div 590) \approx 25^\circ$. A bearing measured clockwise from north is $360^\circ - 25^\circ = 335^\circ$, about north-northwest.

Answer: About 650 km (about 405 miles) on a bearing of about 335°, north-northwest.

PRACTICE

1. **EASY** What is the difference between nutmeg and mace?
2. **EASY** Name the five original clove islands.
3. **EASY** What do the letters VOC stand for, and when and by whom was it chartered?
4. **EASY** Who led the conquest of the Banda Islands, and in what year?
5. **MEDIUM** Use the map. Which large island lies just east of the clove islands, and which island lies just north of the Banda Islands?

(Use the map or drawing “The Spice Islands.” shown earlier in this lesson.)

6. **MEDIUM** Ternate lies at 0.79° N. How far north of the equator is it, in km and miles?

7. **MEDIUM** Run Island lies about 0.21° of longitude west of Banda Neira at almost the same latitude (4.5° S). How far apart are they?
8. **MEDIUM** In a model chain, a spice starts at a price of 1 and each of 6 middlemen adds 50% to the price he paid. What is the final price?
9. **HARD** Banda to Batavia is about 2,550 km (1,600 miles). A VOC ship averages 5 knots. How many days is the voyage? Why would ships still plan it around the monsoon?
10. **HARD** In a dice model, a voyage succeeds on a roll of 3–6 (2/3 chance). What is the probability that at least one of four independent voyages succeeds?
11. **HARD** Explain how geography made a nutmeg monopoly possible and how geography helped end it.
12. **CHALLENGE** In a paragraph, give a fair, non-presentist judgment of the VOC: name its real achievements and its real wrongs, judging by the standards and knowledge of its own time.

COMMON MISTAKES

- Thinking spices were valued mainly to hide spoiled meat. People who could afford spices could usually afford fresh meat; spices were prized for flavor, medicine and prestige.
- Confusing pepper with the fine spices. Pepper grew widely in India and Sumatra; cloves, nutmeg and mace came only from the far smaller Moluccan and Banda islands.
- Imagining the VOC as an ordinary shop. It was chartered to build forts, make treaties and wage war, so it acted as a state as well as a business.

Make it a game • Spice Auction. Make small bags of beans labeled pepper, cinnamon, cloves, nutmeg and mace. The auctioneer announces how many of each came home this year (roll a die for each). Players bid with play money; the rarer the spice this year, the higher bids should go. After five rounds, the auctioneer becomes “the company” and may destroy part of the supply before the auction. Discuss: how did destroying supply change prices, and who gained and who lost?

Scripture. “For the love of money is the root of all evil: which while some coveted after, they have erred from the faith, and pierced themselves through with many sorrows.” (1 Timothy 6:10, KJV)

Trade in spices was not evil; spices are good gifts, and Scripture names them with delight. But the desire for a monopoly’s profits drove men to terrible deeds in Banda. The love of money, not money itself, is the root Paul warns against.

Practice answers

1. They come from the same fruit: nutmeg is the seed, mace is the red lacy covering around the seed.
2. Ternate, Tidore, Moti, Makian and Bacan.

3. *Vereenigde Oostindische Compagnie*, the United East India Company, chartered by the States General of the Dutch Republic on March 20, 1602.
4. Jan Pieterszoon Coen, governor-general of the VOC, in 1621.
5. Halmahera lies east of the clove islands; Seram lies north of the Banda Islands.
6. $0.79 \times 111.2 \approx 88$ km; $88 \div 1.609 \approx 55$ miles.
7. Near the equator $1^\circ \approx 111$ km ($\cos 4.5^\circ \approx 0.997$), so $0.21 \times 111 \approx 23$ km (about 14 miles).
8. $1 \times 1.5^6 = 11.39$, so about 11.4 times the starting price.
9. 5 knots = 9.26 km/h = about 222 km a day. $2,550 \div 222 \approx 11.5$ days. The winds of the Java and Banda seas also reverse with the seasons (the west monsoon of about December–March and the east monsoon of about June–September), so a ship sailing against them would be slow or stopped; timing still mattered.
10. Chance all four fail = $(1/3)^4 = 1/81$. Chance at least one succeeds = $1 - 1/81 = 80/81 \approx 98.8\%$.
11. Nutmeg grew only on the tiny Banda Islands, so a power that held those few islands with forts and ships could control the whole world supply. The monopoly ended when seedlings were carried out (Poivre to Mauritius in 1770, and later British plantings in Ceylon, Penang and the West Indies), because the tree could grow in other tropical places with similar climate and soil.
12. Model answer: The VOC was a remarkable achievement in organization and finance: it raised capital from many investors, spread the risk of dangerous voyages, made shares tradable, found faster routes like the Brouwer route and ran a trading network from the Cape to Japan for nearly two centuries. But it used force to take what it could not buy. The conquest of Banda in 1621 killed, starved, enslaved or drove out most of the islanders, and the plantations that followed were worked by slaves; the destruction of clove trees and the torture and execution of the English at Ambon were also condemned in their own day. People of the time knew that killing and enslaving the innocent was wrong, and some Dutch critics said so. A fair judgment honors the skill and names the wrongs plainly.

2.5 MANILA GALLEONS

OBJECTIVES

- Explain how Andrés de Urdaneta found the eastward return across the Pacific in 1565 by using the great circle of winds and currents of the North Pacific.
- Describe the Manila galleon trade (1565–1815): Mexican and Peruvian silver for Chinese silk and porcelain, and why China wanted silver.
- Compare great-circle and parallel distances across the Pacific, calculate voyage speeds, and compute the weight and value of silver cargoes.

Warm-up. Fill a large round bowl or a clean sink with water and sprinkle black pepper on the surface. Blow gently across the bottom half of the bowl from right to left with a straw, and across the top half from left to right. Watch the pepper. What path does it follow? Sketch it. You have just made a model of the circle of winds and currents that carried the Manila galleons.

Video. Coming soon. The Manila galleons and the Acapulco–Manila trade, 1565–1815: search The History Guy, Drive Thru History with Dave Stotts, Smithsonian and Library of Congress; NASA or NOAA material on the North Pacific gyre and the Kuroshio for the winds and currents; Kings and Generals (HS) for Anson’s capture of the Covadonga.

KEY TERMS

galleon

A large, multi-decked sailing ship with square sails on the fore and main masts and a lateen on the mizzen, used by Spain for both war and cargo from the 1500s to the 1700s.

tornaviaje

Spanish for “return voyage”: the eastward route from the Philippines across the North Pacific to Mexico, first sailed successfully in 1565.

gyre

A great circular system of ocean currents and winds. In the North Pacific it turns clockwise: westward in the tropics, northward along Asia, eastward in the middle latitudes and southward along North America.

Kuroshio

The “Black Current,” a strong, warm current flowing north along the Philippines, Taiwan and Japan, the Pacific counterpart of the Gulf Stream.

peso de ocho (piece of eight)

The Spanish silver coin worth eight reales, weighing about 27 g (just under 1 oz), minted in Mexico and Peru and used as trade money across the world.

great circle

The shortest path between two points on a globe, lying on a circle whose center is the center of the earth.

CORE IDEAS

The story. On June 1, 1565, the ship *San Pedro* left the island of Cebu in the Philippines and sailed not east toward Mexico, but north. On board as chief navigator was Andrés de Urdaneta, an Augustinian friar who had been a seaman and soldier before he took vows. For more than forty years Spanish ships had crossed the Pacific westward with the trade winds, but every attempt to sail back east had failed, beaten by those same winds. Urdaneta reasoned that the Pacific must work like the Atlantic, where Portuguese captains returning from Africa swung far out to the northwest to find westerly winds home. He took the *San Pedro* up past the latitude of Japan, near 39° or 40° N, where the westerlies blew, then ran east across the whole ocean, sighted the coast of California and followed it south. The ship reached Acapulco on October 8, 1565, after about 129 days; many of the crew had died on the way. A smaller ship of the same expedition had reached Mexico first by a similar northern path, but it was Urdaneta's careful record that made the route a road. For the next 250 years the galleons used it.

How it worked. The North Pacific is a great wheel. Near the tropic, the **northeast trade winds** blow steadily toward Asia, and the North Equatorial Current flows west. Along the coast of Asia the warm **Kuroshio** runs north past Taiwan and Japan. In the middle latitudes the **westerlies** and the North Pacific Current carry everything east, and along North America the California Current flows south. The galleon trade simply rode the wheel (Figure hb-pacific-wheel). Ships left Acapulco in February or March, ran west with the trades along about 13° N to Guam, and reached Manila in about three months. Returning, they left Manila in June or July, using the southwest monsoon of the Philippine summer to clear the islands through the San Bernardino Strait, climbed north into the westerlies, crossed the ocean, made landfall on the California coast and followed it south to Acapulco. The return took four to six months and sometimes more, the longest regular voyage in the world. Scurvy, storms and typhoons killed many men; some galleons simply vanished.

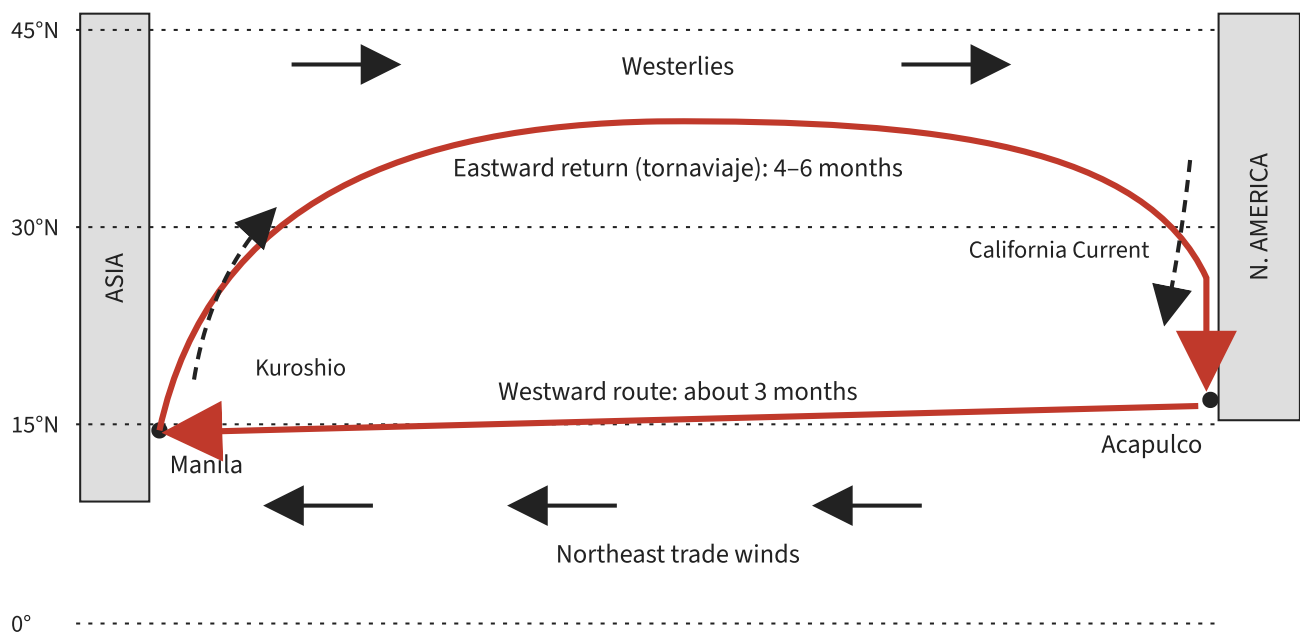
Technology overcoming geography. The galleon was the container ship of its day. The Manila galleons were built at Cavite and other Philippine yards from tropical hardwoods by Filipino shipwrights and laborers, many of them conscripted under the Spanish system of forced labor. They grew from a few hundred tons in the 1500s to well over a thousand tons in the 1700s, with high sides, several decks and great holds. But the real breakthrough was not the hull; it was *knowledge* of the wind system. Once Urdaneta had shown how the ocean's wheel turned, the largest ocean on earth became a regular trade route, crossed once or twice a year in each direction for two and a half centuries. Geography still set the rules: the shortest route on the globe was useless if the winds blew against it.

The big idea: silver for silk. Why sail at all? Because China wanted silver and Spanish America had it. The mines of Potosí in Peru and of Zacatecas and Guanajuato in Mexico produced silver in huge amounts, which you will study in Unit 4. Meanwhile, in the 1570s and 1580s the Ming government began requiring many taxes to be paid in silver, and silver was worth more in China, measured against gold, than in Europe or America. So silver flowed west across the Pacific, and Chinese junks from Fujian, where the Ming had eased the sea ban in 1567, sailed to Manila each spring with silk, porcelain, lacquer and other goods to

meet it. Manila was founded by Miguel López de Legazpi in 1571, and historians often date the birth of a truly worldwide trade from that year, when silver from the Americas began to reach China directly by the Pacific. The Spanish crown tried to limit the trade to protect Spanish merchants, allowing in 1593 only two ships a year and setting a ceiling on the value of their cargoes, but smuggling and overloading were constant.

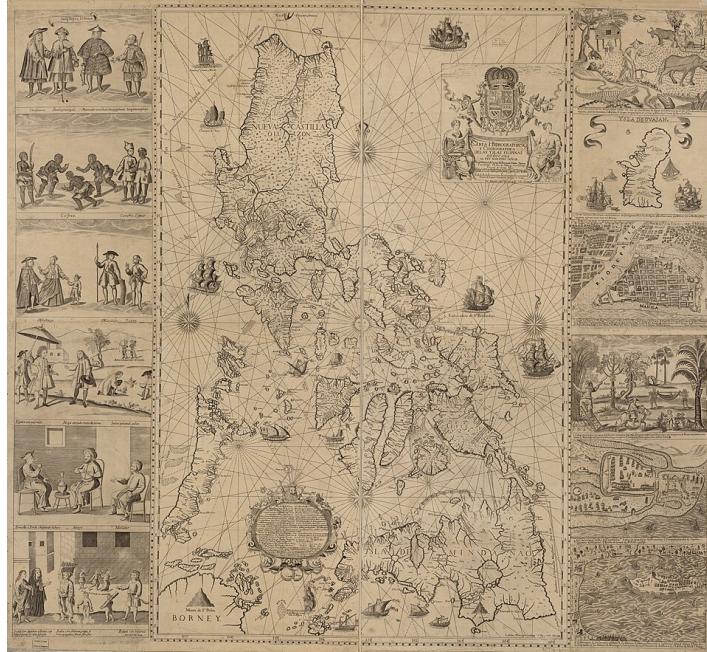
On the map. Manila, Acapulco and the islands of the Marianas (where Guam was the regular stop for water and food) were the anchors of the route. Manila became one of the most mixed cities in the world: Spaniards, Filipinos, Chinese, Japanese, Malays and others. The Chinese merchants and craftsmen, called Sangleys, outnumbered the Spaniards many times over and lived in a district called the Parián. Spanish fear of them led to terrible violence: in 1603, after a Chinese uprising, Spanish forces and their allies killed many thousands of Chinese residents. At the other end, the silks and porcelain sold at the Acapulco fair went on by mule to Mexico City and across to Veracruz, and some reached Spain and Peru. The last galleon sailed in 1815, as Mexico fought for its independence.

The lesson for a geographer. The Manila galleons show the whole Indian Ocean idea of this unit carried to the Pacific: seasonal winds, a long route bent to fit them, and two economies with different goods and different prices joined by the sea. They also show that the shape of trade is set not only by distance, but by currents, winds and the knowledge to use them.



The wheel of the North Pacific and the two galleon routes.

PICTURE STUDY



Carta Hydrographica y Chorographica de las Yslas Filipinas (Hydrographic and Chorographic Chart of the Philippine Islands), Pedro Murillo Velarde, S.J. (mapmaker); engraved by Nicolás de la Cruz Bagay, 1734 ·

Copper engraving on paper, printed in Manila · This copy: Library of Congress, Geography and Map Division, Washington, D.C.; other original prints survive in libraries and archives in Spain, the Philippines and elsewhere

Pedro Murillo Velarde was a Spanish Jesuit priest who taught law in Manila and wrote a history of the Jesuits in the Philippines. In 1734 he published this great map of the islands, engraved in Manila by the Filipino engraver Nicolás de la Cruz Bagay. It was the most detailed map of the Philippines yet made, and it is often called the mother of Philippine maps.

The chart shows the islands, their coasts and their harbors, along with the sea routes ships followed among them and out toward the open Pacific. Around the main map are small engraved scenes of the peoples of the islands and smaller maps of places of interest, so the chart is both a working map and a picture of a society.

Look closely

- Find Manila and Manila Bay on the island of Luzon. Why would this harbor make a good base for the galleon trade?
- Look for the dotted or drawn lines of sailing routes. Can you find the way out of the islands toward the east, through the strait between Luzon and Samar?
- Look at the scenes in the side panels. How many different kinds of people can you find?
- Find a compass rose and a scale. What would a pilot use each for?

Talk about it

1. Why would the Spanish government and the galleon pilots want an accurate map of the Philippine coasts?
2. The map was made by a Spanish priest and engraved by a Filipino craftsman. What does that suggest about Manila in 1734?
3. What would you add to this map to show the galleon trade across the Pacific?

PROJECT: THE WHEEL OF THE PACIFIC: GLOBE AND STRING

You will measure the galleon routes on a real globe with string, compare them with the shortest route, and build a model of the Pacific wind and current wheel. You will see for yourself why the shortest way across the Pacific was not the way the galleons sailed.

You will need

- A globe (a school or library globe works well)
- String or thin yarn, a ruler or tape measure, and small sticky notes
- A large shallow pan or tub of water, black pepper or small paper bits, and a straw or small fan
- Colored pencils and a blank outline map of the Pacific

Steps

1. Find the globe's scale: measure the length of string that spans the equator from 0° to 90° E (a quarter of the earth, about 10,000 km or 6,200 miles). Divide to get km per cm of string.
2. Stretch a string tightly across the globe from Acapulco (about 17° N, 100° W) to Manila (about 15° N, 121° E). This tight string is the great circle. Measure it and convert to km.
3. Now lay string along the westward galleon route: west from Acapulco along about 13°–15° N to Guam (about 13° N, 145° E), then to Manila. Measure and convert.
4. Lay string along the return route: from Manila north past the east of Taiwan and Japan to about 38° N, east across the ocean along about 38°–40° N to the California coast near 40° N, then south along the coast to Acapulco. Measure and convert.
5. Record the three distances in a table. Mark on sticky notes where the shortest route would have met headwinds.
6. In the pan, blow from the “east” across the bottom (trade winds) and from the “west” across the top (westerlies). Watch the pepper make a wheel. Mark the galleon routes on your outline map with arrows showing the winds and currents that helped each.
7. Write a paragraph explaining why the galleons did not follow the great circle.

Tips

- Keep the string tight and pressed to the globe; a loose string gives a longer distance than the real great circle.
- Your route measurements will be rough, within a few hundred kilometers. That is fine for comparing routes.

Check your work

- I measured and converted all three routes and recorded them in a table.
- My map shows both galleon routes with the winds and currents labeled.
- I can explain why the shortest route was not the fastest.

MAP NOTEBOOK

1. Draw the North Pacific wheel: four arrows for the trade winds, the Kuroshio, the westerlies and the California Current, and the two galleon routes.
2. Draw a piece of eight (both sides, from a picture) and label its weight and silver content.
3. Make a two-column cargo list: “Westward from Acapulco” (silver coins, bars, some cochineal and passengers and officials) and “Eastward from Manila” (silk, porcelain, lacquerware, spices, cotton cloth).

From history. On June 20, 1743, off Cape Espíritu Santo in the Philippines, the British commodore George Anson, near the end of a voyage around the world in HMS *Centurion*, captured the Manila galleon *Nuestra Señora de Covadonga*, inbound from Acapulco. She carried about 1.3 million pieces of eight. Anson had lost most of his men to scurvy on the way, but the treasure, paraded through London in wagons the next year, made him rich and famous. Of all the galleons in 250 years, only a handful were ever captured by enemies; storms, reefs and typhoons took far more.

WORKED EXAMPLES

Example 1. Acapulco is at 16.85° N, 99.9° W and Manila at 14.6° N, 121.0° E. (a) Find the great-circle distance using $\cos c = \sin \phi_1 \sin \phi_2 + \cos \phi_1 \cos \phi_2 \cos \Delta\lambda$, with 1° of arc = 111.2 km. (b) Find the distance sailing west along the parallel of 15° N for the same change in longitude. Which is shorter, and why did the galleons sail the longer one?

(Use the map or drawing "The wheel of the North Pacific." shown earlier in this lesson.)

1. Difference in longitude: going west across the Pacific from 99.9° W to 121.0° E is $360^\circ - 99.9^\circ - 121.0^\circ = 139.1^\circ$.
2. $\sin 16.85^\circ \times \sin 14.6^\circ = 0.2899 \times 0.2521 = 0.0731$. $\cos 16.85^\circ \times \cos 14.6^\circ = 0.9571 \times 0.9677 = 0.9262$. $\cos 139.1^\circ = -0.7559$.
3. $\cos c = 0.0731 + 0.9262 \times (-0.7559) = 0.0731 - 0.7001 = -0.6270$, so $c \approx 128.8^\circ$.
4. (a) Great circle: $128.8 \times 111.2 \approx 14,320$ km (about 8,900 miles).
5. (b) Along 15° N: 1° of longitude = $111.2 \times \cos 15^\circ \approx 107.4$ km, so $139.1 \times 107.4 \approx 14,940$ km (about 9,280 miles).
6. The great circle is about 600 km shorter, but it bulges far north, to nearly 39° N, out of the trade winds and into the belt of westerlies, which blow against a westbound ship. Along 13° - 15° N the trade winds blow steadily from behind, so the longer route was much faster and safer.

Answer: Great circle about 14,300 km (8,900 miles); along 15° N about 14,900 km (9,300 miles). The parallel route is about 4% longer but has steady following winds the whole way.

Example 2. Urdaneta's San Pedro left Cebu on June 1, 1565 and reached Acapulco on October 8, 1565. Count the days. If his track was about 15,000 km (9,300 miles), find his average speed in km per day and in knots. Compare with a westward galleon covering about 14,900 km in 90 days.

1. Days: June 2-30 is 29 days, plus July 31, August 31, September 30 and October 1-8 (8 days): $29 + 31 + 31 + 30 + 8 = 129$ days.
2. Average: $15,000 \div 129 \approx 116$ km a day; $116 \div 24 \approx 4.8$ km/h; $4.8 \div 1.852 \approx 2.6$ knots.
3. Westward: $14,900 \div 90 \approx 166$ km a day; $166 \div 24 \approx 6.9$ km/h ≈ 3.7 knots.
4. The return was slower on average because the ship had to climb north out of the trade winds, cross a zone of variable winds, and fight storms on the long northern crossing.

Answer: 129 days; about 116 km a day (about 2.6 knots), compared with about 166 km a day (3.7 knots) on the westward run.

Example 3. The 1593 rules allowed the galleons to bring back silver worth 500,000 pesos a year to Manila. A peso of eight reales weighed about 27.07 g and was about 93% pure silver. Find the total weight of the coins and of the pure silver in tonnes. Smugglers often carried several times the legal amount; what would three times the limit weigh?

1. Weight of coins: $500,000 \times 27.07 \text{ g} = 13,535,000 \text{ g} = 13,535 \text{ kg} \approx 13.5 \text{ tonnes}$ (about 14.9 short tons).
2. Pure silver: $13.5 \text{ t} \times 0.93 \approx 12.6 \text{ tonnes}$.
3. Three times the limit: $3 \times 13.5 \text{ t} \approx 40.6 \text{ tonnes}$ of coin.
4. Check: one tonne is 1,000,000 g, and $27 \text{ g} \times 500,000 = 13.5 \text{ million g}$, which agrees.

Answer: About 13.5 tonnes of coin containing about 12.6 tonnes of pure silver; three times the limit would be about 40.6 tonnes.

PRACTICE

1. **EASY** Give the years of the Manila galleon trade and name its two end ports.
2. **EASY** Who found the eastward return route across the Pacific, and in what year?
3. **EASY** What did the galleons carry westward to Manila, and what did they carry eastward to Acapulco?
4. **EASY** Name the warm current that flows north along Taiwan and Japan.
5. **MEDIUM** Use the diagram. Which winds carried galleons from Acapulco to Manila, and which carried them back?
(Use the map or drawing “The wheel of the North Pacific.” shown earlier in this lesson.)
6. **MEDIUM** Why did China want silver in the late 1500s?
7. **MEDIUM** A westward galleon sails about 14,900 km in 90 days. A modern container ship crosses the same distance at 18 knots. How many days does the container ship need?
8. **MEDIUM** One degree of longitude at the equator is about 111.2 km. How long is one degree of longitude at 40° N, where the galleons crossed eastward?
9. **HARD** Model arbitrage: suppose in Spain 1 oz of gold buys 12 oz of silver, and in China 1 oz of gold buys only 6 oz of silver. A merchant takes 1,200 oz of silver to China, buys gold, and brings the gold back to Spain. How much silver can he get for it? What is his gain before costs?
10. **HARD** Admiral George Anson captured the galleon *Covadonga* in 1743 with about 1.3 million pieces of eight on board. At 27.07 g each, what did the coins weigh in tonnes and in short tons (1 short ton = 907 kg)?
11. **HARD** A galleon leaves Acapulco on March 1 and reaches Guam (about 12,300 km, or 7,600 miles, along its route) after 60 days. On what date does it arrive, and what is its average speed in knots?
12. **CHALLENGE** In a paragraph, explain why historians say worldwide trade was “born” around 1571, and give a fair account of who gained and who suffered in the galleon trade.

COMMON MISTAKES

- Assuming ships cross an ocean along the shortest line. Sailing ships followed the winds and currents, so the real routes bent far from the great circle.
- Thinking the galleons carried silver to Spain. The Manila galleons carried American silver west to Asia; Spain's Atlantic treasure fleets carried silver east to Seville.
- Confusing the gyre's directions. In the North Pacific the wheel turns clockwise: west in the tropics, east in the middle latitudes.

Make it a game · Galleon Year. Set up a calendar track of 12 months on the floor with paper squares. One player is the Acapulco galleon, the other the Manila galleon. Each turn, draw a card: "fair wind" (move 2 months forward), "calm" (move 1), "storm" (lose a cargo token), "scurvy" (lose a crew token) or "typhoon" (only in July–October: roll a die, and on a 1 lose the ship). The Acapulco galleon must leave by March and the Manila galleon by July or wait a year. First to complete a round trip with cargo and crew wins. Discuss: which voyage was more dangerous, and why?

Scripture. "For the king had at sea a navy of Tharshish with the navy of Hiram: once in three years came the navy of Tharshish, bringing gold, and silver, ivory, and apes, and peacocks." (1 Kings 10:22, KJV)

Solomon's ships made long voyages that returned only once in three years, laden with treasure. The Manila galleons, like Solomon's navy, show how long-distance sea trade joins distant lands, and how patiently merchants must wait upon the seasons God has set.

Practice answers

1. 1565–1815; Manila in the Philippines and Acapulco in Mexico.
2. Andrés de Urdaneta, an Augustinian friar and navigator, in 1565.
3. Westward: mostly silver (coins and bars) from Mexico and Peru. Eastward: Chinese silk and porcelain, lacquerware, spices, cotton cloth and other Asian goods.
4. The Kuroshio (Japan Current).
5. The northeast trade winds carried them west in the tropics; the westerlies carried them east in the middle latitudes, near 40° N.
6. The Ming government began requiring many taxes to be paid in silver, and silver was worth more in China (measured against gold and goods) than in Europe or the Americas, so merchants could buy Chinese goods cheaply with it.
7. 18 knots = 33.3 km/h = about 800 km a day. $14,900 \div 800 \approx 18.6$, about 19 days.
8. $111.2 \times \cos 40^\circ \approx 111.2 \times 0.766 \approx 85.2$ km (about 53 miles).
9. In China: $1,200 \div 6 = 200$ oz of gold. In Spain: $200 \times 12 = 2,400$ oz of silver. He doubles his silver: a gain of 1,200 oz, or 100%, before costs and risks. (These are rounded model ratios; real ratios varied over time.)
10. $1,300,000 \times 27.07 \text{ g} \approx 35,191,000 \text{ g} \approx 35.2$ tonnes. $35,191 \text{ kg} \div 907 \approx 38.8$ short tons.
11. March 1 + 60 days: 30 days to March 31, 30 more to April 30, so it arrives April 30. Speed: $12,300 \div 60 = 205$ km a day ≈ 8.5 km/h ≈ 4.6 knots.

12. Model answer: With the founding of Manila in 1571, silver from the mines of Spanish America began to flow regularly across the Pacific to China, linking the Americas, Asia and (through Mexico and Spain) Europe in one trading system for the first time. Chinese merchants and producers, Spanish officials and merchants in Manila and Mexico, and the Spanish crown gained, and Chinese silks and porcelain became common in Mexico and beyond. But the trade rested on hard labor: Native and other workers in the silver mines, Filipino laborers conscripted to cut timber and build the galleons, and sailors who died by the hundreds of scurvy and storms on the return. The Chinese of Manila were both essential and feared, and suffered massacres such as that of 1603. A fair account names both the achievement of joining the world and the cost in human lives.

UNIT 2 TEST

Answer each question. Show your work for every calculation, give units, and give both metric and U.S. customary units where asked. Use complete sentences for explanations. Use 1 knot = 1.852 km/h, 1 mile = 1.609 km, and 1° of latitude = 111 km. The test is worth 100 points.

1. (7 pts) Explain why the wind over the Arabian Sea blows from the southwest in summer and from the northeast in winter. Give the approximate months of each monsoon.
2. (7 pts) A Roman ship crosses about 3,600 km (2,240 miles) from Ocelis to Muziris in 40 days. Find its average speed in km per day and in knots. If the same ship sailed against the monsoon at one-quarter of that speed, how long would the crossing take?
3. (7 pts) A pilot measures the Pole Star (corrected) at 7 isba with his kamal. One isba is 1/224 of a circle. What is his latitude, and how many kilometers north or south does one isba represent?
4. (7 pts) Describe how an older dhow was built and rigged. Give one advantage of a sewn hull and explain why the lateen sail suited long monsoon runs better than frequent tacking.
5. (8 pts) Kilwa (about 9.0° S) lies about 1,350 km (840 miles) north of Sofala (about 20.2° S). Explain, using the monsoon, why Kilwa became the middleman for the gold of Sofala. What is a place like Kilwa called?
6. (7 pts) Give the date and significance of each: (a) Ibn Battuta at Kilwa; (b) Almeida takes Kilwa and sacks Mombasa; (c) the Omani capture of Fort Jesus; (d) the closing of the Zanzibar slave market.
7. (7 pts) Who was Zheng He? Give the dates of his voyages, the emperor who began them, and three purposes of the voyages.
8. (7 pts) The History of Ming gives the largest treasure ships as 44 zhang long. At 3.1 m per zhang, what is that in meters and feet? Many historians estimate about 65 m instead. How many times the length of the Santa María (18 m) is each figure? Give one piece of evidence on each side of the debate.
9. (6 pts) In which seasons did the Ming fleets leave China and return, and why? Give two reasons the court ended the voyages after 1433.
10. (7 pts) Where did cloves and nutmeg originally grow? Explain how this geography made a monopoly possible and how geography later helped end it.
11. (8 pts) A voyage has a 2-in-3 chance of returning, paying 3 times the stake. Investor A stakes 600 guilders on one voyage; investor B stakes 200 on each of three independent voyages. Find each investor's expected return and chance of losing everything, and explain what this shows about the VOC.
12. (7 pts) Describe the conquest of Banda in 1621 factually. Then give one real achievement of the VOC. Write as a historian judging by the standards of the time.
13. (8 pts) Explain how Urdaneta found the eastward route across the Pacific in 1565. Then compute: his ship left Cebu on June 1 and reached Acapulco on October 8. How many

days was that, and what was the average speed in knots if the track was about 15,000 km?

14. (7 pts) The legal limit of 1593 let the galleons bring 500,000 pesos of silver a year to Manila. At 27.07 g per peso, what did that weigh in tonnes? Why did China want so much silver?

UNIT PROJECT: THE INDIAN OCEAN TRADE WORLD: MAP AND MONSOON GAME

Make a large hand-drawn map of the Indian Ocean trade world from East Africa to China, with an inset of the Pacific galleon routes. Mark at least twelve ports (including Aden, Hormuz, Cambay, Calicut, Galle, Malacca, Mogadishu, Mombasa, Zanzibar, Kilwa, Sofala, Banda and Manila), draw the summer and winter monsoon winds in two colors, trace the routes of the dhows, Zheng He's fleets, the VOC's Brouwer route and the Manila galleons, and draw the chief goods of each region beside it. Use the map as the board for your finished monsoon-calendar sailing game.

Beside the map, include your game rules and month deck, a ship's log from one full game, and a one-page essay answering this question: *How did the seasons and the shape of the ocean decide where the great trading cities grew and who grew rich from the spice trade?* Name at least one real achievement and one real wrong from the unit.

- **Accuracy:** Ports, islands, straits and routes are placed correctly, the monsoon winds point the right way for each season, and the goods match their regions.
- **Game and records:** The game rules follow the real monsoon calendar, the month deck is correct, and the ship's log is complete and dated.
- **Explanation:** The essay uses geographic reasoning (seasons, distance, risk, choke points, scarcity) and gives an honest account of both achievements and wrongs.
- **Care:** The map and game are neat, colorful, clearly labeled and sturdy enough to play.

Answer key

1. Land heats and cools faster than water. In summer Asia becomes hot, air rises over it and pressure falls, so moist air flows in from the cooler ocean; the earth's rotation turns it into a southwest wind (about June–September). In winter Asia becomes cold, heavy air spreads outward from the interior, and the wind blows from the northeast toward the warmer ocean (about November–March).
2. $3,600 \div 40 = 90$ km a day; $90 \div 24 = 3.75$ km/h; $3.75 \div 1.852 \approx 2.0$ knots. At one-quarter speed (22.5 km a day) it would take $3,600 \div 22.5 = 160$ days.
3. $1 \text{ isba} = 360^\circ \div 224 \approx 1.607^\circ$. $7 \times 1.607^\circ \approx 11.25^\circ \text{ N}$ (the latitude of Calicut). One isba $\approx 1.607 \times 111 \approx 178$ km (about 111 miles).
4. Its hull planks (often Indian teak) were sewn together with coir cord from coconut husks and caulked with fiber and oil, and it carried one or two triangular lateen sails on long slanting yards. A sewn hull flexed in surf and could be beached and repaired with local materials. The lateen sail held a steady beam or quarter wind well, but changing tack meant swinging the heavy yard around the mast, so it suited weeks of steady monsoon wind.
5. Arabian and Indian ships could reach the Swahili ports and Kilwa on the northeast monsoon and return on the southwest, but the monsoon weakens to the south, so going on to Sofala

and back risked missing the wind home and losing a year. Kilwa's own ships carried gold and ivory from Sofala, and Kilwa sold them to the northern ships, taking a share of the trade. Kilwa was a break-of-bulk point (an entrepôt).

6. (a) 1331: his account describes Kilwa as one of the most beautiful and well-built towns, ruled by a generous sultan. (b) 1505: the Portuguese seize the coast to control the gold trade; Kilwa declines. (c) 1698: Oman becomes master of the coast after a siege begun in 1696. (d) 1873: under British pressure, Sultan Barghash closes the market where many thousands of enslaved Africans had been sold each year.
7. A Muslim-born court eunuch from Yunnan who served the Yongle Emperor and commanded the Ming treasure fleets on seven voyages, 1405–1433. Purposes (any three): to display the power and legitimacy of the Yongle Emperor; to bring foreign rulers into the tributary system and carry their envoys to China; to deliver gifts of silk and porcelain; to gather luxuries such as pepper, gems, incense and rare animals; to suppress pirates and secure the sea lanes.
8. $44 \times 3.1 = 136.4 \text{ m} \approx 448 \text{ ft}$; $136.4 \div 18 \approx 7.6$ times. $65 \div 18 \approx 3.6$ times. For very large ships: the official Ming history figure and an 11 m rudder post found in 1957 at the Nanjing shipyard site. Against the largest figure: doubts that a wooden ship of 136 m could sail well, and the fact that the history was compiled long afterward.
9. They sailed out in winter on the northeast monsoon and returned in summer on the southwest monsoon. Reasons (any two): the cost; the death of the Yongle Emperor; officials' hostility to the eunuch-led voyages and to foreign luxuries; the need to spend on defense against the Mongols, the Grand Canal and Beijing; the policy of the sea ban.
10. Cloves grew only on five small islands off Halmahera (Ternate, Tidore, Moti, Makian, Bacan); nutmeg and mace only in the tiny Banda Islands. Because the supply came from a few small islands, a power holding them with forts and ships could control it. The monopoly ended when seedlings were smuggled out (Poivre to Mauritius in 1770) and the trees were planted in other tropical lands such as Zanzibar, Ceylon, Penang and Grenada.
11. A: expected $(2/3) \times 1,800 = 1,200$ guilders; chance of ruin $1/3$. B: each voyage expected $(2/3) \times 600 = 400$, total 1,200 guilders; chance of ruin $(1/3)^3 = 1/27 \approx 3.7\%$. The expected return is the same but the risk of ruin is far lower when money is spread across voyages, which is what a joint-stock company like the VOC did for its many investors.
12. In 1621 Governor-General Jan Pieterszoon Coen invaded the Banda Islands to enforce a nutmeg monopoly. Bandanese were killed in fighting, executed (including dozens of leaders), starved or enslaved and deported; of about 15,000 people perhaps a thousand remained. The groves were made into plantations worked by enslaved people. Killing and enslaving the innocent was known to be wrong then, and some Dutch critics said so. Achievements (any one): raising large capital from many investors with tradable shares; spreading risk across voyages; the faster Brouwer route; a trading network from the Cape to Japan that lasted nearly two centuries.
13. Reasoning from the Atlantic, where ships returning from Africa swung northwest to find westerlies, he sailed north from the Philippines along the Kuroshio to near $39^\circ\text{--}40^\circ \text{ N}$, ran east with the westerlies, sighted California and followed the coast south. Days: $29 \text{ (June)} + 31 + 31 + 30 + 8 = 129$. Speed: $15,000 \div 129 \approx 116 \text{ km a day} \approx 4.8 \text{ km/h} \approx 2.6 \text{ knots}$.
14. $500,000 \times 27.07 \text{ g} = 13,535 \text{ kg} \approx 13.5 \text{ tonnes}$. The Ming government required many taxes to be paid in silver, and silver was worth more in China (against gold and goods) than in the Americas or Europe, so it bought Chinese silk and porcelain cheaply.

THE GREAT STRAITS

God made the seas with doors. Most of the world's goods travel by sea because a ship can carry more for less than any wagon, train or plane, but the sea lanes are not spread evenly across the oceans. They crowd together at a few narrow places where the land nearly closes: **straits** between continents and islands, and the two great **canals** people have cut where nature left no passage. Whoever lives beside these doors, keeps them safe or threatens them has a voice in the commerce of the whole world. "And hath made of one blood all nations of men for to dwell on all the face of the earth, and hath determined the times before appointed, and the bounds of their habitation" (Acts 17:26).

In this unit you will visit the great choke points one by one: Malacca, where Albuquerque came in 1511 for the door of the spice trade; Hormuz and the Bab-el-Mandeb, through which much of the world's oil flows; Gibraltar and the Bosphorus, the doors of two enclosed seas; Suez and Panama, the man-made straits; and Dover and the Danish Straits, the sea doors of northern Europe. For each you will ask four questions: **How much passes? How wide? How deep? What is the way around?** You will look at each from orbit in NASA's satellite images and build a choke-point risk table of the kind shipping companies, insurers and navies keep.

Current events are part of this subject, because straits are threatened and reopened in our own time. We present them factually and with dates, without taking sides in the quarrels of the nations, and we leave room for students to check the latest reports as of 2026. The course midterm, covering Units 1 to 3, follows this unit.

BEFORE YOU BEGIN

- Can read latitude and longitude and locate places on a world map
- Can convert between kilometers, miles and nautical miles and use $\text{speed} = \text{distance} \div \text{time}$
- Knows the Indian Ocean monsoon trade and the spice routes from Unit 2
- Can compute percents and simple ratios

MASTERY CHECKLIST

- I can locate the ten great choke points of world shipping on a blank map and name the waters each connects.
- I can give the approximate width, depth or size limit, traffic and main alternative of each strait and canal, with a year for figures that change.
- I can explain the history that made each strait important, from Malacca in 1511 to the Suez and Panama canals, and name both the achievements and the wrongs plainly.
- I can explain two-layer flow at Gibraltar and the Bosphorus and how Marsigli discovered it.

- I can calculate distance and time saved by a canal, the cost of a detour, and the water used by a lock.
- I can judge the risk at a choke point by weighing traffic, width, depth and alternatives, and describe current events neutrally.

OPTIONAL BOOKS AND RESOURCES

- **NASA Earth Observatory** (<https://earthobservatory.nasa.gov/>): Free. Satellite images and astronaut photographs of every strait in this unit, each with an explanatory caption. Search by the name of the strait or canal for the picture studies.
- **World Oil Transit Chokepoints, U.S. Energy Information Administration** (https://www.eia.gov/international/analysis/special-topics/World_Oil_Transit_Chokepoints): Free. The standard reference for oil flows through Malacca, Hormuz, the Bab-el-Mandeb, Suez, the Turkish Straits, the Danish Straits and Panama, with maps and dated figures. Useful for updating the risk table.
- **Panama Canal Authority** (<https://pancanal.com/>): Free. Official information on the locks, the expansion, transit numbers and water levels in Gatun Lake. Check here for the current draft and transit limits.

3.1 MALACCA: THE BUSIEST STRAIT IN THE WORLD

OBJECTIVES

- Locate the Strait of Malacca and the Singapore Strait, describe their length, width and depth, and explain why so much of the trade between the Indian Ocean and East Asia must pass through them.
- Tell how control of this strait passed from the Malacca Sultanate to the Portuguese (1511), the Dutch (1641) and the British, and why Raffles founded Singapore at its southern door in 1819.
- Define choke point, traffic separation scheme and transit passage, and use traffic, oil-flow and detour figures to judge how much the world depends on Malacca and what the alternatives cost.

Warm-up. Pour dry rice into a funnel set over a bowl and time how long it takes to empty. Now pour the same rice into a wide bowl tipped over a second bowl. The funnel is slower because everything must squeeze through one narrow neck. Next, put a single dried bean in the neck of the funnel and pour again. What happens to the flow? Write one sentence: what would a “funnel” look like on a map of the sea?

Watch. *Global Chokepoints Explained* (Ticket To Know, 6:10).

<https://www.youtube.com/watch?v=nPfofGLVe7o>

With the big idea: watch this to see why the Strait of Malacca is one of a few narrow 'chokepoints' that much of the world's shipping has to pass through.

Note: Captions were not available to check; preview it first. Malacca is only one part of this video, which also covers Bab el-Mandeb, Panama, Gibraltar and Hormuz. It does not cover the 1511 Portuguese capture of Malacca or the founding by Parameswara.

Backup video. *Starry Night Journey Through the Strait of MALACCA - Time-lapse [4K, 60fps]* (SeaTube, 2:38). <https://www.youtube.com/watch?v=gXpRXF2WexU>

With On the map: watch this time-lapse filmed from a giant container ship and count how many ships share the lanes as it sails from near Singapore up the Strait of Malacca at night.

KEY TERMS

strait

A narrow passage of water joining two larger bodies of water, such as two seas or a sea and an ocean.

choke point

A narrow place on a trade route where traffic is crowded together, so that a blockage, accident or attack there would hold up a large share of the world's trade.

traffic separation scheme

A set of one-way sea lanes, marked on charts and approved by the International Maritime Organization, that keeps ships going in opposite directions apart in crowded waters.

transit passage

The right, set out in the 1982 United Nations Convention on the Law of the Sea, of ships and aircraft of all nations to pass continuously and quickly through a strait used for international navigation, even when the strait lies inside the territorial sea of the coastal states.

entrepôt

A trading port where goods from many places are landed, stored, bought and sold and shipped on again. Malacca and later Singapore were great entrepôts.

draft

The depth of a ship's hull below the waterline. A strait's shallowest point limits the draft of the ships that can use it.

CORE IDEAS

The story. In August 1511 a Portuguese fleet under Afonso de Albuquerque stormed the city of Malacca on the west coast of the Malay Peninsula. Malacca was then one of the richest ports in Asia. A prince named Parameswara had founded it around 1400, and its sultans had made it the place where ships from India, Arabia, China and the Spice Islands met to trade. Albuquerque had sailed there for one reason: he wanted the door through which the spices of the East reached the West. A Portuguese apothecary named Tomé Pires, who lived in Malacca soon after the conquest, wrote in his *Suma Oriental* that whoever is lord of Malacca has his hand on the throat of Venice. He meant that the spice trade which had made Venice rich would now be squeezed at Malacca. The conquest was violent, as most conquests of that age were, and the sultan's court fled south to found the Sultanate of Johor. The Portuguese held the city for 130 years until the Dutch, allied with Johor, took it after a long siege in January 1641.

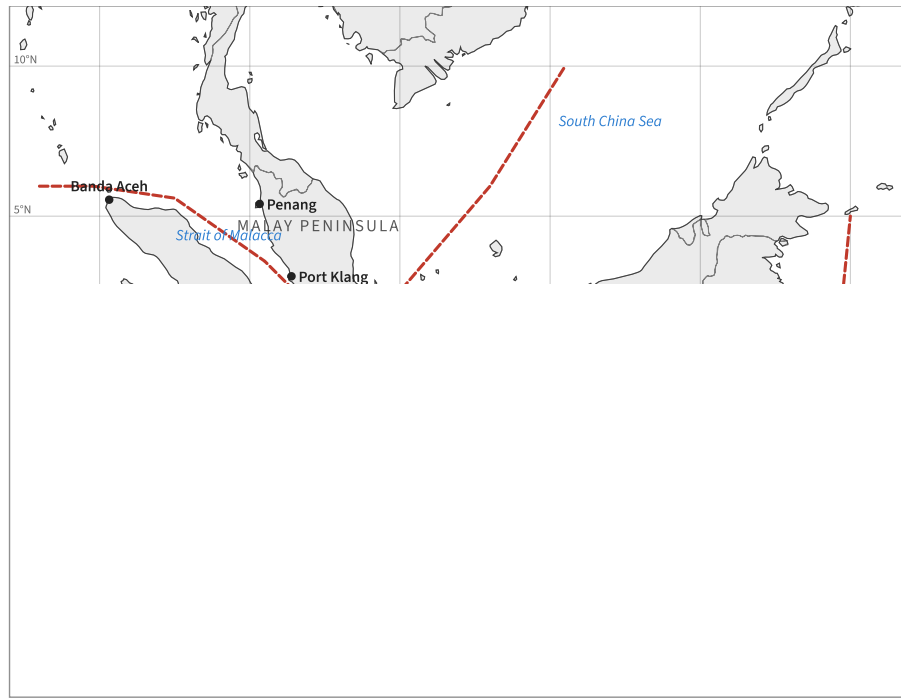
How it worked. The **Strait of Malacca** runs about 800 km (500 miles) between the Malay Peninsula and the island of Sumatra. It is about 250 km (155 miles) wide at its northern mouth but narrows to about 65 km (40 miles) toward the south, and at its southern end it joins the **Singapore Strait**, where the deep-water route through the Phillips Channel is only about 2.8 km (1.7 miles) wide. The sea floor is part of a broad, shallow shelf, and in places the channel is only about 25 m (82 feet) deep, so the largest ships that can pass, called *Malaccamax* ships, draw about 20.5 m (67 feet). For sailing ships the strait had a second gift: it lies where the two monsoons of the Indian Ocean and the South China Sea meet. A merchant from Gujarat rode the southwest monsoon east, waited in Malacca for the wind to change, and sailed home on the northeast monsoon. Malacca grew rich by being the place where ships waited, and the waiting made it an **entrepôt**.

The big idea. A **choke point** is a narrow place that much of the world's traffic must pass. Malacca is the shortest sea route between the Indian Ocean and the Pacific, so it carries the oil of the Persian Gulf to China, Japan and Korea and carries the manufactured goods of East Asia back toward India, Africa and Europe. Malaysian port authorities count more than

80,000 ship passages a year, and the U.S. Energy Information Administration (EIA) estimated that about 23 million barrels of oil and oil products a day passed through it in 2023, more than through any other strait. When British agent Stamford Raffles saw the importance of the southern door, he signed a treaty with the local rulers in February 1819 and founded Singapore there; the Anglo-Dutch Treaty of 1824 then gave Britain Malacca as well. Today Singapore, independent since 1965, is one of the busiest ports in the world because it sits beside this funnel. Under the 1982 Law of the Sea Convention, ships of all nations have the right of **transit passage**, and Malaysia, Indonesia and Singapore manage a **traffic separation scheme** that keeps the one-way lanes apart.

Risks and answers. A narrow, crowded strait has dangers: collisions, groundings, and piracy among the many islands. After a rise in pirate attacks around the year 2000, the three coastal states began coordinated naval patrols in 2004 and shared air patrols the next year, and attacks on ships underway fell sharply. Planners also ask what would happen if the strait were blocked. The main alternatives lie through Indonesia: the **Sunda Strait** between Sumatra and Java, which is narrow, shallow in places and swept by strong currents, and the **Lombok Strait** between Bali and Lombok, which is more than 150 m deep and is already used by the very largest tankers that cannot fit through Malacca. Either detour adds distance and days at sea. China, which receives much of its imported oil through Malacca, has also built oil and gas pipelines across Myanmar to Yunnan; some Chinese writers have called this dependence the “Malacca dilemma.” A canal across the narrow Kra Isthmus of Thailand has been proposed for centuries but, as of 2026, has never been built.

On the map. Find the strait between about 6°N, 95°E at its northwest entrance and Singapore at about 1.3°N, 103.8°E (see the map below). Trace a tanker’s path from the Persian Gulf: across the Arabian Sea, south of Sri Lanka, past the northern tip of Sumatra near Banda Aceh, down the long strait past Penang, Port Klang and Malacca, around Singapore and out into the South China Sea. Then trace the two detours, south through the Sunda Strait or far east through the Lombok Strait and the Makassar Strait. Finally, on the world map of choke points, notice that Malacca is only one of a handful of narrow doors through which most of the world’s sea trade must pass. In the rest of this unit you will visit the others one by one, and for each you will ask the same four questions: how much passes, how wide, how deep, and what is the way around?



The Strait of Malacca and its two main alternatives. The direct route (red) runs between Sumatra and the Malay Peninsula; the detours pass through the Sunda Strait or the Lombok Strait.



The world's main sea-lane choke points, the subject of this unit. The Cape of Good Hope is not a strait but is the great "way around" when Suez or Bab-el-Mandeb is closed.

PICTURE STUDY



The Strait of Malacca and Singapore from orbit, NASA Earth Observatory (MODIS instrument on NASA's Aqua satellite), 22 August 2025 · True-color satellite image · NASA Earth Observatory, earthobservatory.nasa.gov

NASA's Terra and Aqua satellites carry an instrument called MODIS that photographs the whole earth every one or two days. The Earth Observatory website publishes the clearest of these pictures with a caption that explains what you are seeing. Search the site for "Strait of Malacca" or "Singapore." Because the region is so often cloudy, a clear image is a prize; note the date, the satellite and the scale in your notebook as a historian would note the maker and date of a painting.

A satellite image is not a map. No one has chosen what to label or leave out; it shows the land and water as light reflected them on a single day. That makes it a primary source for the geographer, and it lets you check the maps in your atlas against the real shape of the earth.

Look closely

- Find the Malay Peninsula and Sumatra. Which coast looks straighter, and which has more river mouths and mudflats?
- Look for the brown or tan plumes where rivers carry silt into the strait. What do they tell you about how shallow this sea may be?
- Find Singapore at the southern tip. Can you see the gray of the city or the many small islands of the Riau group to its south?
- If the image is sharp enough, look for the thin white lines of ship wakes. Which way do they run?

Talk about it

1. Why might a satellite image be more trustworthy than a hand-drawn map for judging the width of a strait? What can a good map show that a satellite image cannot?
2. From the picture alone, why do you think a city grew up at the southern end of the strait rather than in the middle?

PROJECT: THE CHOKE-POINT RISK TABLE, PART 1: SETTING UP AND MALACCA

Over this unit you will build one large table that a shipping company, an insurer or a navy might keep: for each great strait, how much traffic passes, how wide and deep it is, what could close it, and what the way around would cost. Today you set up the table and fill in the first row for Malacca. You will add rows in every lesson and turn the finished table, with a world map, into your unit portfolio.

You will need

- A large sheet of poster paper or two sheets of graph paper taped side by side (or a spreadsheet)
- Ruler, pencil, fine black pen and three colored pencils (green, yellow, red)
- An atlas or printed world map, and access to the EIA “World Oil Transit Chokepoints” page if available
- Calculator

Steps

1. Rule a table with nine columns: Choke point; Connects; Narrowest width (km and miles); Limiting depth or ship size; Traffic (ships per year, with year); Oil or key cargo (with year); Main risks; Alternative route and extra distance or time; Risk rating.
2. Rule ten rows and write the names down the first column: Malacca, Hormuz, Bab-el-Mandeb, Gibraltar, Bosphorus and Dardanelles, Suez Canal, Panama Canal, Dover Strait, Danish Straits, and one extra row for the Cape of Good Hope as the great “way around.”
3. Fill in the Malacca row from this lesson: Indian Ocean to South China Sea; about 2.8 km (1.7 miles) at the Phillips Channel; about 25 m (82 ft), so ships to about 20.5 m draft; more than 80,000 ships a year; about 23 million barrels of oil a day (2023).
4. Under Main risks, list at least three (for example: collision, grounding, piracy, war, a blocked channel).
5. Under Alternatives, write Sunda Strait (narrow, shallow in places, strong currents) and Lombok-Makassar (deep, longer), and a third: pipelines across Myanmar.
6. Give Malacca a risk rating: green (many good alternatives), yellow (alternatives exist but are costly), or red (almost no alternative). Write one sentence defending your color.
7. Keep your table safe; you will add to it in every lesson of the unit.

Tips

- Always write the year beside a traffic or oil figure. Trade numbers change every year, and an undated number is half a fact.

- A risk rating is a judgment, not a measurement. Two careful students may disagree; what matters is that you give reasons from the evidence.

Check your work

- My table has all nine columns and ten rows labeled.
- The Malacca row is complete, with units and years.
- I can defend my risk color for Malacca in one or two sentences.

MAP NOTEBOOK

1. Draw a freehand map of the Strait of Malacca. Label Sumatra, the Malay Peninsula, Penang, Port Klang, Malacca, Singapore, the Sunda Strait and the Lombok Strait, and draw arrows for the southwest and northeast monsoons.
2. Make a timeline strip: about 1400 Malacca founded; 1511 Portuguese conquest; 1641 Dutch conquest; 1819 Singapore founded; 1824 Anglo-Dutch Treaty; 1965 Singapore independent; 2004 coordinated patrols begin.
3. Copy Tomé Pires's idea in your own words and write two sentences on whether it is still true of Malacca today, and whose "throat" it might be now.

From history. Long before Malacca, the Buddhist kingdom of Srivijaya, centered near Palembang on Sumatra, grew rich from about the 600s by controlling the same sea route. The Chinese monk Yijing stopped there in 671 on his way to India and stayed to study Sanskrit, and he wrote that more than a thousand monks lived in its capital. Srivijaya's power rested on the same geography as Malacca's and Singapore's: whoever keeps the strait safe and the port well run draws the trade of two oceans.

WORKED EXAMPLES

Example 1. Malaysian authorities count more than 80,000 ship passages a year through the Strait of Malacca. Using 80,000 as a round figure, find the average number of ships per day and per hour, and the average time between ships passing one point.

1. Ships per day: $80,000 \div 365 \approx 219$ ships a day.
2. Ships per hour: $219 \div 24 \approx 9.1$ ships an hour.
3. Time between ships: $60 \text{ min} \div 9.1 \approx 6.6$ minutes.
4. Since ships travel in both directions, a watcher on shore would see, on average, one ship every 6 or 7 minutes, day and night, all year.

Answer: About 219 ships a day, about 9 an hour, or one ship roughly every 6.6 minutes.

Example 2. The EIA estimated that about 23 million barrels of oil and oil products a day passed through Malacca in 2023. A barrel is 159 liters (42 U.S. gallons). A very large crude carrier (VLCC) carries about 2 million barrels. (a) How many liters a day is this? (b) How many full VLCC loads a day would that equal?

1. (a) $23,000,000 \times 159 \text{ L} = 3,657,000,000 \text{ L}$, about 3.7 billion liters (about 966 million gallons, since $23,000,000 \times 42 = 966,000,000$).
2. (b) $23,000,000 \div 2,000,000 = 11.5$ VLCC loads.
3. In fact much of the oil moves in smaller tankers too, so the number of tankers is higher, but the comparison shows the scale: the equal of a dozen supertanker loads every day.

Answer: (a) About 3.7 billion liters (about 966 million gallons) a day. (b) About 11.5 VLCC loads a day.

Example 3. A tanker sailing from the Persian Gulf to Japan must avoid Malacca and go through the Lombok Strait. Planners' estimates of the extra distance vary with the ports chosen; use an extra 1,600 km (about 860 nautical miles). The tanker steams at 14 knots (1 knot = 1 nautical mile per hour = 1.852 km/h). It costs about \$40,000 a day to run. (a) How many extra days at sea? (b) What extra cost per voyage?

1. Convert the speed: $14 \text{ knots} \times 1.852 = 25.9 \text{ km/h}$.
2. Extra hours: $1,600 \div 25.9 \approx 61.8$ hours. (Check in nautical miles: $860 \div 14 \approx 61.4$ hours.)
3. Extra days: $61.8 \div 24 \approx 2.6$ days.
4. Extra cost: $2.6 \times \$40,000 \approx \$104,000$ per voyage, before extra fuel is counted separately.

Answer: About 2.6 extra days and roughly \$100,000 extra per voyage at these assumptions. Small for one ship, but enormous when multiplied by hundreds of voyages a week.

PRACTICE

1. **EASY** Name the two land masses on either side of the Strait of Malacca and the city at its southern end.
2. **EASY** Define choke point in your own words and name one reason Malacca is one.
3. **EASY** Convert the width of the Phillips Channel, 2.8 km, to miles (1 mile = 1.609 km) and to nautical miles (1 nautical mile = 1.852 km).
4. **EASY** Put in order: the Dutch take Malacca; Raffles founds Singapore; Parameswara founds Malacca; Albuquerque takes Malacca.

5. **MEDIUM** Under the Law of the Sea, a country's territorial sea reaches 12 nautical miles from its coast. If a strait is 1.5 nautical miles wide, is any part of it outside territorial waters? Why do ships still have the right to pass?
6. **MEDIUM** Explain how the monsoon winds helped make Malacca an entrepôt in the age of sail.
7. **MEDIUM** A Malaccamax ship has a draft of about 20.5 m. Convert this to feet (1 m = 3.28 ft). Why can't a deeper ship use the strait?
8. **MEDIUM** Use the map *hb-malacca-map*. If Malacca were closed, name the two straits through Indonesia a ship could use instead, and give one drawback of each.
(Use the map or drawing "Use this map for problem 8." shown earlier in this lesson.)
9. **MEDIUM** At 12 knots, how long does a ship take to sail the 800-km length of the Strait of Malacca? Give the answer in hours.
10. **HARD** If the oil flow through Malacca is 23 million barrels a day and a detour forced 30 percent of it to take a route 2.6 days longer, how many extra barrel-days of oil would be "at sea" each day? What does that tied-up oil mean for buyers?
11. **HARD** Explain in a short paragraph why Raffles chose the southern end of the strait for Singapore rather than a point in the middle of it.
12. **CHALLENGE** Weigh the idea of a canal across the Kra Isthmus of Thailand. Give two arguments for it and two against it, using the geography of this lesson.

COMMON MISTAKES

- Thinking the Strait of Malacca is narrow along its whole length. It is wide in the north; the true bottleneck is at the southern end in the Singapore Strait.
- Forgetting that depth matters as much as width. A strait can be wide enough for a ship but too shallow for it, which is why the largest tankers go through Lombok.
- Quoting traffic or oil figures without a year. The numbers rise and fall with trade, so always say when a figure was measured.

Make it a game • Funnel Race. Mark a long, narrow "strait" on the floor with two lines of tape about 30 cm (1 foot) apart, opening into wide "seas" at each end. Each player pushes toy cars or paper boats from one sea to the other in one minute. Round 1: anyone may go any way. Round 2: add a traffic separation scheme, one lane each way. Round 3: drop a "wreck" (a book) in one lane and see what happens. Count how many boats get through each round, and discuss which rules moved the most traffic safely.

Scripture. "They that go down to the sea in ships, that do business in great waters; These see the works of the LORD, and his wonders in the deep." (Psalm 107:23-24, KJV)

The psalmist knew that sea trade is real business, done in "great waters," and that the sailor sees God's works there. The shape of the seas and straits is part of the order God gave the earth, and the merchants who learn it are reading His handiwork.

Practice answers

1. The Malay Peninsula (Malaysia) and the island of Sumatra (Indonesia); Singapore lies at the southern end.
2. A narrow place on a trade route where much traffic is crowded together, so that closing it would disrupt a large share of trade. Malacca is the shortest sea route between the Indian Ocean and the Pacific, so a great share of Asia's oil and goods must pass through it.
3. $2.8 \div 1.609 \approx 1.7$ miles; $2.8 \div 1.852 \approx 1.5$ nautical miles.
4. Parameswara founds Malacca (about 1400); Albuquerque takes Malacca (1511); the Dutch take Malacca (1641); Raffles founds Singapore (1819).
5. No. Each shore claims 12 nautical miles, far more than the 1.5-mile width, so the whole strait is territorial sea. Ships may still pass because the 1982 Convention gives all ships the right of transit passage through straits used for international navigation.
6. Malacca lay where the monsoon systems of the Indian Ocean and the South China Sea met. Ships from the west arrived on one monsoon and had to wait for the wind to change before sailing home, while ships from China and the islands arrived on the other. Merchants waiting for the winds met, stored and exchanged their goods at Malacca, so it became a great trading port.
7. $20.5 \times 3.28 \approx 67$ feet. The shallowest parts of the channel are only about 25 m (82 ft) deep; a deeper-drafted ship would have too little water under its keel to pass safely, so the very largest tankers use the deeper Lombok Strait.
8. The Sunda Strait (between Sumatra and Java): narrow, shallow in places and with strong currents, so unfit for the largest ships. The Lombok Strait (between Bali and Lombok): deep, but the route through it and the Makassar Strait is much longer, adding days and cost.
9. $12 \times 1.852 = 22.2$ km/h; $800 \div 22.2 \approx 36$ hours, about a day and a half.
10. Diverted oil: $0.30 \times 23 = 6.9$ million barrels a day. Each day's diverted oil spends 2.6 more days at sea: $6.9 \times 2.6 \approx 17.9$ million extra barrels in transit at any moment. Buyers must wait longer, more tankers are needed to carry the same daily flow, and freight rates and insurance costs rise.
11. At the southern end, every ship using the strait, whether bound for China, the Spice Islands or Java, had to pass close by. The island also had a sheltered harbor and lay at the meeting of the Malacca and Singapore straits and the routes to the South China Sea and the Java Sea. A port in the middle of the strait would be passed by only the through traffic, while Singapore stood at a crossroads where several routes met.
12. For: it would shorten voyages between the Indian Ocean and the Gulf of Thailand and South China Sea; it would give a second route if Malacca were blocked, lowering choke-point risk; it could bring trade to Thailand. Against: the cost of digging through the isthmus would be enormous; ships would save only part of the distance and might still prefer Singapore's port services; it would create a new choke point of its own; it would divide Thailand's territory and raise security questions. Any two well-reasoned points on each side are acceptable.

3.2 HORMUZ AND BAB-EL-MANDEB: THE OIL STRAITS

OBJECTIVES

- Locate the Strait of Hormuz and the Bab-el-Mandeb, describe their width and setting, and explain why they matter so much to the world's supply of oil and liquefied natural gas.
- Describe, factually and in order, the main events that have threatened these straits: the Tanker War of 1984–1988 and the attacks on Red Sea shipping that began in late 2023.
- Calculate how much oil could bypass Hormuz by pipeline and how much longer a voyage becomes when ships avoid the Red Sea by sailing around the Cape of Good Hope.

Warm-up. Fill a sink or basin with water and pull the plug. All the water in the basin, from every corner, must leave through one small hole. Now imagine the basin is the Persian Gulf and the plughole is the Strait of Hormuz. Write down: what else could you do if the plug hole were blocked? (Hint: think about a straw or a hose over the edge.)

Watch. *The Oil Deal That Tied Britain to the Strait of Hormuz* (The Photographed Past, 3:59). <https://www.youtube.com/watch?v=jGNb90PkCZg>

With the big idea: watch this short archival film to see how Britain's switch from coal to oil in 1914 first made the Strait of Hormuz important to a great sea power.

Note: Captions were not available to check; preview it first. It comes from a small channel, so listen to make sure the narration is a real voice and not a computer-generated one. It covers 1908–1914 British oil history, not the 1987 Tanker War or Operation Earnest Will in the lesson's story.

Backup video. *Time-lapse (110x): Red Sea, Abu Ali Channel & Bab El Mandeb Strait [4K, 60fps]* (SeaTube, 3:29). <https://www.youtube.com/watch?v=IP6W9AOWbiY>

With On the map: watch this time-lapse to see a ship sail down the Red Sea and through the narrow Bab-el-Mandeb, and find the strait on your map as it goes.

KEY TERMS

barrel

The standard unit for measuring oil: 42 U.S. gallons (about 159 liters). Oil flows are given in barrels per day (b/d).

very large crude carrier (VLCC)

A supertanker that carries about 2 million barrels of crude oil, typically about 330 m (1,080 ft) long.

liquefied natural gas (LNG)

Natural gas cooled to about $-162\text{ }^{\circ}\text{C}$ ($-260\text{ }^{\circ}\text{F}$) so that it becomes a liquid taking up about 1/600 of its gas volume, and can be carried in special tankers.

bypass pipeline

A pipeline built to carry oil around a choke point, so that some of it can still reach the sea if the strait is closed.

convoy

A group of merchant ships sailing together under the protection of warships.

war-risk insurance

Extra insurance that shipowners must buy to send a ship into waters where it might be attacked. Its cost rises sharply when a strait becomes dangerous.

CORE IDEAS

The story. Early on the morning of 24 July 1987, a convoy of American warships was escorting two tankers north up the Persian Gulf toward Kuwait. Iraq and Iran had been at war since 1980, and since 1984 both sides had been attacking tankers in what came to be called the **Tanker War**; hundreds of merchant ships were hit. Kuwait had asked for protection, and the United States had allowed eleven Kuwaiti tankers to fly the American flag so its navy could guard them. The largest of the convoy, the supertanker *Bridgeton*, struck a mine near Farsi Island. The blast tore a hole in its hull, but its huge size and many separate tanks kept it afloat, and it steamed on to Kuwait with the small warships following in its wake for safety. The episode, part of an escort operation called Earnest Will, showed both how vulnerable the oil routes were and how hard it is to close them completely. The war at sea brought real tragedies on several sides: an Iraqi missile struck the frigate USS *Stark* in May 1987, killing 37 sailors, and in July 1988 the cruiser USS *Vincennes* mistook Iran Air Flight 655 for an attacking warplane and shot it down, killing all 290 people aboard. A ceasefire ended the war in August 1988.

How it worked. The **Strait of Hormuz** joins the Persian Gulf to the Gulf of Oman and the Arabian Sea. To the north lies Iran; to the south lies the Musandam Peninsula, a rocky, fjord-cut point that belongs to Oman. At its narrowest the strait is about 39 km (21 nautical miles, 24 miles) wide, but the deep-water shipping lanes are much narrower: an inbound and an outbound lane, each about 3 km (2 miles) wide, with a buffer zone between. The water is deep enough for the largest tankers. Every barrel of oil that leaves the ports of Kuwait, Iraq, Qatar, Bahrain and most of Saudi Arabia, the United Arab Emirates and Iran by sea must pass this way. The EIA estimated the flow at about 20 million barrels a day in 2023 and 2024, roughly one-fifth of the world's oil consumption, and about one-fifth of the world's trade in LNG, much of it from Qatar, also passes. History here is old: the island kingdom of Hormuz was a rich trading port in the Middle Ages, the Portuguese seized it in 1515, and in 1622 the Persian army of Shah Abbas, carried and supported by ships of the English East India Company, drove them out. The nearby port of Bandar Abbas still bears the shah's name.

The second strait. At the other end of the Arabian Peninsula, the **Bab-el-Mandeb** (Arabic for "Gate of Grief") joins the Red Sea to the Gulf of Aden and the Indian Ocean. Yemen lies on one side; Djibouti and Eritrea lie on the other. The strait is about 29 km (18 miles) wide, and the island of Perim splits it into a narrow eastern channel and a wider western one, where the shipping lanes run. Any ship bound between Asia and Europe by way of the Suez

Canal must pass it. In 2023 the EIA estimated that about 8.7 million barrels of oil a day passed the Bab-el-Mandeb, along with a large share of the container trade between Asia and Europe. In November 2023 the Houthi movement, which controls much of western Yemen, seized the car carrier *Galaxy Leader* and began attacking merchant ships with missiles and drones, saying it was acting over the war in Gaza. Ships were struck and several were sunk in 2024 and 2025. Many shipping lines sent their vessels the long way around Africa, and traffic through the strait and the Suez Canal fell by roughly half in 2024. As of 2026, students should check current shipping reports to see how far traffic has returned.

The big idea. A strait is a *risk* to trade when three things are true: much traffic depends on it, it is narrow enough to be threatened from the shore, and the alternatives are poor. For Hormuz the alternatives are few. Saudi Arabia's East-West pipeline can carry about 5 million barrels a day across the desert from the oil fields near Abqaiq to the Red Sea port of Yanbu, and the United Arab Emirates' pipeline from Habshan to Fujairah, opened in 2012, can carry about 1.5 million barrels a day to a port outside the strait. The EIA estimated that only about 2.6 million barrels a day of this capacity was unused and available in an emergency, a small fraction of the flow through the strait. For the Bab-el-Mandeb the alternative is long but real: the Cape of Good Hope. Prudent planning, a navy's escort, **war-risk insurance**, stored oil reserves in importing countries and spare pipeline capacity are the ways nations and companies prepare for a closing. Such a closing was long threatened, and in 2026 it happened. After the United States and Israel struck Iran on 28 February 2026, traffic through Hormuz fell from about 100 ships a day to a handful, and it stayed far below normal for months. As of 2026, students should check current shipping reports for the latest situation.

On the map. Using the map below, find Hormuz at about 26.6°N, 56.4°E and the Bab-el-Mandeb at about 12.6°N, 43.4°E. Trace the oil's two main paths: east from Hormuz across the Arabian Sea toward India, Malacca and East Asia; or southwest around Yemen, through the Bab-el-Mandeb, up the Red Sea and through the Suez Canal toward Europe. Trace the two bypass pipelines, and notice that Saudi Arabia's line ends on the Red Sea, so its oil escapes Hormuz but must still pass either the Suez Canal northward or the Bab-el-Mandeb southward. Geography does not let anyone escape all the choke points at once.



The two oil straits and the two main pipelines that bypass Hormuz. The Saudi line reaches the Red Sea, which itself is entered through the Bab-el-Mandeb or the Suez Canal.

PICTURE STUDY



The Strait of Hormuz and the Musandam Peninsula from orbit, NASA Earth Observatory (MODIS satellite image), 6 December 2018 · True-color satellite image · NASA Earth Observatory, earthobservatory.nasa.gov

The Musandam Peninsula, the tip of Oman that points north into the Strait of Hormuz, is one of the most striking sights from space: bare, folded mountains plunging into the sea, with long, narrow inlets that sailors call the fjords of Arabia. Search NASA Earth Observatory for

“Strait of Hormuz” or “Musandam.” Astronauts have photographed it many times because the dry air over Arabia is usually clear.

As you look, remember that the shipping lanes are invisible from orbit. What the picture shows is the physical frame that makes this water a choke point: a bend of mountains on one side, the coast and islands of Iran on the other, and one opening between two seas.

Look closely

- Find the Musandam Peninsula and the coast of Iran. Where is the gap between them narrowest?
- Look for the islands in the strait. How might islands help or hinder ships, and those who guard or threaten them?
- Compare the color of the water in the shallow Persian Gulf with the water of the Gulf of Oman. What might cause the difference?
- Look at the land. Do you see rivers, farms or forests? What does that tell you about the climate here?

Talk about it

1. Why does the shape of the land around Hormuz make it easier to threaten ships here than in the open Arabian Sea?
2. A satellite picture is taken on one day. What does it fail to show about the importance of this strait?

PROJECT: THE CHOKE-POINT RISK TABLE, PART 2: THE OIL STRAITS

Add the Hormuz and Bab-el-Mandeb rows to your risk table, then make a small model that shows why bypass pipelines matter but cannot replace the strait.

You will need

- Your risk table from Lesson 3.1
- A shallow baking pan, water, modeling clay, two drinking straws and a measuring cup
- Calculator and colored pencils

Steps

1. Fill in the Hormuz row: Persian Gulf to Gulf of Oman; about 39 km (24 miles), lanes about 3 km (2 miles) each way; deep enough for the largest tankers; about 20 million barrels of oil a day (2023–2024) and about one-fifth of world LNG trade.
2. Under Alternatives for Hormuz, write: Saudi East-West pipeline to Yanbu (about 5 million b/d) and UAE Habshan-Fujairah pipeline (about 1.5 million b/d); EIA estimate of unused capacity about 2.6 million b/d.
3. Fill in the Bab-el-Mandeb row: Red Sea to Gulf of Aden; about 29 km (18 miles); deep enough for any ship that can use the Suez Canal; about 8.7 million b/d of oil (2023);

risks: attacks from shore, piracy in the Gulf of Aden, war in Yemen; alternative: the Cape of Good Hope.

4. Build the model: shape a “gulf” of clay in one end of the pan with a narrow opening into the rest of the pan, and fill it with water to a marked line. Push two straws through the clay wall as “pipelines.”
5. Block the opening with a ball of clay. Tilt the pan gently and catch what flows out through the straws in the measuring cup for 30 seconds. Then unblock the opening and repeat.
6. Compare the two amounts and write the ratio. Then compare 2.6 million b/d of spare pipeline capacity with 20 million b/d through the strait, and color the two rows of your table with a risk rating.

Tips

- The model is a picture, not a measurement. The point is to see that the straws carry only a small part of what the open strait carries.
- Write “as of 2026, check current reports” beside the Bab-el-Mandeb traffic figure; it has changed a great deal since 2023.

Check your work

- Both rows are filled in with units and years.
- I can explain why bypass pipelines reduce but do not remove the risk at Hormuz.
- I can name the long way around for ships that avoid the Bab-el-Mandeb.

MAP NOTEBOOK

1. Draw a map of the Arabian Peninsula and label the Persian Gulf, the Strait of Hormuz, the Musandam Peninsula, the Gulf of Oman, the Red Sea, the Bab-el-Mandeb, the Gulf of Aden, Yanbu, Fujairah and Djibouti.
2. Make a timeline: 1515 Portuguese seize Hormuz; 1622 Persian and English force takes it; 1980 Iran-Iraq War begins; 1984–1988 Tanker War; July 1987 *Bridgeton* strikes a mine; 2012 Habshan–Fujairah pipeline opens; November 2023 attacks on Red Sea shipping begin.
3. Draw a bar graph comparing oil flows (2023): Malacca about 23 million b/d, Hormuz about 20, Bab-el-Mandeb about 8.7.

From history. In 1869, the year the Suez Canal opened, the Bab-el-Mandeb suddenly became one of the world’s main sea roads. Britain had already taken Aden, on the Yemeni coast just east of the strait, in 1839, and it became a coaling station where steamships bound for India refueled. France established a foothold on the opposite shore in the 1860s, which grew into French Somaliland and is today the independent Republic of Djibouti (1977). Then as now, ownership of the shores of a strait gave a nation a voice in the trade that passed it.

WORKED EXAMPLES

Example 1. About 20 million barrels of oil a day passed through the Strait of Hormuz in 2023–2024. The EIA estimated about 2.6 million barrels a day of unused bypass pipeline capacity. If the strait were closed and every unused barrel of pipeline capacity were put to use, what percent of the normal flow could still reach the sea, and what percent would be stranded?

1. Percent that could bypass: $2.6 \div 20 = 0.13 = 13\%$.
2. Percent stranded: $100\% - 13\% = 87\%$.
3. Stranded volume: $20 - 2.6 = 17.4$ million barrels a day.

Answer: About 13 percent could bypass the strait; about 87 percent (roughly 17.4 million barrels a day) would be stranded.

Example 2. Under the Law of the Sea, each coastal state may claim a territorial sea 12 nautical miles wide. (1 nautical mile = 1.852 km.) The Strait of Hormuz is about 39 km wide at its narrowest and the Bab-el-Mandeb about 29 km. Show that both straits lie entirely within territorial seas, and say what legal right lets foreign ships pass.

1. Two territorial seas, one from each shore: $2 \times 12 = 24$ nautical miles.
2. In kilometers: $24 \times 1.852 = 44.4$ km.
3. Hormuz: $39 \text{ km} < 44.4 \text{ km}$. Bab-el-Mandeb: $29 \text{ km} < 44.4 \text{ km}$. Both straits are narrower than two territorial seas, so the claims meet and overlap in the middle.
4. The 1982 Convention gives all ships the right of transit passage through straits used for international navigation, so coastal states may regulate traffic but may not suspend passage. (Not every country has ratified the Convention, and some dispute how it applies, which is one reason these straits are tense.)

Answer: Both straits are narrower than 44.4 km (24 nautical miles), so they lie wholly within territorial seas; foreign ships pass under the right of transit passage.

Example 3. Shipping companies reported in 2024 that sending a ship from Asia to northern Europe around the Cape of Good Hope instead of through the Red Sea and Suez added roughly 3,500 nautical miles. (a) How many extra days is this for a container ship at 16 knots? (b) For a weekly service, each ship makes a round trip, so how many extra days per round trip? (c) If a round trip normally takes 84 days and each week needs one departure, how many ships does the service need before and after?

1. (a) $3,500 \div 16 = 218.75$ hours; $218.75 \div 24 \approx 9.1$ days.
2. (b) Both ways: $2 \times 9.1 \approx 18.2$ days, about 18 days.
3. (c) Before: $84 \div 7 = 12$ ships. After: $84 + 18 = 102$ days; $102 \div 7 \approx 14.6$, so 15 ships are needed to keep one departure every week.
4. The service needs about 3 more ships to carry the same cargo, which is why freight rates rose when ships avoided the Red Sea.

Answer: (a) About 9 extra days each way. (b) About 18 extra days per round trip. (c) About 12 ships before and 15 after.

PRACTICE

1. **EASY** Which two bodies of water does the Strait of Hormuz connect? Which countries lie on its two shores?
2. **EASY** Which two bodies of water does the Bab-el-Mandeb connect, and which countries border it?
3. **EASY** Convert 20 million barrels a day to liters a day (1 barrel = 159 L).
4. **EASY** What was the Tanker War, and in what years was it fought?
5. **MEDIUM** What does “Bab-el-Mandeb” mean? Suggest why sailors might have given it that name.
6. **MEDIUM** The Saudi East-West pipeline ends at Yanbu on the Red Sea. Explain why this pipeline frees Saudi oil from Hormuz but not from every choke point.
7. **MEDIUM** Use the map *hb-oil-straits-map*. Find Habshan and Fujairah. On which body of water does Fujairah lie, and why did the United Arab Emirates build its pipeline terminal there?
(Use the map or drawing “Use this map for problem 7.” shown earlier in this lesson.)
8. **MEDIUM** A VLCC carries 2 million barrels. If 20 million barrels a day pass Hormuz, how many VLCC loads is that per day and per year?
9. **MEDIUM** Name four ways importing nations and shipping companies prepare for the closing of an oil strait.
10. **HARD** In 2023 about 8.7 million barrels a day of oil passed the Bab-el-Mandeb. If flows fell to about 4 million barrels a day in 2024, by what percent did they fall?
11. **HARD** Why did the supertanker *Bridgeton* survive a mine that might have sunk a smaller ship? What lesson did the escorting navy draw?
12. **CHALLENGE** Write a short, neutral paragraph (5–7 sentences) for a shipping company’s risk report explaining why both Hormuz and the Bab-el-Mandeb are rated high risk. Use at

least three numbers with years and do not take sides in any of the region's conflicts.

COMMON MISTAKES

- Confusing the two straits. Hormuz is the door of the Persian Gulf; the Bab-el-Mandeb is the southern door of the Red Sea.
- Assuming that bypass pipelines can replace a strait. They can carry only a small part of the flow.
- Treating a threat to close a strait as if it were a closure. Report what actually happened, with dates, and keep claims and facts separate.

Make it a game · Tanker Dispatcher. Draw a large outline of Arabia on paper with Hormuz, the Bab-el-Mandeb, Suez, Yanbu and Fujairah marked. Each player is a dispatcher with ten tanker tokens (coins) at the Gulf ports. Each turn a parent draws an event card: "Hormuz open," "Hormuz threatened: insurance doubles," "Red Sea closed: go around the Cape," "Pipeline open." Players move tokens by the cheapest safe route and pay the cost on the card in play money. The dispatcher who delivers all ten with the most money left wins.

Scripture. "A prudent man foreseeth the evil, and hideth himself; but the simple pass on, and are punished." (Proverbs 22:3, KJV)

A risk table is an exercise in prudence. Wise nations, companies and families think ahead about what could go wrong and prepare, not out of fear but out of good stewardship of what has been entrusted to them.

Practice answers

1. The Persian Gulf and the Gulf of Oman (leading to the Arabian Sea). Iran lies to the north; Oman's Musandam Peninsula lies to the south.
2. The Red Sea and the Gulf of Aden (leading to the Indian Ocean). Yemen on the east; Djibouti and Eritrea on the west.
3. $20 \times 1000 \times 159 = 3,180,000$ L, about 3.2 billion liters a day.
4. The part of the Iran-Iraq War in which both sides attacked oil tankers and other merchant ships in and near the Persian Gulf, from 1984 to the ceasefire in 1988.
5. It is Arabic for "Gate of Grief" (often translated "Gate of Tears"). Its narrow passage, reefs, islands and strong winds made it dangerous for sailing ships, and many were wrecked there.
6. From Yanbu, tankers must either sail north through the Suez Canal (or use the SUMED pipeline across Egypt) to reach the Mediterranean, or sail south through the Bab-el-Mandeb to reach Asia. So the oil escapes Hormuz but still depends on Suez or the Bab-el-Mandeb.
7. Fujairah lies on the Gulf of Oman coast, outside the Strait of Hormuz. Oil pumped there can be loaded onto tankers without passing through the strait, so the UAE can export some oil even if Hormuz is closed.
8. $20 \div 2 = 10$ VLCC loads a day; $10 \times 365 = 3,650$ loads a year.
9. Any four: bypass pipelines; strategic oil reserves stored in importing countries; naval escorts or convoys; war-risk insurance; buying oil from other regions; rerouting ships (for example, around the Cape of Good Hope); spare tanker capacity.

10. Drop: $8.7 - 4 = 4.7$ million b/d. Percent: $4.7 \div 8.7 \approx 0.54$, a fall of about 54 percent, roughly half.
11. A supertanker like the *Bridgeton* (about 400,000 tons deadweight, bigger even than a typical VLCC) is enormous and divided into many separate tanks, so a hole in one part does not flood the whole ship, and the oil and water are nearly the same weight, so the ship stays afloat. The navy learned that its escort warships were more vulnerable to mines than the tankers; minesweeping and careful route-clearing were needed, and the small warships followed the tanker for safety.
12. Answers will vary. A strong answer states that about 20 million b/d of oil (2023–2024) and about one-fifth of world LNG pass Hormuz; that the strait is about 39 km wide with narrow lanes, close to shore on both sides; that bypass pipelines had only about 2.6 million b/d of spare capacity; that about 8.7 million b/d passed the Bab-el-Mandeb in 2023 before attacks from Yemen caused many ships to reroute around Africa in 2024; that the Cape route adds about 3,500 nautical miles; and it describes events factually (Tanker War 1984–1988, Red Sea attacks from November 2023) without assigning blame or using loaded language.

3.3 GIBRALTAR AND THE BOSPORUS: DOORS TO THE MEDITERRANEAN AND THE BLACK SEA

OBJECTIVES

- Locate the Strait of Gibraltar, the Bosphorus and the Dardanelles, give their approximate widths and lengths, and explain why each is the only sea door of an enclosed sea.
- Explain the two-layer currents of Gibraltar and the Bosphorus and how Luigi Ferdinando Marsigli discovered the Bosphorus undercurrent in 1679–1680.
- Describe how control of these straits shaped commerce, from Mehmed II's fortress of 1452 and Britain's capture of Gibraltar in 1704 to the Montreux Convention of 1936 and the Black Sea grain trade.

Warm-up. Fill a clear glass halfway with very salty water dyed with a few drops of food coloring. Very slowly pour plain water over the back of a spoon onto the top so it floats as a separate layer. Look from the side: do the layers mix at once? Write a sentence predicting what would happen in a narrow channel joining a salty sea to a fresher one.

Watch. *"This Is Gibraltar"- 16mm Rock of Gibraltar Documentary (Circa 1957)* (Canada 160 Archive, 14:32). <https://www.youtube.com/watch?v=wEuPRzctZNq>
After the story: watch this old film to see the Rock of Gibraltar up close and how its position guards the entrance to the Mediterranean.

Note: Captions were not available to check; preview it first. This is a film from about 1957, so its view of Gibraltar as a British base and its picture of daily life are dated. It covers only Gibraltar, not the Bosphorus or the fall of Constantinople in 1453.

Backup video. *Time-lapse (84x): Gibraltar Strait transit, westbound [4K / UHD, 60fps]* (SeaTube, 1:56). <https://www.youtube.com/watch?v=42SoTQg1zww>
With On the map: watch this time-lapse of a ship sailing west through the Strait of Gibraltar and look for Europe on one side and Africa on the other.

KEY TERMS

enclosed sea

A sea almost surrounded by land and joined to the ocean only by one or a few narrow straits, such as the Mediterranean and the Black Sea.

sill

A raised ridge on the sea floor across a strait that limits how deep water can flow between two seas. The Camarinal Sill lies across the Strait of Gibraltar.

salinity

The amount of salt dissolved in seawater, usually given in grams of salt per kilogram of water. Saltier water is denser and sinks beneath fresher water.

two-layer flow

A current pattern in which water flows one way at the surface and the opposite way near the bottom, because the two seas have different salinities.

Turkish Straits

The Bosphorus, the Sea of Marmara and the Dardanelles together, the only sea route between the Black Sea and the Mediterranean.

Montreux Convention

The treaty of 1936 that gives Turkey control of the Turkish Straits, guarantees free passage for merchant ships in peacetime, and limits the passage of warships.

CORE IDEAS

The story. In the spring of 1452 the young Ottoman sultan Mehmed II brought thousands of masons and laborers to the narrowest point of the Bosphorus, a few miles north of Constantinople, and in about four months they raised a great fortress of stone towers and walls. The Turks called it Rumeli Hisarı, the Castle of Rumelia; it was also nicknamed *Boğazkesen*, which can mean “strait-cutter” or “throat-cutter.” Across the water stood an older Ottoman fort, and between them the strait is only about 700 m (2,300 feet) wide. Cannon on both shores could now stop any ship coming down from the Black Sea with grain for the besieged city. In November 1452 a Venetian ship that refused to halt was sunk by a cannon shot; its captain was executed by impalement as a warning, a cruel but common punishment of the age. On 29 May 1453 Constantinople fell, the Byzantine Empire ended, and the sultans held the door to the Black Sea for more than four centuries.

How it worked. The **Turkish Straits** are a chain: the **Bosphorus**, about 31 km (19 miles) long and as narrow as about 700 m, with several sharp bends and the city of Istanbul on both banks; the Sea of Marmara; and the **Dardanelles**, about 61 km (38 miles) long and about 1.2 to 6 km (0.75 to 3.7 miles) wide. In ancient times Athens fed itself partly with grain shipped from the Black Sea through these waters, which is why it guarded the Hellespont, the old Greek name for the Dardanelles. At the other end of the Mediterranean, the **Strait of Gibraltar** is about 58 km (36 miles) long and narrows to about 14 km (9 miles) between Spain and Morocco. The ancients called the two headlands the Pillars of Hercules. In 711 the Muslim commander Tariq ibn Ziyad crossed from Africa and landed beneath the great rock that still bears his name: *Jabal Tariq*, the Mountain of Tariq, became “Gibraltar.” In 1704 an English and Dutch fleet captured the Rock, and Spain ceded it to Britain in the Treaty of Utrecht in 1713. As of 2026 it remains a British Overseas Territory, which Spain still claims.

How they figured it out. Sailors had long noticed that the surface water of the Bosphorus runs steadily from the Black Sea toward the Sea of Marmara, yet fishermen said their nets, let down deep, were pulled the other way. In 1679 and 1680 a young Italian nobleman, Luigi Ferdinando Marsigli, was in Constantinople with a Venetian embassy. He lowered weighted lines with floats into the strait and found that the deep water indeed flowed north toward the Black Sea. He measured the weight of water from the surface and from the depths and found the deep water heavier, because it was saltier. Back home he built a tank divided by a wall with holes in it, filled one side with salt water and the other with fresh, both colored, and

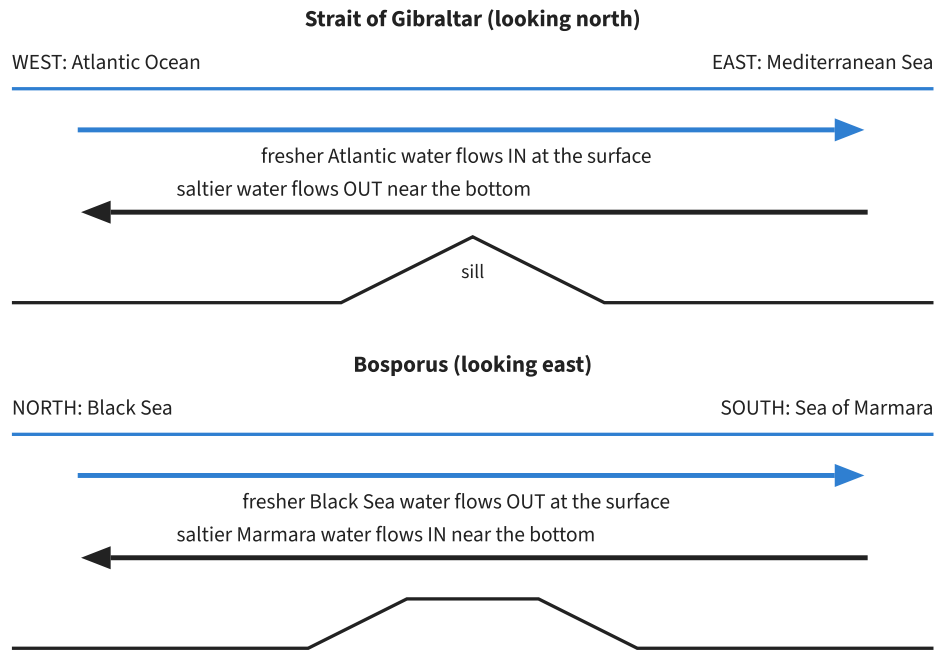
watched the heavy salt water slide along the bottom while the light fresh water flowed over the top. He published his findings in Rome in 1681. It was one of the first real experiments in oceanography.

The big idea. Both straits are the only sea doors of **enclosed seas**, and both have **two-layer flow**, for opposite reasons. The Black Sea receives the Danube, the Dnieper, the Don and other great rivers, so it has more fresh water than it can evaporate; light, fresher water spills out at the surface, and heavy, salty Mediterranean water creeps in beneath. The Mediterranean, in a hot, dry climate, loses more water by evaporation than its rivers and rain supply; Atlantic water pours in at the surface at Gibraltar, while saltier, heavier Mediterranean water flows out over the **sill** along the bottom. For commerce the lesson is simple: a sea with one door belongs to whoever can keep the door open. Ships from the ports of Ukraine, Russia, Romania, Bulgaria and Georgia must pass Istanbul. Under the **Montreux Convention** of 1936, merchant ships pass freely in peacetime, while warships are limited; in February 2022, after Russia invaded Ukraine, Turkey closed the straits to warships of the warring states as the convention allows. From July 2022 to July 2023 an agreement made with Turkish and United Nations help let about 33 million tonnes of Ukrainian grain and food leave the Black Sea through the Bosphorus.

On the map. Using the map below, find Gibraltar at about 36.0°N, 5.6°W and the Bosphorus at about 41.1°N, 29.1°E. Then trace a grain ship from Odesa: south across the Black Sea, through the Bosphorus under the bridges of Istanbul, across the Sea of Marmara, down the Dardanelles past Çanakkale, through the Aegean islands, west across the Mediterranean, and out through Gibraltar into the Atlantic. Count the choke points it passes. On the Strait of Gibraltar notice the great modern ports on both shores, Algeciras in Spain and Tanger Med in Morocco, opened in 2007, which earn their living from the ships that must pass this door. The Bosphorus is also crossed by bridges (the first opened in 1973) and by the Marmaray railway tunnel under the strait (2013), a reminder that a strait divides land as much as it joins seas.



The two doors of the Mediterranean world. A ship from the Black Sea must pass the Bosphorus, the Dardanelles and Gibraltar to reach the open Atlantic.



Two-layer flow (not to scale). At both straits the saltier, heavier water flows along the bottom and the fresher, lighter water flows over it in the opposite direction.

PICTURE STUDY



The Strait of Gibraltar seen from the International Space Station, Astronaut photograph, published by NASA Earth Observatory, 23 August 2013 (Expedition 36) · Digital photograph taken from orbit · NASA Johnson Space Center, Gateway to Astronaut Photography of Earth ([spaceflight.nasa.gov gallery](http://spaceflight.nasa.gov/gallery))

Astronauts on the International Space Station have photographed the Strait of Gibraltar many times, because it is one of the easiest places on earth to recognize from orbit: two continents almost touching, with an ocean on one side and a sea on the other. Search NASA Earth Observatory for “Strait of Gibraltar.” Some of the best images catch the sun reflecting off the water, which makes the surface patterns of the currents and the waves inside the sea visible.

Compare the photograph with a map. A map shows the strait from straight above; an astronaut usually looks at an angle, so the far shore appears closer and smaller. Learning to read oblique views like this is the same skill pilots and navigators use.

Look closely

- Find Spain, Morocco, the Atlantic and the Mediterranean. Which way is north in the picture?
- Look for the Rock of Gibraltar on the Spanish side and Ceuta on the African side. How close do the two continents come?
- If the photo shows sunglint, look for curved bands or ripples in the water. These are signs of currents and internal waves where Atlantic water flows in.
- Look at the mountains on both shores. Why might the ancients have thought of the two headlands as gateposts?

Talk about it

1. Why would a navy or a merchant prize a harbor at Gibraltar, Algeciras, Ceuta or Tangier?
2. What can the photograph tell you about the strait that a table of numbers cannot, and what can the numbers tell you that the photograph cannot?

PROJECT: MARSIGLI'S TANK: A TWO-LAYER STRAIT IN A BOX

Repeat the experiment Marsigli described in 1681. You will build a two-chamber "strait" with salty water on one side and fresh water on the other, open the door between them, and watch the two-layer flow form. Then add the Gibraltar and Bosphorus rows to your risk table.

You will need

- A clear plastic box or loaf-shaped container about 30 cm (12 in) long
- A piece of stiff cardboard or plastic cut to fit snugly across the middle as a removable divider, wrapped in plastic film and sealed at the edges with modeling clay
- Warm water, table salt (about 4 tablespoons), two food colorings (blue and red), measuring cups
- Towels, a flashlight, and your risk table

Steps

1. Fit the divider across the middle of the box and seal its edges with clay.
2. Fill one side with salty water (dissolve the salt in about 1 liter of warm water) colored red. This is the Mediterranean.
3. At the same time fill the other side to the same height with fresh water colored blue. This is the Atlantic (or, for the Bosphorus, the Black Sea).
4. Lift the divider straight up, slowly and smoothly. Watch from the side with a flashlight behind the box.
5. Sketch what you see after 5, 15 and 60 seconds. Which color slides along the bottom? Which flows over the top? Label the direction of each layer.
6. Repeat with a small ridge of clay on the floor where the divider stood, to stand for the Camarinal Sill. What changes?
7. Add the Gibraltar row to your risk table (about 14 km or 9 miles wide; deep, sill about 300 m; roughly 300 ships a day in recent estimates; alternatives: none by sea for the western Mediterranean, the Suez Canal for the east). Add the Bosphorus-Dardanelles row (about 700 m at the narrowest; sharp bends, strong currents, a city of millions on both shores; about 40,000 ships a year in recent years; no sea alternative; pipelines and railways as partial alternatives).

Tips

- Pour both sides at the same time so the water level stays equal and the divider does not bend.
- If the colors mix too fast, use more salt or colder fresh water; the bigger the difference in density, the cleaner the layers.

Check your work

- I can explain why the salty water moved along the bottom.
- I can draw the direction of both layers at Gibraltar and at the Bosphorus and explain why they differ.
- Both new rows of my risk table are complete with units and years.

MAP NOTEBOOK

1. Draw the Turkish Straits from the Black Sea to the Aegean. Label the Bosphorus, Istanbul, the Sea of Marmara, the Dardanelles, Çanakkale and Gallipoli, and mark Rumeli Hisarı at the narrowest point of the Bosphorus.
2. Draw the Strait of Gibraltar and label Spain, Morocco, the Rock of Gibraltar, Algeciras, Tarifa, Ceuta, Tangier and Tanger Med. Add arrows for the two-layer flow.
3. Make a three-column chart of rulers of the Bosphorus: Byzantine (to 1453), Ottoman (1453–1922), Republic of Turkey (from 1923). Beside each, write one way it used or regulated the strait.

From history. In 1915, during the First World War, Britain and France tried to force the Dardanelles with battleships to reach Constantinople and open a sea route to their ally Russia. On 18 March 1915 the Allied fleet steamed into the strait and ran into a line of mines that Ottoman sailors had quietly laid in a bay ten days before; three battleships were sunk and others damaged. The landings on the Gallipoli peninsula that followed failed after months of terrible fighting, and the Allies withdrew in January 1916. The Ottoman commander Mustafa Kemal, later called Atatürk, made his name there. The strait's narrowness, currents and mines had defeated the strongest navies in the world.

WORKED EXAMPLES

Example 1. A ship steams through the Bosphorus, about 31 km (19 miles) long, at 10 knots (1 knot = 1.852 km/h). How long does the passage take? How many times wider is the Strait of Gibraltar (about 14 km) than the narrowest point of the Bosphorus (about 0.7 km)?

1. Speed in km/h: $10 \times 1.852 = 18.52$ km/h.
2. Time: $31 \div 18.52 \approx 1.67$ hours, about 1 hour 40 minutes.
3. Width ratio: $14 \div 0.7 = 20$.

Answer: About 1 hour 40 minutes; Gibraltar is about 20 times wider than the narrowest point of the Bosphorus.

Example 2. A tanker leaves the southern end of the Bosphorus at Istanbul (about 41.0°N, 29.0°E) and crosses the Sea of Marmara to the entrance of the Dardanelles at Gelibolu (about 40.4°N, 26.7°E). Estimate the straight-line distance using a flat-map approximation: 1° of latitude = 111 km, and 1° of longitude = $111 \text{ km} \times \cos(\text{latitude})$. Then find the total length of the passage from the Black Sea to the Aegean (Bosphorus 31 km, Dardanelles 61 km) and the time at 12 knots.

1. North-south difference: $41.0 - 40.4 = 0.6^\circ$, so $0.6 \times 111 \approx 67 \text{ km}$.
2. East-west difference: $29.0 - 26.7 = 2.3^\circ$. At about 40.7°N, $\cos 40.7^\circ \approx 0.758$, so 1° of longitude $\approx 111 \times 0.758 \approx 84 \text{ km}$ and $2.3 \times 84 \approx 193 \text{ km}$.
3. Straight-line distance: $\sqrt{67^2 + 193^2} = \sqrt{4,489 + 37,249} = \sqrt{41,738} \approx 204 \text{ km}$.
4. Whole passage: $31 + 204 + 61 = 296 \text{ km}$, about 300 km (about 160 nautical miles or 185 miles).
5. Time at 12 knots (22.2 km/h): $296 \div 22.2 \approx 13.3 \text{ hours}$.

Answer: The Marmara crossing is about 204 km; the whole passage is about 300 km (160 nautical miles) and takes roughly 13 hours at 12 knots, not counting waiting time for pilots or traffic.

Example 3. Between July 2022 and July 2023, about 33 million tonnes of grain and food left Ukrainian ports through the Bosphorus under the Black Sea agreement. (a) What was the average per day over 360 days? (b) If the average ship carried 30,000 tonnes, about how many ship loads was this in all, and per day?

1. (a) $33,000,000 \div 360 \approx 91,700 \text{ tonnes a day}$.
2. (b) Total loads: $33,000,000 \div 30,000 = 1,100 \text{ loads}$.
3. Per day: $1,100 \div 360 \approx 3 \text{ ship loads a day}$.

Answer: (a) About 92,000 tonnes a day. (b) About 1,100 ship loads, or about 3 loaded grain ships a day passing the Bosphorus (at this assumed ship size).

PRACTICE

1. **EASY** Name the three parts of the Turkish Straits in order from the Black Sea to the Aegean.
2. **EASY** Where does the name “Gibraltar” come from?
3. **EASY** Convert the narrowest width of the Strait of Gibraltar, about 14 km, to miles and nautical miles.
4. **EASY** What did Mehmed II build in 1452, and why?

5. **MEDIUM** Explain why surface water flows *out* of the Black Sea but *into* the Mediterranean.
6. **MEDIUM** How did Marsigli show that the deep current of the Bosphorus flowed north? Name two steps of his method.
7. **MEDIUM** What does the Montreux Convention (1936) guarantee to merchant ships, and what power does it give Turkey over warships?
8. **MEDIUM** Use the map *hb-med-doors-map*, which shows the route as far as the Atlantic. List every strait a ship from Odesa must pass to reach Rotterdam, including any beyond the edge of the map.
(Use the map or drawing "Use this map for problem 8." shown earlier in this lesson.)
9. **MEDIUM** Use the diagram *hb-two-layer-flow*. At Gibraltar, which layer flows east and which flows west? Which layer is saltier?
(Use the map or drawing "Use this diagram for problem 9." shown earlier in this lesson.)
10. **HARD** Ship traffic through the Bosphorus fell from more than 50,000 ships a year in the mid-2000s to about 40,000 in recent years. What is the percent decrease from 50,000 to 40,000? Give one possible reason ships per year could fall even while cargo stays the same.
11. **HARD** Why is the Bosphorus a more dangerous passage for a large tanker than the Strait of Gibraltar, even though both are busy?
12. **CHALLENGE** Write a paragraph comparing how geography made the Bosphorus valuable to the Byzantine emperors and to the Ottoman sultans. Use at least two dates.

COMMON MISTAKES

- Thinking the Bosphorus and the Dardanelles are the same strait. The Bosphorus is at Istanbul on the Black Sea end; the Dardanelles is at Çanakkale on the Aegean end, with the Sea of Marmara between them.
- Getting the two-layer flow backward. The saltier water always goes along the bottom; at Gibraltar it flows out of the Mediterranean, at the Bosphorus it flows into the Black Sea.
- Assuming that a strait wholly inside one country can be closed at that country's pleasure. The Turkish Straits are governed by the Montreux Convention, which guarantees merchant passage in peacetime.

Make it a game • Gatekeeper. One player is the Gatekeeper of a strait (Gibraltar, the Bosphorus or the Dardanelles). The others are merchant captains who must sail paper boats through a gap between two chairs. Before each round the Gatekeeper draws a card: "Peacetime: free passage," "Pilot required: wait one turn," "Wartime: warships barred," or "Storm: strait closed." Captains score a point for each cargo delivered. Halfway through, read the Montreux rules aloud and play again; discuss how clear rules made trade safer for everyone.

Scripture. "But Jonah rose up to flee unto Tarshish from the presence of the LORD, and went down to Joppa; and he found a ship going to Tarshish: so he paid the fare thereof,

and went down into it, to go with them unto Tarshish from the presence of the LORD.”
(Jonah 1:3, KJV)

Tarshish was a far western port, which many scholars place in southern Spain, near the Strait of Gibraltar: for an Israelite, the end of the known sea. Jonah found that no sea lane, however long, carries a man out of God’s presence. The same Lord who set the bounds of the seas rules every strait and harbor.

Practice answers

1. The Bosphorus, the Sea of Marmara and the Dardanelles.
2. From the Arabic *Jabal Tariq*, “Mountain of Tariq,” after Tariq ibn Ziyad, who crossed from Africa and landed there in 711.
3. $14 \div 1.609 \approx 8.7$ miles; $14 \div 1.852 \approx 7.6$ nautical miles.
4. The fortress of Rumeli Hisarı at the narrowest point of the Bosphorus, so that his cannon could stop ships bringing grain and help from the Black Sea to Constantinople before his siege of the city in 1453.
5. The Black Sea gets more fresh water from its great rivers (Danube, Dnieper, Don) than it loses by evaporation, so it has extra, lighter water that spills out at the surface. The Mediterranean loses more by evaporation in its hot, dry climate than its rivers and rain supply, so Atlantic water must flow in at the surface to make up the loss.
6. He lowered weighted lines with floats into the strait and saw that the deep water pulled them northward; he weighed water from the surface and the depths and found the deep water heavier and saltier; and he built a divided tank with salt water on one side and fresh on the other to show the two layers flowing past each other. Any two.
7. It guarantees merchant ships of all nations free passage through the Turkish Straits in peacetime. It limits the number, size and length of stay of warships of non-Black Sea states, and in time of war it lets Turkey close the straits to the warships of the warring states, as it did in 2022.
8. The Bosphorus, the Dardanelles and the Strait of Gibraltar on the map; then, beyond the map, the Strait of Dover before Rotterdam. (The wide Strait of Sicily, which the plotted route crosses, may also be counted.)
9. The upper layer of Atlantic water flows east into the Mediterranean; the lower layer of Mediterranean water flows west into the Atlantic. The lower, outflowing Mediterranean water is saltier.
10. $(50,000 - 40,000) \div 50,000 = 0.20$, a 20 percent decrease. Ships have grown larger, so the same cargo can be carried in fewer ships; some oil has also moved to pipelines. (Other reasonable answers accepted, such as changes in trade or stricter traffic rules.)
11. The Bosphorus is only about 700 m wide at its narrowest, winds through several sharp bends with strong currents, and runs through the middle of Istanbul, a city of many millions, with ferries crossing constantly. A collision or fire there could kill many people and close the only sea route to the Black Sea. Gibraltar is about 20 times wider, straight and open, with room for separate traffic lanes.
12. Answers will vary. A strong answer explains that both ruled a city (Constantinople/Istanbul) set on the narrow strait between Europe and Asia and between the Black Sea and the Mediterranean, so they could tax and protect trade and draw grain and goods from the Black Sea; that Constantine made the city his capital (dedicated in 330); that Mehmed II cut the strait with Rumeli Hisarı in 1452 and took the city in 1453; and that the Ottomans then

controlled the Black Sea trade for centuries. It should use the dates correctly and avoid judging either empire by modern standards while naming real violence plainly.

3.4 SUEZ AND PANAMA: CANALS AS MAN-MADE STRAITS

OBJECTIVES

- Explain why the Suez Canal (1869) could be dug at sea level with no locks while the Panama Canal (1914) needed locks and a lake 26 m (85 ft) above the sea.
- Tell the honest history of both canals: the forced labor at Suez, the French failure and the deaths from disease at Panama, the conquest of yellow fever, the treatment of West Indian workers, and the later handover of each canal to the nation it crosses.
- Calculate the distance and time each canal saves, the water used by a Panama lock, and the effect of a closure such as the grounding of the *Ever Given* in 2021.

Warm-up. Set two plastic cups side by side and a third cup upside down between them as a “hill.” How could you move a toy boat floating in one cup over the hill to the other cup without lifting it out of the water? Sketch an idea using more cups, water and a straw. You have just met the problem the engineers of Panama faced.

Watch. *1869 - The Opening of the Suez Canal* (Singapore Bicentennial, 2:00).

<https://www.youtube.com/watch?v=gqXgtywj7j4>

After the story: watch this short clip about the 1869 opening of the Suez Canal and listen for how it shortened the trip between Europe and Asia.

Note: Captions were not available to check; preview it first. It is made by Singapore's bicentennial project, so much of it is about how the canal helped Singapore grow.

Backup video. *What Really Happened at the Suez Canal?* (Practical Engineering, 11:34).

<https://www.youtube.com/watch?v=Ty-m4pm8oog>

As review: watch this engineer explain how the huge ship *Ever Given* got stuck in the Suez Canal in 2021 and why big ships are hard to steer in narrow canals. Note: Captions were not available to check; preview it first. The host says 'Suez Peninsula' when he means the Suez Isthmus, and he corrects this in the video's description. The video says 'Suez Peninsula'; the correct term is Suez Isthmus.

KEY TERMS

canal

A waterway dug by people to carry ships or barges where no natural water route exists, or to shorten one. A ship canal across an isthmus works as a man-made strait.

isthmus

A narrow strip of land joining two larger land areas and separating two bodies of water, such as the Isthmus of Panama or the Isthmus of Suez.

lock

A chamber with gates at each end in which the water level is raised or lowered to lift or lower a ship from one level of a waterway to another.

sea-level canal

A canal with no locks, whose water stands at the level of the seas at both ends. The Suez Canal is a sea-level canal.

Panamax and Neopanamax

The largest ship sizes that fit the original Panama locks (about 32.3 m or 106 ft wide) and the larger locks opened in 2016 (about 51 m or 168 ft wide). Ships are designed to these limits.

corvée

Forced, unpaid or poorly paid labor that a government demands of its people. Egyptian peasants were drafted by corvée to dig the Suez Canal in its early years.

CORE IDEAS

The story. On 17 November 1869, a procession of ships led by the French imperial yacht *L'Aigle*, carrying the Empress Eugénie, steamed south from Port Said into the newly finished Suez Canal. Kings, princes and reporters from all of Europe had come to Egypt for the celebration. The man behind the canal was Ferdinand de Lesseps, a French diplomat, not an engineer, who in 1854 had won a concession from Egypt's ruler, Said Pasha, and then spent ten years raising money and digging from 1859. The canal joined the Mediterranean to the Red Sea across about 160 km (100 miles) of flat desert and shallow lakes. Five days after it opened, a fast new British sailing ship, the clipper *Cutty Sark*, was launched in Scotland to race tea home from China around the Cape of Good Hope. She was already out of date. Sailing ships could not easily use the canal or beat up the windy Red Sea, but steamers could, and within a few years the steamers had taken most of the China trade by way of Suez.

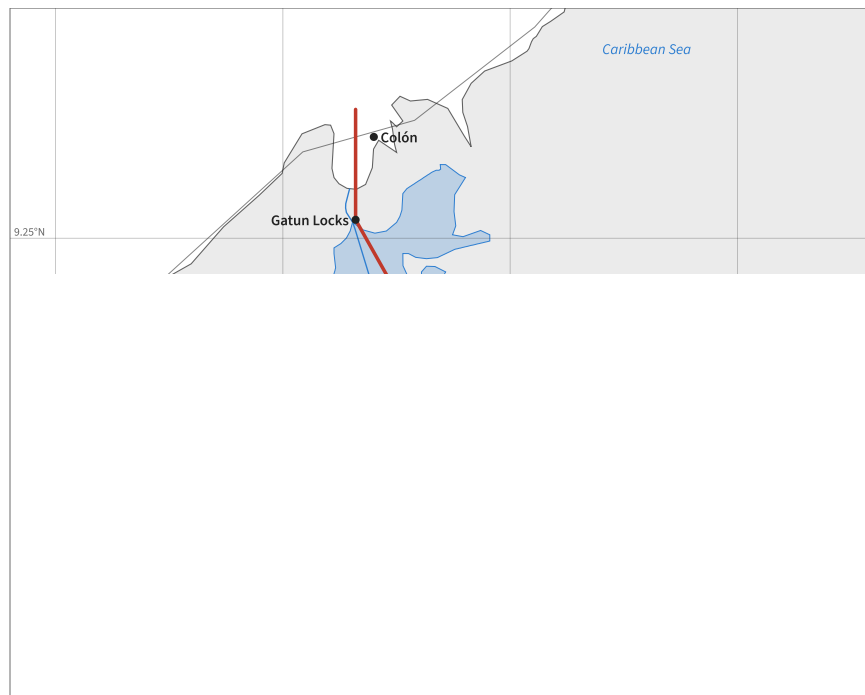
How it worked. At Suez the land is low and the two seas stand at nearly the same level, so the canal could be dug at **sea level** with no locks at all. The cost in human terms was high. In the early years tens of thousands of Egyptian peasants were drafted by **corvée** to dig with hand tools in the desert heat, and many died of disease and hard labor; the records are poor and estimates of the dead vary widely. In 1864 the forced labor was ended, and steam dredges and excavators did most of the remaining work. Panama was far harder. The isthmus is only about 80 km (50 miles) wide, but it is covered with rain forest, crossed by the flood-prone Chagres River, and backed by a mountain ridge. De Lesseps tried there too, beginning in 1881, with a sea-level plan. Landslides, floods, yellow fever and malaria defeated him; an estimated 22,000 workers died, and the French company went bankrupt in 1889. When the United States took up the work in 1904, after backing Panama's break from Colombia in 1903, its engineers chose a canal with **locks**. They dammed the Chagres at Gatun to make a great lake 26 m (85 feet) above the sea, so ships would climb up into the lake, cross the divide on it and through the deep Culebra Cut, and step back down to the other ocean.

Technology overcoming geography. At Panama the problem was not only rock but disease. Building on the work of Carlos Finlay of Cuba and the U.S. Army doctor Walter Reed, who showed that mosquitoes carried yellow fever, Dr. William Gorgas drained pools, screened buildings and fumigated houses until, by 1906, yellow fever was gone from the

Canal Zone. The engineer John Stevens built the railroad system that hauled away the spoil, and George Washington Goethals of the Army Corps of Engineers finished the job. The locks were marvels: chambers 305 m (1,000 feet) long and 33.5 m (110 feet) wide, filled and emptied by gravity alone through great culverts in the walls, with electric locomotives called “mules” guiding the ships. The workforce came largely from Barbados, Jamaica and other Caribbean islands. They were paid on a “silver roll” at far lower wages than the mostly white Americans on the “gold roll,” and lived in separate quarters, a real injustice of the system as it was run. The official records count about 5,600 deaths among the workers between 1904 and 1914, most of them West Indians. The canal opened on 15 August 1914, when the steamer *Ancon* made the first official transit, just as the First World War began in Europe.

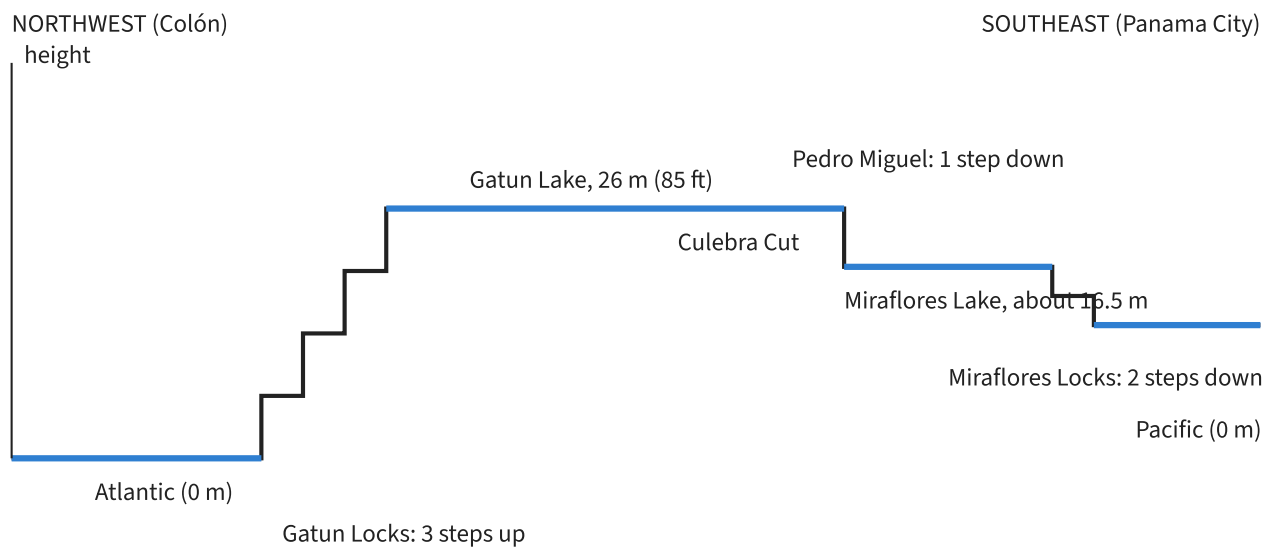
The big idea. A ship canal is a **man-made strait**, and it brings all the benefits and the risks of a natural one. It saves enormous distances: Suez cut about 8,900 km (5,500 miles) from a voyage between the Arabian Sea and London, and Panama cut a New York to San Francisco voyage from about 22,500 km (14,000 miles) around Cape Horn to about 9,500 km (5,900 miles). But a canal is also a choke point that someone owns and someone can close. Britain bought Egypt’s shares in the Suez company in 1875 under Prime Minister Disraeli; the Convention of Constantinople (1888) declared the canal open to ships of every nation in war and peace; Egypt nationalized the canal in 1956; it was closed from 1967 to 1975 after the Six-Day War, trapping fifteen ships in the Great Bitter Lake for eight years. Panama took full control of its canal on 31 December 1999 under the treaties of 1977. In March 2021 the giant container ship *Ever Given*, about 400 m (1,312 ft) long, ran aground across the Suez Canal and blocked it for six days, while hundreds of ships waited at each end. Panama has its own weak point: every ship that passes the old locks uses about 200 million liters (52 million gallons) of fresh water from Gatun Lake, so in the dry year of 2023–2024 the canal authority had to limit the number and draft of ships.

On the map. Use the maps below. At Suez, follow the canal south from Port Said past Ismailia and through the Great Bitter Lake to the city of Suez; it is now about 193 km (120 miles) long, and a parallel channel added in 2015 lets ships pass in both directions along part of it. In 2023 about 26,000 ships passed, roughly one-eighth of world sea trade, though attacks in the Red Sea cut the number about in half in 2024. At Panama, notice a surprise: the canal runs from the Atlantic at Colón *southeast* to the Pacific at Panama City, because the isthmus bends like an S. Since 2016, a second, larger set of locks at Agua Clara and Cocolí has carried Neopanamax ships with water-saving basins that reuse much of each lockage’s water.

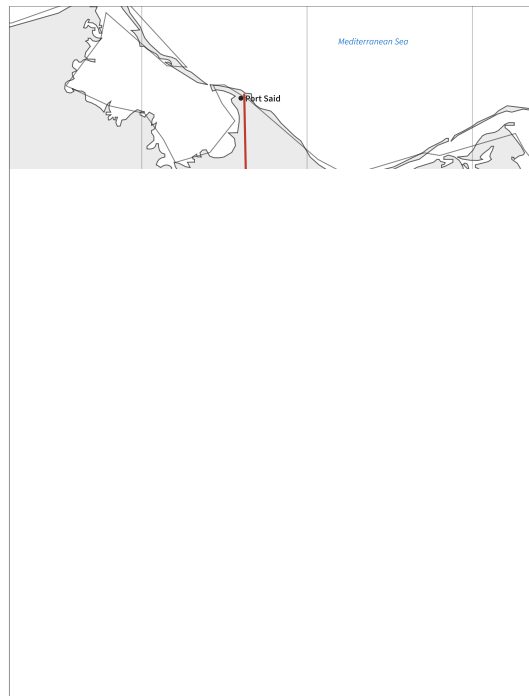


The Panama Canal. Note that the Pacific end lies east of the Atlantic end, because the isthmus bends.

Panama Canal profile (heights exaggerated)



A profile of the original Panama Canal (heights exaggerated). Ships climb 26 m (85 ft) in three steps at Gatun and come down in one step at Pedro Miguel and two at Miraflores.



The Suez Canal, a sea-level canal with no locks, about 193 km (120 miles) long.

PICTURE STUDY



The Panama Canal from the International Space Station, Crew of ISS Expedition 6 (NASA), 30 January 2003
 · Digital astronaut photograph (Electronic Still Camera, 85 mm lens) · NASA Johnson Space Center, Gateway to Astronaut Photography of Earth (frame ISS006-E-23743), featured by NASA Earth Observatory (now at science.nasa.gov/earth/earth-observatory); public domain

Astronauts on the International Space Station photograph the earth every day with handheld cameras. On a January afternoon in 2003 an Expedition 6 crew member photographed the whole Panama Canal in one frame: about 80 km (50 miles) of water running southeast from

Colón on the Caribbean, through the man-made Gatun Lake, to Panama City on the Pacific. NASA Earth Observatory published the picture with a caption that points out the thick rainforest along the canal and the trade-wind clouds pouring south through the gap in the mountains.

Look at the picture as an engineer would. Gatun Lake was made by people: when the Gatun Dam closed the Chagres River, the water rose and drowned hilltops into islands. The forest around the lake is not only scenery; it gathers the rain that fills the lake that works the locks.

Look closely

- Find Gatun Lake. Why does it have so many branching arms and islands?
- Trace the canal from the Caribbean coast to the Pacific. Which direction does it run? (It is not west to east!)
- Look for the narrow places near each coast where the locks lift ships up to the lake and lower them again. This photograph was taken in 2003, before the newer, larger locks were built beside the old ones in 2016.
- Look at the forest and the clouds over the isthmus. Why would the canal authority want to protect that forest?

Talk about it

1. How does this image show that the Panama Canal depends on rain as much as on concrete and steel?
2. If you could photograph the Suez Canal from the same height, how would the land around it look different, and why does that difference explain why Suez needs no locks?

Safety first. Use only cool tap water for the lock model and keep it on a towel or in a tray. Ask an adult to cut the bottle with a craft knife.

PROJECT: A WORKING MODEL LOCK

Build a model lock from plastic bottles or food containers, raise and lower a toy boat with water alone, and measure how much water each lockage uses. Then add the Suez and Panama rows to your risk table.

You will need

- Three clear plastic food containers or the bottom halves of 2-liter bottles, of the same size
- Two pieces of stiff plastic cut as sliding gates, and modeling clay to seal them
- A board and books to set the containers at three heights like steps
- Two short pieces of flexible tubing (aquarium tubing) and binder clips to pinch them shut
- A small foam or cork boat, a measuring cup, a ruler and a towel

Steps

1. Set the three containers in a row as steps: low (the sea), middle (the lock chamber) and high (the lake). Join each pair with a short tube near the bottom, pinched shut with a clip; these are the culverts.
2. Fill the high container (the lake) nearly full and the low one (the sea) about one-quarter full.
3. Float the boat in the sea. Open the lower culvert so the chamber's water matches the sea, then move the boat into the chamber.
4. Close the lower culvert. Open the upper culvert and watch the chamber fill by gravity until it reaches the lake level. Move the boat up into the lake.
5. Measure: how many centimeters did the water rise in the chamber? Multiply by the chamber's floor area to find the volume of water used. Where did that water go when you lowered the next boat down?
6. Add the Suez row to your risk table (about 193 km long, no locks; Suezmax ships to about 20 m draft; about 26,000 ships in 2023; risks: groundings, war, attacks in the Red Sea; alternative: the Cape of Good Hope, about 3,500 nautical miles more from Asia to northern Europe). Add the Panama row (about 80 km; locks 33.5 m and 55 m wide; roughly 13,000 to 14,000 oceangoing transits a year before the 2023–2024 drought; risk: low water in Gatun Lake; alternatives: Cape Horn or the Strait of Magellan, the Suez route, or U.S. railroads across the continent).

Tips

- Clay seals leak a little; keep a towel handy and press the clay firmly.
- Notice that no pump is needed to lift the boat. The real Panama locks also fill and drain by gravity alone, but the water that flows down to the sea must be replaced by rain.

Check your work

- My lock raises and lowers a boat using only gravity.
- I can explain where the water goes each time a ship passes.
- Both canal rows of my risk table are complete with units and years.

MAP NOTEBOOK

1. Draw the profile of the Panama Canal from the Atlantic to the Pacific, showing the three Gatun locks, Gatun Lake at 26 m (85 ft), the Culebra Cut, Pedro Miguel lock, Miraflores Lake and the two Miraflores locks.
2. Draw a map of the Suez Canal and label Port Said, Ismailia, Lake Timsah, the Great Bitter Lake, Suez, the Sinai Peninsula and the Nile Delta.
3. Make a two-column timeline, one column for each canal: Suez 1854, 1859, 1869, 1875, 1888, 1956, 1967–1975, 2015, 2021; Panama 1881, 1889, 1903, 1904, 1906, 1914, 1977, 1999, 2016, 2023.

From history. The dream of a Suez canal is very old. The Greek historian Herodotus, writing in the 400s BC, described a canal dug from the Nile to the Red Sea, begun by the pharaoh Necho and completed under the Persian king Darius, wide enough for two

warships to row abreast. Ancient canals of this kind joined the Red Sea to the Nile, not directly to the Mediterranean, and they silted up and were reopened several times before being abandoned. When Napoleon's surveyors studied the isthmus in 1799, they wrongly calculated that the Red Sea stood about 10 m (33 ft) higher than the Mediterranean, and the error discouraged a direct canal for decades until later surveys showed the seas were nearly level.

WORKED EXAMPLES

Example 1. The original Panama lock chambers are about 305 m long and 33.5 m wide. Gatun Locks lift ships 26 m in three equal steps. (a) How much water does it take to raise the water in one chamber by one step? (b) A ship crossing from ocean to ocean drains about one chamber-step of lake water at the top lock on each side. Estimate the lake water used per transit in liters and U.S. gallons ($1 \text{ m}^3 = 1,000 \text{ L} = 264.2 \text{ gallons}$), and compare with the published figure of about 200 million liters (52 million gallons).

1. One step: $26 \div 3 \approx 8.67 \text{ m}$.
2. Volume of one step: $305 \times 33.5 \times 8.67 \approx 88,600 \text{ m}^3$.
3. Two such volumes (one on each side of the lake): $2 \times 88,600 = 177,200 \text{ m}^3$.
4. In liters: $177,200 \times 1,000 \approx 177 \text{ million L}$. In gallons: $177,200 \times 264.2 \approx 46.8 \text{ million gallons}$.
5. This is close to the published 200 million liters (52 million gallons); the difference comes from the real chambers' shape, the Pacific tides and water used in other operations.

Answer: About $88,600 \text{ m}^3$ per step and about 177 million liters (47 million gallons) per transit by this estimate, close to the published figure of about 200 million liters (52 million gallons).

Example 2. Before the Panama Canal, a ship from New York to San Francisco sailed about 22,500 km (14,000 miles) around Cape Horn. Through the canal the voyage is about 9,500 km (5,900 miles). (a) How much shorter is the canal route, in km and as a percent? (b) How many days does it save at 12 knots (22.2 km/h)?

1. (a) Distance saved: $22,500 - 9,500 = 13,000 \text{ km}$ (about 8,100 miles).
2. Percent saved: $13,000 \div 22,500 \approx 0.58 = 58\%$.
3. (b) Hours saved: $13,000 \div 22.2 \approx 586 \text{ hours}$; days: $586 \div 24 \approx 24.4 \text{ days}$.

Answer: (a) About 13,000 km (8,100 miles), about 58 percent shorter. (b) About 24 days saved at 12 knots.

Example 3. The Suez Canal shortens a voyage between the Arabian Sea and London by about 8,900 km. (a) How many days does it save for a ship at 20 knots and for a ship at 8 knots? (b) In 2023 about 26,000 ships passed the canal. If the canal were closed for six days, as during the *Ever Given* grounding of March 2021, about how many ships would be delayed at that rate?

1. (a) $20 \text{ knots} = 20 \times 1.852 = 37.0 \text{ km/h}$; $8,900 \div 37.0 \approx 240 \text{ hours} = 10 \text{ days}$.
2. $8 \text{ knots} = 8 \times 1.852 = 14.8 \text{ km/h}$; $8,900 \div 14.8 \approx 601 \text{ hours} \approx 25 \text{ days}$.
3. (b) Ships per day: $26,000 \div 365 \approx 71$. In six days: $71 \times 6 \approx 427$ ships.
4. This matches the reports from 2021 that several hundred ships were waiting by the time the *Ever Given* was freed.

Answer: (a) About 10 days at 20 knots and about 25 days at 8 knots. (b) About 430 ships delayed at the 2023 rate.

PRACTICE

1. **EASY** Which two bodies of water does each canal join?
2. **EASY** Give the opening year of each canal and the name of the ship that made the first official transit of the Panama Canal.
3. **EASY** Why does the Suez Canal need no locks?
4. **EASY** Who was William Gorgas, and why was his work essential to building the Panama Canal?
5. **MEDIUM** Give three reasons the French effort at Panama (1881–1889) failed.
6. **MEDIUM** Use the diagram *hb-panama-profile*. If Gatun Lake is 26 m above sea level and the Pedro Miguel lock lowers ships about 9.5 m, about how high is Miraflores Lake above sea level? How much do the two Miraflores locks lower a ship at average Pacific sea level?
(Use the map or drawing “Use this diagram for problem 6.” shown earlier in this lesson.)
7. **MEDIUM** Use the map *hb-panama-map*. In which direction does a ship travel from the Atlantic end to the Pacific end of the Panama Canal? Explain the surprise.
(Use the map or drawing “Use this map for problem 7.” shown earlier in this lesson.)
8. **MEDIUM** What were the “gold roll” and the “silver roll” in the Panama Canal Zone? State the injustice plainly.
9. **MEDIUM** What did the Convention of Constantinople (1888) declare about the Suez Canal? Name one time the canal was nevertheless closed.
10. **HARD** The Neopanamax locks are about 427 m long and 55 m wide. How many times larger is the floor area of a new chamber than an old one (305 m $\times$ 33.5 m)?
11. **HARD** Explain why a drought affects the Panama Canal but cannot affect the Suez Canal in the same way.

12. **CHALLENGE** Write a balanced paragraph on the role of the United States in Panama's independence (1903) and the canal's construction, giving both achievements and wrongs, and ending with the handover in 1999.

COMMON MISTAKES

- Thinking the Panama Canal is at sea level like Suez. It lifts ships 26 m (85 ft) into Gatun Lake.
- Thinking the Panama locks pump water uphill. They fill by gravity from the lake; the water ends up in the sea and must be replaced by rain.
- Assuming the Atlantic end of the Panama Canal is east of the Pacific end. Because of the S-shaped isthmus, it is the other way around.

Make it a game • Lock Master. Draw six squares on the floor in a row as lock steps: Atlantic (0 m), Gatun 1, 2, 3, Gatun Lake (26 m), then down through Pedro Miguel and Miraflores to the Pacific. Each player is a ship. To enter a lock, a player must answer a question from this lesson; to leave it, the Lock Master rolls a die: on a 1 the lake is low and the ship must wait a turn. The first ship to reach the far ocean wins; then play the Suez version, a straight race with no locks but one "sandstorm" square that blocks the channel for a turn.

Scripture. "For which of you, intending to build a tower, sitteth not down first, and counteth the cost, whether he have sufficient to finish it?" (Luke 14:28, KJV)

De Lesseps succeeded at Suez and failed at Panama partly because he did not count the true cost of a different land: mountains, floods and disease. Good engineering, like good stewardship, begins by studying the ground God has made and honestly reckoning what a work will require.

Practice answers

1. Suez joins the Mediterranean Sea and the Red Sea (Gulf of Suez). Panama joins the Atlantic (Caribbean Sea) and the Pacific Ocean.
2. Suez opened in 1869 (17 November); Panama opened in 1914 (15 August), with the steamer *Ancon*.
3. The land across the Isthmus of Suez is low and flat, and the Mediterranean and the Red Sea stand at nearly the same level, so the canal can be dug at sea level.
4. He was the U.S. Army doctor in charge of sanitation. Using the discovery that mosquitoes carry yellow fever and malaria, he drained standing water, screened buildings and fumigated, ending yellow fever in the Canal Zone by 1906 and greatly reducing malaria, so the workers could survive.
5. Any three: the sea-level plan required impossible amounts of digging through the mountains; landslides in the cuts; the floods of the Chagres River; yellow fever and malaria, which killed an estimated 22,000 workers; poor management and the company's bankruptcy in 1889.
6. $26 - 9.5 = 16.5$ m. The two Miraflores locks lower ships about 16.5 m in all, about 8.25 m each (the exact lift varies with the large Pacific tides).

7. Toward the southeast. The Isthmus of Panama bends in an S-shape running east-west, so at the canal the Caribbean coast lies to the north and the Pacific coast to the south, and Panama City is east of Colón.
8. Two pay systems. Mostly white American skilled workers were paid on the gold roll in U.S. gold currency with better wages, housing and privileges; the great majority of laborers, mostly black West Indians, were paid on the silver roll at much lower wages and lived in separate, poorer quarters. Men doing hard and dangerous work were paid and housed less because of their race and origin.
9. That the canal should be open to the ships of every nation in war and in peace. It was closed by war from 1967 to 1975 (after the Six-Day War); it was also blocked during the Suez Crisis of 1956-1957.
10. New: $427 \times 55 = 23,485 \text{ m}^2$. Old: $305 \times 33.5 = 10,217.5 \text{ m}^2$. Ratio: $23,485 \div 10,217.5 \approx 2.3$ times larger.
11. Panama's locks lift ships into Gatun Lake and use about 200 million liters of fresh lake water per transit, which flows down to the sea; the lake is refilled only by rain. In a dry year the lake falls, so the canal must limit transits and ship drafts. Suez is a sea-level canal filled by the sea itself, so rainfall has no effect on its depth.
12. Answers will vary. A strong answer notes that when Colombia's senate rejected a canal treaty, the United States backed a revolt in Panama in November 1903, used its navy to keep Colombian troops from crushing it, and quickly signed a treaty with Panama's representative Philippe Bunau-Varilla, a Frenchman, giving it the Canal Zone; that many then and since saw this as a wrong to Colombia (the U.S. paid Colombia \$25 million in 1921); that the U.S. then achieved one of the great engineering and medical feats of the age, conquering yellow fever and building a canal the French could not; that West Indian workers bore most of the deaths and were paid and housed unequally; and that under the 1977 treaties Panama took full control on 31 December 1999.

3.5 DOVER AND THE DANISH STRAITS: NORTHERN EUROPE'S SEA DOORS

OBJECTIVES

- Locate the Strait of Dover, the English Channel, the Øresund, the Great Belt and the Little Belt, and explain how they connect the ports of northern Europe and the Baltic to the world ocean.
- Explain how the Spanish Armada (1588) and the Danish Sound Toll (1429–1857) show the strategic and commercial value of northern straits, and how traffic separation, bridges, tunnels and the Kiel Canal (1895) have changed them.
- Use width, depth and bridge-clearance limits to decide which route a ship must take, and compare the time saved by the Kiel Canal and the Channel Tunnel.

Warm-up. Lay out a sheet of paper as the North Sea and place a book across the top edge with a gap of two fingers at one end and a slot under a ruler “bridge” at the other. Slide coins and small toy boats through each gap. Which ones fit under the bridge? Which fit through the narrow gap? Write one sentence: what two measurements of a ship would a harbor pilot need to know before choosing a route?

Watch. *Ten Minute English and British History #18 - The Late Tudors: Elizabeth and the Spanish Armada* (History Matters, 10:00). <https://www.youtube.com/watch?v=87kZSY9On7k>

After the story: watch the second half of this video for the Spanish Armada of 1588 and why King Philip II sent it against England.

Note: Captions were not available to check; preview it first. It covers all of the later Tudors, including the Catholic-Protestant conflicts and executions under Edward, Mary and Elizabeth, and the Armada is only one part.

Backup video. *Kronborg Castle - UNESCO World Heritage Site* (World Heritage Journey, 4:20). <https://www.youtube.com/watch?v=Wvn23YZVcfE>

With On the map: watch this tour of Kronborg Castle and look for how it sits on the narrow sound between Denmark and Sweden, where Danish kings taxed passing ships. Note: Captions were not available to check; preview it first. It also mentions that the castle is the setting of Shakespeare's Hamlet.

KEY TERMS

English Channel

The arm of the Atlantic between southern England and northern France, narrowing eastward to the Strait of Dover, which leads into the North Sea.

Danish Straits

The three channels between Denmark, Sweden and Germany that join the Baltic Sea to the Kattegat and the North Sea: the Øresund (the Sound), the Great Belt and the Little Belt.

toll

A fee charged for using a road, bridge or waterway. Denmark charged the Sound Toll on ships passing the Øresund for more than four centuries.

air draft

The height of a ship from the waterline to its highest point. A ship whose air draft is greater than a bridge's clearance cannot pass under it.

fixed link

A permanent bridge or tunnel across a strait, such as the Channel Tunnel, the Great Belt link or the Øresund Bridge.

Baltic Sea

A shallow, brackish enclosed sea of northern Europe, bordered by nine countries and entered from the ocean only through the Danish Straits (or the Kiel Canal).

CORE IDEAS

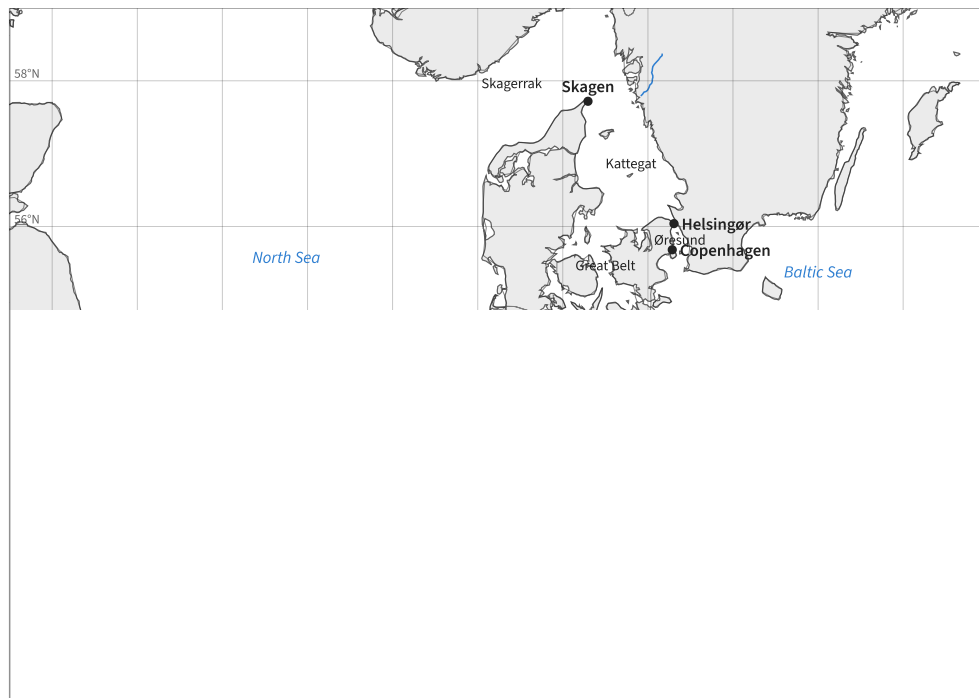
The story. In the summer of 1588 the Spanish Armada, about 130 ships under the Duke of Medina Sidonia, sailed up the English Channel. Its orders were to meet the Duke of Parma's army in the Spanish Netherlands and carry it across the narrow Strait of Dover to invade England. The plan depended on geography that did not cooperate. Parma's barges were shut in by shallow coastal waters and Dutch ships, and the Armada had no deep-water harbor to shelter in. When it anchored off Calais, the English sent in fireships on the night of 7–8 August; the Spanish cut their cables and scattered, and the next day the English fleet fought them off Gravelines. A strong southwest wind then drove the Armada north into the North Sea. With the English in the Channel behind them, the Spanish captains sailed home around Scotland and Ireland, where storms wrecked many ships and thousands of men died. In England and the Netherlands people gave thanks to God; a medal struck to remember the victory bore the Latin words meaning "He blew, and they were scattered."

How it worked. The English Channel is about 560 km (350 miles) long. At the **Strait of Dover** it narrows to about 33 km (21 miles) between the white chalk cliffs of Dover and Cap Gris-Nez in France, and it is shallow, mostly 30 to 50 m deep, with dangerous sandbanks such as the Goodwin Sands. Through this gap pass the ships of Rotterdam, Antwerp, Hamburg and the ports of the Baltic on their way to the Atlantic, so that 400 to 500 ships a day use it, while ferries cross it from side to side. In 1967 it received one of the world's first **traffic separation schemes**, later made mandatory: ships bound southwest keep to the English side and ships bound northeast to the French side, watched by British and French coastguards by radar. Farther north, the Baltic Sea is reached through the **Danish Straits**. The Øresund, between the Danish island of Zealand and Sweden, narrows to about 4 km (2.5 miles) between Helsingør and Helsingborg; the Great Belt, between Zealand and Funen, is wider and deeper and carries the largest ships; and the narrow, winding Little Belt lies farther west.

The big idea. Whoever holds both shores of a strait can tax it. In 1429 King Eric of Pomerania began collecting the **Sound Toll** from every foreign ship passing Helsingør, and Denmark collected it until 1857. Ships had to lower their topsails and anchor under the guns of the castle while the master paid; later the toll was charged on the value of the cargo, and captains who declared too low a value risked having the king buy the cargo at that price. The magnificent castle of Kronborg, rebuilt from 1574 to 1585 by King Frederick II, was paid for largely by the toll, and Shakespeare set *Hamlet* there, at “Elsinore.” The Baltic trade was the backbone of Dutch prosperity in the 1600s: grain from Danzig, timber, tar, hemp and iron for ships flowed west through the Sound, and the Danish clerks recorded every passage. Those Sound Toll registers are still used by historians to measure the trade of northern Europe. In 1857 the maritime nations paid Denmark a lump sum to end the toll forever, and the straits became free international waters for passage.

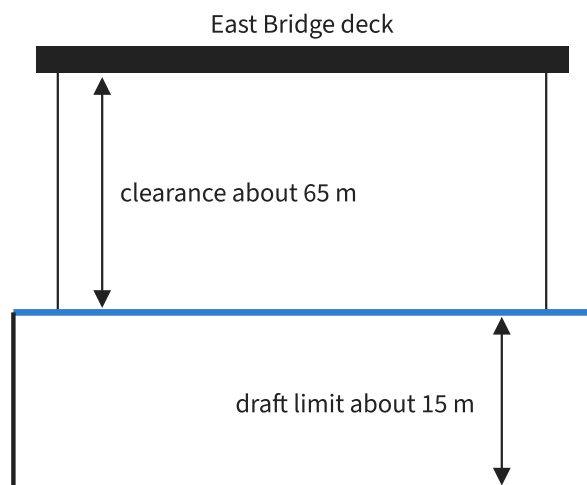
Technology overcoming geography. Northern Europe has answered its straits with engineering. Germany opened the **Kiel Canal** in 1895, about 98 km (61 miles) across the base of the Jutland peninsula, sparing ships an average of about 460 km (250 nautical miles) around Skagen; it carries more ships than either Suez or Panama, though mostly smaller ones. Louis Blériot flew across the Strait of Dover on 25 July 1909 in about 37 minutes, and on 6 May 1994 the **Channel Tunnel** opened: about 50 km (31 miles) long, 38 km (24 miles) of it under the sea, the longest undersea stretch of any tunnel in the world. Denmark linked its islands by the Great Belt bridge and tunnel (opened for rail in 1997 and road in 1998) and to Sweden by the Øresund Bridge and tunnel (2000). These **fixed links** join the lands, but they also set new limits on ships: the Great Belt East Bridge leaves about 65 m (213 ft) of clearance and the Øresund Bridge about 57 m (187 ft), so a very tall ship must use the Drogden channel above the Øresund tunnel, which has no height limit but is only about 8 m (26 ft) deep.

On the map. Using the map below, trace a container ship from the Atlantic up the Channel, through the Strait of Dover, and into Rotterdam, Europe’s largest port. Then trace a tanker from the Russian Baltic ports through the Great Belt, the Kattegat and the Skagerrak into the North Sea. As of 2026, the Danish Straits carry a large part of Russia’s seaborne oil exports, and Denmark and its neighbors have stepped up checks on old tankers out of concern for spills; undersea pipelines and cables on the Baltic floor have also been damaged in several incidents since 2022, with investigations into their causes. With this lesson you have visited all the great straits of the unit. The course midterm follows, covering the caravans of Unit 1, the monsoon seas of Unit 2 and the straits of Unit 3: keep your risk table and maps at hand as you review.



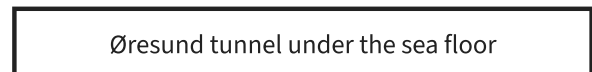
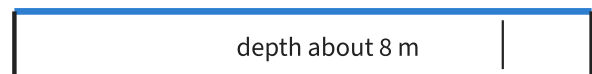
Northern Europe's sea doors. Ships reach the Baltic by the Danish Straits or the Kiel Canal, and reach the Atlantic from the North Sea by the Strait of Dover or around the north of Scotland.

Great Belt route



Drogden channel (Øresund)

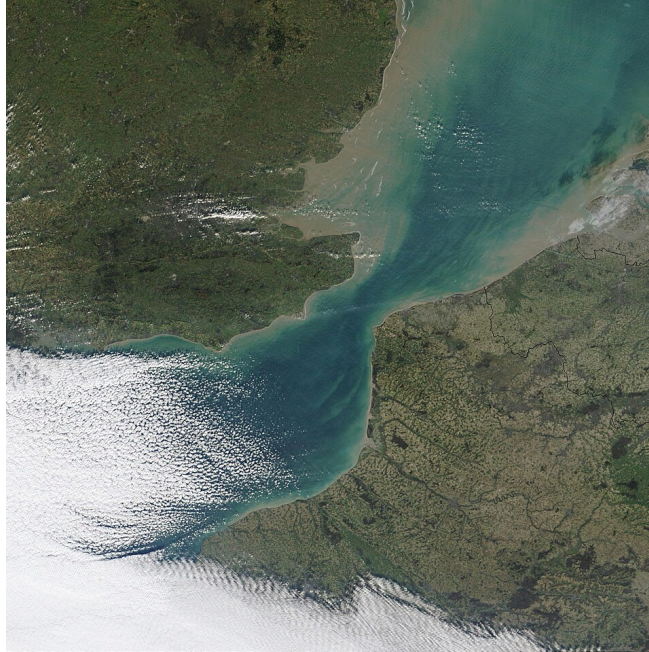
open sky: no height limit
(road and rail run in a tunnel below)



Not to scale. Approximate limits; pilots use exact charted values.

Why ships choose different Danish straits: the Great Belt is deep but has a bridge overhead; the Drogden channel over the Øresund tunnel has open sky but shallow water.

PICTURE STUDY



The Strait of Dover from orbit, NASA (MODIS instrument on the Terra satellite), published by NASA Earth Observatory and Visible Earth, 9 December 2002 · True-color satellite image (MODIS, 250 m resolution) · NASA Earth Observatory, “The Strait of Dover” (image 6840), now at science.nasa.gov/earth/earth-observatory/; public domain

On a clear day the Strait of Dover makes a striking picture from space: two countries almost touching, the chalk downs of Kent facing the cliffs of Cap Blanc-Nez and Cap Gris-Nez, and the water between them often milky green with fine chalk and sediment stirred up by the tides. Search NASA Earth Observatory for “English Channel” or “Strait of Dover.” Clear images of this cloudy corner of Europe are rare, so note the date carefully.

This is the last of the unit’s satellite pictures. Lay it beside your images of Malacca, Hormuz, Gibraltar and Panama and compare them as a set: the same instrument, the same eye from above, but five very different landscapes around five narrow waters.

Look closely

- Find Dover, Calais and the narrowest part of the strait. Does the gap look as small as 33 km (21 miles)?
- Look at the color of the water. Where is it palest? What might the tides be stirring up from the shallow sea floor?
- Compare the landscape of Kent with that of the Strait of Hormuz or the Isthmus of Suez. How does climate show in the pictures?
- Low clouds cover much of the North Sea in this picture. Where would the Thames estuary and the mouths of the Scheldt and the Rhine be? How many great ports can you name within a day’s sail of this strait?

Talk about it

1. Looking at the five satellite pictures of this unit together, which strait looks hardest to defend, and which looks hardest to sail through? Why?
2. Why might a narrow, shallow strait between two friendly countries still be counted as a choke point?

PROJECT: THE CHOKE-POINT RISK TABLE, PART 3: FINISHING AND RANKING

Complete the last two rows of your table, fill in the Cape of Good Hope row as the great “way around,” and rank all the straits from most to least risky. This finished table, with your world map, becomes the unit portfolio.

You will need

- Your risk table from Lessons 3.1–3.4
- Colored pencils, a ruler and a calculator
- A blank outline map of the world (printed or traced)

Steps

1. Fill in the Dover Strait row: English Channel to North Sea; about 33 km (21 miles); mostly 30 to 50 m deep, with sandbanks; 400 to 500 ships a day; risks: collision, fog, grounding, crossing ferries; alternative: around the north of Scotland (much longer).
2. Fill in the Danish Straits row: Kattegat to the Baltic; Øresund about 4 km (2.5 miles) at the narrowest, Drogden about 8 m (26 ft) deep; Great Belt route about 15 m (49 ft) for draft and 65 m (213 ft) bridge clearance; tens of thousands of ships a year; risks: grounding, collision, aging tankers, damage to undersea cables; alternative: the Kiel Canal (for smaller ships).
3. Fill in the Cape of Good Hope row: not a strait but open sea; no width or depth limit; heavy weather; it is the alternative to Suez and the Bab-el-Mandeb, adding about 3,500 nautical miles from Asia to northern Europe.
4. Give every row a risk color (green, yellow, red) and rank the ten from most to least risky. Write two or three sentences explaining your top three.
5. On the world map, mark each choke point with a dot in its risk color, draw the main sea lanes between them in pencil, and add a legend and a title.
6. Trade tables with a classmate or parent and see where your rankings differ. Be ready to defend yours with numbers.

Tips

- Consider all four factors together: traffic, width, depth and alternatives. A very busy strait with a good alternative may be less risky than a less busy one with none.
- Keep dates beside figures that change, especially for the Bab-el-Mandeb, Suez and Panama.

Check your work

- All ten rows are complete with units and years.

- Every row has a risk color and the list is ranked with reasons.
- My world map shows every choke point, the main sea lanes and a legend.

MAP NOTEBOOK

1. Draw a map of the English Channel and the Strait of Dover with the two shipping lanes (southwest-bound on the English side, northeast-bound on the French side), Dover, Calais, Cap Gris-Nez, the Goodwin Sands and the line of the Channel Tunnel.
2. Draw the Danish Straits and label Zealand, Funen, Jutland, Sweden, the Øresund, the Great Belt, the Little Belt, Helsingør, Copenhagen, the Kattegat, the Skagerrak, Skagen and the Kiel Canal.
3. Sketch Kronborg Castle from a picture and write three sentences about the Sound Toll: who collected it, from whom, and when it ended.

From history. In 1658, after a daring march by the Swedish army across the frozen Great Belt and Little Belt in the winter, Denmark was forced in the Treaty of Roskilde to give up Scania and the other provinces on the eastern shore of the Øresund to Sweden. From then on Denmark held only one shore of the Sound, yet it kept collecting the toll for two more centuries, protected by treaties and by the great powers' wish to keep the straits open and peaceful. The Sound Toll was finally ended by the Copenhagen Convention of 1857, in which the trading nations paid Denmark compensation; the United States, which had refused to recognize the toll, made a separate settlement.

WORKED EXAMPLES

Example 1. Three ships approach the Danish Straits bound for the Baltic. The Great Belt route takes ships up to about 15 m draft but has a bridge with 65 m clearance. The Drogden channel of the Øresund has no bridge above it but only about 8 m of water. (Use the figure *hb-danish-limits*.) Ship A: draft 14 m, air draft 55 m. Ship B (a large cruise ship): draft 8.5 m, air draft 70 m. Ship C: draft 7 m, air draft 40 m. Which route can each use? Ignore safety margins.

(Use the map or drawing “Use the depth and clearance limits shown here.” shown earlier in this lesson.)

1. Ship A: $14\text{ m} < 15\text{ m}$ and $55\text{ m} < 65\text{ m}$, so it fits the Great Belt. Its 14 m draft is far too deep for Drogden (8 m). Great Belt only.
2. Ship B: $70\text{ m} > 65\text{ m}$, so it cannot pass under the Great Belt bridge; Drogden has no bridge but is only 8 m deep, and $8.5\text{ m} > 8\text{ m}$. Neither route works at this draft. (In practice, cruise ships built for the Baltic are designed with an air draft under 65 m so they can pass beneath the Great Belt bridge; a ship like this one cannot enter the Baltic by either route.)
3. Ship C: $7\text{ m} < 8\text{ m}$ and $40\text{ m} < 65\text{ m}$, so either route is possible.

Answer: Ship A: Great Belt only. Ship B: neither route at its present draft. Ship C: either route.

Example 2. The Kiel Canal is about 98 km long and spares ships about 460 km compared with sailing around Skagen. Ships must keep to about 15 km/h in the canal; at sea a small freighter makes 12 knots (22.2 km/h). How much time does the canal save? (Hint: the canal route is 460 km shorter, but its 98 km are sailed more slowly.)

1. Time for the extra 460 km at sea: $460 \div 22.2 \approx 20.7$ hours.
2. The 98 km of canal: at sea speed they would take $98 \div 22.2 \approx 4.4$ hours, but in the canal they take $98 \div 15 \approx 6.5$ hours, so the canal costs $6.5 - 4.4 = 2.1$ hours of slower sailing.
3. Net saving: $20.7 - 2.1 = 18.6$ hours, before any waiting time at the locks at each end.

Answer: About 18 to 19 hours saved, less any waiting at the canal locks.

Example 3. Louis Blériot flew across the Strait of Dover in 1909, a flight of roughly 36 km (22 miles), in about 37 minutes. A Channel Tunnel shuttle train covers about 50 km (31 miles) in about 35 minutes. Find the average speed of each in km/h and mph (1 mile = 1.609 km).

1. Blériot: $36 \div (37 \div 60) = 36 \div 0.617 \approx 58$ km/h; $58 \div 1.609 \approx 36$ mph.
2. Shuttle: $50 \div (35 \div 60) = 50 \div 0.583 \approx 86$ km/h; $86 \div 1.609 \approx 53$ mph.
3. The shuttle carries cars, trucks and their passengers in any weather; Blériot carried one man, in calm morning air, and the flight was a triumph because it had never been done.

Answer: Blériot about 58 km/h (36 mph); the shuttle about 86 km/h (53 mph).

PRACTICE

1. **EASY** Name the three Danish Straits and the sea they lead into.
2. **EASY** Convert the width of the Strait of Dover, about 33 km, into miles and nautical miles.
3. **EASY** What was the Sound Toll, and between which years did Denmark collect it?
4. **EASY** When did the Channel Tunnel open, and how much of its length lies under the sea?
5. **MEDIUM** In the Dover Strait traffic separation scheme, which lane do southwest-bound ships use, and why does that match the rule of the road?
6. **MEDIUM** Explain how the narrow sea helped England in 1588, even though the Strait of Dover is only 33 km wide.
7. **MEDIUM** Use the map *hb-north-doors-map*. A ship sails from Hamburg to Gdańsk. Name two routes it could take and the water it would cross on each.
(Use the map or drawing "Use this map for problem 7." shown earlier in this lesson.)
8. **MEDIUM** Why did Denmark, a small kingdom, become rich from the Sound Toll? Use the words "both shores."
9. **MEDIUM** A ship has an air draft of 60 m and a draft of 10 m. Can it pass under the Øresund Bridge (57 m clearance)? Can it use the Drogden channel (about 8 m deep)? What route should it take?
10. **HARD** If 450 ships a day pass the Strait of Dover, how many is that per year, and how does it compare with the roughly 80,000 ships a year counted at Malacca?
11. **HARD** A fixed link joins two lands but can limit ships. Give one example from this lesson of each effect.
12. **CHALLENGE** Midterm review: Write a paragraph comparing any three straits from this unit on four measures: traffic, width, depth and alternatives. Then say which of the three you would rate most at risk and why.

COMMON MISTAKES

- Thinking the English Channel and the Strait of Dover are two different places. The strait is the narrow eastern end of the Channel.
- Forgetting bridges. In the Danish Straits a ship can be too tall for one route as easily as it can be too deep for another.
- Calling the Kiel Canal a Danish strait. It is a German canal across Schleswig-Holstein that lets ships avoid the Danish Straits.

Make it a game · Strait Pilot (Midterm Review). Write each of the ten choke points from your risk table on a card, and on the back write its width, depth or size limit, traffic and alternative. A parent reads out a ship: "Draft 14 m, air draft 70 m, bound from Rotterdam to Shanghai." Players race to name every strait or canal it must pass and any it cannot use. A correct route scores two points; catching a limit (a bridge, a lock or a shallow channel) scores a bonus point. Mix in questions from Units 1 and 2 to review for the midterm.

Scripture. "The LORD on high is mightier than the noise of many waters, yea, than the mighty waves of the sea." (Psalm 93:4, KJV)

The people of 1588 saw the hand of God in the winds that scattered the Armada. Christians have long confessed that the winds and the sea are His, and that nations, fleets and merchants, however strong, act under His providence.

Practice answers

1. The Øresund (the Sound), the Great Belt and the Little Belt; they lead into the Baltic Sea.
2. $33 \div 1.609 \approx 20.5$ miles; $33 \div 1.852 \approx 17.8$ nautical miles.
3. A fee charged by the king of Denmark on foreign ships passing through the Øresund at Helsingør, collected from 1429 until 1857.
4. 6 May 1994. About 38 km (24 miles) of its roughly 50 km (31 miles) lies under the sea.
5. The lane on the English (northwest) side. Ships keep to the right of their course, as on many roads, and for a ship heading southwest the right-hand side is toward England, so opposite traffic streams are kept apart.
6. The Armada had to bring Parma's army across from the Spanish Netherlands, but the shallow coast and Dutch ships kept Parma's barges in harbor, and the Armada had no deep-water port in which to shelter or wait. Anchored in the open off Calais, it was broken up by fireships, beaten at Gravelines and blown north into the North Sea, so it could not hold the strait long enough to carry the army over.
7. Route 1: down the Elbe to Brunsbüttel, through the Kiel Canal to Kiel, then east across the Baltic to Gdańsk. Route 2: down the Elbe into the North Sea, north around Skagen through the Skagerrak and Kattegat, through the Great Belt or the Øresund, and across the Baltic to Gdańsk.
8. Until 1658, Denmark held both shores of the Øresund (including Scania, now in Sweden), and the Sound was the main route between the Baltic and the North Sea. With castles and guns on both shores it could force every foreign ship to stop and pay, and the Baltic trade in grain, timber, tar and iron was very large, so the toll brought great wealth.

9. No: 60 m is higher than 57 m. No: 10 m is deeper than 8 m. It should use the Great Belt, where the bridge clearance is 65 m ($60 < 65$) and the route takes drafts to about 15 m ($10 < 15$).
10. $450 \times 365 = 164,250$ ships a year, about twice Malacca's 80,000. (Counts at different straits are made in different ways, and Dover's include many short-sea ships, so the comparison is rough; Malacca carries more oil and larger ships.)
11. Joining: the Channel Tunnel carries trains, cars and trucks between England and France in about 35 minutes; the Øresund Bridge links Copenhagen and Malmö. Limiting: the Great Belt East Bridge's 65 m clearance and the Øresund Bridge's 57 m clearance stop very tall ships, which must use the shallow Drogden channel.
12. Answers will vary. A strong answer gives accurate figures with years (for example: Malacca, more than 80,000 ships a year and about 23 million b/d of oil in 2023, about 2.8 km wide at the Phillips Channel, about 25 m deep, alternatives Sunda and Lombok; Hormuz, about 20 million b/d in 2023–2024, about 39 km wide, deep, few alternatives beyond pipelines with about 2.6 million b/d spare; Bosphorus, about 40,000 ships a year, about 700 m wide, no sea alternative), and defends a ranking with reasons, such as that Hormuz is most at risk because its alternatives are smallest compared with its flow.

UNIT 3 TEST

Answer each question. Show your work for calculations, give units (km and miles where asked), and use complete sentences for explanations. Use these conversions: 1 mile = 1.609 km; 1 nautical mile = 1.852 km; 1 knot = 1 nautical mile per hour; 1 barrel = 159 liters. The test is worth 100 points.

1. (6 pts) Name the two land masses on either side of the Strait of Malacca, the city at its southern door, and the two Indonesian straits a ship could use instead.
2. (6 pts) Tomé Pires wrote that whoever is lord of Malacca has his hand on the throat of Venice. Explain what he meant and why the Portuguese took Malacca in 1511.
3. (6 pts) More than 80,000 ships a year pass the Strait of Malacca. Using 80,000, how many ships pass per day and per hour on average?
4. (6 pts) Which countries lie on the two shores of the Strait of Hormuz, and about how much oil passed through it each day in 2023–2024? What share of world oil consumption is that?
5. (8 pts) If Hormuz were closed and about 2.6 million barrels a day of spare pipeline capacity could bypass it, what percent of a 20 million barrel-a-day flow could still reach the sea? Name the two bypass pipelines and their end ports.
6. (8 pts) Describe factually what happened to shipping through the Bab-el-Mandeb from November 2023, and calculate how many extra days a container ship at 16 knots needs for one voyage from Asia to northern Europe around the Cape of Good Hope if the detour adds 3,500 nautical miles.
7. (6 pts) Name the three parts of the Turkish Straits in order from the Black Sea, and give the approximate narrowest width of the Bosphorus and of the Strait of Gibraltar.
8. (8 pts) Explain the two-layer flow at Gibraltar and at the Bosphorus, including which way the saltier water flows at each strait and why.
9. (6 pts) What did Mehmed II build in 1452, and what does the Montreux Convention (1936) guarantee today?
10. (8 pts) Explain why the Suez Canal has no locks but the Panama Canal does. Include the height of Gatun Lake.
11. (6 pts) The Panama Canal shortened a voyage from New York to San Francisco from about 22,500 km to about 9,500 km. How many kilometers and what percent were saved?
12. (8 pts) Name one achievement and one wrong in the building of each canal (Suez and Panama).
13. (8 pts) A ship bound for the Baltic has a draft of 7 m and an air draft of 68 m. Can it use the Great Belt route (clearance 65 m, draft limit about 15 m)? The Drogden channel of the Øresund (no height limit, about 8 m deep)? Explain. Then name the canal that lets smaller ships avoid the Danish Straits altogether.
14. (10 pts) Choose the strait or canal you judge most at risk and the one you judge least at risk. For each, give its traffic or cargo figure (with a year), its width or size limit, and its main alternative, and explain your judgment in a short paragraph.

UNIT PROJECT: THE WORLD'S CHOKE POINTS: RISK TABLE AND SEA-LANE MAP

Present your finished choke-point risk table for all ten straits and canals (Malacca, Hormuz, Bab-el-Mandeb, Gibraltar, the Bosphorus and Dardanelles, Suez, Panama, Dover, the Danish Straits and the Cape of Good Hope as the way around), with traffic, width, depth or size limit, key cargo, risks, alternatives and a risk color for each, every changing figure dated. Beside it, draw a world map of the main sea lanes with each choke point marked in its risk color, and include your satellite-image notes from the five picture studies.

Finish with a one-page written briefing, as if for a shipping company's board, that ranks the three choke points you judge most at risk and recommends one practical step the company should take to prepare for each, written neutrally and without taking sides in any nation's quarrels.

- **Accuracy:** Widths, depths, traffic and cargo figures are correct, with units and years, and the choke points and sea lanes are placed correctly on the map.
- **Reasoning:** Risk colors and the ranking are defended with evidence that weighs traffic, width, depth and alternatives together.
- **Briefing:** The written briefing is clear, factual and neutral, and its recommendations follow from the geography.
- **Care:** The table and map are neat, legible and complete, with a title, legend and sources.

Answer key

1. The Malay Peninsula and Sumatra; Singapore; the Sunda Strait and the Lombok Strait.
2. Spices from the East reached Venice by way of Malacca, where the ships of the Indian Ocean and of the Spice Islands and China met. Whoever controlled Malacca could control or cut that trade, choking Venice's supply. The Portuguese took Malacca to control the spice trade at its door.
3. $80,000 \div 365 \approx 219$ per day; $219 \div 24 \approx 9$ per hour.
4. Iran to the north and Oman (Musandam Peninsula) to the south. About 20 million barrels a day, roughly one-fifth of world oil consumption.
5. $2.6 \div 20 = 13\%$. The Saudi East-West pipeline from the Abqaiq area to Yanbu on the Red Sea, and the UAE pipeline from Habshan to Fujairah on the Gulf of Oman.
6. From November 2023 the Houthi movement in Yemen seized a ship and attacked merchant ships with missiles and drones; ships were struck and some sunk, and many lines rerouted around Africa, cutting traffic through the strait and Suez by roughly half in 2024. Extra time: $3,500 \div 16 = 218.75$ hours ≈ 9.1 days.
7. The Bosphorus, the Sea of Marmara and the Dardanelles. The Bosphorus narrows to about 700 m (2,300 ft); Gibraltar to about 14 km (9 miles).
8. At Gibraltar the Mediterranean loses more water by evaporation than rivers and rain supply, so fresher Atlantic water flows east into the sea at the surface while saltier, denser Mediterranean water flows west out over the sill near the bottom. At the Bosphorus the Black Sea receives more fresh river water than it evaporates, so fresher water flows south out of the Black Sea at the surface while saltier Marmara water flows north into the Black Sea near the bottom. In both, the saltier water is heavier and flows along the bottom.

9. The fortress of Rumeli Hisarı at the narrowest point of the Bosphorus, to cut off ships supplying Constantinople from the Black Sea. The Montreux Convention gives Turkey control of the straits, guarantees free passage for merchant ships in peacetime, and limits the passage of warships (allowing Turkey to close the straits to warships of warring states).
10. At Suez the land is low and flat and the Mediterranean and the Red Sea are nearly level, so a sea-level canal could be dug. At Panama a mountain ridge and the flooding Chagres River made a sea-level cut impractical (as the French found), so the Americans dammed the Chagres to make Gatun Lake, about 26 m (85 ft) above sea level, and built locks to lift ships into the lake and lower them on the other side.
11. $22 \times 500 - 9 \times 500 = 13 \times 1000$ km; $13 \times 1000 \div 22 \times 500 \approx 58\%$.
12. Suez: achievement, a 160-km sea-level canal joining two seas, opened in 1869, which cut thousands of kilometers from Europe-Asia voyages; wrong, Egyptian peasants were forced to dig by corvée and many died. Panama: achievements, the conquest of yellow fever under Gorgas and the great locks and Gatun Dam, opened in 1914; wrongs, West Indian workers were paid and housed unequally on the silver roll and bore most of the roughly 5,600 deaths, and the U.S. backing of Panama's break from Colombia in 1903 was seen as a wrong to Colombia. Other accurate examples accepted.
13. Not the Great Belt: 68 m is higher than the 65 m bridge clearance. Yes, Drogden: it has no bridge overhead and the ship's 7 m draft is less than about 8 m. The Kiel Canal (opened 1895) across Schleswig-Holstein lets smaller ships avoid the Danish Straits.
14. Answers will vary. Full credit requires accurate figures with years and units for both choices, a named alternative for each, and reasoning that weighs traffic, width, depth and alternatives. For example: Hormuz most at risk (about 20 million b/d of oil in 2023-2024; about 39 km wide with 3-km lanes; bypass pipelines with only about 2.6 million b/d spare) and Gibraltar least at risk (about 14 km wide, deep, between friendly states, though with no sea alternative for the western Mediterranean).

RESOURCES AND WHERE THEY LIE

“In the beginning God created the heaven and the earth” (Genesis 1:1), and He did not spread its treasures evenly. Salt lies in the Sahara but not in the Sahel; silver in one red mountain of the Andes; coal under Lancashire and the Ruhr; oil around the Persian Gulf; deep black soils in the grasslands of Ukraine and Kansas; rare earths in a few unusual rocks. Trade begins with that unevenness. In this unit you will learn where the great resources lie, why they lie there, and how the cost of moving them has shaped cities, empires and the routes you studied in Units 1 to 3.

Each lesson starts with a real moment: Ibn Battuta among the salt houses of Taghaza in 1352, the silver strike at Potosí in 1545, Abraham Darby’s coke furnace at Coalbrookdale in 1709, Edwin Drake’s well on Oil Creek in 1859, and Britain’s choice in 1846 to buy its bread abroad. You will meet real achievements and real wrongs, among them the mita of Potosí and the forced labor of the Ruhr in the Second World War, and judge them by the standards and knowledge of their own time.

You will also work like an economic geographer: computing caravan and tanker voyages, salt from seawater and copper from low-grade ore, the yearly rate of the sixteenth-century price revolution, Weber’s least-cost location for an ironworks, and producers’ shares of the rare-earth market. The unit ends with a resource-to-product chain for one everyday object, tracing it from mine and field to your own home.

BEFORE YOU BEGIN

- Can estimate distances from latitude and longitude (111 km per degree of latitude) and convert km, miles and nautical miles
- Can compute speed, time and distance and work with percentages and ratios
- Knows the major straits and sea lanes from Unit 3 (Hormuz, Malacca, the Bosphorus, Suez and Panama)
- Can read a world map with a grid and locate continents, major rivers and seas

MASTERY CHECKLIST

- I can explain why salt, silver, coal, oil, grain, copper and rare earths lie where they do, and locate the major sources of each on a world map.
- I can explain why the value of a resource depends on the cost of moving it, and calculate journeys by caravan, barge, pipeline and ship.
- I can explain the price revolution with the quantity equation and weigh its causes.
- I can use Weber’s least-cost reasoning to explain why industry once clustered on coalfields and later moved to the coast.
- I can describe how oil and gas move by pipeline, tanker and LNG carrier, and why each fits a different geography.

- I can explain resource concentration neutrally and compare it with a sea-lane choke point.

OPTIONAL BOOKS AND RESOURCES

- **USGS Mineral Commodity Summaries** (<https://www.usgs.gov/centers/national-minerals-information-center/mineral-commodity-summaries>): Free. The U.S. Geological Survey's yearly two-page summaries of production, reserves and uses for about ninety minerals, including salt, silver, gold, iron ore, copper and rare earths. Ideal for checking current figures in the unit project.
- **Energy Explained, from the U.S. Energy Information Administration** (<https://www.eia.gov/energyexplained/>): Free. Clear explanations, maps and data on oil, natural gas and coal: where they are found, how they are produced and how they move.
- ***I, Pencil*, by Leonard E. Read (1958)** (<https://fee.org/resources/i-pencil/>): Free. A short, famous essay in which a pencil tells the story of the cedar, graphite, rubber and metal that go into it and the many people around the world who make it. The model for the unit portfolio.

4.1 SALT

OBJECTIVES

- Explain why salt was one of the first great trade goods and name its three geographic sources (the sea, rock salt and brine springs), with a real example of each.
- Locate Taghaza, Taoudenni and Timbuktu and explain how the salt-for-gold trade of the western Sahara grew out of physical geography.
- Calculate salt yields from seawater and the distance, time and carrying capacity of a Saharan salt caravan, and use them to explain why transport cost sets the price of a resource.

Warm-up. Pull five packaged foods from your kitchen and read the sodium line on each label. Then imagine your family has no refrigerator, no freezer and no cans. List three foods you could keep through a winter and how you would keep them. How many of your answers need salt? Keep the list for the end of the lesson.

Watch. *Wieliczka Royal Salt Mines - UNESCO World Heritage Site* (World Heritage Journey, 4:19). <https://www.youtube.com/watch?v=FsA3ihntoTg>

After the story: watch this short tour of Poland's Wieliczka salt mine to see how valuable salt was in Europe, and look for the rooms, chapels and statues carved entirely out of salt.

Note: Captions were not available to check; preview it first. The video may give a geological age for the salt deposits in millions of years. The story is about Saharan salt (Taghaza and the caravans to Timbuktu). This video shows a European rock-salt mine near Kraków, Poland, so it is a comparison, not the story's setting.

Backup video. *Nomads: Salt Caravans in the Niger (Accessible Preview)* (Described and Captioned Media Program, 3:37). <https://www.youtube.com/watch?v=5Pl1hYyffFa8>

After the story: watch a real Tuareg camel caravan cross the desert to load salt at Bilma, and compare it with the salt town of Taghaza that Ibn Battuta described. Note: Captions were not available to check; preview it first. This is an accessible preview from an educational distributor, so a describer's voice may read out what is on screen, and distances are given in kilometers. This caravan goes from Timia to Bilma in Niger, not the Taghaza or Taoudenni-to-Timbuktu route in the lesson.

KEY TERMS

halite

The mineral name for rock salt (sodium chloride) found in thick beds underground, left where salty water once dried away.

brine

Water that holds a large amount of dissolved salt, such as seawater or the water of a salt spring or salt well.

saltern (salt pan)

A wide, shallow pond where seawater or brine is left in the sun and wind to evaporate, leaving salt behind.

azalai

The great camel caravans that carried slabs of rock salt from the Saharan mines (Taghaza, later Taoudenni) south to Timbuktu.

break-of-bulk point

A place where goods must be unloaded from one kind of transport and reloaded onto another, such as from camel to river boat; such places often grow into cities.

complementarity

When one region has what another lacks and lacks what the other has, so that both gain by trading.

CORE IDEAS

The story. In the winter of 1352 the Moroccan traveler Ibn Battuta rode south from Sijilmasa, the caravan city on the northern edge of the Sahara. After about twenty-five days he came to Taghaza, one of the strangest towns on earth. Its houses and its mosque, he wrote, were built of blocks of salt and roofed with camel skins. There were no trees, only sand, and the water was brackish. Nothing grew there; every date and every handful of millet had to be carried in. Yet Taghaza was rich, because under the sand lay thick beds of rock salt. The Masufa, a Berber people of the desert, controlled the diggings, and the hard labor was done by enslaved workers who cut the salt into great slabs. Camels carried the slabs south to the lands of the Sahel, where, Ibn Battuta noted, salt was cut into pieces and used as money, and traded for gold. A town no one would choose to live in had become a hinge of the African economy because of what God had laid beneath it.

Why salt mattered. Every person and every grazing animal needs salt to live, and before canning and refrigeration salt was the main way to keep food. Salted fish, salted pork and cheese carried armies, sailors and whole towns through the winter. Herring from the Baltic was packed in salt by the barrel, and the Hanseatic city of Lübeck grew rich partly by carrying salt from the brine springs of Lüneburg to the herring fisheries. Rulers learned early that a thing everyone must buy is easy to tax. The Han emperors of China made salt and iron a state monopoly, and in 81 BC their officials argued over it in a court debate later written up as the *Discourses on Salt and Iron*. France's salt tax, the *gabelle*, was hated for centuries until the Revolution abolished it in 1790. The Romans built the Via Salaria, the "salt road," from the salt pans near the mouth of the Tiber into the hills of central Italy. Pliny the Elder wrote in his *Natural History* that the word *salarium*, an allowance or payment and the root of our word "salary," came from *sal*, salt. Historians still debate whether Roman soldiers were ever actually paid in salt; the word's link to salt is certain, but the popular story that legionaries drew their wages in salt is not proven.

On the map. Salt is common, but it is not evenly spread, and that unevenness is what made it a trade good. It comes from three kinds of places. The first is the sea. Seawater holds about 35 grams of dissolved salts in each kilogram, and on hot, dry, sunny coasts people let it

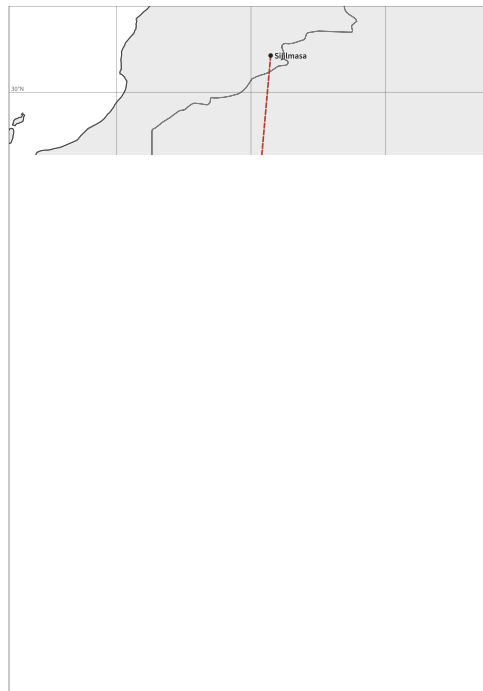
evaporate in shallow **salterns**. The Mediterranean shores, the Bay of Bourgneuf in western France (whose “bay salt” the Hansa shipped north) and the coast of Gujarat in India have made sea salt for centuries. The second is rock salt, the mineral **halite**, lying in thick beds underground. Taghaza and Taoudenni in the Sahara, Wieliczka near Kraków in Poland (mined from the 1200s until 1996), Hallstatt in the Austrian Alps, Cheshire in England and the salt domes of the Texas and Louisiana coast are all rock-salt country. The third is **brine** springs and wells, where salty groundwater rises: Lüneburg in Germany, Droitwich in England and Zigong in Sichuan, where Chinese drillers using bamboo cables and iron bits reached about 1,000 meters (about 3,300 feet) with the Shenhai Well in 1835. Now notice the pattern in West Africa. The Sahara had salt but no gold and little food; the wetter lands to the south had gold and grain but almost no salt. Geography had set the two regions up as natural trading partners, a case of **complementarity**.

How the trade worked. Gold came from the river gravels of Bambuk and Bure in the upper Senegal and Niger country. Salt came from the desert mines. The empires of Ghana and then Mali grew strong by taxing the exchange. Mali’s ruler Mansa Musa made his pilgrimage to Mecca in 1324 with so much gold that, according to the Arab writer al-Umari, its value in Cairo was still depressed years later. Timbuktu stood near the great northern bend of the Niger River, a few miles from its river port of Kabara, exactly where the desert met the water. Camels did poorly in the wet, fly-ridden lands to the south, and boats could not cross the sand, so goods had to be unloaded and reloaded there. Such a **break-of-bulk point** tends to grow into a city. Salt slabs went upriver by boat to Djenné and beyond; gold, ivory, kola nuts and grain went north. The desert trade carried something darker as well: for centuries enslaved people were marched north across the Sahara, and that wrong belongs in the story beside the scholars of Timbuktu’s Sankore mosque and the manuscripts its families kept. Leo Africanus, who visited Timbuktu in the early 1500s, reported that salt there was very scarce and very dear. Moroccan forces seized Taghaza in the 1580s, and in 1591 a Moroccan army crossed the desert and defeated the Songhai empire. Taghaza was abandoned, and the miners opened new pits at Taoudenni, about 140 kilometers (90 miles) to the southeast.

The big idea. Salt teaches the first law of resource geography: a resource is worth what it costs to bring it to the people who need it. A slab that was cheap at Taoudenni was dear in Timbuktu and dearer still in Djenné, because every day on the road added cost. The **azalai** caravans sometimes numbered thousands of camels, each carrying about four slabs of roughly 30 kilograms (66 pounds). They moved in the cooler months at about 35 kilometers (20 miles) a day, and the trip of roughly 660 kilometers (410 miles) in a straight line took about three weeks each way. Where transport is slow and costly, a common thing becomes precious. Where transport is cheap, even a precious thing becomes common.

Technology overcoming geography. Railroads, steamships and modern mining ended salt’s long reign. By the late 1800s salt from Cheshire or Louisiana could be shipped almost anywhere for pennies a sack, refrigeration took over much of its work, and salt monopolies lost their power. Today the world produces roughly 280 million tonnes of salt a year (2020s), led by China, the United States and India, and most of it goes not to the table but into chemical plants and onto winter roads. Yet the old geography has not quite vanished. Into

the twenty-first century camel caravans still carried slabs from Taoudenni to Timbuktu, though trucks now haul much of the load. The salt is still where God laid it; what has changed is the cost of the road.



Salt from the desert, gold from the south: the trans-Saharan salt trade.

PICTURE STUDY



Timbuktu from the Terrace of the Traveller's House, Johann Martin Bernatz, after a sketch by Heinrich Barth, 1858 · Tinted lithograph by M. & N. Hanhart, from a drawing by Bernatz; plate in Volume 4 of Heinrich Barth's *Travels and Discoveries in North and Central Africa* (London: Longman, 1857-1858) · Published book; copies in many libraries, including the Library of Congress and the British Library

The German scholar Heinrich Barth reached Timbuktu in September 1853 after crossing the Sahara on a British-sponsored expedition. He stayed for months, sketching and writing, and was one of the first Europeans to return from the city and describe it in detail. Back in Europe, the artist Johann Martin Bernatz turned his sketches into plates for Barth's five-volume account.

By Barth's time Timbuktu was past the height of its wealth, but it still lived on the meeting of camel and boat: salt from the north, grain and gold from the south. Look for signs of a city built with what the land provided, and of a city that depended on what came from far away.

Look closely

- Find the mosque tower. What is it built of, and why might builders in the Sahel use that material rather than stone or timber?
- Look at the roofs and the streets. Do you see any trees, fields or water? Where must the city's food have come from?
- Find the people and animals in the foreground. Which ones might belong to a caravan?
- Notice how flat the land is. How does that help explain why the Niger and the desert met here?

Talk about it

1. Barth drew Timbuktu as a working trade town, not a fairy-tale city of gold. Why might Europeans have expected something grander?
2. Using the map, explain why a city grew at this spot and not 200 miles north or 200 miles south.
3. What goods would you expect to see in Timbuktu's market, and which direction did each come from?

Safety first. Use the stove or oven only with an adult. Boiling brine spits and the pan stays hot long after the water is gone; use oven mitts and keep the salt pan at the back of the stove.

PROJECT: MAKE SALT LIKE A SALTERN

You will mix a brine as salty as the ocean, evaporate it in two pans of different shapes, and weigh what you get. Along the way you will discover why salt pans along the Mediterranean and the Bay of Bourgneuf were built wide and shallow, and why salt from the sun was cheap only on hot, dry, windy coasts.

You will need

- Table salt or, better, canning salt (no additives)
- A kitchen scale that reads grams
- Two pans of very different shapes: one wide and shallow (a baking sheet with sides or a pie dish) and one narrow and deep (a tall mug or jar)

- Measuring cup and water
- A sunny windowsill, or an oven at its lowest setting with an adult
- Notebook, pencil and ruler; a magnifying glass if you have one

Steps

1. Weigh 35 g of salt and stir it into 1 liter (about 4¼ cups) of warm water until it dissolves. This is about as salty as the open ocean.
2. Pour 250 mL (about 1 cup) into the wide pan and 250 mL into the narrow container. Measure and record the surface area of each (length × width, or $3.14 \times \text{radius}^2$ for a round one).
3. Set both in the same sunny, airy place. Each day at the same time, record the day, the weather and how much water seems to be left.
4. If you are short on time, an adult may put the wide pan in an oven at its lowest setting with the door cracked, and record how long it takes.
5. When the wide pan is dry, scrape and weigh the salt. Compare with the 8.75 g you put in ($35 \text{ g} \times 0.25$). Explain any difference.
6. Look at the crystals with a magnifying glass and sketch their shape. Halite forms cubes.
7. Write a paragraph: Which pan dried first and why? Name two climates where a saltern would work well and two where it would not, using what you know about sun, wind and rain.

Tips

- Evaporation happens at the surface, so the wide pan should win by a large margin. That is the whole secret of a saltern.
- Real seawater also holds magnesium and calcium salts. Saltworkers moved the brine from pond to pond so that the purest salt crystallized in the last one.

Check your work

- I can explain why salterns are wide and shallow.
- I can predict which coasts are good for sea salt using sun, wind and rainfall.
- I can compare the salt I recovered with the salt I put in and explain the difference.

MAP NOTEBOOK

1. Copy the outline of West Africa from the lesson map. Mark Taghaza, Taoudenni, Timbuktu, Djenné, Gao and the Niger River, and shade the Sahara, the Sahel and the wetter south in three colors. Draw arrows labeled “salt” going south and “gold” going north.
2. Draw a cross-section of the three sources of salt side by side: a saltern on a coast, a rock-salt bed with a mine shaft, and a brine well. Label each with one real place.
3. Make a small table titled “Why salt was worth more far away” with columns for place, distance from the mine and probable price (cheap, dear, very dear).

From history. Salt taxes stirred trouble wherever they were heavy. The French *gabelle* charged very different prices from province to province, so smugglers carried salt across internal borders and were punished harshly; the revolutionary National Assembly abolished the tax in 1790. In British India the salt tax and the ban on private salt-making were the target of Mohandas Gandhi's Salt March in 1930, when he walked about 240 miles (390 km) from his ashram near Ahmedabad to the sea at Dandi and picked up a lump of natural salt from the shore.

WORKED EXAMPLES

Example 1. Seawater holds about 35 g of dissolved salts per kilogram, and about 78% of that is sodium chloride (common salt). How many kilograms of seawater must evaporate to make one 30 kg slab of salt, the size of a Taoudenni slab?

1. Sodium chloride per kilogram of seawater: $35 \text{ g} \times 0.78 = 27.3 \text{ g}$.
2. Salt needed: $30 \text{ kg} = 30,000 \text{ g}$.
3. Seawater needed: $30,000 \text{ g} \div 27.3 \text{ g per kg} \approx 1,099 \text{ kg}$.
4. A kilogram of seawater is a little less than a liter, so this is roughly 1,070 liters, more than five bathtubs.

Answer: About 1,100 kg (1.1 tonnes) of seawater, roughly 1,070 liters (about 280 gallons), for one 30 kg slab.

Example 2. Taoudenni lies at about 22.7°N , 4.0°W and Timbuktu at about 16.8°N , 3.0°W . Estimate the straight-line distance between them in kilometers and miles. Use 111 km per degree of latitude, and $111 \text{ km} \times \cos(\text{latitude})$ per degree of longitude at the middle latitude. Then find how many days a caravan needs at 35 km a day.

(Use the map or drawing "Measure the azalai route from Taoudenni to Timbuktu." shown earlier in this lesson.)

1. North-south: $22.7^\circ - 16.8^\circ = 5.9^\circ$; $5.9 \times 111 \text{ km} \approx 655 \text{ km}$.
2. Middle latitude $\approx 19.7^\circ$; $\cos 19.7^\circ \approx 0.94$. East-west: $1.0^\circ \times 111 \times 0.94 \approx 104 \text{ km}$.
3. Distance $\approx \sqrt{(655^2 + 104^2)} = \sqrt{(429,025 + 10,816)} = \sqrt{439,841} \approx 663 \text{ km}$.
4. In miles: $663 \div 1.609 \approx 412 \text{ miles}$.
5. Days: $663 \div 35 \approx 18.9$, so about 19 days, and more on the ground because the route bends between wells.

Answer: About 660 km (410 miles) in a straight line, about 19 days of travel at 35 km a day.

Example 3. An azalai of 1,000 camels carries 4 slabs of 30 kg on each camel. (a) How many tonnes of salt does it carry? (b) A modern bulk ship loads 50,000 tonnes of salt at a Mexican or Australian salt works. How many such caravans would it take to carry one shipload?

1. (a) Per camel: $4 \times 30 \text{ kg} = 120 \text{ kg}$. Whole caravan: $1,000 \times 120 \text{ kg} = 120,000 \text{ kg} = 120 \text{ tonnes}$.
2. (b) $50,000 \text{ t} \div 120 \text{ t per caravan} \approx 417 \text{ caravans}$.
3. That is about 417,000 camel loads, carried by a ship with a crew of about twenty people.

Answer: (a) 120 tonnes. (b) About 417 caravans of 1,000 camels each. This is why cheap sea transport ended salt's value as a luxury.

PRACTICE

1. **EASY** Name the three geographic sources of salt and give one real place for each.
2. **EASY** What Latin word is the root of "salary," what does it come from, and what part of the popular story is uncertain?
3. **EASY** Why did Timbuktu grow where it did?
4. **EASY** In what year did Mansa Musa make his pilgrimage to Mecca, and what happened to the value of gold in Cairo?
5. **MEDIUM** Using 27.3 g of sodium chloride per kilogram of seawater, how much salt can be made from 500 kg of seawater?
6. **MEDIUM** Taghaza is at about 23.6°N , 5.0°W and Taoudenni at about 22.7°N , 4.0°W . Estimate the distance between the two mines in km and miles.
(Use the map or drawing "The old mine and the new mine." shown earlier in this lesson.)
7. **MEDIUM** Use the map. Taghaza is at about 23.6°N , 5.0°W and Timbuktu at about 16.8°N , 3.0°W . Estimate the straight-line distance in km and miles.
(Use the map or drawing "From Taghaza to Timbuktu." shown earlier in this lesson.)
8. **MEDIUM** A caravan travels from Taoudenni to Timbuktu (663 km each way) and back at 35 km a day, and spends 5 days loading at the mine. How long is the round trip?
9. **MEDIUM** One camel carries 120 kg of salt. A desert truck carries 20 tonnes. How many camels does one truck replace?
10. **HARD** Explain the complementarity between the Sahara and the lands south of it, using physical geography (rainfall, rock, rivers).
11. **HARD** Why did salt, which is one of the commonest minerals on earth, sell for so much in Timbuktu in the 1500s and for so little in New Orleans in 1900?
12. **CHALLENGE** Write a short paragraph evaluating this claim: "Salt was valuable because it is rare." Use at least two real places from the lesson.

COMMON MISTAKES

- Thinking salt was precious because it is rare. It is abundant; it was precious where it was far away, hard to carry or heavily taxed.
- Repeating that salt was traded “weight for weight” for gold, or that Roman soldiers were paid in salt, as settled fact. Both are popular exaggerations or unproven; say what the sources actually support.
- Placing Timbuktu in the middle of the desert. It sits at the desert’s southern edge, near the Niger River, and that location is the reason it existed.

Make it a game • Salt or Gold?. Two players, two piles of tokens: dried beans are salt and pennies are gold. One player is a desert merchant who starts with 20 beans; the other is a Sahel merchant who starts with 10 pennies. Roll a die each round: on 1–2 a sandstorm costs the desert merchant 2 beans on the road; on 3–4 a toll at Timbuktu costs 1 bean; on 5–6 the road is clear. Then bargain for a trade. After five rounds, each player explains why the price of salt rose or fell as the road grew harder or easier. Switch roles and play again.

Scripture. “Ye are the salt of the earth: but if the salt have lost his savour, wherewith shall it be salted? it is thenceforth good for nothing, but to be cast out, and to be trodden under foot of men.” (Matthew 5:13, KJV)

Jesus spoke to people who knew exactly what salt was worth: it kept food from spoiling and gave it savor, and they paid for it. To be the salt of the earth is to be useful and preserving in the world, the way a precious, needed good is.

Practice answers

1. The sea (salterns on the Mediterranean, the Bay of Bourgneuf or Gujarat); rock salt or halite (Taghaza, Taoudenni, Wieliczka, Hallstatt, Cheshire, Gulf Coast salt domes); brine springs and wells (Lüneburg, Droitwich, Zigong). Accept any other real example, such as Guérande or Guerrero Negro for sea salt, or salt lakes and brines such as the Great Salt Lake or Salar de Uyuni.
2. *Salarium*, which Pliny the Elder said came from *sal*, salt. The link to salt is certain, but historians debate whether Roman soldiers were ever actually paid in salt.
3. It stood near the northern bend of the Niger, where the desert met the river. Camels did poorly in the wet lands farther south and boats could not cross the sand, so goods were unloaded and reloaded there: a break-of-bulk point.
4. 1324. He spent and gave away so much gold that its value in Cairo stayed depressed for years, according to al-Umari.
5. $500 \times 27.3 \text{ g} = 13,650 \text{ g}$, about 13.7 kg (about 30 pounds).
6. North-south: $0.9^\circ \times 111 \approx 100 \text{ km}$. East-west: $1.0^\circ \times 111 \times \cos 23^\circ (0.92) \approx 102 \text{ km}$. Distance $\approx \sqrt{(100^2 + 102^2)} \approx 143 \text{ km}$, about 89 miles.
7. North-south: $6.8^\circ \times 111 \approx 755 \text{ km}$. East-west: $2.0^\circ \times 111 \times \cos 20.2^\circ (0.94) \approx 209 \text{ km}$. Distance $\approx \sqrt{(755^2 + 209^2)} \approx 783 \text{ km}$, about 487 miles, roughly 500 miles.

8. Travel: $2 \times 663 \div 35 \approx 37.9$, about 38 days. Plus 5 days loading: about 43 days, roughly six weeks.
9. $20,000 \text{ kg} \div 120 \text{ kg} \approx 167$ camels.
10. The dry Sahara had rock-salt beds but almost no rain, so little food and no gold-bearing rivers. The wetter savanna and forest edge to the south had rain, crops and gold in river gravels, but no salt deposits, and its people and herds needed salt in a hot climate. Each region had what the other lacked, so both gained by trading salt for gold and grain.
11. Price depends largely on the cost of bringing a good to the buyer. Timbuktu's salt came hundreds of kilometers by camel across the desert, with slow travel, small loads, water stops and tolls. By 1900 salt from Louisiana's domes or by rail and steamship moved in huge loads at low cost per tonne, so it was cheap.
12. Answers should argue that the claim is mostly false: salt is abundant in the sea and in many rock-salt and brine deposits (Wieliczka, Lüneburg, Zigong, the Gulf Coast). It was valuable where it was absent and costly to bring, as in Timbuktu and the Sahel, and where rulers taxed it, as with the Han monopoly or the French *gabelle*. Its value came from distance, transport cost and taxes, not rarity. A strong answer notes that cheap modern transport made it cheap everywhere.

4.2 SILVER AND GOLD

OBJECTIVES

- Tell the story of Potosí's Cerro Rico from its discovery in 1545 through Toledo's reforms, naming both its real achievements and its real wrongs, including the mita.
- Trace on a map the routes by which American silver reached Seville, and through Manila and Europe, China.
- Explain the sixteenth-century price revolution with the quantity equation of money, compute its yearly rate, and weigh the arguments of its critics.

Warm-up. Empty a jar of coins onto the table, or use a handful of paper clips as “coins.” Price three things in the room (a pencil, an apple, a book) in coins. Now imagine a ship arrives and everyone in your family suddenly has twice as many coins, but there are no more pencils, apples or books than before. What do you think happens to the prices? Write your guess and keep it.

Watch. *Potosi: The Silver Mine that Changed the World* (The History Guy: History Deserves to Be Remembered, 13:43). <https://www.youtube.com/watch?v=5BebknA0PeU>
After the story: watch The History Guy explain how Cerro Rico's silver flowed through Potosí and the Spanish treasure fleets to the rest of the world, and listen for how Spanish silver became world money.

Note: Captions were not available to check; preview it first. The video describes the harsh forced labor and the deaths of many native miners under Spanish rule, and the description mentions a short plug for the host's bow tie.

Backup video. *Potted History of Silver Part 1: Potosi* (Pan's Purse, 7:50).
<https://www.youtube.com/watch?v=9OyPg-G40EI>

After the story: watch to see how silver from Potosí's Cerro Rico was mined and minted and how it spread around the world. Note: Captions were not available to check; preview it first. It probably describes the harsh forced labor (the mita) and the many miners who died at Potosí.

KEY TERMS

Cerro Rico

“Rich Hill,” the mountain above Potosí in the Bolivian Andes whose silver veins made it the greatest silver source in the world in the late 1500s.

mita

A rotating forced-labor draft of Andean men, adapted from an Inca labor system and organized by Viceroy Francisco de Toledo in the 1570s to supply workers to Potosí and the mercury mine of Huancavelica.

amalgamation (patio process)

A way of refining silver by grinding ore and mixing it with mercury and salt; the mercury bonds with the silver and is later driven off by heat. It made low-grade ore profitable.

piece of eight

The Spanish silver coin worth eight reales (the Spanish dollar), about 27 grams at about 93% silver, minted in Potosí, Mexico City and elsewhere and used around the world.

price revolution

The long, steady rise of prices in Europe from about 1500 to about 1650, when prices in Spain roughly quadrupled during the 1500s.

quantity equation

$M \times V = P \times Y$: the amount of money times how often it is spent equals the price level times the real quantity of goods sold.

CORE IDEAS

The story. In 1545, the story goes, an Andean herder named Diego Huallpa was caught out at night on the slopes of a reddish mountain in the high plain of what is now Bolivia. He built a fire to keep warm, and in the morning he found bright threads of silver that had melted out of the rock beneath the coals. Whether every detail of the tale is true, Spanish miners had registered claims on the mountain by April 1545, and the rush began. They named it the **Cerro Rico**, the Rich Hill. Below it grew Potosí, at about 4,090 meters (13,420 feet), one of the highest cities on earth, in a cold, treeless land where almost nothing grew. By the early 1600s it may have held around 160,000 people, more than most cities in Europe, and the Spanish crown had granted it the title of Imperial Villa. Spanish speakers still say of a great treasure that it is “worth a Potosí.”

How it worked. At first the ore was so rich that miners smelted it in small clay wind furnaces called *huayrachinas*, an Andean invention, set on the hillsides where the strong winds fanned the charcoal. By the 1560s the richest surface ore was gone and output fell. Then Francisco de Toledo, Viceroy of Peru, reached Potosí in 1572 and rebuilt the whole system. He brought in **amalgamation**, the patio process worked out in Mexico by Bartolomé de Medina in the 1550s: ore was ground fine and mixed with salt and mercury, which seized the silver. The mercury came from Huancavelica in Peru, a mine of cinnabar ore more than 1,200 kilometers (750 miles) to the northwest. Engineers built a chain of dams and reservoirs in the Kari Kari hills above the city and led the water down a channel called the Ribera, where dozens of water-powered mills, the *ingenios*, crushed the ore. And Toledo organized the **mita**, a labor draft that sent about 13,000 men a year from sixteen highland provinces to work in turns at the mountain. Output soared, and by the 1590s Potosí was the greatest silver source in the world.

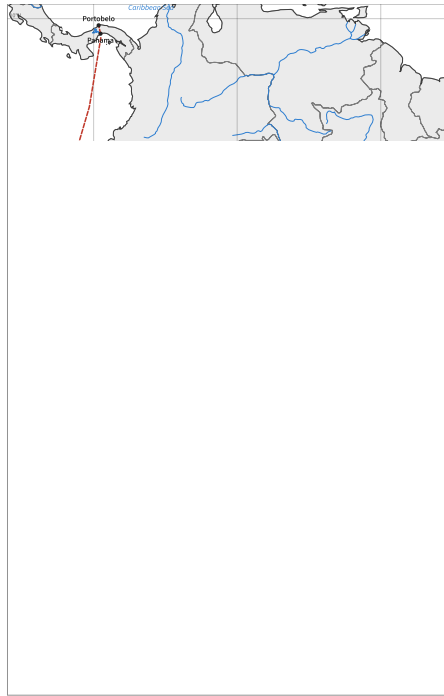
The cost. The achievement was real, and so was the suffering. Mita men walked for weeks with their families to reach the city, then climbed hundreds of feet of ladders in narrow, airless shafts, carried loads of ore on their backs, and came out into freezing air. Mercury poisoned the workers at Huancavelica and in the refining yards. No one knows how many died, but villages emptied as families fled their home districts to escape the draft, and some Spanish priests and officials of the time protested that the mines were devouring the Indians.

Enslaved Africans were also brought up to Potosí, many of them to work in the royal mint. Spanish law itself counted the native people as free vassals of the crown, and the mita's harshness was condemned by people living at the time, not only by later historians. The mountain has been called "the mountain that eats men," and the name was earned.

On the map. Silver left Potosí as bars and coins, stamped at the city's mint, the Casa de la Moneda, founded in 1572. Llama trains and mules carried it down to the Pacific port of Arica, about 500 kilometers (300 miles) away; ships took it north to Callao, the port of Lima, and on to Panama. Mules crossed the isthmus to Portobelo on the Caribbean, where the treasure fleet loaded it for Havana and then Seville, the only port in Spain allowed to receive it. Much silver also slipped out illegally down the long road to Buenos Aires. Mexico's mines at Zacatecas (found in 1546) and Guanajuato poured out still more, and from Acapulco the Manila galleons carried silver across the Pacific (you met them in Unit 2). The final buyer for much of it was China, whose Ming government in the late 1500s began collecting taxes in silver. American silver was the first truly global money: the piece of eight passed in London, Istanbul, Delhi and Canton.

The big idea. What happens when the supply of money grows faster than the supply of goods? By official count, as gathered by the historian Earl J. Hamilton, about 17,000 tonnes of silver and about 180 tonnes of gold arrived in Seville between 1503 and 1660, and smuggling added more. Over the 1500s prices in Spain rose roughly fourfold, and prices rose across Europe. Two thinkers saw why. The Spanish priest Martín de Azpilcueta of the School of Salamanca noted in 1556 that money was worth less where it was plentiful, and the French jurist Jean Bodin argued in 1568 that the abundance of gold and silver was the chief cause of rising prices. Economists today write the idea as the **quantity equation**, $M \times V = P \times Y$. If the quantity of money (M) grows while the speed of spending (V) and the goods produced (Y) change less, the price level (P) must rise. Critics add that prices had begun rising before the great silver imports, that Europe's population was growing fast, and that kings such as Henry VIII debased their coins. Most historians now see several causes working together, with silver an important one. And Spain did not stay rich: the silver paid for wars and foreign goods, and the crown defaulted on its debts in 1557, 1560, 1575 and 1596.

Gold, and silver today. Gold has its own map. West Africa's gold fed the Mediterranean for centuries (Lesson 4.1); Brazil's Minas Gerais boomed after gold was found in the 1690s; James Marshall found gold at Sutter's Mill in California on January 24, 1848; and the Witwatersrand reef, found in 1886, made Johannesburg the gold capital of the world. Gold backed currencies under the gold standard until the United States ended the dollar's convertibility into gold in 1971. In the 2020s the world mines about 3,000 tonnes of gold a year, led by China, Russia and Australia, and about 25,000 tonnes of silver, led by Mexico, China and Peru. Most silver now goes into industry, such as electronics and solar panels. Small miners' cooperatives still work the Cerro Rico as of 2026, honeycombed and lower than it was in Toledo's day.



The silver road: from the Cerro Rico to the treasure fleet.

PICTURE STUDY



Description of Cerro Rico and the Imperial Villa of Potosí, Gaspar Miguel de Berrío, 1758 · Oil on canvas (about 262 × 181 cm) · Museo Colonial Charcas, Universidad San Francisco Xavier, Sucre, Bolivia

Gaspar Miguel de Berrío was a painter of Potosí itself, and in 1758 he painted his city as a kind of map. The Cerro Rico rises like a great cone above the town, laced with paths and mine mouths. Below lies the city laid out in a Spanish grid, with its churches and plazas, and along the stream runs the Ribera, lined with the water-powered mills that crushed the ore. Numbers and inscriptions name the places, as on a surveyor's plan.

By 1758 Potosí had passed its peak of the late 1500s, but it was still one of the great cities of the Spanish Empire. Berrío shows it with pride: the mountain, the water works, the churches and the busy traffic of llamas and people. Read it the way you would read a map, and then ask what it does not show.

Look closely

- Find the Cerro Rico. How has the artist shown the mines and the paths that lead to them?
- Find the city grid and its churches. Why would a Spanish colonial city be laid out on a grid?
- Follow the water. Where does the painter show the reservoirs, the channel and the mills, and why does a silver city in a dry land need so much water engineering?
- Look for llamas, carts and people. What do they tell you about how ore and goods moved?

Talk about it

1. This painting is part portrait and part map. What can it teach a geographer that a modern map could not, and what might be left out?
2. The painting celebrates Potosí's wealth and works. Using what you have learned about the mita, what would a mita worker's picture of the same mountain show?
3. Compare the painting with the lesson map. Which way would silver leave this city, and how far would it travel before it reached Seville?

PROJECT: THE SILVER FLEET COMES IN: A PRICE REVOLUTION MARKET

You will run a small market for several rounds, then let a "silver fleet" arrive with more money while the goods stay the same. You will record prices each round, build a price index, and test the quantity equation with your own data.

You will need

- Three or more players (family members work well)
- About 200 dried beans or pennies to be pieces of eight
- Index cards for goods: 6 "bread," 4 "cloth," 4 "candles" (or real snacks)
- Notebook, pencil and a calculator; graph paper

Steps

1. Choose one player as the seller of goods. Give each buyer 10 beans. Put 6 bread, 4 cloth and 4 candle cards on the table.
2. Round 1: the seller auctions each card one at a time to the highest bidder. Record the winning price of every card. Unsold cards are carried over.
3. Collect the goods back. Round 2: the silver fleet arrives. Give each buyer 20 beans (double the money), but put out the same 14 goods. Auction again and record prices.
4. Round 3: give each buyer 40 beans and the same goods. Auction and record.

5. Round 4: give each buyer 40 beans but add 7 extra goods (half again as many). Auction and record.
6. For each round, find the average price per good. Make Round 1 = 100 and compute a price index for the others (average price ÷ Round 1 average × 100).
7. Graph the price index against the round. Then write a paragraph: Did the price level roughly follow the money supply? What happened in Round 4 when goods increased? How does this match the quantity equation, $M \times V = P \times Y$?

Tips

- Real markets are messier than a game: people save, hoard and spend in other towns. That is one reason the real price revolution was about 1 to 2 percent a year, not a doubling overnight.
- Keep the goods the same in Rounds 1-3 so you test only one change at a time.

Check your work

- I can compute a price index from my own market data.
- I can explain what happens to prices when money grows faster than goods.
- I can name at least one other cause of the price revolution besides silver.

MAP NOTEBOOK

1. Draw the silver road on an outline map of the Americas and the Atlantic: Potosí, Arica, Callao, Panama, Portobelo, Havana and Seville. Add the Buenos Aires smuggling road in a dashed line and the Acapulco-Manila galleon route.
2. Sketch a cross-section of the Cerro Rico with the city at its foot. Label the city at 4,090 m (13,420 ft) and the summit at about 4,800 m (15,700 ft), and draw a mine shaft and a reservoir with a channel to a mill.
3. Draw a piece of eight, both sides, as accurately as you can from a photograph, and write its weight and silver content beside it.

From history. The Spanish dollar was so trusted that the young United States based its own money on it. The Coinage Act of 1792 defined the U.S. dollar as a silver coin close in weight to the Spanish piece of eight, and foreign coins, chiefly Spanish and Mexican, remained legal tender in the United States until Congress ended that status in 1857. The habit of dividing a dollar into eighths, from the eight reales, lasted even longer: American stock prices were quoted in fractions such as $\frac{3}{8}$ and $\frac{5}{8}$ until the exchanges switched to decimals in 2001.

WORKED EXAMPLES

Example 1. Potosí lies at about 4,090 m and the summit of the Cerro Rico at about 4,800 m. Convert both to feet ($1 \text{ m} = 3.281 \text{ ft}$), find how far the summit rises above the city, and compare Potosí with Denver, the “Mile High City” (5,280 ft).

1. City: $4,090 \times 3.281 \approx 13,420 \text{ ft}$.
2. Summit: $4,800 \times 3.281 \approx 15,750 \text{ ft}$.
3. Rise: $4,800 - 4,090 = 710 \text{ m}$, or $15,750 - 13,420 = 2,330 \text{ ft}$.
4. Compared with Denver: $13,420 \div 5,280 \approx 2.5$.

Answer: City about 13,420 ft; summit about 15,750 ft; the summit rises about 710 m (2,330 ft) above the city. Potosí is about 2.5 times as high as Denver.

Example 2. Suppose a Spanish price index stood at 100 in 1501 and 400 in 1600. What steady yearly rate of increase would produce this? How many years did prices take to double at that rate?

1. Growth factor over 99 years (about 100): $400 \div 100 = 4$.
2. Yearly factor: $4^{(1/100)}$. Using logarithms: $\ln 4 = 1.386$; $1.386 \div 100 = 0.01386$; $e^{0.01386} \approx 1.0140$.
3. So prices rose about 1.4% a year.
4. Doubling time by the rule of 70: $70 \div 1.4 = 50 \text{ years}$. Check: $1.014^{50} \approx 2.0$.

Answer: About 1.4% a year, doubling about every 50 years. The “revolution” was slow by modern standards but steady for a century and more.

Example 3. A piece of eight weighed about 27.0 g and was about 93% silver. (a) How much pure silver was in one coin? (b) Hamilton’s official count of silver reaching Seville from 1503 to 1660 was about 17,000 tonnes. How many pieces of eight is that equal to?

1. (a) $27.0 \text{ g} \times 0.93 \approx 25.1 \text{ g}$ of pure silver per coin.
2. (b) $17,000 \text{ t} = 17,000 \times 1,000,000 \text{ g} = 1.7 \times 10^{10} \text{ g}$.
3. $1.7 \times 10^{10} \text{ g} \div 25.1 \text{ g per coin} \approx 6.8 \times 10^8 \text{ coins}$.
4. That is about 680 million coins, without counting smuggled silver.

Answer: (a) About 25 g of pure silver. (b) About 680 million pieces of eight.

PRACTICE

1. **EASY** In what year were Spanish claims registered on the Cerro Rico, and in what modern country is Potosí?

2. **EASY** What was the mita, who organized it at Potosí, and about how many men did it draft each year?
3. **EASY** Why did Potosí depend on Huancavelica, and what was the danger there?
4. **MEDIUM** Potosí is at about 19.6°S, 65.8°W and Arica at about 18.5°S, 70.3°W. Estimate the straight-line distance in km and miles. If a llama train covered about 20 km a day, how many days was the trip?
(Use the map or drawing “Potosí to the port of Arica.” shown earlier in this lesson.)
5. **MEDIUM** About 17,000 tonnes of silver reached Seville officially from 1503 to 1660. What is the average per year?
6. **MEDIUM** A price index rose from 100 to 400. By what percent did prices rise?
7. **MEDIUM** Use $M \times V = P \times Y$. If the money supply doubles, velocity stays the same and the quantity of goods grows by 50%, by what percent does the price level change?
8. **MEDIUM** A treasure chest held 3,000 pieces of eight of 27.0 g each. How much did the coins weigh in kilograms and pounds (1 kg = 2.205 lb)?
9. **MEDIUM** Place in order of discovery: the Witwatersrand gold reef, the Cerro Rico, Sutter’s Mill, Minas Gerais gold. Give the year or decade of each.
10. **HARD** Potosí to Buenos Aires is about 1,800 km (1,130 miles) by straight line, while the official route ran by Arica, Callao, Panama, Portobelo and Havana to Seville. Why did the Spanish crown forbid the shorter Atlantic outlet through Buenos Aires for most of the colonial period?
11. **HARD** Spain received more American silver than any other country, yet the crown defaulted on its debts four times under Philip II. Explain in three or four sentences why the silver did not make Spain lastingly rich.
12. **CHALLENGE** Write a paragraph evaluating the claim: “American silver alone caused the European price revolution.” Use the quantity equation and at least two other causes.

COMMON MISTAKES

- Thinking more money means more wealth. More coins with the same goods mean higher prices; real wealth is goods and services.
- Telling Potosí as only a story of riches, or only a story of cruelty. Both the engineering achievement and the suffering of the mita are part of the true history.
- Forgetting the Pacific. Much American silver went west through Manila to China, not only east to Spain.

Make it a game • Treasure Fleet. Draw the silver road on a long strip of paper: Potosí, Arica, Callao, Panama, Portobelo, Havana, Seville. Each player starts at Potosí with 10 silver tokens. Roll a die to move one stop on a 3 or higher. At each stop draw a card the parent has made: storm (lose 2), pirates (lose 3 unless you roll a 6), customs tax (pay 1), fair winds (move again), smuggle to Buenos Aires (leave the road and keep all your silver, but lose 5 if the next roll is 1 or 2). The player who reaches Seville with the most silver wins. Afterward, discuss: why did the crown accept slow fleets and heavy taxes instead of the shorter road?

Scripture. “Surely there is a vein for the silver, and a place for gold where they fine it. Iron is taken out of the earth, and brass is molten out of the stone.” (Job 28:1–2, KJV)

Job knew that metals lie in particular places, in veins that must be found, dug and refined. The chapter goes on to say that men dig through rock and darkness for treasure but that wisdom is worth more than gold or silver, a fitting word for the story of Potosí and of Spain.

Practice answers

1. 1545; Bolivia.
2. A rotating forced-labor draft of Andean men, adapted from an Inca system; organized by Viceroy Francisco de Toledo in the 1570s; about 13,000 men a year from sixteen highland provinces.
3. Huancavelica supplied the mercury needed for amalgamation, which made lower-grade ore profitable after the rich surface ore was gone. Mercury mining and refining poisoned workers.
4. North-south: $1.1^\circ \times 111 \approx 122$ km. East-west: $4.5^\circ \times 111 \times \cos 19^\circ (0.946) \approx 473$ km. Distance $\approx \sqrt{(122^2 + 473^2)} \approx 488$ km, about 300 miles (precise coordinates give about 494 km). At 20 km a day, about 25 days, and longer on the winding mountain road.
5. $1660 - 1503 + 1 = 158$ years. $17,000 \div 158 \approx 108$ tonnes a year.
6. $(400 - 100) \div 100 \times 100\% = 300\%$.
7. P is proportional to $M \div Y$: $2 \div 1.5 \approx 1.33$. Prices rise by about 33%.
8. $3,000 \times 27.0 \text{ g} = 81,000 \text{ g} = 81 \text{ kg}$, about 179 lb, too heavy for one man to carry far.
9. Cerro Rico (1545); Minas Gerais (1690s); Sutter’s Mill, California (1848); Witwatersrand (1886).
10. The crown wanted all silver to travel in the guarded fleet system through a few controlled ports so it could collect its share (the royal fifth and other taxes), protect the treasure from pirates and enemies, and keep the trade monopoly of Seville’s merchants. An open port at Buenos Aires would have leaked silver to smugglers and foreign traders, which is exactly what happened illegally.
11. Much of the silver was spent on wars in Italy, the Netherlands and against the Ottomans and England, and on goods bought from other countries, so it flowed out of Spain to bankers and producers abroad. Rising prices made Spanish goods dearer and less competitive. The crown borrowed against future fleets and could not always pay. Wealth that comes from digging money is not the same as wealth from producing goods.
12. A strong answer says the claim is too simple. By the quantity equation, a large rise in M with slower growth in Y should raise P, and Azpilcueta and Bodin saw this at the time. But prices had started rising before the great silver imports, Europe’s population was growing fast and pressing on food supplies, and kings such as Henry VIII debased their coins, adding to the money supply in another way. Velocity may also have changed as trade grew. Silver was an important cause among several.

4.3 COAL AND IRON

OBJECTIVES

- Explain how coke smelting at Coalbrookdale (1709), the steam engine and the canal tied Britain's first industrial cities to its coalfields.
- Locate Britain's major coalfields and the Ruhr, and trace the Ruhr's rise, its troubled twentieth century and its decline.
- Use Weber's least-cost reasoning (ton-kilometers) to find the cheapest site for an ironworks, and explain why modern steel mills moved to the coast.

Warm-up. Hold a sheet of paper, a pencil and a metal spoon. Which one is heaviest for its size? Now imagine you must make one spoon from ore dug in one place and fuel dug in another, and sell it in a third. Would you build your workshop near the ore, near the fuel or near the buyers? Write your guess and one reason.

Watch. *Zollverein Coal Mine Industrial Complex - UNESCO World Heritage Site* (World Heritage Journey, 4:14). <https://www.youtube.com/watch?v=t1cTwoBx3T4>
With On the map: find the Ruhr Valley in western Germany, then watch this tour of the huge Zollverein coal mine to see how coal powered Germany's industry in the late 1800s and early 1900s.

Note: Captions were not available to check; preview it first. The story is set at Coalbrookdale in England in 1709. This video covers a later German coal complex in the Ruhr.

KEY TERMS

coke

Coal baked in a closed oven to drive off tar and gases, leaving nearly pure carbon that burns hot and is strong enough to hold up a tall furnace load.

blast furnace

A tall furnace into which iron ore, fuel and limestone are loaded from the top while air is blown in at the bottom, producing molten iron.

coalfield

A region where coal seams lie close enough to the surface to be mined, such as South Wales, Yorkshire or the Ruhr.

weight-losing material

A raw material that loses much of its weight in processing (like coal, which is burned away), so it pays to process it near where it is dug.

least-cost location

Alfred Weber's idea (1909) that a factory will tend to locate where the total cost of moving raw materials in and products out is lowest.

ton-kilometer

One tonne of freight moved one kilometer; a common measure for comparing transport work and cost.

CORE IDEAS

The story. In 1709, in the narrow valley of Coalbrookdale beside the River Severn in Shropshire, a Quaker ironmaster named Abraham Darby succeeded in smelting iron ore with **coke** instead of charcoal. For centuries English furnaces had burned charcoal, and charcoal meant forests; an ironworks could only grow as large as the woods around it could feed. Coal was plentiful in Britain, but raw coal's sulfur spoiled the iron and it crumbled under the weight of the furnace load. Baked into coke, it worked. Seventy years later Darby's grandson, Abraham Darby III, cast the parts of the world's first large iron bridge across the Severn a short way downstream. The Iron Bridge, spanning about 30 meters (100 feet), was raised in 1779 and opened to traffic in 1781, and it still stands, proof that iron had become cheap enough to build with.

How it worked. Coal, iron and steam fed one another. Mines filled with water as they went deeper, so in 1712 Thomas Newcomen set up a steam engine near Dudley Castle to pump out a coal mine; it burned so much fuel that it paid only where coal was nearly free, at the pithead. James Watt's separate condenser, patented in 1769, cut fuel use sharply, and Watt and Matthew Boulton's engines were soon driving mills and blowing furnaces. Cheaper iron made better engines; better engines dug more coal; more coal made more iron. Moving coal was the bottleneck. A packhorse could carry only a small load on muddy roads, so in 1761 the Duke of Bridgewater opened a canal from his mines at Worsley to Manchester, and the price of coal in Manchester is said to have fallen by about half. A horse that could carry about an eighth of a tonne on its back could pull a barge of about 30 tonnes along a canal. Railways, born on colliery wagonways, finished the work in the next century.

On the map. Lay a map of Britain's coalfields over a map of its industrial cities and they nearly match. The Lancashire coalfield fed Manchester's cotton mills; the Black Country and Birmingham sat on the South Staffordshire field; Sheffield's steel grew on the Yorkshire field; Glasgow rose on the coal of the Scottish Central Belt; and Newcastle shipped so much coal from the Northumberland and Durham field that "carrying coals to Newcastle" became the English phrase for a pointless errand. The steam coal of the South Wales valleys, prized by navies because it burned hot with little smoke, poured out through Cardiff to coaling stations around the world. British coal output peaked in 1913 at about 290 million tonnes, with more than a million miners. Coal was a **weight-losing material**: it went into the furnace and came out as heat and smoke, so it paid to bring the ore to the coal, not the coal to the ore.

The Ruhr. Germany's great coalfield lies between the Ruhr and Lippe rivers, just east of where they join the Rhine. In 1811 Friedrich Krupp founded a small steel works in Essen; his son Alfred built it into one of the largest industrial firms on earth. August Thyssen built huge works at Duisburg on the Rhine, Europe's busiest river, and canals such as the Dortmund-Ems (1899) and the Rhine-Herne (1914) tied the district to the sea. By 1900 the Ruhr was the industrial heart of continental Europe, and that made it a prize. When Germany fell behind on its war reparations, French and Belgian troops occupied the Ruhr in 1923. In the

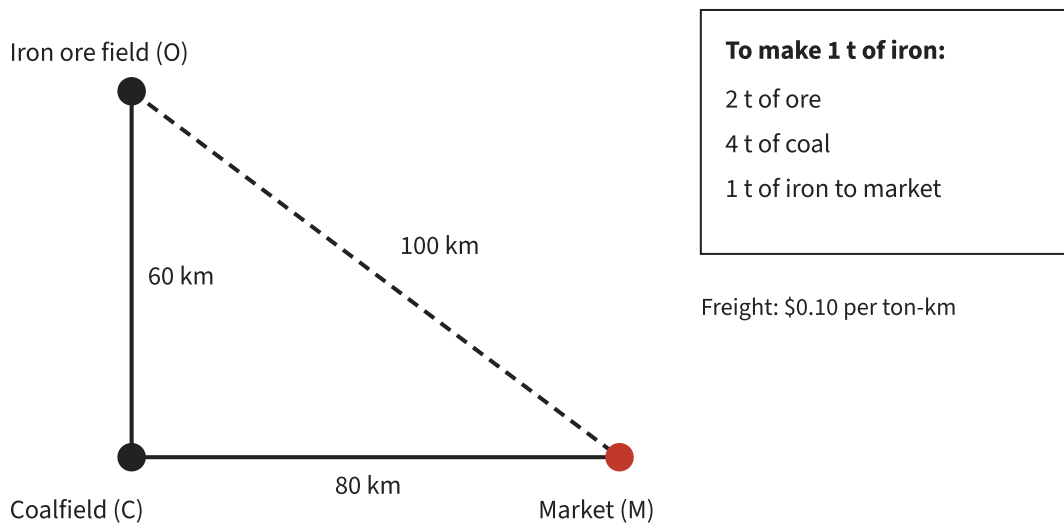
Second World War its mines and mills ran partly on the forced labor of hundreds of thousands of foreign workers and prisoners, and after the war Alfried Krupp was convicted at Nuremberg in 1948 for using slave labor. In 1951 France, West Germany, Italy and the Benelux countries pooled their coal and steel in the European Coal and Steel Community, so that the Ruhr and Lorraine could no longer be armed against each other. Ruhr coal output topped 120 million tonnes in the late 1950s, then declined as cheaper oil and imported coal arrived. The last hard-coal mine, Prosper-Haniel in Bottrop, closed in December 2018, and the Zollverein colliery in Essen is now a UNESCO World Heritage Site.

The big idea. In 1909 the German economist Alfred Weber proposed a simple model of industrial location. Add up the **ton-kilometers** of moving each raw material to a site and the product to market; the site with the lowest total is the **least-cost location**. In the 1800s a ton of iron took more tons of coal than of ore, so ironworks crowded onto the coalfields. As furnaces grew more efficient, coal per ton of iron fell, the best local ores ran out, and ore began to come from overseas. The least-cost point moved to the coast, where ships could unload ore and coal side by side. The great steelworks of the later 1900s stand at tidewater: IJmuiden in the Netherlands, Dunkirk in France, Pohang in South Korea, and the shore mills of Japan and China. In America the same logic built Pittsburgh on Appalachian coal and fed it with iron ore from Minnesota's Mesabi Range, carried down the Great Lakes by lake freighters.

Technology overcoming geography. The bulk carrier changed the map again. A Capesize ship, so named because when fully laden it is too big for the Panama and Suez canals and must round the great capes, carries about 180,000 tonnes of ore. Today the great iron-ore exporters are Australia, from the Pilbara through Port Hedland and Dampier, and Brazil, from Carajás and Minas Gerais. China, which makes more than half the world's steel and mines about half the world's coal, imports more than a billion tonnes of iron ore a year (2020s). A coalfield that once had to be beside the furnace can now be a hemisphere away. Yet the old pattern still shows on the map: Britain's and the Ruhr's cities sit where they do because God laid coal beneath them.



The Industrial Revolution's map: Britain's coalfield cities and the Ruhr.



Weber's location triangle: where should the ironworks go?

Thinking About Time

What the sign says. Museum signs and textbooks call the age of many coal beds the “Carboniferous” and assign it a very great age in years.

What we observe. What is actually measured is the coal itself: its seams, its plant fossils, and the layers of rock above and below it. The ages come from assumptions about how

fast layers formed and how radioactive elements decayed over unobserved time.

How Christians read it. Many Christians who read Genesis as history understand much of the world's coal as vast masses of plants uprooted and buried rapidly during the Flood (Genesis 6–9), which would explain the thick, widespread seams and the well-preserved plant fossils within them.

PICTURE STUDY



Coalbrookdale by Night, Philip James de Loutherbourg, 1801 · Oil on canvas · Science Museum, London

Philip James de Loutherbourg was a painter born in Strasbourg who settled in London and became famous for stage scenery and dramatic landscapes. Like many visitors around 1800, he traveled to Shropshire to see the ironworks of the Severn Gorge, which had become one of the wonders of Britain. This painting shows the Bedlam furnaces at Madeley Wood, near Coalbrookdale, blazing in the dark.

Visitors described the scene with a mix of awe and fear: the roar of the blast, the glare on the clouds, the smoke filling the valley. De Loutherbourg painted it as something almost unearthly. Look at it as a geographer too: a valley, a river, fuel, ore and roads, all in one place.

Look closely

- Find the source of the light. What is burning, and why would the furnaces run through the night?
- Look at the foreground. What tools, carts or iron pieces can you find, and how were heavy things moved?

- Notice the landscape around the works. Is this a city, a village or open country? What does that tell you about where early industry grew?
- Find the smoke. How does the painter use it to make the scene feel dramatic?

Talk about it

1. Why would a painter in 1801 think an ironworks was a fit subject for a landscape painting, as earlier painters had chosen mountains and storms?
2. Using the lesson map, explain why ironworks grew in this valley rather than in London.
3. Does the painting celebrate industry, warn against it or both? Give evidence from the picture.

PROJECT: WEBER'S FRAME: FINDING THE LEAST-COST IRONWORKS WITH STRING AND WEIGHTS

Weber's location problem can be solved with a physical model called a Varignon frame. Strings pulled by weights through three holes in a board act like the "pull" of each raw material and the market. The knot where they meet settles at the least-cost point. You will build one and test how the best site moves when the recipe for iron changes.

You will need

- A sheet of stiff cardboard or thin plywood about 60 × 60 cm, set across two chairs so the underside hangs free
- Three strings about 1 m long, tied together at one small ring or knot
- Three small paper cups or bags and a supply of identical washers, coins or marbles as weights
- Pencil, ruler, tape, a sharp tool for holes (adult help)
- Graph paper

Steps

1. Draw the triangle from the lesson figure on the board at 3 mm per km: ore field O and coalfield C 180 mm apart, coalfield C and market M 240 mm apart. Check that O to M measures 300 mm.
2. With an adult, make a smooth hole at each corner. Thread one string down through each hole and tie a cup to each string under the board.
3. Recipe 1 (early 1800s): put 2 weights in the ore cup, 4 in the coal cup and 1 in the market cup. Lift the knot, let it go and tap the board gently so the knot settles. Mark where it stops.
4. Recipe 2 (efficient furnace): put 2 weights in the ore cup, 1 in the coal cup and 1 in the market cup. Let the knot settle and mark it.
5. Recipe 3 (imported ore and coal arriving at the coast, big market): try 2, 1 and 4. Mark it.
6. Check each result with ton-kilometer arithmetic at the three corners, as in the worked example. Does the knot move toward the corner with the largest total pull?

7. Write a paragraph explaining why the Ruhr and the Black Country grew on coal, and why later steelworks were built at seaports.

Tips

- Friction at the holes makes the knot stop a little short; tapping the board helps. If one weight is larger than the other two combined, the knot will be pulled right to that corner.
- Weber's model leaves out labor costs, land, water, government and history. Note one thing it leaves out that might matter for a real ironworks.

Check your work

- I can build and use a Varignon frame to find a least-cost point.
- I can compute ton-kilometers for three possible sites.
- I can explain why the best site moved from the coalfield to the coast.

MAP NOTEBOOK

1. Trace Britain and the lower Rhine from the lesson map. Shade the coalfields named in the lesson and mark the industrial cities on them. Add the Bridgewater Canal from Worsley to Manchester.
2. Draw a cross-section of a blast furnace with labels for ore, coke and limestone going in at the top, the air blast, the slag and the molten iron coming out at the bottom.
3. Make a three-column timeline: Britain, the Ruhr and the world, with at least four dates in each column from 1709 to 2018.

From history. Coal smoke had a price that people of the time noticed. London had burned "sea coal" shipped from Newcastle since the Middle Ages, and complaints about the smoke are old; in 1661 the diarist John Evelyn wrote a pamphlet, *Fumifugium*, urging that smoky trades be moved out of the city. The worst event came in December 1952, when a cold, windless spell trapped coal smoke over London for about five days in the Great Smog. Thousands of deaths were blamed on it, and Parliament passed the Clean Air Act of 1956, which created smoke-free zones and pushed homes toward cleaner fuels.

WORKED EXAMPLES

Example 1. Weber's triangle (see the figure): an ore field O, a coalfield C and a market M. $O-C = 60$ km, $C-M = 80$ km, $O-M = 100$ km. To make 1 tonne of iron takes 2 tonnes of ore and 4 tonnes of coal, and 1 tonne of iron must go to market. Freight costs \$0.10 per ton-kilometer. Which corner is the cheapest site for the ironworks?

(Use the map or drawing "Compare the freight bill at each corner." shown earlier in this lesson.)

1. At the coalfield C: bring ore $2 \text{ t} \times 60 \text{ km} = 120 \text{ t-km}$; send iron $1 \text{ t} \times 80 \text{ km} = 80 \text{ t-km}$. Total $200 \text{ t-km} \times \$0.10 = \$20$.
2. At the ore field O: bring coal $4 \text{ t} \times 60 \text{ km} = 240 \text{ t-km}$; send iron $1 \text{ t} \times 100 \text{ km} = 100 \text{ t-km}$. Total $340 \text{ t-km} = \$34$.
3. At the market M: bring ore $2 \text{ t} \times 100 \text{ km} = 200 \text{ t-km}$; bring coal $4 \text{ t} \times 80 \text{ km} = 320 \text{ t-km}$. Total $520 \text{ t-km} = \$52$.
4. The coalfield has the lowest cost, because coal is the heaviest input and it is burned away (weight-losing).

Answer: The coalfield, at \$20 per tonne of iron, against \$34 at the ore field and \$52 at the market.

Example 2. A packhorse carried about $1/8$ tonne of coal. A canal horse could pull a barge of about 30 tonnes. (a) How many packhorses did one canal horse replace? (b) If a mill needed 600 tonnes of coal a month, how many packhorse loads and how many barge loads was that?

1. (a) $30 \div 0.125 = 240$ packhorses.
2. (b) Packhorse loads: $600 \div 0.125 = 4,800$.
3. Barge loads: $600 \div 30 = 20$.

Answer: (a) About 240 packhorses. (b) 4,800 packhorse loads, or 20 barge loads. No wonder the Bridgewater Canal cut the price of coal in Manchester.

Example 3. A Capesize ship loads 180,000 tonnes of iron ore at Port Hedland, Western Australia, for Qingdao, China, a sea route of roughly 3,600 nautical miles. (a) How long is the voyage at 12 knots? (b) Give the distance in km and miles (1 nautical mile = 1.852 km = 1.151 miles). (c) How many 30-tonne canal barges would carry the same ore?

1. (a) Time = distance $\div$ speed = $3,600 \div 12 = 300$ hours; $300 \div 24 = 12.5$ days.
2. (b) $3,600 \times 1.852 \approx 6,670$ km; $3,600 \times 1.151 \approx 4,140$ miles.
3. (c) $180,000 \div 30 = 6,000$ barges.

Answer: (a) About 12½ days. (b) About 6,670 km (4,140 miles). (c) 6,000 barges, carried by one ship with a crew of about twenty.

PRACTICE

1. **EASY** What did Abraham Darby achieve at Coalbrookdale in 1709, and why did it matter?
2. **EASY** The Iron Bridge spans about 30.6 m. Convert to feet (1 m = 3.281 ft).
3. **EASY** What does “carrying coals to Newcastle” mean, and what geographic fact lies behind it?
4. **EASY** Name the three Ruhr cities on the lesson map and the river that ties the Ruhr to the sea.
(Use the map or drawing “The Ruhr and the Rhine.” shown earlier in this lesson.)
5. **MEDIUM** Rework the Weber triangle (O–C 60 km, C–M 80 km, O–M 100 km) with an efficient furnace: 2 t ore and 1 t coal per tonne of iron (instead of the 4 t of coal in the figure’s box). Find the ton-kilometers at each corner. Which is cheapest now?
(Use the map or drawing “Change the recipe and the best site moves.” shown earlier in this lesson.)
6. **MEDIUM** British coal output peaked in 1913 at about 290 million tonnes. If about 1.1 million miners worked that year, about how many tonnes did each miner produce on average? About how many per working day, if the year had 290 working days?
7. **MEDIUM** Ruhr coal output was above 120 million tonnes in the late 1950s, and the last hard-coal mine closed in 2018. How many years passed between 1957 and the closing? What two changes caused the long decline?
8. **MEDIUM** Duisburg (51.4°N, 6.8°E) and Dortmund (51.5°N, 7.5°E) bracket the Ruhr. Estimate the east–west distance in km and miles.
9. **MEDIUM** A lake freighter carries 60,000 tonnes of Mesabi iron ore from Duluth, Minnesota, to a Lake Erie port about 800 miles away at 13 mph. How long does the trip take, and how many 30-tonne canal barges would the cargo fill?
10. **HARD** Why did the great steelworks of the late twentieth century (IJmuiden, Dunkirk, Pohang) stand at the coast rather than on coalfields?
11. **HARD** Explain the feedback loop among coal, iron and steam in eighteenth-century Britain.
12. **CHALLENGE** Write a paragraph: Was the Ruhr’s geography a blessing or a curse in the twentieth century? Use at least three events from the lesson.

COMMON MISTAKES

- Thinking Britain industrialized first only because of inventors. Inventors mattered, but they worked on a land where coal, iron ore, water and navigable rivers and coasts lay close together.
- Using Weber's model as if it were a law. It is a model that leaves out labor, land prices, government policy and history; use it to reason, not to predict exactly.
- Assuming industry still must sit on coal. Cheap bulk shipping moved the least-cost point to the coast.

Make it a game · Where Do We Build the Works?. Draw a large triangle on paper with three corners labeled Ore, Coal and Market, and write a distance on each side. A parent or friend calls out a "recipe" (for example, 2 ore, 4 coal, 1 product). Each player has one minute to compute the ton-kilometers at each corner and point to the cheapest one. Correct answer scores a point; first to correctly explain why the best corner changed when the recipe changed scores two. Play five rounds with different recipes and distances.

Scripture. "A land wherein thou shalt eat bread without scarceness, thou shalt not lack any thing in it; a land whose stones are iron, and out of whose hills thou mayest dig brass." (Deuteronomy 8:9, KJV)

Moses described the Promised Land partly by what lay beneath it. Resources are part of God's provision for a people, placed in particular lands; the coal and iron of Britain and the Ruhr were gifts long before anyone knew how to use them.

Practice answers

1. He smelted iron ore with coke instead of charcoal. Ironmaking was freed from the limit of forests and could use Britain's plentiful coal.
2. $30.6 \times 3.281 \approx 100.4$ ft, about 100 feet.
3. Doing something pointless, bringing a thing to a place that already has plenty. Newcastle sat on the Northumberland and Durham coalfield and was Britain's great coal-shipping port.
4. Duisburg, Essen and Dortmund; the Rhine.
5. At C: ore $2 \times 60 = 120$ + iron $1 \times 80 = 80$, total 200 t-km. At O: coal $1 \times 60 = 60$ + iron $1 \times 100 = 100$, total 160 t-km. At M: ore $2 \times 100 = 200$ + coal $1 \times 80 = 80$, total 280 t-km. The ore field is now cheapest.
6. $290,000,000 \div 1,100,000 \approx 264$ tonnes per miner per year; $264 \div 290 \approx 0.9$ tonne per working day.
7. $2018 - 1957 = 61$ years. Cheaper oil replaced coal for many uses, and cheaper imported coal (from mines that were easier to work, carried by bulk ship) undercut deep Ruhr mines.
8. $0.7^\circ \times 111 \times \cos 51.5^\circ (0.62) \approx 48$ km, about 30 miles. The heart of the Ruhr is a strip only about 50 km long.
9. $800 \div 13 \approx 61.5$ hours, about $2\frac{1}{2}$ days. $60,000 \div 30 = 2,000$ barges.
10. Furnaces used much less coal per tonne of iron, and the best local ores were used up, so both ore and coal increasingly came from overseas by bulk ship. Unloading both at a deep-water

port and making steel there avoided an extra overland haul, so the least-cost point moved to tidewater.

11. Deeper coal mines flooded, so steam engines (Newcomen, then Watt) pumped them out. The engines burned coal and were built of iron. Coke-smelted iron needed coal. Cheaper iron made more engines; more engines dug more coal; more coal made more iron. Canals and later railways carried the coal and iron, and themselves needed iron.
12. A strong answer weighs both: the coal and the Rhine made the Ruhr Europe's industrial heart and brought work and wealth; but that same concentration made it a prize, leading to the French and Belgian occupation of 1923 and to its use as the arsenal of Nazi Germany, worked partly by forced labor (Krupp's conviction in 1948). After the war the European Coal and Steel Community (1951) tried to make the Ruhr a shared resource rather than a cause of war. Later, competition from oil and cheaper coal closed the mines (2018), so geography's gift lasted only as long as transport costs kept coal local.

4.4 OIL AND GAS

OBJECTIVES

- Explain where oil and gas are found, using the parts of a petroleum trap (source, reservoir, cap rock) and real fields such as Spindletop, Masjed Soleyman and Ghawar.
- Describe how oil and gas move from field to market by pipeline, tanker and LNG carrier, and why each fits different geography.
- Calculate pipeline fill, tanker voyage times, LNG volumes and choke-point shares with real figures.

Warm-up. Pour a little water into a clear glass, then add a spoonful of cooking oil and stir hard. Watch for one minute. Where does the oil go? Now hold a small upside-down cup in a bowl of water and blow a few bubbles under it through a straw. Where does the air collect? Write one sentence predicting where oil and gas collect underground.

Watch. *Oil and Gas Industry Overview [Training Basics Series]* (Kimray Inc, 7:48). <https://www.youtube.com/watch?v=O-giUD9TEtQ>.

With the big idea: watch after reading how oil traps and wells work, and look for the short history at 0:43, the reservoir and pay-zone sections, and how oil moves from the well to the refinery (upstream, midstream, downstream).

Note: Captions were not available to check; preview it first. This is an industry training video from an oilfield equipment maker, so expect some technical terms, and the geology part may say oil formed over millions of years.

KEY TERMS

reservoir rock

Porous, permeable rock, usually sandstone or limestone, whose tiny spaces hold oil, gas and water like a hard sponge.

cap rock

A layer that fluids cannot pass through, such as shale or salt, sealing the top of a reservoir so oil and gas are trapped beneath it.

trap

A shape in the rock layers that stops oil and gas from rising further, such as an anticline (an upward arch), a fault or the flank of a salt dome.

barrel

The standard unit for oil: 42 U.S. gallons, about 159 liters.

VLCC

Very Large Crude Carrier, a supertanker that carries about 2 million barrels of crude oil.

LNG

Liquefied natural gas: gas chilled to about $-162\text{ }^{\circ}\text{C}$ ($-260\text{ }^{\circ}\text{F}$) until it becomes a liquid taking up about 1/600 of its volume as a gas, so it can be shipped by sea.

CORE IDEAS

The story. In the summer of 1859, on Oil Creek near the lumber village of Titusville in northwestern Pennsylvania, a former railroad conductor named Edwin Drake was trying to do something new: to drill for oil the way men drilled for salt brine. His backers at the Seneca Oil Company had dubbed him “Colonel” to impress the locals. Water and gravel kept caving into the hole until Drake drove an iron pipe down to bedrock and drilled inside it. On August 27 the bit reached about 69½ feet (21 meters), and the next morning the driller, William “Uncle Billy” Smith, found oil standing in the pipe. Within months Oil Creek was crowded with derricks. Refined into kerosene, rock oil lit the lamps of America and Europe more cheaply than whale oil, and within a dozen years John D. Rockefeller’s Standard Oil Company, founded in 1870, was building an empire on it.

Where it lies. Oil and gas are not found in underground lakes. They fill the tiny pore spaces of **reservoir rock**, usually sandstone or limestone. They form from buried plant and animal matter in fine-grained source rock, then creep upward because they are lighter than the water that also fills the rock. Most would leak away at the surface unless something stopped them. A **trap** does: an arch of layers called an anticline, sealed above by **cap rock** such as shale or salt, or a fault that slides a sealing layer across the path. In the trap the fluids sort themselves by weight: gas at the top, oil in the middle, water below. On January 10, 1901, at Spindletop near Beaumont, Texas, a well drilled into the flank of a buried salt dome blew in at an estimated 100,000 barrels a day and gushed for nine days before it was capped. The salt of Lesson 4.1, pushed up from below, had made the trap.

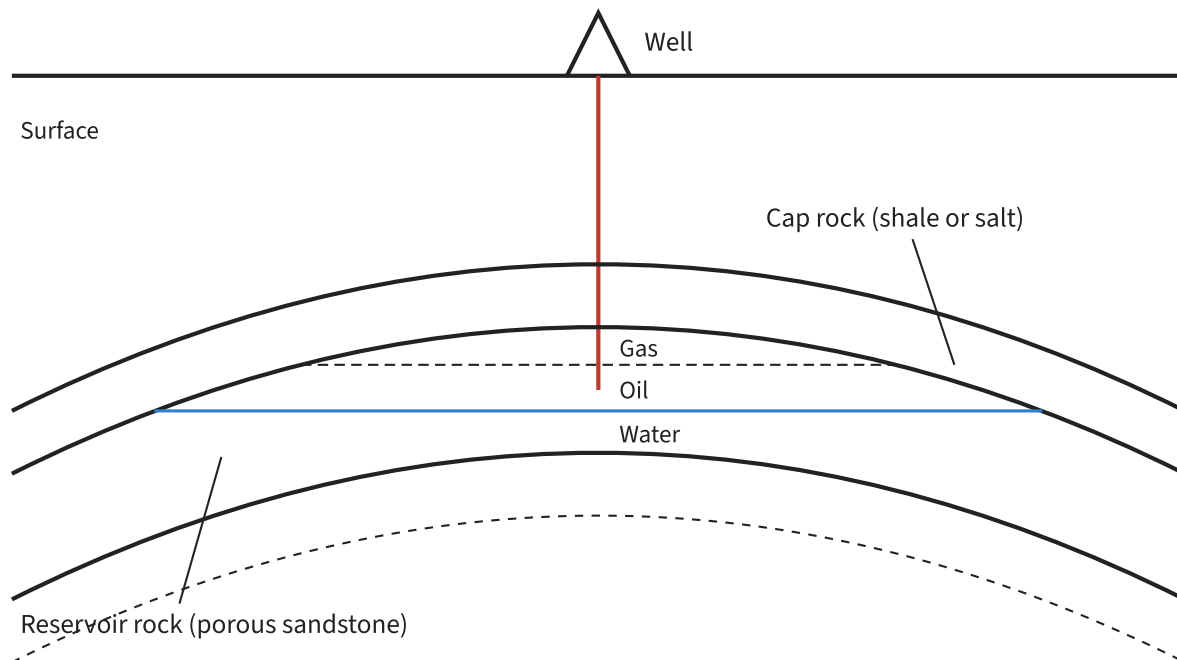
On the map. The world’s greatest oil province rings the Persian Gulf. On May 26, 1908, after years of failure, George Reynolds, drilling for the English investor William Knox D’Arcy, struck oil at Masjed Soleyman in Persia. A few years later Winston Churchill, as First Lord of the Admiralty, moved the Royal Navy from coal to oil, and in 1914 the British government bought a controlling share of the Anglo-Persian Oil Company. In March 1938 an American company struck oil at Dammam No. 7 in Saudi Arabia, and in 1948 geologists found Ghawar, the largest conventional oil field ever discovered. As of the mid-2020s the largest proved reserves lie in Venezuela (mostly heavy oil of the Orinoco belt), Saudi Arabia, Iran, Canada (the oil sands of Alberta) and Iraq. Other great provinces include western Siberia, the North Sea (opened from 1969), the Gulf of Mexico and the Permian Basin of Texas and New Mexico. Natural gas often lies with oil; the largest gas field on earth sits under the Persian Gulf, shared between Qatar (the North Field) and Iran (South Pars).

How it moves. Early oil traveled in wooden barrels on wagons and rafts; the 42-gallon barrel became the industry’s unit. In 1865 Samuel Van Syckel laid an iron pipeline about five miles from the Pithole field to a railroad, and the teamsters who had hauled the barrels tore at it. In 1879 the Tidewater Pipeline carried crude more than 100 miles over the Allegheny Mountains. At sea, the German-owned *Glückauf*, built on the Tyne in 1886, carried oil loose in its hull and became the pattern for the modern tanker. When the Suez Canal was closed in 1956 and again from 1967 to 1975, tankers had to sail around Africa, and owners answered with giant ships: a **VLCC** carries about 2 million barrels. On land, pipelines rule. The Trans-Alaska Pipeline, finished in 1977, runs about 800 miles (1,287 km) from Prudhoe Bay on the

frozen Arctic coast to the ice-free port of Valdez, and the Soviet-built Druzhba (“Friendship”) system, begun in the 1960s, was built to carry Russian crude thousands of kilometers west into central and eastern Europe. A pipeline is cheap to run but fixed in place, binding seller and buyer for decades; a tanker costs more per mile but can sail to any port that pays.

The gas problem. Gas is far bulkier than oil for the energy it holds, so it moves either by pipeline or as **LNG**, chilled to about $-162\text{ }^{\circ}\text{C}$ ($-260\text{ }^{\circ}\text{F}$) until it shrinks to about 1/600 of its volume. The first LNG cargo crossed the Atlantic in 1959, when the converted freighter *Methane Pioneer* sailed from Lake Charles, Louisiana, to Canvey Island in England. Because liquefaction plants and terminals are costly, gas markets long stayed regional, tied to pipelines. As of 2026 the United States, Qatar and Australia are the largest LNG exporters, and the U.S. has been the world’s largest since 2023.

The big idea and technology overcoming geography. Oil lies where God laid it, often far from the people who use it, so the geography of oil is the geography of routes. The world uses about 100 million barrels a day (2020s), and in 2024 about 20 million barrels a day passed through the Strait of Hormuz (Unit 3), roughly a fifth of the world’s use. Technology has also changed where oil can be produced. Horizontal drilling combined with hydraulic fracturing opened oil and gas locked in tight shale rock, and U.S. crude production more than doubled between 2008 and 2019, making the United States the world’s largest producer as of the mid-2020s, ahead of Saudi Arabia and Russia.



An anticline trap: gas over oil over water, sealed by cap rock.



Where oil lies and how it moves: pipelines and tanker lanes.

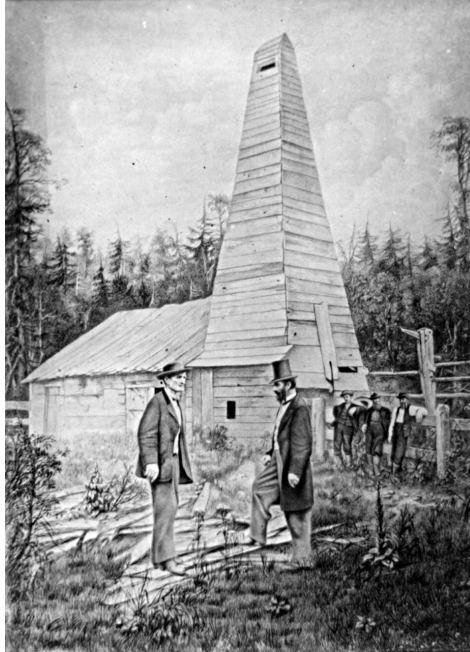
Thinking About Time

What the sign says. Textbooks often give the source rocks of oil fields very great ages in years.

What we observe. What is measured is the rock and the oil today: their layers, their chemistry and the fossils in them. The ages depend on assumptions about how fast layers formed and how radioactive elements decayed over long unobserved time.

How Christians read it. Many Christians who read Genesis as history understand much of the buried plant and animal matter that became oil and gas as material laid down rapidly during the Flood (Genesis 6–9); laboratory work has also shown that heat and pressure can turn organic matter into oil-like substances in a short time.

PICTURE STUDY



Edwin L. Drake at the Drake Well, Titusville, Pennsylvania, John A. Mather, about 1866 (sometimes dated 1861); this print copyrighted 1890 · Photograph (this copy is a retouched reproduction, copyrighted 1890) · Library of Congress, Prints and Photographs Division (cph.3a14109); Mather's negatives are at the Drake Well Museum and Park, Titusville, Pennsylvania

John A. Mather was a photographer who came to Titusville as the oil boom began and spent decades photographing the derricks, boomtowns, teamsters and fires of the Pennsylvania oil region. This picture shows Edwin Drake, in the tall hat, standing with his friend Peter Wilson, a Titusville druggist, in front of the rebuilt engine house and derrick of the well that started it all.

The scene is plain, almost homely: boards, barrels and mud. Yet within a generation this kind of well had spread to Texas, Baku, Persia and beyond. Look at it as a record of a technology at its very beginning.

Look closely

- Find the derrick. What is it made of, and what was it for?
- Find the engine house. What power do you think drove the drill, and what fuel did it burn?
- Look at the ground and the barrels. How was the oil stored and moved away?
- Compare the clothes and setting with the way an oil field looks today. What has changed most?

Talk about it

1. Drake earned little from his well and died a poor man in 1880, while others grew rich. What does that tell you about the difference between being first and controlling transport and refining?

2. Why was Titusville a hard place to ship oil from in 1859? How did pipelines change that?
3. If you could ask Mather one question about what he saw in the oil region, what would it be?

PROJECT: AN OIL TRAP IN A BOX

Geologists look for traps: places where rock layers form a sealed arch. You will build a cross-section of an anticline in a clear box, push water and then oil into the reservoir from below, and “drill” at the crest and on the flank to see where the oil collects. Then you will use your trap to plan how to ship the oil.

You will need

- A clear plastic box or large jar with straight sides
- Aquarium gravel or coarse sand (reservoir rock)
- Modeling clay or plasticine (cap rock and base rock)
- A crumpled ball of aluminum foil the size of a fist (to make the arch)
- Flexible tubing or a long bendable straw, and a syringe or turkey baster
- Water, about ½ cup of vegetable oil (a few drops of oil paint stirred in will darken it), paper towels
- Two drinking straws for “wells”

Steps

1. Press a flat layer of clay across the bottom of the box: this is the sealed base. Set the foil ball in the middle to make the arch.
2. Lay one end of the tubing on the clay at the low edge of the box so it will open into the gravel. Cover the foil and the tube end with 3–4 cm of damp gravel, shaped into an arch.
3. Cover the gravel completely with a layer of clay about 1 cm thick, pressed firmly against the box walls: this is the cap rock. The tube should stick out at the side.
4. With the syringe, slowly push water into the gravel until it is full. Then push in the oil a little at a time. Watch through the side of the box where it goes.
5. Push one straw through the cap rock at the very crest of the arch and another on the flank, near the box wall. Draw from each with the syringe. Which well gives oil, and which gives water?
6. Measure the depth from the surface of the clay to the oil, and sketch your cross-section with labels for reservoir, cap rock, oil, water and the two wells.
7. Finally, suppose your field is on a frozen coast 800 miles from an ice-free port. Write a short plan: pipeline, tanker or both? Give two reasons.

Tips

- Go slowly: real oil migrates over long stretches of time through tiny pores. If oil pushes out around the edges, the cap rock has a leak, which is exactly why real traps need a

good seal.

- Wash oily gravel with dish soap and hot water, or throw it away in the trash, not down the drain.

Check your work

- I can label the parts of a trap and explain why gas, oil and water separate.
- I can show why a well at the crest finds oil and a well on the flank finds water.
- I can choose between pipeline and tanker for a real geography and explain why.

MAP NOTEBOOK

1. On a world outline, mark the five countries with the largest proved oil reserves (as of the mid-2020s) and the three largest producers. Use two colors and a key. Which countries appear on both lists?
2. Draw the Trans-Alaska Pipeline from Prudhoe Bay to Valdez over a simple outline of Alaska. Label the Brooks Range and the Alaska Range it crosses and the port it ends at.
3. Draw a side view of a VLCC and an LNG carrier with its round or boxy tanks. Under each, write what it carries, how much, and at what temperature.

From history. Before Drake, people had used oil and asphalt where they seeped from the ground for thousands of years: to waterproof boats and baskets, to set stones and to light lamps. In the 1850s the Polish pharmacist Ignacy Łukasiewicz distilled kerosene from seep oil and helped light a hospital in Lwów with a kerosene lamp in 1853, and wells were dug for oil in Galicia and near Baku on the Caspian before Titusville. Drake's achievement was to show that drilling, borrowed from the salt-brine wells of the Appalachians, could reach oil in quantity, and the method spread around the world within a few years.

WORKED EXAMPLES

Example 1. The Trans-Alaska Pipeline is 48 inches (1.22 m) in diameter and about 1,287 km long. (a) How many barrels does it hold when full (1 barrel = 0.159 m³)? (b) If it carries about 480,000 barrels a day, how many days does oil take to travel from Prudhoe Bay to Valdez?

1. Radius = $1.22 \div 2 = 0.61$ m. Cross-section = $\pi \times 0.61^2 \approx 3.1416 \times 0.372 \approx 1.169$ m².
2. Length = 1,287 km = 1,287,000 m. Volume $\approx 1.169 \times 1,287,000 \approx 1,505,000$ m³.
3. Barrels $\approx 1,505,000 \div 0.159 \approx 9,470,000$ barrels, about 9.5 million.
4. (b) Time $\approx 9,470,000 \div 480,000 \approx 19.7$ days.

Answer: (a) About 9.5 million barrels. (b) About 20 days for oil to travel the length of the line at that rate.

Example 2. A VLCC loads 2 million barrels at Ras Tanura, Saudi Arabia, for Ningbo, China, a route of roughly 6,000 nautical miles through the Strait of Hormuz and the Strait of Malacca. (a) How long is the voyage at 13 knots? (b) How many U.S. gallons does it carry? (c) What is the route in km?

(Use the map or drawing “Follow the VLCC through two choke points.” shown earlier in this lesson.)

1. (a) $6,000 \div 13 \approx 461.5$ hours; $461.5 \div 24 \approx 19.2$ days.
2. (b) $2,000,000 \times 42 = 84,000,000$ gallons.
3. (c) $6,000 \times 1.852 \approx 11,100$ km (about 6,900 miles).

Answer: (a) About 19 days. (b) 84 million gallons. (c) About 11,100 km.

Example 3. A typical LNG carrier holds about $174,000 \text{ m}^3$ of LNG. When warmed back to a gas, LNG expands about 600 times. (a) How much gas does one cargo deliver? (b) If a city uses 5 million m^3 of gas a day in winter, how many days does one cargo supply?

1. (a) $174,000 \times 600 = 104,400,000 \text{ m}^3$, about 104 million m^3 of gas.
2. (b) $104,400,000 \div 5,000,000 \approx 20.9$ days.

Answer: (a) About 104 million m^3 of gas. (b) About 21 days of winter supply for that city.

PRACTICE

1. **EASY** When and where did Edwin Drake strike oil, and how deep was the well in feet and meters?
2. **EASY** Name the two rock layers labeled in the figure and the shape of the layers that forms the trap, and give the order in which gas, oil and water lie in it.
(Use the map or drawing “Read the trap from top to bottom.” shown earlier in this lesson.)
3. **EASY** Convert one VLCC cargo of 2 million barrels to liters (1 barrel ≈ 159 L).
4. **MEDIUM** In 2024 about 20 million barrels a day passed through the Strait of Hormuz, while the world used about 100 million barrels a day. What share is that? How many full VLCCs a day would carry it?
5. **MEDIUM** The Trans-Alaska Pipeline is about 800 miles long. Convert to km. At its 1988 peak it carried about 2 million barrels a day. How long did oil take to pass through it then, if it held about 9.5 million barrels?
6. **MEDIUM** Saudi Arabia holds roughly 267 billion barrels of proved reserves and produces about 9 million barrels a day. Compute the reserves-to-production ratio in years. Why is this not a countdown to the last barrel?
7. **MEDIUM** A Q-Max LNG carrier holds about $266,000 \text{ m}^3$ of LNG. How much gas is that after it is warmed ($\times 600$)?
8. **MEDIUM** How many years passed between Drake’s well and Spindletop, and between Masjed Soleyman and Dammam No. 7?

9. **MEDIUM** A tanker sails 11,000 nautical miles from the Persian Gulf to Rotterdam around the Cape of Good Hope instead of about 6,400 nautical miles through Suez. At 14 knots, how many extra days does the Cape route take?
10. **HARD** Why does Prudhoe Bay oil travel by pipeline to Valdez and only then by tanker, instead of loading tankers at Prudhoe Bay?
11. **HARD** Explain why the world gas trade has been more regional than the oil trade.
12. **CHALLENGE** Write a paragraph: How did the closing of the Suez Canal (1956, and 1967–1975) and the arrival of shale drilling each show “technology overcoming geography” in oil, and what geography did neither overcome?

COMMON MISTAKES

- Picturing oil in underground lakes or caves. It fills the tiny pores of reservoir rock, like water in a sponge.
- Confusing reserves with resources or with a fixed supply. Proved reserves are what can be produced profitably with known technology, and the number changes as technology and prices change.
- Treating gas as if it moved like oil. Gas needs pipelines or the costly LNG chain, which shapes where it can be sold.

Make it a game · Pipeline or Tanker?. Make cards naming real oil and gas moves: Prudhoe Bay to Valdez, Ras Tanura to Ningbo, western Siberia to Germany, Texas shale to a Gulf port, Qatar to Japan, the North Sea to Scotland, Alberta to the U.S. Midwest. Players draw a card and have 30 seconds to say “pipeline,” “tanker,” “LNG carrier” or a combination, and one geographic reason. A parent judges; a correct answer with a good reason scores two points. Bonus point: name a choke point on the route.

Scripture. “Make thee an ark of gopher wood; rooms shalt thou make in the ark, and shalt pitch it within and without with pitch.” (Genesis 6:14, KJV)

Pitch, a tar or bitumen, is one of the oldest uses of petroleum-like materials, and the first is in God’s command to Noah. Long before engines and lamps, men used the sticky products of the earth to keep water out of their vessels.

Practice answers

1. August 27–28, 1859, on Oil Creek near Titusville, Pennsylvania; about $69\frac{1}{2}$ feet, or 21 meters ($69.5 \times 0.3048 \approx 21.2$ m).
2. Reservoir rock, cap rock, and the arch (anticline) that forms the trap. From top to bottom: gas, oil, water, because they separate by density.
3. $2,000,000 \times 159 = 318,000,000$ L, about 318 million liters.
4. $20 \div 100 = 20\%$, one-fifth. $20,000,000 \div 2,000,000 = 10$ VLCC loads a day (in fact many smaller tankers also carry it).
5. $800 \times 1.609 \approx 1,287$ km. $9,500,000 \div 2,000,000 \approx 4.75$ days, under five days.
6. $9,000,000 \times 365 \approx 3.29$ billion barrels a year; $267 \div 3.29 \approx 81$ years. It is not a countdown because “proved reserves” grow as new fields are found, technology improves and prices

change what is worth producing, and production rates change too.

7. $266,000 \times 600 = 159,600,000 \text{ m}^3$, about 160 million m^3 .
8. $1901 - 1859 = 42$ years; $1938 - 1908 = 30$ years.
9. Extra distance $4,600 \text{ nm} \div 14 \text{ knots} \approx 329 \text{ hours} \approx 13.7 \text{ days}$, about two weeks.
10. Prudhoe Bay lies on the Arctic coast, where the sea is frozen or ice-choked most of the year and far from markets by any sea route. Valdez, on Prince William Sound in southern Alaska, is ice-free all year, so a pipeline across the mountains brings the oil to a port where tankers can load in every season.
11. Gas holds much less energy per unit of volume, so it must move by pipeline or be liquefied at about -162°C into LNG, which needs costly liquefaction plants, special ships and regasification terminals. Pipelines tie particular sellers to particular buyers. Oil is a liquid at normal temperature and can go by ordinary tanker to almost any port, so it trades as one world market.
12. A strong answer explains that the Suez closures forced tankers around Africa, and shipowners answered with VLCCs whose size cut the cost per barrel so much that the long route paid; and that horizontal drilling with hydraulic fracturing made oil in tight shale rock producible, more than doubling U.S. output between 2008 and 2019. Neither changed where the oil actually lies, the need to cross narrow straits such as Hormuz and Malacca, or the distance between producers and users.

4.5 GRAIN, COPPER AND RARE EARTHS

OBJECTIVES

- Explain why the world's breadbaskets lie in the mid-latitude grasslands and trace how their grain reaches the sea, beginning with Britain's repeal of the Corn Laws in 1846.
- Locate the great copper belts and rare-earth sources, from Ytterby (1787) to Chuquicamata and Bayan Obo, and explain why ore grade and processing matter as much as the deposit.
- Calculate grain yields and loads, copper recovered from low-grade ore, and producers' shares of a mineral market, and explain resource concentration in neutral terms.

Warm-up. Look at the ingredient list on a loaf of bread and find the flour. Then pick up a phone, earbuds or a small speaker (do not open it). Make two quick guesses: In what country was the wheat in your bread probably grown? Which metals are inside the device, and where on earth might they have been dug? Write your guesses down to check at the end.

Watch. *Rare earth elements* (Our Metallic Earth, 20:13).

<https://www.youtube.com/watch?v=fe5z2pAacRA>

With the big idea: watch the part about rare earths and listen for what these elements are, why they are hard to mine and refine even though they are not truly rare, and what magnets and other products need them.

Note: Captions were not available to check; preview it first. The video runs about 20 minutes, and its tags suggest it talks about the 'energy transition' and 'green energy', so check how much of it is framed around climate.

KEY TERMS

breadbasket

A region that grows far more grain than its people eat and exports the rest, such as the U.S. Corn Belt and Great Plains, the Canadian Prairies, the Argentine Pampas and the black-earth lands of Ukraine and southern Russia.

chernozem

"Black earth," a deep, dark, fertile grassland soil rich in organic matter, found across Ukraine and southern Russia and similar to the prairie soils of North America.

ore grade

The share of a valuable metal in the rock that is mined; most copper ore today is well under 1% copper.

porphyry copper deposit

A huge body of rock with copper minerals spread through it, formed with molten rock beneath mountain ranges such as the Andes and the Rockies; it is mined in giant open pits.

rare-earth elements

Seventeen metals (the fifteen lanthanides plus scandium and yttrium) used in strong magnets, screens and catalysts; they are not truly rare but are scattered and very hard to separate.

resource concentration

When most of the world's supply of a resource, or of its processing, comes from one or a few places, so that trouble in one place affects buyers everywhere.

CORE IDEAS

The story. In 1846 the British Parliament, led by Prime Minister Sir Robert Peel, voted to repeal the Corn Laws, the duties that had kept foreign grain out of Britain to protect British farmers. Peel acted in the shadow of the potato blight that struck Ireland in 1845, and the vote split his own party. In effect, Britain decided to buy much of its bread from abroad. Within a generation it was doing so. Railroads carried prairie wheat to Chicago, where steam-powered grain elevators (first built at Buffalo by Joseph Dart in 1842) lifted it from cars into bins, and the Chicago Board of Trade, founded in 1848, set prices for the world. Steamships carried it across the Atlantic, while Russian wheat poured out of the Black Sea port of Odessa. The idea was old; Rome had fed itself largely on grain shipped from Egypt and North Africa, and the apostle Paul was wrecked on an Alexandrian grain ship whose crew threw the wheat overboard to lighten her (Acts 27). What was new was the scale.

On the map: the breadbaskets. The great grain lands share a physical geography. They lie in the middle latitudes, mostly on natural grasslands where centuries of grass roots built deep, dark soils: the **chernozem** of Ukraine and southern Russia, the prairie soils of the American Midwest and the Canadian Prairies, the Pampas of Argentina. The land is flat, the summers warm with long days, and the rain moderate, enough for grain but often too little for forest. In the 2020s Russia is the world's largest wheat exporter, with the European Union, Canada, Australia, the United States, Ukraine and Argentina among the other leaders. The United States grows the most corn, and Brazil has become the largest soybean grower and exporter, thanks largely to the *cerrado*, a vast tropical savanna whose acid soils Brazilian scientists, working through the research agency Embrapa (founded in 1973), learned to correct with lime and new crop varieties. Grain moves by water wherever it can: barges down the Mississippi to the Gulf ports, which ship roughly half or more of U.S. corn and soybean exports; ships through the Bosphorus from the Black Sea; and bulk carriers from Santos and Paranaguá in Brazil.

Copper. Copper was among the first metals people worked, and its name comes from the island of Cyprus, which supplied the ancient Mediterranean (Latin *aes Cyprium*, later *cuprum*). Mixed with tin it made bronze, which is why museum signs speak of a "Bronze Age." But copper's great age began with electricity. It conducts better than any metal but silver at a fraction of the price, and when Thomas Edison opened his Pearl Street power station in New York in 1882, copper wire carried the current. Most of the world's copper comes from **porphyry deposits** strung along the mountain chains of the Pacific rim. Chile, from mines such as Chuquibambilla and Escondida in the Atacama Desert, produces roughly a

quarter of the world's copper (2020s); the Democratic Republic of the Congo and Peru come next, and the Central African Copperbelt runs across Katanga and Zambia. In Utah, Bingham Canyon has been mined since 1906 and is now about 1.2 kilometers ($\frac{3}{4}$ mile) deep and 4 kilometers ($2\frac{1}{2}$ miles) across. Because the **ore grade** is usually well under 1%, a mine must move mountains of rock for each tonne of metal.

Rare earths. In 1787 a Swedish army lieutenant and amateur chemist, Carl Axel Arrhenius, picked up a heavy black stone in a feldspar quarry at Ytterby, a village on an island near Stockholm. In 1794 the Finnish chemist Johan Gadolin found a new "earth" in it, and over the next century chemists pulled from Ytterby's minerals a whole family of new elements. Four are named for the village: yttrium, ytterbium, terbium and erbium. The **rare-earth elements** are not truly rare; some are more common in the earth's crust than lead. But they are scattered, they occur together, and they are so alike chemically that separating them takes hundreds of steps. From the 1960s through the 1980s the Mountain Pass mine in California, found in 1949, was the world's leading source. Then China's huge Bayan Obo deposit in Inner Mongolia and its separation plants took over. As of the mid-2020s China mines roughly 70% of the world's rare earths and refines about 90%, and in 2025 it added export licensing rules for several rare earths and magnets. Australia, the United States and others are expanding mines and plants. The most important use is the neodymium-iron-boron magnet, developed in the early 1980s, which makes possible tiny phone speakers and vibration motors, small powerful motors in electric cars and drones, and large wind-turbine generators.

The big idea. Every resource has three geographies. The physical geography is where God laid the deposit or the soil. The economic geography is the cost of digging, refining and carrying it: a fertile prairie a thousand miles from water transport, or copper ore at 0.5%, may be worth little until railroads, barges and bigger machines arrive. The political geography is who controls the land, the processing and the trade. When most of a resource, or most of its refining, sits in one country, geographers speak of **resource concentration**, a kind of choke point on land, much like the straits of Unit 3. Buyers respond as shippers do with straits: by finding second routes, building stockpiles and developing new sources. Joseph did the same in Egypt when he stored grain in the seven good years (Genesis 41), and the promise after the Flood still stands: "While the earth remaineth, seedtime and harvest, and cold and heat, and summer and winter, and day and night shall not cease" (Genesis 8:22).



Breadbaskets, copper and rare earths: a world resource map.

PICTURE STUDY



The Harvesters, Pieter Bruegel the Elder, 1565 · Oil on wood · The Metropolitan Museum of Art, New York

Pieter Bruegel the Elder painted *The Harvesters* in 1565 as one of a series of pictures of the seasons and the labors of the year for an Antwerp merchant, Niclaes Jongelinck. Five of the series survive. This one shows the grain harvest in high summer in the Low Countries: men mowing with scythes, women binding sheaves, and a crew resting at midday with bread, porridge and pears.

Bruegel made his career in Antwerp, then the great trading city of northern Europe, where ships unloaded Baltic grain from Danzig, before moving to Brussels in 1563. His painting is about one field, but it reaches to the horizon, where a road leads toward a port and ships ride at anchor. Look for the link between the field and the sea.

Look closely

- Find the uncut wheat, the cut sheaves and the stacked stooks. How many steps of the harvest can you see?
- Look at the workers at rest. What are they eating, and where did each food come from?
- Follow the road into the distance. What do you find at the end of it?
- Notice the shape of the land. Why would flat, open country suit grain?

Talk about it

1. Bruegel shows people living from their own field, but also a harbor with ships. How does the painting show both a local and a trading economy?
2. Compare this harvest of 1565 with a modern Kansas or Saskatchewan harvest. What has changed and what has stayed the same?
3. Why might a merchant in Antwerp want paintings of farm labor in his house?

Safety first. Neodymium magnets are far stronger than fridge magnets. They can pinch skin badly when they snap together, they can shatter, and they are very dangerous if a small child swallows more than one. Keep them away from little children, phones, credit cards and anyone with a pacemaker. Use the stove only with an adult.

PROJECT: TWO CHAINS: FIELD TO FLATBREAD, ROCK TO MAGNET

You will follow two resource chains by hand. First you will bake a flatbread and work backward to how much wheat and how much field it took. Then you will test a rare-earth magnet against an ordinary one and work backward to the mines and refineries behind it. The result is a practice run for the unit project.

You will need

- Kitchen scale; 300 g of flour (whole wheat if you have it), water, a pinch of salt, a little oil; a skillet
- One ordinary fridge magnet and one small neodymium disc magnet (hardware or craft store)
- A box of steel paper clips
- World outline map, colored pencils, notebook and calculator

Steps

1. Mix 300 g of flour, a pinch of salt and enough water to make a soft dough. Divide into six pieces, roll thin and cook in a hot dry or lightly oiled skillet with an adult, about a minute a side.
2. Calculate: whole wheat flour is about the same weight as the wheat it came from; white flour is about 75% of the wheat's weight. How much wheat made your flour?
3. A good Kansas wheat field yields about 3.4 tonnes per hectare, which is 0.34 kg per square meter. How many square meters of field grew your wheat? Mark out that area

on the floor or in the yard with string.

4. Magnet test: hang a chain of paper clips from the fridge magnet, adding one at a time until it fails. Record the number. Repeat with the neodymium magnet. Compare the two, and compare their sizes.
5. Look up (or use the lesson) where neodymium is mined and refined, where iron ore and boron come from, and where magnets are made. Draw both chains on the world map with arrows: field, elevator, mill and kitchen for the bread; mine, separation plant, magnet factory and device for the magnet.
6. Write a paragraph: Which chain crosses more borders? Which has more steps in one country? Which would be harder to replace if one link broke?

Tips

- The magnet test is not exact science, since paper clips vary, but the difference is so large that the lesson is clear: a tiny rare-earth magnet can do the work of a large ordinary one, which is why devices could shrink.
- Keep your chain maps; you will use the same method for the unit portfolio.

Check your work

- I can compute the field area behind a loaf or flatbread.
- I can explain why rare-earth magnets made small motors and speakers possible.
- I can draw a resource chain on a world map and point out where it is concentrated.

MAP NOTEBOOK

1. On a world outline, shade the five great breadbaskets named in the lesson and draw the main water route by which each sends grain to sea.
2. Draw the Andes from Peru to central Chile and mark Chuquicamata and Escondida. Beside the map, sketch an open pit as a stepped bowl and label its benches, the haul road and the ore grade.
3. Copy the periodic table's lanthanide row and circle the four elements named for Ytterby. Add a note on what neodymium is used for.

From history. Grain became a world commodity partly through a clever piece of paperwork. In 1856 the Chicago Board of Trade began grading wheat by quality, such as "No. 1 spring wheat." Once grain of the same grade was treated as interchangeable, a farmer's wagonload could be poured into an elevator bin with everyone else's, and the farmer received a warehouse receipt for so many bushels of that grade instead of his own sacks. Receipts could be bought and sold, and soon merchants were trading contracts for grain to be delivered months ahead. Those contracts grew into the modern futures market.

WORKED EXAMPLES

Example 1. A Kansas farmer harvests a 160-acre quarter section of wheat at 50 bushels per acre. A bushel of wheat is 60 lb (27.2 kg). Find the harvest in bushels, short tons and metric tonnes, and the yield in tonnes per hectare (1 acre = 0.4047 ha).

1. Bushels: $160 \times 50 = 8,000$ bushels.
2. Pounds: $8,000 \times 60 = 480,000$ lb; short tons: $480,000 \div 2,000 = 240$ short tons.
3. Kilograms: $8,000 \times 27.2 = 217,600$ kg ≈ 218 tonnes.
4. Hectares: $160 \times 0.4047 \approx 64.8$ ha. Yield: $218 \div 64.8 \approx 3.4$ t/ha.

Answer: 8,000 bushels = 240 short tons $\approx$ 218 tonnes, a yield of about 3.4 tonnes per hectare.

Example 2. A copper mine processes 100,000 tonnes of ore at a grade of 0.6% copper, and the mill recovers 90% of the copper. (a) How much copper is produced? (b) How many tonnes of rock are mined for each tonne of copper?

1. Copper in the ore: $100,000 \times 0.006 = 600$ t.
2. Recovered: $600 \times 0.90 = 540$ t.
3. Rock per tonne of copper: $100,000 \div 540 \approx 185$ t (and in an open pit, more waste rock must be moved besides the ore).

Answer: (a) 540 tonnes of copper. (b) About 185 tonnes of ore for each tonne of copper.

Example 3. Rounded U.S. Geological Survey estimates for world rare-earth mine production in 2024 are about 390,000 tonnes (rare-earth oxide), of which China produced about 270,000, the United States about 45,000, Myanmar about 31,000 and Australia about 13,000. Find each country's share and the share of the top two together.

1. China: $270,000 \div 390,000 \approx 0.69 = 69\%$.
2. United States: $45,000 \div 390,000 \approx 11.5\%$.
3. Myanmar: $31,000 \div 390,000 \approx 7.9\%$. Australia: $13,000 \div 390,000 \approx 3.3\%$.
4. Top two: $69\% + 11.5\% \approx 81\%$.

Answer: China about 69%, United States about 11.5%, Myanmar about 8%, Australia about 3%; the top two together about 81%. (China's share of refining is higher still, about 90%.)

PRACTICE

1. **EASY** When were the Corn Laws repealed, and what did the repeal mean for where Britain got its bread?
2. **EASY** Give three physical reasons the world's breadbaskets lie in mid-latitude grasslands.
3. **EASY** Name the four elements named for Ytterby, and the year the first black stone was found there.
4. **EASY** Which country produces the most copper, and name one of its mines and the desert where it lies.
(Use the map or drawing "Find the copper of the Andes." shown earlier in this lesson.)
5. **MEDIUM** A Mississippi River barge carries about 1,500 short tons of corn. A bushel of corn weighs 56 lb. How many bushels is one barge? How many in a tow of 15 barges?
6. **MEDIUM** A grain truck carries about 25 short tons. How many truckloads equal one 1,500-ton barge, and how many equal a 15-barge tow?
7. **MEDIUM** Bingham Canyon is about 1.2 km deep. Convert to feet and miles (1 km = 3,281 ft = 0.621 mi). How many Iron Bridges (100 ft) stacked end to end would reach the bottom?
8. **MEDIUM** Suppose Russia exports 48 million tonnes of wheat in a year. How many bushels is that (1 bushel = 27.2 kg)? How many 60,000-tonne bulk ships would carry it?
9. **MEDIUM** Odesa is at about 46.5°N, 30.7°E and the northern entrance of the Bosphorus at about 41.2°N, 29.1°E. Estimate the distance in km and miles, and the sailing time at 12 knots (1 nautical mile = 1.852 km).
(Use the map or drawing "Black Sea grain to the Bosphorus." shown earlier in this lesson.)
10. **HARD** Why are rare earths called "rare," and why is the name misleading? Why does separation matter more than mining for who controls the supply?
11. **HARD** Explain how Brazil's cerrado is an example of technology overcoming geography.
12. **CHALLENGE** Write a paragraph comparing the concentration of rare-earth refining with a sea-lane choke point such as Malacca or Hormuz. Name two ways a buying country might reduce its risk. Keep your answer factual and neutral.

COMMON MISTAKES

- Thinking the best farmland is in the tropics because plants grow fastest there. The great grain exporters are mid-latitude grasslands with deep soils, flat land and seasonal climates.
- Taking "rare earths" literally. They are not especially rare; they are hard to separate, and processing is the bottleneck.
- Looking only at where a resource is mined. Refining, manufacturing and the transport route are often more concentrated, and more important, than the mine.

Make it a game • Resource Detective. A parent prepares cards with clues to a resource region, such as "black earth, flat, Black Sea port" (Ukraine and southern Russia), "desert, Andes, open pit" (Chile's copper), "island village near Stockholm, 1787"

(Ytterby), “Inner Mongolia, magnets” (Bayan Obo), “barges, Gulf of Mexico” (the Corn Belt and the Mississippi). Players race to point to the place on a world map and name the resource. Two points for the place, one for the resource, one bonus for naming the sea route or port it leaves by.

Scripture. “And all countries came into Egypt to Joseph for to buy corn; because that the famine was so sore in all lands.” (Genesis 41:57, KJV)

In the King James Bible “corn” means grain in general. Joseph’s Egypt was the first breadbasket in Scripture: a fertile river valley, wisely managed, from which grain flowed to other lands in time of need. Stewardship of the harvest is an old and godly kind of geography.

Practice answers

1. 1846. Britain removed the duties that kept foreign grain out, so it came to import much of its wheat from North America, Russia and later Argentina, Australia and India.
2. Deep, dark fertile soils built by grass roots (chernozem, prairie soils); flat land easy to plow and harvest; warm summers with long days and moderate rainfall suited to grain.
3. Yttrium, ytterbium, terbium and erbium; 1787.
4. Chile; Chuquibambilla or Escondida, in the Atacama Desert.
5. $1,500 \times 2,000 = 3,000,000 \text{ lb} \div 56 \approx 53,600$ bushels per barge; $\times 15 \approx 804,000$ bushels, about 800,000.
6. $1,500 \div 25 = 60$ trucks per barge; $60 \times 15 = 900$ trucks for the tow.
7. $1.2 \times 3,281 \approx 3,940$ ft; $1.2 \times 0.621 \approx 0.75$ mile. $3,940 \div 100 \approx 39$ Iron Bridges.
8. $48,000,000,000 \text{ kg} \div 27.2 \approx 1.76$ billion bushels. $48,000,000 \div 60,000 = 800$ shiploads.
9. North-south: $5.3^\circ \times 111 \approx 588$ km. East-west: $1.6^\circ \times 111 \times \cos 43.9^\circ (0.72) \approx 128$ km. Distance $\approx \sqrt{(588^2 + 128^2)} \approx 602$ km, about 374 miles, or about 325 nautical miles. At 12 knots, about 27 hours.
10. They were first found in a few unusual minerals and were hard to isolate, so early chemists thought them rare. In fact several are more common in the crust than lead, but they are scattered and occur mixed together, and they are so alike chemically that separating them takes many steps, special chemistry and skilled plants. Ore can be mined in many countries, but whoever owns the separation and magnet-making plants controls the usable supply.
11. The cerrado is a vast tropical savanna with acid, nutrient-poor soils that long supported little farming. From the 1970s Brazilian scientists, working through Embrapa, learned to correct the soil with lime and fertilizer and bred crop varieties suited to the tropics. Together with roads and ports, this turned it into one of the world’s great soybean and corn regions, making Brazil the largest soybean exporter.
12. A strong answer explains that in both cases a large share of a vital flow passes through one place: oil through a narrow strait, rare earths through one country’s refineries (about 90% in China as of the mid-2020s). A disruption there, whether war, accident or policy (such as China’s 2025 export licensing), affects buyers everywhere. Ways to reduce risk include developing other mines and separation plants (Australia, the United States), keeping stockpiles, recycling magnets from old devices, and designing products that use less of the scarce elements, just as shippers use pipelines and alternative routes around a strait.

UNIT 4 TEST

Answer each question. Show your work for every calculation, give units (km and miles where asked), and use complete sentences for explanations. Use 111 km per degree of latitude. The test is worth 100 points.

1. (6 pts) Name the three geographic sources of salt and give one real place for each.
2. (8 pts) An azalai of 800 camels leaves Taoudenni for Timbuktu, about 660 km away. Each camel carries four 30 kg slabs, and the caravan covers 33 km a day. (a) How many tonnes of salt does it carry? (b) How many days does the trip take? (c) Give the distance in miles.
3. (6 pts) Explain why Timbuktu grew where it did, using the terms break-of-bulk point and complementarity.
4. (6 pts) What were the mita and amalgamation at Potosí, and why did Potosí depend on Huancavelica?
5. (8 pts) Suppose a price index rose from 100 to 250 over 60 years. Find the steady yearly rate of increase and the doubling time at that rate.
6. (7 pts) Using $M \times V = P \times Y$: if the money supply triples, velocity stays the same and the real quantity of goods doubles, what happens to the price level? Name one cause of the price revolution other than American silver.
7. (6 pts) Map reading: list in order the places silver passed through on the official route from Potosí to Spain, and name the illegal shortcut.
8. (8 pts) An ore field O, a coalfield C and a market M form a triangle: O-C = 50 km, C-M = 120 km, O-M = 130 km. One tonne of iron needs 3 t of ore and 5 t of coal, and 1 t of iron goes to market. Find the ton-kilometers at each corner and choose the least-cost site.
9. (7 pts) Give three events in the history of the Ruhr with their dates, and explain why later steelworks were built at seaports rather than on coalfields.
10. (6 pts) Match each city to its coalfield: Manchester, Cardiff, Newcastle, Essen. Then state what Abraham Darby achieved in 1709.
11. (8 pts) A VLCC carrying 2 million barrels sails about 5,800 nautical miles at 14 knots. (a) How many days does the voyage take? (b) How many U.S. gallons does it carry? (c) What is the distance in km?
12. (7 pts) Describe an anticline trap and the order of gas, oil and water in it. Then explain why Prudhoe Bay oil travels by pipeline to Valdez before it goes by tanker.
13. (7 pts) A mine processes 250,000 tonnes of ore grading 0.5% copper and recovers 88% of it. How much copper does it produce, and how many tonnes of ore are processed per tonne of copper?
14. (10 pts) Essay (one or two paragraphs): Choose grain, copper or rare earths. Explain its physical geography (where it lies and why), its economic geography (cost of producing and moving it) and its political geography (who controls it), with at least two real places and one figure with a year. Keep the political part factual and neutral.

UNIT PROJECT: FROM THE EARTH TO MY HANDS: A RESOURCE-TO-PRODUCT CHAIN

Choose one everyday object in your home, such as a pencil, a loaf of bread, a soda can, a copper pipe, a cell phone, a gallon of gasoline or a box of salt. Following the example of Leonard Read's essay *I, Pencil* (1958), trace at least four of its raw materials back to the places on earth where they are mined, grown or pumped, using the USGS Mineral Commodity Summaries or other reliable sources for current figures.

Draw a large world map showing each source, every processing step and the route to your home, with arrows marked by transport type (pipeline, rail, barge, bulk ship, container ship, truck) and the straits or canals they pass through. Add a one-page written explanation of where the chain is most concentrated or vulnerable, and close with a reflection on the providence that set these resources in their places and the many people whose work brings them to you.

- **Accuracy:** At least four raw materials are traced to real, correctly located sources, with figures that are rounded, sourced and dated.
- **Map:** The world map clearly shows sources, processing steps, routes, transport types and choke points, with a key and a title.
- **Analysis:** The written explanation identifies the most concentrated or vulnerable link and explains it with physical, economic and political geography in neutral terms.
- **Care and reflection:** The work is neat and readable, and the reflection thoughtfully connects resources, work and providence.

Answer key

1. The sea, evaporated in salterns (Mediterranean shores, Bay of Bourgneuf, Gujarat); rock salt or halite (Taghaza, Taoudenni, Wieliczka, Hallstatt, Cheshire, Gulf Coast salt domes); brine springs and wells (Lüneburg, Droitwich, Zigong). Accept any other correctly placed real example, such as Guérande or Guerrero Negro for sea salt, or the Great Salt Lake or Salar de Uyuni for salt lakes and brines. Two points each.
2. (a) $800 \times 4 \times 30 \text{ kg} = 96,000 \text{ kg} = 96 \text{ tonnes}$. (b) $660 \div 33 = 20 \text{ days}$. (c) $660 \div 1.609 \approx 410 \text{ miles}$.
3. Timbuktu stood near the northern bend of the Niger at the edge of the desert, where camel caravans from the salt mines met river boats from the south. Goods had to be unloaded and reloaded there (a break-of-bulk point). The desert had salt but no gold or grain; the south had gold and grain but no salt (complementarity), so the exchange point became a city.
4. The mita was a rotating forced-labor draft of Andean men, organized by Viceroy Toledo in the 1570s, that sent about 13,000 men a year to the mines. Amalgamation (the patio process) refined ground ore with mercury and salt, making low-grade ore profitable. Huancavelica supplied the mercury.
5. Factor 2.5; $\ln 2.5 \approx 0.916$; $0.916 \div 60 \approx 0.0153$, so about 1.5% a year. Doubling time $\approx 70 \div 1.5 \approx 46 \text{ years}$ (about 45 years).
6. P is proportional to $M \div Y = 3 \div 2 = 1.5$, so prices rise 50%. Other causes: rapid population growth, debasement of coins by kings such as Henry VIII, or changes in velocity as trade grew.

7. Potosí, Arica, Callao (Lima), Panama, across the isthmus to Portobelo, Havana, Seville. The illegal shortcut ran overland to Buenos Aires.
8. At C: ore $3 \times 50 = 150$ + iron $1 \times 120 = 120$, total 270 t-km. At O: coal $5 \times 50 = 250$ + iron $1 \times 130 = 130$, total 380 t-km. At M: ore $3 \times 130 = 390$ + coal $5 \times 120 = 600$, total 990 t-km. The coalfield is the least-cost site.
9. Any three: Krupp founded in Essen (1811); Dortmund-Ems Canal (1899) or Rhine-Herne Canal (1914); French and Belgian occupation (1923); forced labor in the Second World War and Alfred Krupp's conviction (1948); European Coal and Steel Community (1951); last hard-coal mine closed (2018). Later mills used less coal per tonne of iron and imported ore and coal by bulk ship, so the least-cost location moved to deep-water ports.
10. Manchester: Lancashire. Cardiff: South Wales. Newcastle: Northumberland and Durham. Essen: the Ruhr. In 1709 at Coalbrookdale Darby smelted iron with coke instead of charcoal.
11. (a) $5,800 \div 14 \approx 414$ hours ≈ 17.3 days. (b) $2,000,000 \times 42 = 84,000,000$ gallons. (c) $5,800 \times 1.852 \approx 10,700$ km.
12. Rock layers bend into an upward arch; oil and gas rise through porous reservoir rock until a sealing cap rock (shale or salt) stops them at the crest. They separate by density: gas on top, oil in the middle, water below. Prudhoe Bay is on the ice-bound Arctic coast; the pipeline carries oil about 800 miles (1,287 km) to Valdez, an ice-free port where tankers can load all year.
13. $250,000 \times 0.005 = 1,250$ t in the ore; $\times 0.88 = 1,100$ t recovered. $250,000 \div 1,100 \approx 227$ tonnes of ore per tonne of copper.
14. Grade with this guide: physical geography accurate with real places, such as mid-latitude grasslands with chernozem and prairie soils, the Andes porphyry belt (Chuquicamata, Escondida), or Bayan Obo and Mountain Pass (3 points); economic geography such as barges and bulk ships, low ore grades and huge pits, or costly separation (3 points); political geography factual and neutral, such as Russia as the largest wheat exporter, Chile's quarter of world copper, or China's roughly 70% of rare-earth mining and 90% of refining as of the mid-2020s (2 points); clear writing with a dated figure (2 points).

THE MODERN TRADE MAP

The course has followed the camel, the dhow, the galleon and the clipper along the great routes of the world. In this last unit you arrive in the present. Why do countries trade at all, even when one could make everything itself? David Ricardo answered with four numbers about English cloth and Portuguese wine in 1817, and his idea of **comparative advantage** still frames how economists think about trade. Then you will meet Malcom McLean, the North Carolina trucker whose steel boxes, beginning with the *Ideal X* in 1956, cut the cost of loading a ship by more than ninety percent and made distance cheap.

You will visit four of the world's great ports, Shanghai, Singapore, Rotterdam and Los Angeles-Long Beach, and learn to read a port by its site and situation. You will sort the world's goods into what flies, what floats and what flows, from Colombian roses to Alaskan crude oil. Finally you will put the whole course to work by tracing one real product from its raw materials to your own front door and drawing its journey on a world trade-flow map.

The Psalmist wrote of "they that go down to the sea in ships, that do business in great waters" (Psalm 107:23). Modern trade is still that business. The sea lanes and straits God placed in the earth still draw the main lines of the map, and honest dealing, fair weights and peace still make trade a blessing to the nations.

BEFORE YOU BEGIN

- Can name the major straits and canals of world shipping and locate them on a map (Unit 3)
- Can explain where major resources such as oil, grain and metals are found and how they move (Unit 4)
- Can convert between kilometers, miles and nautical miles and compute time from distance and speed
- Can compute percentages, ratios and simple averages

MASTERY CHECKLIST

- I can explain comparative advantage with Ricardo's wine-and-cloth example and compute opportunity costs and gains from trade.
- I can tell how Malcom McLean's container lowered the cost of shipping and calculate with TEU, knots and nautical miles.
- I can compare Shanghai, Singapore, Rotterdam and Los Angeles-Long Beach by site, situation, hinterland and role as gateway or hub.
- I can explain why some goods fly, most float and fluids flow, and calculate freight as a share of price and pipeline flow.
- I can trace a real product's journey to my home, naming each port, strait, canal and mode, with distance, time and risk.

- I can weigh fairly both the gains of trade and its real costs to particular workers and places.

OPTIONAL BOOKS AND RESOURCES

- **David Ricardo, *On the Principles of Political Economy and Taxation* (free at the Library of Economics and Liberty)**
(<https://www.econlib.org/library/Ricardo/ricP.html>): Free. Read chapter 7, “On Foreign Trade,” for the wine-and-cloth example in Ricardo’s own words (Lesson 5.1). The passage is short; the rest of the book is for advanced readers.
- **Leonard E. Read, “I, Pencil” (Foundation for Economic Education)**
(<https://fee.org/resources/i-pencil/>): Free. The short 1958 essay that opens Lesson 5.5. Read it aloud as a family before starting the product-journey project.
- **Econ Lowdown, from the Federal Reserve Bank of St. Louis**
(<https://www.econlowdown.org/>): Free. Short lessons and videos on comparative advantage, trade and transport costs for high school students.

5.1 COMPARATIVE ADVANTAGE: RICARDO'S WINE AND CLOTH

OBJECTIVES

- Tell how David Ricardo, in *On the Principles of Political Economy and Taxation* (1817), used English cloth and Portuguese wine to show why two countries can both gain from trade.
- Distinguish absolute advantage from comparative advantage, compute opportunity costs from a production table, and show the total gain from specialization.
- Explain how geography (climate, soil, resources, skills and distance) shapes what places make and trade, and weigh the main criticisms of free-trade arguments fairly.

Warm-up. Two people must make 10 sandwiches and fold 10 shirts. Parent: 1 minute per sandwich, 1 minute per shirt. Student: 2 minutes per sandwich, 4 minutes per shirt. The parent is faster at both. Should the parent do everything? With a timer and a pencil, figure out how long the jobs take if each does half of each task, and then if the student makes all the sandwiches and the parent folds all the shirts and makes the rest of the sandwiches. Which plan finishes first? Keep your numbers: you will meet the same puzzle in Ricardo.

Watch. *Law of Comparative Advantage* (EconplusDal, 12:30).

<https://www.youtube.com/watch?v=YboSszwySzU>

After the story: watch how the teacher works through Ricardo's example with a simple table, and look for how opportunity cost shows which country should make which good.

Note: Captions were not available to check; preview it first. This is a British economics teacher's lesson, so expect British terms and possibly different numbers or goods from the book's wine and cloth example. The video may use its own numbers or goods instead of Ricardo's England and Portugal, wine and cloth.

Backup video. *Sources of Comparative Advantage* (Marginal Revolution University, 8:02). https://www.youtube.com/watch?v=vT_uVJ4zoik

As review: watch for the different sources of comparative advantage (geography, climate, natural resources, capital and skills, scale and institutions), and listen for the mention of Ricardo's Portugal wine and England cloth. Note: Captions were not available to check; preview it first. It is a college-level lecture, so younger students may need help with terms like 'increasing returns to scale'.

KEY TERMS

absolute advantage

The ability to produce a good with fewer resources (for example, fewer hours of labor) than another producer.

comparative advantage

The ability to produce a good at a lower opportunity cost than another producer. Trade follows comparative, not absolute, advantage.

opportunity cost

What must be given up to get something: here, how much of one good a country forgoes to make one more unit of the other.

specialization

Concentrating work on the goods a person, region or country produces at the lowest opportunity cost, and trading for the rest.

terms of trade

The rate at which one good is exchanged for another (for example, 1 bolt of cloth for 1 cask of wine). Both sides gain when it falls between their opportunity costs.

autarky

A condition of no trade, in which a country produces everything it uses.

CORE IDEAS

The story. In April 1817 a London publisher, John Murray, brought out a thick book by a retired stockbroker named David Ricardo: *On the Principles of Political Economy and Taxation*. Ricardo was the son of a Sephardic Jewish family from Amsterdam, had made a fortune on the London exchange (much of it dealing in the government loans of the Napoleonic wars), and had read Adam Smith's *Wealth of Nations* while on holiday in Bath. He was a hard-headed man of figures, and his seventh chapter, "On Foreign Trade," contains the most famous four numbers in economics. Ricardo imagined that in England the cloth a country needed might take the labor of 100 men for a year, and the wine 120 men. In Portugal the same cloth might take 90 men and the same wine only 80. Portugal, in his example, was better at *both*. Even so, Ricardo argued, Portugal would gain by making wine and buying English cloth, and England would gain by making cloth and buying Portuguese wine. The economist Robert Torrens had sketched the same idea in 1815, but Ricardo's neat table made it stick.

How it worked. Adam Smith in 1776 had explained trade by **absolute advantage**: "It is the maxim of every prudent master of a family, never to attempt to make at home what it will cost him more to make than to buy." The tailor buys his shoes and the shoemaker buys his coat. But what if one side is better at everything? Ricardo's answer was to compare **opportunity costs**. In England, making one unit of wine uses 120 worker-years that could have made 1.2 units of cloth. In Portugal, one unit of wine uses 80 worker-years that could have made only about 0.89 units of cloth. So wine is "cheaper" in Portugal in the only sense that matters: it costs less cloth. Turn it around and cloth is cheaper in England, where it costs about 0.83 wine instead of 1.125 wine in Portugal. Each country has a **comparative advantage** in one good. If England puts all 220 of its workers into cloth, it makes 2.2 units; if Portugal puts all 170 of its workers into wine, it makes 2.125 units. Before trade the two countries together made 2 cloth and 2 wine. After specializing they make more of both, with the same workers. Trading at any rate between their two opportunity costs, say one cloth for one wine, both are better off. The figure shows the two countries' production limits crossing at the old "one of each" point.

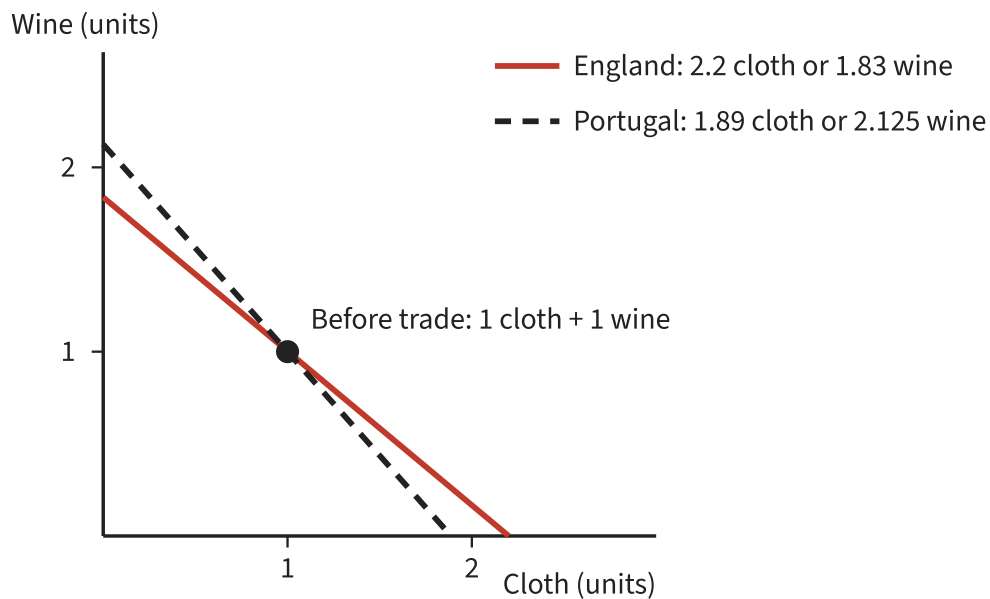
The big idea. Comparative advantage is the economic form of a truth every family knows: the best use of each person's time depends not on what one does well, but on what one does *best compared to everyone else*. A surgeon may type faster than the office secretary, but the surgeon's hour is worth far more in the operating room. Many years later the American economist Paul Samuelson told how the mathematician Stanislaw Ulam challenged him to name one idea in the social sciences that is both true and not obvious. Samuelson named comparative advantage: it is logically true, and thousands of intelligent people have never grasped it. Notice what the idea does *not* say. It does not say every person in both countries gains. English vintners (if there were any) and Portuguese weavers would have to change work, and that change has real costs for real families. It assumes workers can move between trades, that transport is cheap enough, and that the countries stay at peace. Critics have pressed each point. Alexander Hamilton's *Report on Manufactures* (1791) and the German economist Friedrich List's *National System of Political Economy* (1841) argued that a young nation may need to protect "infant industries" until they can compete, and many nations guard industries they think vital in war. Supporters answer that protection usually costs consumers more than it saves and invites retaliation. A careful student learns the logic first and then weighs these arguments on the evidence.

On the map. Ricardo did not pick his goods at random. Portugal's Douro valley, with hot dry summers and steep slate slopes cut into terraces, made fortified port wine that English merchants shipped from Porto. England had wet pastures for sheep, coal, water power and the new spinning mills of Yorkshire and Lancashire. The Methuen Treaty of 1703 had already tied the two: Portugal admitted English woolens, and England taxed Portuguese wine at a lower rate than French wine. Geography supplies the raw differences that comparative advantage turns into trade: climate and soil (coffee in the highlands of Colombia, wheat on the Great Plains), resources in the ground (iron ore in Western Australia, copper in Chile), harbors and rivers, and the skills a people builds up over generations (watchmaking in the Swiss Jura, chips in Taiwan). As of 2026, Brazil and the United States are the world's great soybean exporters, Chile is the largest copper producer, and the Netherlands, a small country, is one of the largest exporters of farm goods by value, thanks to rich delta soil, greenhouses and the port of Rotterdam.

Technology overcoming geography. Ricardo's example leaves out one cost: getting the cloth to Lisbon and the wine to London. Every cask had to be loaded by hand, sailed across the Bay of Biscay and unloaded again. If moving the goods costs more than the gain from specializing, there is no trade at all, and each country makes its own. That is why the history of trade is also the history of transport. Every cheaper ship, canal, railroad and, above all, the shipping container (Lesson 5.2) widened the circle in which comparative advantage could work. When freight costs fall, places that were too far apart to trade become partners, and the world map of who makes what changes. The rest of this unit follows that story from the box to the port to the pipeline and finally to your own front door.

A Christian reading. Scripture pictures the church as a body with many members, none able to say to another, "I have no need of thee." The same pattern runs through creation. God did not give every land the same soil, rain and stone. The vine grows on one hillside and the sheep graze on another, and people are drawn to serve one another across the sea.

Comparative advantage describes that interdependence in numbers; honest weights, fair dealing and peace make it work.



Ricardo's two countries. Each line shows the most one country can make with all its workers (England 220 worker-years, Portugal 170). Before trade each makes 1 cloth and 1 wine, the point where the lines cross. England's line reaches farther along the cloth axis; Portugal's reaches higher on the wine axis.

PICTURE STUDY



Portrait of David Ricardo, Thomas Phillips, about 1821 · Oil on canvas · National Portrait Gallery, London (NPG L241, on loan from the Ricardo family since 2007)

Thomas Phillips was one of the leading portrait painters of Regency London; he painted Lord Byron, William Blake and the scientist Michael Faraday. He painted David Ricardo near the end of Ricardo's short life. By then Ricardo had retired from the stock exchange, bought a country estate, Gatcombe Park in Gloucestershire, and entered Parliament (1819), where he argued against the Corn Laws that taxed imported grain. He died in 1823, aged 51.

Most famous economic ideas began as arguments over real policy. Ricardo's case for free trade was written while Britain debated whether to keep out foreign grain to protect its landowners. The Corn Laws were finally repealed in 1846, more than twenty years after his death.

Look closely

- Look at the face and eyes. What kind of man does the painter want you to see: a dreamer, a gambler or a careful thinker?
- Notice how plain the background and clothing are. What does that simplicity draw your eye toward?
- Compare this portrait with a merchant's portrait from the age of the spice trade (Unit 2). What is missing here that a Dutch merchant might have been painted with: globes, ships, goods?
- Look at the light. Where does it fall, and what does it leave in shadow?

Talk about it

1. Ricardo made his fortune trading government debt, yet he is remembered for an idea about cloth and wine. Why might a man of figures see a pattern others missed?
2. Why do you think a single clear example (four numbers) persuaded more people than long arguments had?
3. Is a portrait good evidence about a person's ideas? What would you need to read instead?

PROJECT: THE KITCHEN-TABLE TRADE EXPERIMENT

You will test comparative advantage with your own hands. Two "countries" (two people) will make two simple goods: paper boats and paper stars (or folded envelopes and paper chains). First each country works alone and makes some of both. Then each specializes by comparative advantage and trades. You will count whether the two together really end up with more.

You will need

- Two people (student and a parent or sibling)
- A stack of scrap paper (at least 40 sheets), scissors and tape
- A kitchen timer or phone stopwatch
- Graph paper, ruler, pencil and two colored pencils

Steps

1. Choose two goods that take different skills, for example paper boats (folding) and paper chains of 10 links (cutting and taping).
2. Timing round: each person makes as many boats as possible in 3 minutes, then as many chains as possible in 3 minutes. Record the counts in a table titled "Output per 3 minutes."
3. From the table, compute each person's opportunity cost of one boat (in chains) and of one chain (in boats). Decide who has the comparative advantage in each good. Note whether one person has an absolute advantage in both.
4. Autarky round: give each person 6 minutes. Each spends 3 minutes on each good. Record the total boats and chains for both people together.
5. Specialization round: again 6 minutes each, but each person makes only the good of his or her comparative advantage (if one person's two opportunity costs are close, that person may split time). Record the totals.
6. Trade: agree on a terms-of-trade rate between your two opportunity costs and swap goods so that each person ends with some of both. Record what each person has.
7. On graph paper, draw each person's production-possibilities line (as in the lesson figure), mark the autarky point and the after-trade point, and write three sentences: Did the pair make more in total? Did each person end up better off? What would have wiped out the gain (for example, a long walk to make the trade)?

Tips

- Practice each good once before timing, so the first round is not just learning.
- If the faster person is better at both, that is the best case: it is exactly Ricardo's Portugal.
- Real people get faster with practice. Note whether specializing also made each person quicker; Adam Smith said this was one of the great gains of the division of labor.

Check your work

- I computed opportunity costs correctly from my own times.
- I showed with real counts whether specialization raised total output.
- I chose a terms-of-trade rate between the two opportunity costs and explained why.

MAP NOTEBOOK

1. Draw a small map of England and Portugal with the Bay of Biscay between them. Mark London, Leeds (wool cloth), Porto and the Douro valley (port wine), and draw a two-headed arrow for the cloth-and-wine trade.
2. Copy Ricardo's table (cloth 100 and wine 120 for England; cloth 90 and wine 80 for Portugal) and write the four opportunity costs beside it.
3. List five things in your kitchen and the country each came from. Beside each, guess the geographic reason (climate, soil, resource or skill) that place has a comparative advantage in it.

From history. Ricardo wrote while Parliament debated the Corn Laws of 1815, which taxed imported grain to keep prices high for British landowners. Ricardo argued that the laws made bread dear for workers and held back manufacturing. The Anti-Corn Law League, led by the manufacturers Richard Cobden and John Bright, carried the fight on after his death, and Prime Minister Robert Peel repealed the laws in 1846, splitting his own Conservative Party. The Irish famine, which made dear bread a matter of life and death, helped force the decision.

WORKED EXAMPLES

Example 1. Ricardo's table: in England a unit of cloth takes 100 worker-years and a unit of wine 120; in Portugal cloth takes 90 and wine 80. Which country has an absolute advantage in each good, and which has the comparative advantage in each?

(Use the map or drawing "England's line is flatter toward cloth; Portugal's rises higher toward wine." shown earlier in this lesson.)

1. Absolute advantage: Portugal needs fewer workers for cloth ($90 < 100$) and for wine ($80 < 120$), so Portugal has the absolute advantage in both.
2. England's opportunity cost of 1 wine = $120 \div 100 = 1.2$ cloth. Portugal's = $80 \div 90 \approx 0.89$ cloth. Portugal gives up less cloth for each wine.
3. England's opportunity cost of 1 cloth = $100 \div 120 \approx 0.83$ wine. Portugal's = $90 \div 80 = 1.125$ wine. England gives up less wine for each cloth.
4. The lower opportunity cost marks the comparative advantage.

Answer: Portugal has the absolute advantage in both goods, but its comparative advantage is in wine (0.89 cloth per wine against England's 1.2). England's comparative advantage is in cloth (0.83 wine per cloth against Portugal's 1.125).

Example 2. Before trade each country makes 1 cloth and 1 wine, using all its workers (England 220, Portugal 170). If each specializes completely in its comparative-advantage good, how much of each good does the pair make? What is the gain? Then show that a trade of 1 cloth for 1 wine leaves each country better off.

1. Before trade the pair makes $1 + 1 = 2$ cloth and $1 + 1 = 2$ wine.
2. England puts all 220 worker-years into cloth: $220 \div 100 = 2.2$ cloth.
3. Portugal puts all 170 worker-years into wine: $170 \div 80 = 2.125$ wine.
4. Gain: $2.2 - 2 = 0.2$ cloth and $2.125 - 2 = 0.125$ wine, with no extra workers.
5. Trade 1 cloth for 1 wine. England now has 1.2 cloth and 1 wine (0.2 cloth more than before). Portugal has 1 cloth and 1.125 wine (0.125 wine more than before).
6. Another way to see it: England gets a wine for 100 worker-years of cloth instead of 120 worker-years of its own wine (saving 20); Portugal gets a cloth for 80 worker-years of wine instead of 90 (saving 10).

Answer: The pair makes 2.2 cloth and 2.125 wine instead of 2 and 2: a gain of 0.2 cloth and 0.125 wine. After a 1-for-1 trade, England has 1.2 cloth and 1 wine, Portugal 1 cloth and 1.125 wine; both are better off.

Example 3. In Ricardo's example the 1-for-1 trade saves England 20 worker-years per wine and Portugal 10 worker-years per cloth. Suppose shipping costs, measured in labor, are added. (a) If shipping one unit of wine to London costs 15 worker-years (paid by England) and shipping one unit of cloth to Lisbon costs 15 worker-years (paid by Portugal), does each country still gain? (b) What is the largest total shipping cost, for one cloth and one wine together, at which trade gains anything at all?

1. (a) England: saving 20 – shipping 15 = 5 worker-years. England still gains.
2. Portugal: saving 10 – shipping 15 = –5 worker-years. Portugal would lose at these terms and would refuse this trade.
3. Could new terms of trade rescue the deal? Changing the rate only moves gain from one side to the other. The total saving is $20 + 10 = 30$ worker-years and the total shipping cost is $15 + 15 = 30$, so the combined gain is $30 - 30 = 0$. No rate can leave both better off.
4. (b) The total gain from one exchange is $20 + 10 = 30$ worker-years. Trade gains something only while shipping both cargoes costs less than 30 worker-years.

Answer: (a) England still saves 5 worker-years but Portugal loses 5; since the total saving (30) equals the total shipping cost (30), no rate of exchange can make both better off, and trade stops. (b) Shipping must cost less than 30 worker-years for one cloth and one wine together. Cheaper transport is what lets comparative advantage work.

PRACTICE

1. **EASY** In what year and in what book did David Ricardo publish his wine-and-cloth example?
2. **EASY** Define absolute advantage and comparative advantage in one sentence each.
3. **EASY** In Ricardo's example, which country was better (needed fewer workers) at making both goods? Did that mean it should make both?
4. **EASY** Name the 1703 treaty that linked English woolens and Portuguese wine, and say what each side received.
5. **MEDIUM** Country A: 1 worker-day makes 6 tons of wheat or 2 radios. Country B: 1 worker-day makes 4 tons of wheat or 4 radios. Find each country's opportunity cost of 1 radio (in wheat). Who should make radios?
6. **MEDIUM** Using problem 5, name a terms-of-trade rate (tons of wheat per radio) at which both countries gain, and explain why it works.
7. **MEDIUM** Using Ricardo's numbers, how many worker-years does England save on each unit of wine it buys from Portugal at 1 cloth per wine? How many does Portugal save on each unit of cloth?
8. **MEDIUM** Give two geographic reasons the Douro valley of Portugal suited wine, and two reasons northern England suited woolen cloth around 1800.
9. **HARD** Suppose Portugal's wine cost rose from 80 to 100 worker-years (a bad decade of disease in the vines), all other numbers unchanged. Recompute Portugal's opportunity cost of wine. Does the pattern of trade still hold?
10. **HARD** When would two countries gain nothing from trade according to Ricardo's logic? Give a numerical example.
11. **HARD** State the "infant industry" argument of Hamilton (1791) and List (1841), and one common reply by free-trade economists.
12. **CHALLENGE** Write a short paragraph (4–6 sentences): Comparative advantage says trade makes a nation as a whole better off. Who might lose in the short run, and how should a fair-minded citizen weigh those losses against the gains?

COMMON MISTAKES

- Confusing absolute and comparative advantage. Being faster at everything does not mean doing everything; compare opportunity costs, not raw times.
- Dividing the wrong way when computing opportunity cost. The opportunity cost of wine is (labor for wine) ÷ (labor for cloth), measured in units of cloth given up.
- Forgetting transport and adjustment costs. Ricardo's model shows a possible gain; distance, shipping, war and the cost of changing jobs can shrink or erase it.

Make it a game · Who Should Make It?. One player writes a quick two-country table (two goods, two countries, labor needed for each). The other has 30 seconds to name each country's comparative advantage and a terms-of-trade rate that helps both. Score 1 point for the correct advantages and 1 for a valid rate. Bonus point if the table is a "trick" where one country is better at both and the player still gets it right. Play to 10.

Scripture. “If the whole body were an eye, where were the hearing? If the whole were hearing, where were the smelling? But now hath God set the members every one of them in the body, as it hath pleased him.” (1 Corinthians 12:17–18, KJV)

Paul is speaking of the church, not of nations, yet the pattern he describes runs through creation: different gifts, placed by God, serving one another. Comparative advantage is that pattern at work in the vineyards and mills of the world.

Practice answers

1. 1817, in *On the Principles of Political Economy and Taxation* (chapter 7, “On Foreign Trade”).
2. Absolute advantage: producing a good with fewer resources than another producer.
Comparative advantage: producing a good at a lower opportunity cost than another producer.
3. Portugal. No: Portugal gains more by making only wine, where its advantage is greatest, and buying English cloth.
4. The Methuen Treaty. Portugal admitted English woolen cloth; England charged lower duties on Portuguese wine than on French wine.
5. A: 1 radio costs $6 \div 2 = 3$ tons of wheat. B: 1 radio costs $4 \div 4 = 1$ ton of wheat. B has the comparative advantage in radios; A in wheat (A gives up $1/3$ radio per ton, B gives up 1 radio per ton).
6. Any rate between 1 and 3 tons of wheat per radio, for example 2. A pays 2 tons for a radio that would cost it 3 tons to make; B gets 2 tons of wheat for a radio that cost it only 1 ton.
7. England: $120 - 100 = 20$ worker-years per wine. Portugal: $90 - 80 = 10$ worker-years per cloth.
8. Douro: hot, dry summers; steep, well-drained slate slopes terraced for vines (and the river to carry casks to Porto). Northern England: wet pastures for sheep; water power and coal for mills (also skilled workers and ports).
9. Portugal: 1 wine = $100 \div 90 \approx 1.11$ cloth. England: 1.2 cloth. Portugal’s cost is still lower, so Portugal keeps the comparative advantage in wine and England in cloth, though the gain from trade is smaller (the two opportunity costs are closer).
10. When their opportunity costs are the same. Example: Country X makes 1 cloth in 100 and 1 wine in 100 worker-years; Country Y makes 1 cloth in 50 and 1 wine in 50. Both have an opportunity cost of 1 cloth per wine, so specializing adds nothing (and transport would make trade a loss).
11. Argument: a young nation’s new industries cannot yet compete with established foreign producers, so temporary tariffs let them grow until they can. Reply: protection raises prices for consumers, the “temporary” tariffs often become permanent, and protected industries may never become efficient; it may also invite retaliation.
12. Answers will vary. A strong answer notes that workers and owners in industries that face cheaper imports may lose jobs or income, while consumers and exporters gain; that the losses are concentrated and visible while the gains are spread widely; that moving to new work takes time and skill; and that a citizen should weigh both honestly, considering aid for adjustment, national security goods, and the long-run evidence rather than slogans.

5.2 THE CONTAINER REVOLUTION: MALCOM MCLEAN AND THE COST OF SHIPPING ⚙️

OBJECTIVES

- Tell the story of Malcom McLean, the *Ideal X* (April 26, 1956) and the rise of Sea-Land, and explain why a steel box changed world trade.
- Compare the cost and time of break-bulk and container handling, and use TEU, knots and nautical miles to calculate ship capacity and voyage times.
- Explain how cheap container shipping reshaped the map of ports, factories and jobs, naming both its gains and its real costs.

Warm-up. Put 30 small mixed objects (spoons, socks, cans, pencils, toy cars) on a table. Time how long it takes to carry them one at a time into a shoebox across the room. Now put the same objects into three plastic tubs and time carrying the tubs. Which was faster? What did you have to do before the second trip that you did not do before the first?

Watch. *Malcom McLean: The Modern Intermodal Shipping Container / Heroes of Progress / Ep. 17* (Human Progress, 2:30). <https://www.youtube.com/watch?v=Ua2ZCn13JDc>

After the story: watch this two-and-a-half-minute profile of Malcom McLean and listen for how the shipping container cut the cost and time of loading ships.

Note: Captions were not available to check; preview it first. It comes from HumanProgress.org, a free-market think-tank project, so it focuses on how trade made people better off.

Backup video. *Shipping Containers & Bubble Wrap / Maddie's Do You Know 🧐 Series 2, Episode 1 / FULL EPISODE!* (Maddie's Do You Know?, 14:15).

<https://www.youtube.com/watch?v=0SFGGTd9p7Y>

Before the project: younger students can watch the shipping-container half of this episode to see containers being stacked, lifted by cranes and moved through a port. Note: Captions were not available to check; preview it first. It is a British children's show (CBeebies), so expect British terms, and about half the episode is about bubble wrap rather than shipping.

KEY TERMS

break-bulk cargo

Goods loaded piece by piece (sacks, bales, barrels, crates) by gangs of dockworkers. Nearly all general cargo moved this way before the 1960s.

intermodal container

A standard steel box that moves between ship, train and truck without its contents being unloaded.

TEU (twenty-foot equivalent unit)

The standard measure of container capacity: one 20-foot container. A 40-foot box counts as 2 TEU (also called an FEU).

twist lock and corner casting

The steel fittings at each corner of a container and the rotating locks that grip them, so boxes can be stacked, lifted and locked to a truck chassis, railcar or deck.

knot and nautical mile

A nautical mile is 1.852 km (about 1.15 statute miles), one minute of latitude. A knot is one nautical mile per hour.

economies of scale

Falling cost per unit as size grows. A ship twice as large costs much less than twice as much to build, crew and fuel per box.

CORE IDEAS

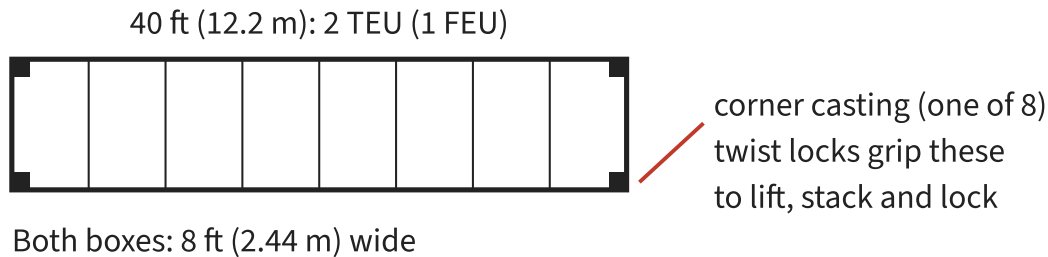
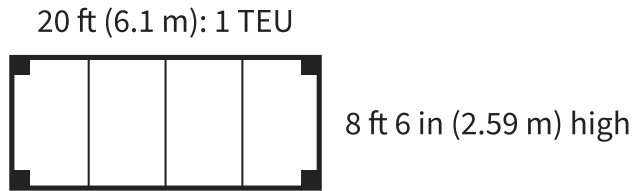
The story. On April 26, 1956, an old tanker named the *Ideal X* slipped away from Port Newark, New Jersey, bound for Houston. She was a T2 tanker built in the Second World War, and her new owner had fitted her with a raised steel deck above the pipes. On that deck rode 58 aluminum trailer bodies, each 35 feet long, which cranes had lifted straight off their wheels and set down in rows. The owner was Malcom McLean, a trucker from Maxton, North Carolina, who had started in 1934 with one secondhand truck and built one of the largest trucking firms in the country. McLean later remembered waiting a whole day in 1937 at a pier in Hoboken while longshoremen unloaded his cotton bales by hand and wondering why the whole trailer could not simply be lifted aboard. In 1955 he sold his trucking company and bought a shipping line to find out. When the *Ideal X* reached Houston, trucks were waiting to hook up the boxes and drive away.

How it worked. Before McLean, a general cargo ship was loaded like a moving van packed by hand. Gangs of longshoremen carried sacks, barrels, bales, cartons and crates into slings, swung them into the hold and stowed each piece by muscle and judgment. A ship might spend a week or more in port, and theft and damage were common. By one study McLean's company used, loading loose cargo cost about \$5.83 a ton in 1956; the *Ideal X* was loaded for about 16 cents a ton. In 1957 his *Gateway City* became the first ship built with "cells," steel guide rails in the holds into which cranes dropped 226 boxes, stacked and locked without any stowing by hand. His engineer Keith Tantlinger designed the corner castings and twist locks that let a box be lifted from any corner and clamped to a deck, a truck chassis or a railcar. McLean renamed the firm Sea-Land in 1960. In 1962 a container terminal opened at Port Elizabeth, New Jersey, beside the New Jersey Turnpike, and in May 1966 Sea-Land's *Fairland* began regular container service across the Atlantic to Rotterdam. During the Vietnam War McLean's ships carried military supplies to Cam Ranh Bay and filled the empty boxes in Japan on the way home, opening the Pacific trade. In the late 1960s the International Organization for Standardization fixed the standard sizes (8 feet wide, 20 and 40 feet long), so any box would fit any ship, crane, train and truck in the world.

The big idea. The container did not make ships faster; it made *ports* faster. The great cost of shipping had never been the sea passage but the handling at each end, piece by piece, and the waiting. By turning thousands of different shapes into one standard shape, the box let machines do the lifting, let ships spend a day in port instead of a week, and let a factory seal a box in Guangdong that is not opened until it reaches a warehouse in Ohio. Because the ship spends most of its life at sea, it pays to build ever larger ones: **economies of scale**. The *Ideal X* carried 58 boxes. The largest ships afloat as of 2026 carry about 24,000 TEU, are about 400 m (1,312 ft) long and sail with crews of about 25. As of the mid-2020s the world's container fleet could carry about 30 million TEU. Shipping a single pair of shoes or a television across the Pacific now costs a small fraction of its shelf price. That is the transport cost Ricardo left out of his example, shrunk nearly to zero.

On the map. Cheap boxes redrew the map. Container ships need deep water, wide channels, huge flat yards for stacking and rail and highway links, not crowded finger piers in old city centers. The busy piers of Manhattan, Brooklyn and San Francisco and the London Docks emptied in the 1960s and 1970s, while new terminals rose at Port Elizabeth, Oakland, Felixstowe and the Maasvlakte at Rotterdam. Factories no longer had to sit near their customers or even near a coast; they could go wherever labor, land and skills were cheapest and a port was near. That is a large part of why East Asia became the world's workshop and why the world's busiest ports today are in China (Lesson 5.3). The routes followed the sea lanes and straits of Unit 3: Asia to North America across the Pacific, Asia to Europe through Malacca and Suez, and Europe to North America across the Atlantic. Ships too large for the old Panama locks (built to "Panamax" size) pushed the expansion of the canal, whose larger locks opened in 2016.

Technology overcoming geography. The container is a plain steel box, yet it may have done more to tie the world together than the jet airplane. Its gains were enormous: cheaper goods for families everywhere, new jobs and rising incomes in exporting countries, and far less theft and breakage. Its costs were also real and should be named. Longshore work, a hard and proud trade in port cities for generations, shrank to a fraction of its former size, and dock neighborhoods lost their reason to exist. Unions fought the change and won pay guarantees for some workers; many others found new work. Factory towns that faced new competition from abroad also bore the cost. McLean himself was no saint of the story: a bold dealmaker, he sold Sea-Land in 1969, and a later shipping venture, United States Lines, went bankrupt in 1986 after betting on slow, fuel-saving ships just as oil prices fell. Like the dhow and the clipper before it, the box did not abolish distance; it made distance cheap.



The two standard boxes. A 20-foot container is one TEU; a 40-foot container is two. Both are 8 ft (2.44 m) wide; the standard height is 8 ft 6 in (2.59 m), and “high-cube” boxes are 9 ft 6 in (2.90 m).

PICTURE STUDY



South Street, New York, Detroit Publishing Company (photographer not recorded), about 1900 · Photochrom print (color added to a black-and-white photograph), published by the Detroit Photographic Company · Beinecke Rare Book & Manuscript Library, Yale University (this copy); the Library of Congress holds the company’s glass-plate negatives of the same waterfront

Around 1900 the Detroit Publishing Company photographed American cities, harbors and landmarks and sold the pictures as prints and postcards; the Library of Congress now holds thousands of its glass negatives. Its views of South Street, on the East River in lower

Manhattan, show the old break-bulk waterfront at its height: sailing ships moored bow-in to the piers, their long bowsprits stretching over the street, and wagons, barrels and crates everywhere.

Every one of those barrels and crates was lifted by a person. Compare this scene with a modern container terminal (Lesson 5.3), where the street, the wagons and nearly all the people are gone, and you see the container revolution in one glance.

Look closely

- Count the different kinds of packages you can see: barrels, crates, bales, sacks. Why would loading so many shapes take so long?
- Find the ships' bowsprits. How close to the street are the ships? Why did ports have to be in the middle of the city?
- Look for people working. How many jobs can you see in this one block?
- Where would a modern 400-meter container ship fit in this scene?

Talk about it

1. What happened to waterfronts like South Street after the 1960s, and why?
2. List two gains and two losses that the container brought to a port city like New York.
3. Why does the old photograph need no cranes, and why does a modern port need huge ones?

PROJECT: BREAK-BULK VERSUS THE BOX: A LOADING RACE AND A STOWAGE PLAN

You will run your own small container revolution. First you will time loading a "ship" by hand, piece by piece, and then with standard boxes. Then you will plan the stowage of a container ship that calls at three ports, the same puzzle that ship planners solve every day.

You will need

- A large cardboard box or plastic bin (the ship's hold) and 6 to 8 identical small boxes, such as tea boxes or shoe boxes (the containers)
- About 40 mixed small objects (cans, socks, pencils, toy blocks, spoons)
- A stopwatch, kitchen scale (optional), masking tape, markers
- Graph paper and colored pencils

Steps

1. Break-bulk round: place the 40 objects on a table across the room (the warehouse). Carry them to the hold one or two at a time and pack them so they will not slide. Time the loading, then time the unloading back to the table.
2. Container round: "stuff" the same objects into the small boxes at the warehouse (time this separately; it is done away from the ship). Then carry the boxes to the hold and stack them. Time loading and unloading.

3. Record a table: time at the ship for break-bulk, time at the ship for containers, and time spent stuffing boxes. Compute how many times faster the ship was turned around.
4. Stowage puzzle: label your small boxes with three destinations, for example S (Singapore), R (Rotterdam) and N (New York), and mark two as “heavy.” The ship calls at Singapore first, then Rotterdam, then New York.
5. Stack the boxes in the hold so that (a) the boxes for the first port can be removed without moving any others, and (b) heavy boxes sit low. Draw your stowage plan on graph paper as a cross-section, coloring each port differently.
6. Weigh each box if you have a scale. Write each weight on the box and on your plan. Real shippers must declare a verified weight before a container is loaded.
7. Write a paragraph: Where did the container save time, and where did it simply move the work (to the warehouse)? Why did that change make ships so much cheaper to run?

Tips

- The fair test is the time the ship waits at the dock, because a ship earns money only at sea.
- Planners call a box that must be moved to reach another one a “restow.” Each one costs time and money; try for zero.
- If a heavy box is high on the stack, the ship is top-heavy. Real planners check the ship’s stability on a computer.

Check your work

- I timed both methods and calculated the speed-up at the dock.
- My stowage plan unloads each port’s boxes without restows and keeps heavy boxes low.
- I explained why turning a ship around faster lowers the cost of shipping.

MAP NOTEBOOK

1. Draw a 20-foot and a 40-foot container to scale (1 cm = 2 ft) and label the corner castings, the doors and the TEU count.
2. On an outline map of the United States, mark Port Newark and Houston and draw the route of the *Ideal X* down the Atlantic coast, around Florida and across the Gulf of Mexico.
3. Sketch a cross-section of a cellular container ship: the hull, the cell guides in the hold, the hatch covers, and boxes stacked on deck above them.

From history. McLean was not the only pioneer. On the West Coast, the Matson Navigation Company, which served Hawaii, began carrying containers on deck in 1958 and in 1959 installed one of the first purpose-built container cranes at Alameda, California. Matson’s engineers worked out much of the science of stowing and handling boxes, and the competition between Matson’s and Sea-Land’s designs is one reason

international standards were needed. The ISO standards of the late 1960s settled the matter: a world of boxes that all fit together.

WORKED EXAMPLES

Example 1. In 1956 loading loose (break-bulk) cargo cost about \$5.83 a ton; the *Ideal X* was loaded for about \$0.16 a ton. For a cargo of 1,000 tons, find the cost each way and the ratio.

1. Break-bulk: $1,000 \times \$5.83 = \$5,830$.
2. Container: $1,000 \times \$0.16 = \160 .
3. Ratio: $5.83 \div 0.16 \approx 36$.
4. Savings: $\$5,830 - \$160 = \$5,670$, about 97 percent of the loading cost.

Answer: About \$5,830 by hand versus about \$160 in boxes: loading cost about 36 times less, a saving of roughly 97 percent.

Example 2. A container ship carries 3,500 forty-foot containers and 1,800 twenty-foot containers. What is the load in TEU? If the ship is rated at 9,000 TEU, what percentage of its capacity is used?

(Use the map or drawing “Count TEU by length: 20 ft = 1 TEU, 40 ft = 2 TEU.” shown earlier in this lesson.)

1. Each 40-foot box = 2 TEU: $3,500 \times 2 = 7,000$ TEU.
2. Each 20-foot box = 1 TEU: $1,800 \times 1 = 1,800$ TEU.
3. Total: $7,000 + 1,800 = 8,800$ TEU.
4. Share of capacity: $8,800 \div 9,000 \approx 0.978$, or about 98 percent.

Answer: 8,800 TEU, about 98 percent of the ship’s 9,000-TEU rating.

Example 3. The sea route from Shanghai to Los Angeles is about 5,700 nautical miles. How long does the crossing take at 18 knots? At 14 knots (“slow steaming” to save fuel)? Give the distance in kilometers and statute miles.

1. At 18 knots: $5,700 \div 18 \approx 317$ hours; $317 \div 24 \approx 13.2$ days.
2. At 14 knots: $5,700 \div 14 \approx 407$ hours; $407 \div 24 \approx 17.0$ days.
3. Slow steaming adds about $17.0 - 13.2 \approx 3.8$ days.
4. Distance: $5,700 \times 1.852 \approx 10,560$ km; $5,700 \times 1.151 \approx 6,560$ statute miles.

Answer: About 13 days at 18 knots and about 17 days at 14 knots. The route is about 10,600 km (about 6,560 miles).

PRACTICE

1. **EASY** What was the *Ideal X*, and when and between which ports did she make her famous voyage?
2. **EASY** Define TEU. How many TEU is a 40-foot container?
3. **EASY** What did Keith Tantlinger contribute to the container system?
4. **EASY** Convert 20 knots to kilometers per hour and miles per hour.
5. **MEDIUM** A 40-foot container holds 6,000 boxed pairs of shoes. Shipping the container from Asia to the U.S. West Coast costs \$2,400. What is the ocean freight cost per pair? If the shoes sell for \$80 a pair, what percentage of the price is ocean freight?
6. **MEDIUM** A standard 20-foot container is about 20 ft long, 8 ft wide and 8 ft 6 in high on the outside. Find its outside volume in cubic feet and in cubic meters (1 ft = 0.3048 m).
7. **MEDIUM** The *Ideal X* carried 58 containers of 35 feet. Roughly how many TEU is that (treat each 35-foot box as 35/20 TEU)? How many times larger is a modern 24,000-TEU ship?
8. **MEDIUM** Explain in two or three sentences why the container cut shipping costs even though container ships are not much faster at sea than older cargo ships.
9. **HARD** A break-bulk ship spends 7 days loading and unloading at each end of a 10-day voyage. A container ship on the same route spends 1 day at each end. How many round trips can each make in a 360-day year? Assume each round trip is: port, voyage out, port, voyage home.
10. **HARD** Name two ports or waterfronts that declined and two that grew because of the container, and give the geographic reason.
11. **HARD** A ship planner must load boxes for three ports in the order Singapore, Colombo, Rotterdam (Singapore first). Which port's boxes should be at the bottom of each stack, and why?
12. **CHALLENGE** In a short paragraph, weigh the container revolution: name at least two groups who gained and two who bore real costs, and explain why the overall verdict of most historians is that it was a great achievement.

COMMON MISTAKES

- Thinking the container made ships much faster at sea. Its great saving was in port handling time and labor, not sea speed.
- Counting containers instead of TEU. A 40-foot box is 2 TEU; mixing the two gives wrong capacities.
- Confusing knots with miles per hour or kilometers per hour. A knot is one nautical mile (1.852 km) per hour.

Make it a game • Stack It Right. Draw a 4-by-4 grid as a ship's bay. One player calls out boxes with a port and a weight (for example, "Rotterdam, heavy") for a ship calling at Singapore, then Colombo, then Rotterdam. The other places each box on the grid as it is called, bottom row first. When all 16 are placed, unload port by port. Each restow costs 1 point and each heavy box above a light one costs 1 point. Lowest score wins; switch roles.

Scripture. “A false balance is abomination to the LORD: but a just weight is his delight.” (Proverbs 11:1, KJV)

Since July 1, 2016, international rules have required every loaded container to have a verified gross weight before it goes aboard, because boxes declared lighter than they were had helped cause stack collapses and accidents. Solomon’s rule about honest weights is now written into the safety law of the sea.

Practice answers

1. A converted Second World War T2 tanker fitted with a deck for containers. She sailed from Port Newark, New Jersey, to Houston, Texas, on April 26, 1956, carrying 58 containers.
2. Twenty-foot equivalent unit: the capacity of one 20-foot container. A 40-foot container is 2 TEU.
3. He designed the container’s corner castings and twist locks (and worked on the cell-guide system), so boxes could be lifted, stacked and locked to ships, trucks and railcars.
4. $20 \times 1.852 = 37.0$ km/h; $20 \times 1.151 \approx 23.0$ mph.
5. $\$2,400 \div 6,000 = \0.40 per pair. $0.40 \div 80 = 0.005$, or 0.5 percent of the price.
6. $20 \times 8 \times 8.5 = 1,360$ ft³. In meters: $6.096 \times 2.438 \times 2.591 \approx 38.5$ m³.
7. $58 \times 35 \div 20 = 101.5$, about 100 TEU. $24,000 \div 100 \approx 240$ times larger (about 236 times using 101.5).
8. The main costs were handling and waiting in port: loading piece by piece took days and many workers, with theft and damage. Standard boxes let cranes load a ship in hours, so ships spend far more time at sea earning money, and goods move to trains and trucks without being unpacked.
9. Break-bulk round trip: $7 + 10 + 7 + 10 = 34$ days, so $360 \div 34 \approx 10.6$, about 10 round trips. Container: $1 + 10 + 1 + 10 = 22$ days, so $360 \div 22 \approx 16.4$, about 16 round trips. The same ship hull does about 55 percent more work a year ($16.4 \div 10.6 \approx 1.55$).
10. Declined: Manhattan and Brooklyn piers, the London Docks (also San Francisco’s piers). Grew: Port Elizabeth/Newark, Oakland, Felixstowe, Rotterdam’s Maasvlakte. Container terminals need deep water, large flat land for stacking boxes, and highway and rail links, which crowded old city-center piers lacked.
11. Rotterdam’s, because they come off last. Boxes for Singapore go on top so they can be lifted off first without moving (restowing) any others; Colombo’s go in the middle.
12. Answers will vary. Gainers: consumers (cheaper goods), exporters and workers in new manufacturing regions, shippers (less theft and damage), new port cities. Costs: longshoremen whose jobs disappeared, old waterfront neighborhoods, some factory towns facing import competition. Historians judge it a great achievement because it lowered the cost of nearly everything traded, raised incomes in many poor countries and joined world markets, while acknowledging that the transition was hard for particular workers and places.

5.3 PORTS AND HUBS: SHANGHAI, SINGAPORE, ROTTERDAM AND LOS ANGELES–LONG BEACH

OBJECTIVES

- Distinguish a port's site from its situation and explain, using Shanghai's Yangshan port (2005), why the largest ships demand deep water, open land and fast links inland.
- Compare four great ports (Shanghai, Singapore, Rotterdam and Los Angeles–Long Beach) by throughput, hinterland and role as gateway or transshipment hub.
- Calculate with port statistics: throughput ratios, transshipment shares, distances from latitude and longitude, and the depth a ship needs at low and high tide.

Warm-up. Lay a world map or globe in front of you. Put a coin on four places you think would make the best ports in the world and one sentence for each on why. Now check: are your coins on a river mouth, a strait, a deep bay or a long open coast? Keep your guesses and compare them with the four ports in this lesson.

Watch. *Time-lapse (60x): arrival Long Beach (CA, USA) [4K / UHD]* (SeaTube, 2:00). https://www.youtube.com/watch?v=D_EWGoNCK-M

With On the map: watch this two-minute sped-up view from a ship's bridge as it enters the Port of Long Beach, and look for the container cranes, stacks of boxes and the bridge over the channel.

Note: This is footage set to music with no narration. It was filmed in 2013, and the Gerald Desmond Bridge shown here has since been replaced by a new bridge, which opened in 2020. The old Gerald Desmond Bridge in the video no longer stands; it was replaced by the Long Beach International Gateway bridge.

Backup video. *How Ports Operate* (SMART Maritime and Transportation Center, 4:01). https://www.youtube.com/watch?v=td2-ZPbQw_c

With the big idea: watch how a container moves from ship to crane to yard to truck or train, and think about why big hubs like Shanghai and Rotterdam need so much space and deep water. Note: Captions were not available to check, and the video has no description; preview it first. It explains how ports work in general and does not cover the four ports in the lesson.

KEY TERMS

site

The physical character of a place itself: depth of water, shelter, firm land, tides.

situation

A place's location relative to other places: sea lanes, rivers, markets, resources and the hinterland.

hinterland

The inland region a port serves, the area that sends exports through it and receives its imports.

gateway port

A port where most cargo enters or leaves the surrounding country by truck, rail or barge.

transshipment hub

A port where containers are moved from one ship to another, often from a large mainline ship to smaller feeder ships, without ever leaving the port.

draft

The depth of water a loaded ship needs below the waterline. The largest container ships draw about 16 m (about 52 ft).

CORE IDEAS

The story. In December 2005 a new port opened on two small rocky islands, Xiaoyangshan, in the East China Sea about 30 km (19 miles) off the coast. To reach them, Chinese engineers had built the Donghai Bridge, about 32.5 km (20 miles) long, one of the longest sea bridges in the world at the time, carrying a highway for container trucks. Why go to such trouble? Shanghai sits near the mouth of the Yangtze, China's greatest river, whose basin holds hundreds of millions of people and a large share of the nation's factories. That is a matchless situation. But the river also carries an enormous load of silt, and the old docks along the Huangpu River and the Yangtze estuary were too shallow for the newest container ships. Shanghai solved a poor site by finding a better one offshore: Yangshan Deep-Water Port, with water deep enough for the largest ships afloat. In 2010 Shanghai passed Singapore as the world's busiest container port, and as of 2026 it still holds first place, handling about 49 million TEU in 2023.

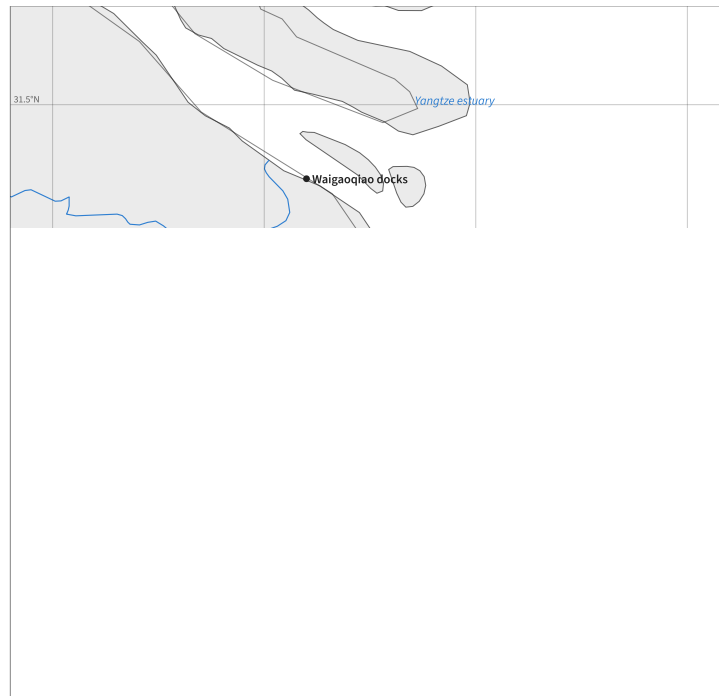
How it works. A modern container terminal is a machine for turning a ship around. Ship-to-shore gantry cranes, the largest as tall as a 30-story building with their booms raised, lift boxes from the cells of a ship at about 25 to 40 moves an hour each, and several cranes work one ship at once. Straddle carriers or driverless vehicles shuttle the boxes to a stacking yard, where yard cranes pile them by destination. Trucks and trains collect them at the gate. At Yangshan's fourth phase (opened 2017) and at Rotterdam's Maasvlakte, much of this is automated and directed by computer. Every port needs three things. First, **depth**: a fully loaded 24,000-TEU ship draws about 16 m, so channels and berths must be dredged deeper than that, with room under the keel. Second, **land**: acres of flat, firm ground for stacking boxes, often made by pumping sand from the seabed. Third, **links** to the hinterland by rail, highway, river barge or pipeline. A deep harbor with no road inland is just a beautiful bay.

The big idea. Ports serve two different purposes. A **gateway** port is a door into a country: most of its boxes are going to or from the hinterland. Los Angeles and Long Beach, side by side on San Pedro Bay, are the great gateway of the United States, together handling about 16.6 million TEU in 2023 and a large share (roughly a third or more) of the nation's container imports. Their harbor was largely made by men: a federal breakwater begun in 1899 sheltered a shallow bay, and in 2002 the Alameda Corridor, a 20-mile rail expressway partly sunk in a trench, opened to speed trains to the rail yards near downtown Los Angeles

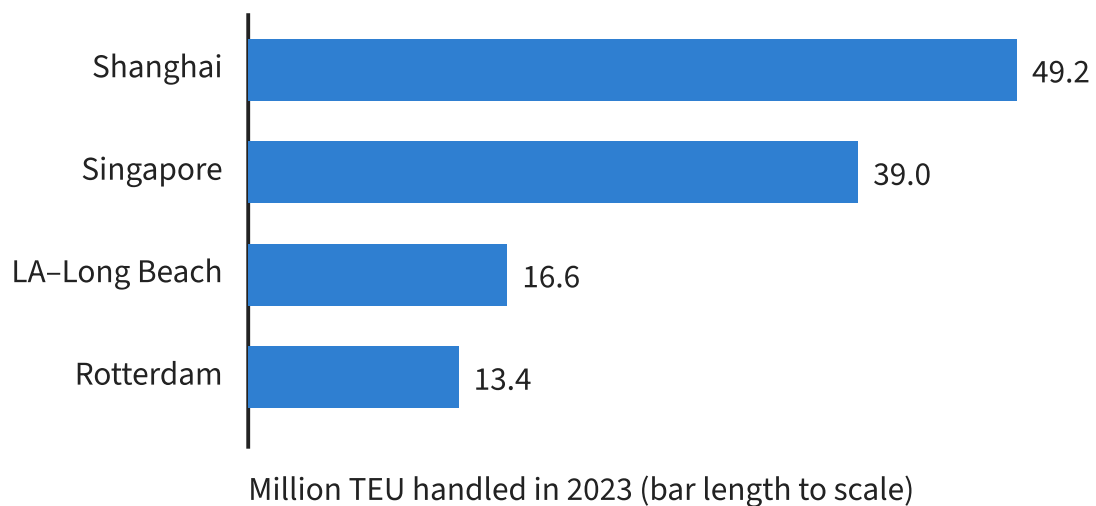
and on across the continent. A **transshipment hub** is different: it is a switching yard on a sea lane, where boxes move from ship to ship. Singapore is the great example. Founded as a British trading post by Stamford Raffles in 1819 at the tip of the Malay Peninsula, it sits where the Strait of Malacca meets the South China Sea, on the main route between East Asia and Europe, India and the Middle East. Most of its roughly 39 million TEU (2023) never enter Singapore at all. They arrive on one ship and leave on another. Hubs work like airline hubs: big mainline ships call at a few great ports, and smaller feeder ships fan out to dozens of lesser ones.

On the map. Rotterdam shows what a river can do. It sits in the delta where the Rhine and the Maas (Meuse) reach the North Sea, at the mouth of the busiest inland waterway in Europe. When the old river mouth silted up, the Dutch cut the Nieuwe Waterweg (New Waterway), opened in 1872, straight to the sea. After the Second World War, when German bombing and the retreating German army had wrecked much of the port, the Dutch rebuilt and pushed seaward with Europoort and the Maasvlakte, and in 2013 opened Maasvlakte 2, about 2,000 hectares (about 5,000 acres) of new land pumped up from the sea. For about four decades after 1962 Rotterdam was the busiest port in the world by tonnage, and it is still Europe's largest, handling about 13.4 million TEU and some 440 million tonnes of all cargo in 2023: oil, coal, ore, grain and boxes. Barges carry containers up the Rhine to Duisburg and Basel, and pipelines carry oil to refineries in Belgium and Germany. Its hinterland is the industrial heart of Europe. Compare the four ports: two gateways (Los Angeles-Long Beach and Rotterdam), one hub (Singapore), and one giant that is both (Shanghai). As of 2026 most of the ten busiest container ports in the world are in China.

Technology overcoming geography. Each of these ports was once limited by nature: a silting river, a shallow bay, a small swampy island. Each overcame its site with engineering, by dredging, breakwaters, land reclamation, bridges and rail corridors, while keeping its priceless situation. Singapore, with little land of its own, is building a single giant port at Tuas on its western shore, planned to handle about 65 million TEU a year when finished in the 2040s. Yet the sea lanes do not move. Every port in this lesson owes its rank to the strait, river or coast beside it, the same geography that made Tyre, Venice and Amsterdam great. The prophet Ezekiel described Tyre as a city "situate at the entry of the sea," and that phrase still names what a great port must have.

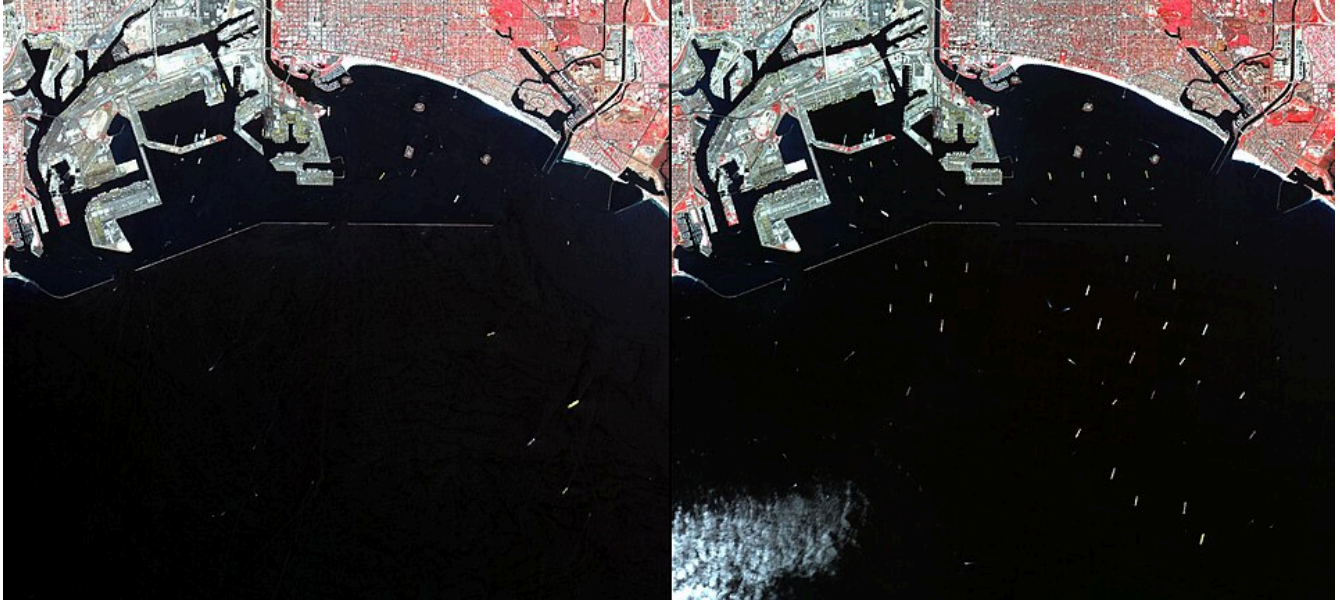


Shanghai's solution to a shallow, silty site: the Yangshan Deep-Water Port on offshore islands, reached by the Donghai Bridge (about 32.5 km) from Luchaogang.



Container throughput of the four ports in 2023, in millions of TEU (rounded). Singapore's total counts each transshipped box twice, once off and once on.

PICTURE STUDY



Los Angeles–Long Beach Harbors from orbit, before and after the 2015 port backlog,
NASA/METI/AIST/Japan Space Systems and the U.S./Japan ASTER Science Team (ASTER instrument on
NASA's Terra satellite), 4 July 2014 (left) and 8 March 2015 (right) · Pair of satellite images · NASA
Photojournal, PIA19249 (public domain)

NASA's Terra satellite carries a Japanese-built camera called ASTER that can see objects as small as a large ship. In 2015 NASA put two ASTER views of the twin ports of Los Angeles and Long Beach side by side. On July 4, 2014, about 14 ships were unloading and 7 waited outside. On March 8, 2015, just after a long labor dispute at West Coast ports had ended, 19 ships were at the docks and 47 were waiting offshore. These two ports together handled about a third of the containers coming into the United States.

The long straight line offshore is the federal breakwater; the rectangular islands and piers inside it are land made by dredging and filling. Count the ships outside the breakwater and you can see how one slowdown at one port backs up trade across the whole Pacific.

Look closely

- Find the breakwater. What does it protect the harbor from, and from which direction do the big Pacific swells come?
- Find the container terminals. How can you tell them from oil terminals or parks?
- Count the ships waiting outside the breakwater in each picture. What changed between 2014 and 2015?
- Look for the rail lines and roads leading inland. Where do they go?

Talk about it

1. How much of what you see is natural shoreline and how much was made by people? Give evidence.

2. If you were planning a new terminal here, where would you put it, and what would you need to build first?
3. Compare this view with the South Street photograph from Lesson 5.2. What has changed about the size and shape of a port?

PROJECT: PORT SCORECARD AND TERMINAL PLAN

You will act as a port planner. First you will score the four great ports of this lesson on site and situation. Then you will design a small container terminal to scale on graph paper, using real dimensions for ships, cranes and boxes.

You will need

- Atlas or online map (satellite view)
- Graph paper, ruler, pencil, colored pencils
- Calculator
- Optional: modeling clay, a baking pan of water and small blocks to build a 3-D model of your terminal

Steps

1. Make a scorecard with rows for Shanghai, Singapore, Rotterdam and Los Angeles-Long Beach and columns for: natural depth, shelter, available flat land, river or rail links inland, position on a main sea lane, and size of hinterland. Score each 1 (poor) to 5 (excellent) and write one sentence of evidence for each score.
2. Add up the scores. Which port has the best natural site? The best situation? Write a paragraph on how engineering made up for each port's weakest score.
3. Now design a terminal on graph paper at 1 square = 20 m. Draw a straight quay 800 m long (two berths for 400-m ships) along a channel you label 17 m deep.
4. Place six ship-to-shore cranes along the quay, a stacking yard behind it (rows of 20-ft boxes are 6.1 m long and 2.44 m wide; leave lanes for vehicles), a truck gate and a rail siding.
5. Estimate how many TEU your yard can hold if boxes stack 5 high. Show your arithmetic.
6. If each crane makes 30 moves an hour and a ship must exchange 6,000 boxes, how many hours will three cranes need? Write it on your plan.
7. Optional: build the terminal in clay in a pan of water, with a channel deeper than the rest of the pan.

Tips

- A satellite view at the same scale as your plan helps you see how real terminals are laid out.
- Remember the hinterland: a terminal that can unload boxes faster than trucks and trains can take them away will soon jam.

- Look up one real terminal's quay length and number of cranes and compare it to your plan.

Check your work

- My scorecard gives evidence for every score and separates site from situation.
- My terminal plan is drawn to scale with a labeled channel depth, cranes, yard, gate and rail.
- I calculated yard capacity and crane hours correctly.

MAP NOTEBOOK

1. On a world outline map, mark Shanghai, Singapore, Rotterdam and Los Angeles-Long Beach and draw the main sea lanes that join them (across the Pacific, through Malacca and Suez, and across the Atlantic).
2. Draw a simple site-and-situation diagram for one port: a small inset of the harbor itself (site) beside a larger map of its region and routes (situation).
3. Sketch a ship-to-shore gantry crane beside a container ship in cross-section and label the boom, trolley, spreader and the cells of the ship.

From history. When the Rotterdam port was heavily damaged in the Second World War, the city chose to rebuild it larger and farther seaward rather than restore the old docks. The Botlek, Europoort and Maasvlakte areas, built from the 1950s on, moved the port about 40 km (25 miles) west of the old city center toward the sea, in step with the growing size of oil tankers and, later, container ships.

WORKED EXAMPLES

Example 1. In 2023 Shanghai handled about 49.2 million TEU, and Los Angeles and Long Beach together about 16.6 million TEU. How many times more did Shanghai handle? If Rotterdam handled about 13.4 million TEU, what percentage of Shanghai's total is that?

(Use the map or drawing "Read the bars: Shanghai 49.2, Singapore 39.0, LA-Long Beach 16.6, Rotterdam 13.4" shown earlier in this lesson.)

1. Ratio: $49.2 \div 16.6 \approx 2.96$, about 3 times.
2. Rotterdam share: $13.4 \div 49.2 \approx 0.272$.
3. As a percentage: about 27 percent.

Answer: Shanghai handled about 3 times as many TEU as the two California ports together; Rotterdam handled about 27 percent of Shanghai's total.

Example 2. A hub port handles 39 million TEU in a year. Suppose 80 percent of these moves are transshipment: boxes unloaded from one ship and loaded onto another, so each such box is counted twice (once off, once on). (a) How many TEU of moves are transshipment, and how many are gateway (local) moves? (b) How many actual TEU of transshipped cargo passed through?

1. (a) Transshipment moves: $0.80 \times 39 = 31.2$ million TEU. Gateway moves: $39 - 31.2 = 7.8$ million TEU.
2. (b) Each transshipped box is counted twice, so the actual cargo is $31.2 \div 2 = 15.6$ million TEU.
3. So the port's headline figure of 39 million TEU represents about $15.6 + 7.8 = 23.4$ million TEU of actual cargo.

Answer: (a) 31.2 million TEU of transshipment moves and 7.8 million TEU of gateway moves. (b) About 15.6 million TEU of cargo was transshipped; the port touched about 23.4 million TEU of actual cargo in all.

Example 3. Yangshan port is at about 30.62° N, 122.07° E; central Shanghai (People's Square) is at about 31.23° N, 121.47° E. Estimate the straight-line distance between them. (One degree of latitude ≈ 111 km; one degree of longitude $\approx 111 \times \cos(\text{latitude})$ km.)

(Use the map or drawing "Measure from central Shanghai to Yangshan." shown earlier in this lesson.)

1. Difference in latitude: $31.23 - 30.62 = 0.61^\circ$. North-south distance: $0.61 \times 111 \approx 67.7$ km.
2. Difference in longitude: $122.07 - 121.47 = 0.60^\circ$. At about 30.9° N, $\cos 30.9^\circ \approx 0.858$, so 1° of longitude ≈ 95.3 km. East-west distance: $0.60 \times 95.3 \approx 57.2$ km.
3. Straight-line distance: $\sqrt{(67.7^2 + 57.2^2)} = \sqrt{(4,583 + 3,272)} = \sqrt{7,855} \approx 88.6$ km.
4. In miles: $88.6 \times 0.621 \approx 55$ miles.

Answer: About 89 km (about 55 miles) in a straight line, so every box trucked between Yangshan and the city crosses the 32.5-km Donghai Bridge and then a long stretch of highway (or goes by barge up the Yangtze).

PRACTICE

1. **EASY** Define site and situation, and give one example of each for Singapore.
2. **EASY** What is the difference between a gateway port and a transshipment hub? Name one example of each.
3. **EASY** Why did Shanghai build Yangshan port on islands 30 km offshore?
4. **EASY** What canal opened in 1872 to give Rotterdam a direct route to the North Sea?

5. **MEDIUM** A ship draws 16.0 m and the port requires an under-keel clearance of 10 percent of draft. What depth of water does it need? The channel is 15.0 m deep at low tide and the tidal range is 3.5 m. Can the ship enter at low tide? At high tide?
6. **MEDIUM** Three cranes each make 30 moves an hour. A ship must unload 3,000 boxes and load 3,000. How many hours does the work take? How many days?
7. **MEDIUM** Rotterdam handled about 440 million tonnes of cargo in 2023. If containers accounted for about 13.4 million TEU averaging 10 tonnes of cargo each, roughly what share of the tonnage was containerized? What makes up much of the rest?
8. **MEDIUM** What is the Alameda Corridor, and why was it built?
9. **HARD** Rotterdam is at about 51.95° N, 4.1° E and Singapore at about 1.27° N, 103.8° E. Explain, using a globe or world map, why a ship between them sails much farther than the great-circle distance, and name the straits and canal on its route.
10. **HARD** In 2023 Singapore handled about 39.0 million TEU and Shanghai about 49.2 million. Find the percentage by which Shanghai exceeded Singapore. Why is comparing these two totals a little like comparing apples and oranges?
11. **HARD** A terminal yard is 600 m by 300 m. Suppose 40 percent of its area is lanes and equipment space, and the rest holds 20-ft boxes (6.1 m × 2.44 m each) stacked 5 high. About how many TEU can it hold?
12. **CHALLENGE** Write a paragraph comparing Rotterdam and Los Angeles-Long Beach as gateways: describe each one's hinterland and the means used to reach it, and explain why river barges matter more at one than the other.

COMMON MISTAKES

- Confusing site with situation. A deep harbor is a good site; being on a busy sea lane near a rich hinterland is a good situation. Great ports need the situation most and can often engineer the site.
- Comparing hub and gateway totals as if they meant the same thing. Transshipped boxes are counted twice, once off and once on.
- Forgetting tides and under-keel clearance. A channel's charted depth is usually at low water; ships need extra depth below the keel.

Make it a game • Hub or Gateway?. One player names a port (Shanghai, Singapore, Rotterdam, Los Angeles, Long Beach, Hamburg, Antwerp, Busan, Dubai's Jebel Ali, Panama's Balboa, Algeciras, Savannah, Houston, Santos). The other must say "hub," "gateway" or "both," point to it on a world map, and name the sea lane or river that makes it important. One point for each correct part; check answers in an atlas or online. First to 15 wins.

Scripture. "And say unto Tyrus, O thou that art situate at the entry of the sea, which art a merchant of the people for many isles, Thus saith the Lord GOD; O Tyrus, thou hast said, I am of perfect beauty." (Ezekiel 27:3, KJV)

Ezekiel 27 describes Tyre's trade with the whole known world, and then its fall. The city's situation made it rich, but its pride made it forget the Lord who gives every place its gifts. Great ports are a blessing to many nations; they are not a reason for boasting.

Practice answers

1. Site: the physical nature of the place (Singapore: a small island with sheltered deep water along its southern shore). Situation: its position relative to other places (Singapore: at the southern end of the Strait of Malacca on the main sea lane between East Asia and Europe, India and the Middle East).
2. A gateway port mainly moves cargo between ships and its inland hinterland (Los Angeles–Long Beach, Rotterdam). A transshipment hub mainly moves boxes from ship to ship (Singapore).
3. The old docks on the Huangpu River and the silty Yangtze estuary were too shallow for the largest container ships; the islands offered deep water.
4. The Nieuwe Waterweg (New Waterway).
5. Needed: $16.0 \times 1.10 = 17.6$ m. Low tide: $15.0 \text{ m} < 17.6 \text{ m}$, so no. High tide: $15.0 + 3.5 = 18.5 \text{ m} \geq 17.6 \text{ m}$, so yes (it must time its arrival near high water).
6. Total moves 6,000. Cranes together: $3 \times 30 = 90$ moves an hour. $6,000 \div 90 \approx 66.7$ hours, about 2.8 days.
7. $13.4 \times 10 = 134$ million tonnes; $134 \div 440 \approx 0.30$, about 30 percent. Most of the rest is bulk: crude oil and oil products, coal, iron ore, grain and other dry and liquid bulk.
8. A 20-mile rail expressway, opened in 2002 and partly built in a trench, linking the Ports of Los Angeles and Long Beach with the rail yards near downtown Los Angeles. It speeds container trains inland and removes them from many street crossings.
9. The great circle crosses Europe and Asia over land, so a ship must follow the sea: from the North Sea through the Strait of Dover, around Spain and through the Strait of Gibraltar, across the Mediterranean, through the Suez Canal, down the Red Sea through Bab-el-Mandeb, across the Arabian Sea and Indian Ocean, and through the Strait of Malacca to Singapore (or around the Cape of Good Hope if Suez is not used).
10. $(49.2 - 39.0) \div 39.0 = 10.2 \div 39.0 \approx 0.26$, about 26 percent more. Singapore is mostly transshipment, so many boxes are counted twice (off and on); Shanghai is mostly a gateway, so more of its count is distinct cargo to and from China.
11. Area: $600 \times 300 = 180,000 \text{ m}^2$. Stacking area: 60 percent = $108,000 \text{ m}^2$. One box footprint: $6.1 \times 2.44 \approx 14.9 \text{ m}^2$. Ground slots: $108,000 \div 14.9 \approx 7,250$. Stacked 5 high: about 36,000 TEU.
12. Answers will vary. Rotterdam serves the Rhine and Maas basins (the Netherlands, Germany's Ruhr, Belgium, eastern France and Switzerland) by barge on the Rhine, by rail, road and pipeline; the navigable Rhine gives it cheap water transport deep into Europe. Los Angeles–Long Beach serves Southern California and, by rail (through the Alameda Corridor and transcontinental lines), Chicago, Texas and the Midwest; no large navigable river flows from the interior to San Pedro Bay, so rail and truck do the work.

5.4 AIR CARGO AND PIPELINES: WHAT FLIES, WHAT FLOATS AND WHAT FLOWS

OBJECTIVES

- Tell how the first air cargo flight (Dayton to Columbus, 1910) and the first successful oil pipeline (Pithole, Pennsylvania, 1865) began two new ways of moving goods.
- Explain why some goods fly, most float and liquids and gases flow, using value-to-weight ratio, urgency, perishability and form, and why Anchorage, Memphis and Hong Kong are air cargo giants.
- Calculate great-circle detours, freight cost as a share of price, and pipeline flow speeds and volumes, giving answers in metric and U.S. units.

Warm-up. Gather five things from your house: a phone or other small electronic device, a can of soup, a bottle of medicine or vitamins, a bunch of bananas or an apple, and a glass of water. For each, guess: did it (or its ingredients) reach your town by air, by ship, or by pipe? Line them up from most valuable per pound to least valuable per pound. Do you notice a pattern?

Watch. *How Pipelines Are Installed Under the Ocean - Network and Repair Underwater* (3D Living Studio, 9:21). <https://www.youtube.com/watch?v=dQHAYOZrrpg>
With the big idea: watch the animated sections on how oil and gas pipelines are laid on the seabed and repaired, to see what 'what flows' looks like underwater.

Note: Captions were not available to check; preview it first. It opens with a sponsor message for a VPN service, which you can skip. The lesson focuses on air cargo and land pipelines such as the Trans-Alaska Pipeline. This video covers only undersea (offshore) pipelines.

Backup video. *What Really Happened During the Gas Explosions in the Merrimack Valley?* (Practical Engineering, 16:43). <https://www.youtube.com/watch?v=QPL8dh6b1M0>
As review: older students can watch this to learn how natural gas reaches homes through pressure-controlled distribution lines, and why pipeline safety matters. Note: Captions were not available to check; preview it first. It tells the story of a real 2018 gas disaster in which one person died and 22 were injured, and it includes a sponsor message for Nebula that you can skip. The lesson covers long-distance pipelines; this video is about local gas distribution lines and an accident.

KEY TERMS

value-to-weight ratio

How much a good is worth for each kilogram or pound. Goods with a high ratio can bear the high cost of air freight.

belly cargo

Freight carried in the lower holds of passenger airliners, as opposed to dedicated freighter aircraft.

cold chain

An unbroken chain of refrigerated storage and transport that keeps perishable goods (flowers, fish, many medicines) cold from producer to customer.

pipeline throughput

The volume a pipeline moves in a period, usually in barrels a day for oil or cubic meters (or cubic feet) a day for gas.

barrel (bbl)

The standard unit for oil: 42 U.S. gallons, about 159 liters.

liquefied natural gas (LNG)

Natural gas cooled to about -162°C (-260°F), where it becomes a liquid about 1/600 of its gas volume, so it can be shipped in special tankers.

CORE IDEAS

The story. On November 7, 1910, a young pilot named Philip Parmalee, one of the Wright brothers' exhibition flyers, took off in a Wright Model B from the Huffman Prairie near Dayton, Ohio, with a package of silk strapped beside him. A Columbus department store, the Morehouse-Martens Company, had hired the Wrights to deliver the silk by air as a publicity stunt. Parmalee followed the roads and rail lines about 65 miles (105 km) to Columbus in a little over an hour, and the store cut the silk into small swatches and sold them as souvenirs. It was the first air cargo flight paid for by a customer. Forty-five years earlier, in 1865, an oil buyer named Samuel Van Syckel had laid a 2-inch iron pipe about 5 miles (8 km) from the boomtown of Pithole, Pennsylvania, to a railroad at Miller Farm, with pumps to push the oil along. The teamsters who had hauled oil barrels by wagon at high prices saw their living threatened and tore up the pipe, and Van Syckel hired armed guards to protect it. Silk in the air and oil in a pipe: those two small beginnings opened the two other great roads of modern trade.

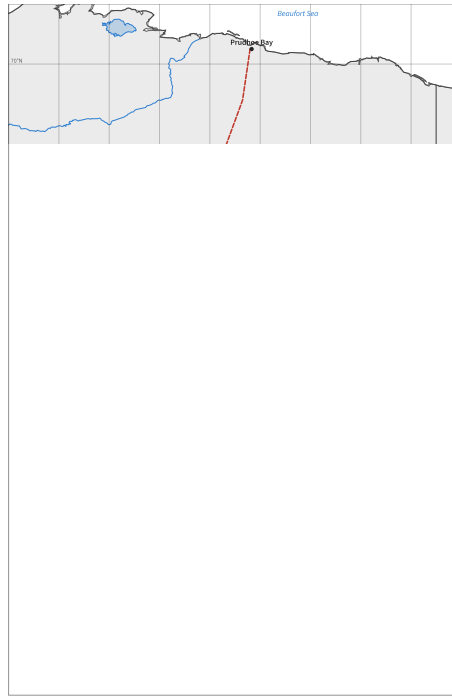
How it works. Each way of moving goods has its own costs. The **ship** is slow but carries enormous loads for very little fuel per ton; as of the mid-2020s ships carry about 80 percent of world trade by volume. The **airplane** is fast but costly, because it must lift its cargo against gravity and burns a great deal of fuel per ton-mile. A Boeing 747-8 freighter carries about 130 tonnes (about 140 short tons); a large container ship carries more than a thousand times as much. Air cargo is less than 1 percent of world trade by weight but roughly a third by value. About half of it rides in freighters and the rest in the bellies of passenger jets. The **pipeline** is the cheapest way to move liquids and gases over land. Once built it runs day and night with few workers, but it is expensive to build, fixed in place, and useful only for things that flow: crude oil, refined fuels, natural gas, water and a few chemicals. Gas that must cross an ocean is chilled into LNG and sent by tanker; the United States became the world's largest LNG exporter in 2023.

The big idea. Which way a good travels depends on a few simple questions. *How much is it worth per pound?* A smartphone worth \$800 and weighing under half a kilogram in its box

can pay air freight of a few dollars without noticing; a bunch of bananas cannot. *How urgent or perishable is it?* Fresh roses from the high plateaus of Colombia and Kenya, salmon from Norway, live lobsters from Maine, life-saving medicines and spare parts for a stopped factory all fly. So do computer chips, which are light, valuable and needed quickly. *What form is it in?* Liquids and gases in large, steady volumes flow through pipes. Everything else, the bulk of grain, ore, coal, cars, furniture and the contents of most containers, floats. A good exam answer uses all three questions: high value and urgency fly, steady large flows of fluids go by pipe, and the great mass of everything else goes by sea, with trucks and trains on each end.

On the map. Air routes follow great circles, the shortest paths on a sphere, which is why flights from East Asia to North America bend far north over the Pacific. Anchorage, Alaska, lies almost exactly on the great circle between Hong Kong or Shanghai and the American Midwest, so freighters stop there to refuel and swap cargo, making it one of the busiest cargo airports in the world. Memphis, Tennessee, home of FedEx's main hub since 1973, is the busiest cargo airport in the United States; every night hundreds of planes fly in, sort their packages and fly out before dawn. Hong Kong has long been the busiest cargo airport in the world, handling roughly 4 to 5 million tonnes a year (2023–2024). Pipelines follow a different map: from oil and gas fields to ports, refineries and cities. The Trans-Alaska Pipeline, finished in 1977, carries crude oil about 800 miles (1,287 km) from Prudhoe Bay on the Arctic coast to the ice-free port of Valdez. Because warm oil would thaw the frozen ground, about half of it runs above ground on supports fitted with heat pipes, and it zigzags so it can flex with heat, cold and earthquakes. It crosses the Denali Fault on sliding beams, and it rode out a magnitude 7.9 earthquake there in 2002 without a spill.

Technology overcoming geography. Air cargo overcame distance and time: a flower cut in Bogotá in the morning can be in a Miami warehouse that night. Pipelines overcame mountains, tundra and the cost of hauling heavy liquids over land; in the Second World War, when German submarines were sinking tankers off the Atlantic coast, the United States built the “Big Inch” pipeline, about 1,250 miles (2,000 km) from East Texas to Pennsylvania, in about a year. Yet geography still rules. Planes need fuel stops and weather, pipelines cross borders that politics can close, and both depend on the sea lanes for most of what they connect. Today another kind of flow runs alongside them: undersea fiber cables carry nearly all intercontinental internet traffic along routes much like the old steamer lanes. What flies, what floats and what flows together make the modern trade map.



The Trans-Alaska Pipeline, about 800 miles (1,287 km) from Prudhoe Bay to Valdez, finished in 1977. Anchorage, the great air cargo stop, lies to the west.

PICTURE STUDY



Berliners Watching a C-54 Land at Tempelhof Airport during the Berlin Airlift, Henry Ries (credited to the U.S. Air Force), 1948 · Black-and-white photograph · Library of Congress, Prints and Photographs Division (cph.3c36389); public domain as a U.S. government photograph

In June 1948 the Soviet Union cut every road, rail line and canal into the western sectors of Berlin, a city of more than two million people deep inside the Soviet zone of Germany. The United States, Britain and their allies answered with the Berlin Airlift: for almost a year,

cargo planes landed at Tempelhof, Gatow and later Tegel every few minutes, day and night, carrying food, medicine and, above all, coal.

This photograph of Berliners watching a U.S. C-54 Skymaster land at Tempelhof became one of the best-known images of the Cold War. It shows something new in history: a great city supplied entirely by air.

Look closely

- Look at the plane. How low is it? Why do you think Tempelhof's approach brought planes so close over the buildings?
- Look at the people watching. What do their posture and faces suggest about what the planes meant to them?
- Look for signs of the war that had ended only three years before.
- What kind of cargo do you think this plane carried? (Most of the tonnage was coal.)

Talk about it

1. Air cargo is usually too expensive for coal. Why was it worth flying coal into Berlin in 1948-1949?
2. What geographic fact made Berlin so hard to supply, and why could planes overcome it when trains and barges could not?
3. What does this photograph teach about the limits of air cargo as well as its strengths?

PROJECT: FLY, FLOAT OR FLOW: A FREIGHT AUDIT AND A PIPE-FLOW EXPERIMENT

In the first part you will audit goods in your home and decide how each one most likely traveled, using the value-to-weight test. In the second part you will build a small "pipeline" from tubing and test how the size of a pipe changes how much it can carry.

You will need

- Kitchen scale and a notebook
- Ten household items with known or estimated prices
- Two lengths of clear vinyl tubing, about 2 m (6 ft) each, of different inside diameters (for example, 6 mm and 12 mm, or 1/4 inch and 1/2 inch), from a hardware store
- A bucket, a measuring jug, a funnel, a stopwatch and a step or chair to raise the bucket

Steps

1. Freight audit: weigh ten items (a phone or tablet, a bottle of medicine, a box of tea, a can of beans, fresh fruit, flowers if you have them, a shoe, a bag of rice, a bottle of cooking oil, a tool). Record price and weight.
2. Compute value per kilogram for each item and rank them. Mark each "fly," "float" or "flow (or made from things that flowed)" and give a reason based on value, urgency, perishability or form.

3. Suppose air freight costs \$4 per kilogram and sea freight \$0.15 per kilogram. For each item, compute air freight as a percentage of its price. Which items could easily bear air freight?
4. Pipe-flow test: fill the bucket and set it on the step. Use one tube as a siphon (or attach it to the funnel held at a fixed height) to drain water into the jug. Time how long it takes to collect 1 liter (or 1 quart).
5. Repeat with the other tube at the same height difference. Do three trials each and average them.
6. Compare: how many times faster did the wider tube deliver water? The wider tube has twice the diameter and four times the area. Did it deliver more or less than four times as much? Write your result.
7. Write a paragraph: why do pipeline builders choose wide pipes, and what does a pipe cost that a tanker truck does not (and the other way around)?

Tips

- Keep the height difference between the water surface and the tube's outlet the same for both tubes, or the test is not fair.
- Wider pipes usually carry more than their extra area alone would suggest, because a smaller share of the water rubs against the wall. That is one reason long-distance pipelines are big.
- Do the water test outdoors or in a tub.

Check your work

- I ranked my items by value per kilogram and explained which would fly, float or flow.
- I computed air freight as a share of price correctly.
- I measured and compared flow through two pipe sizes with a fair test.

MAP NOTEBOOK

1. On an outline map of the North Pacific, draw the great-circle path from Hong Kong to Memphis and mark Anchorage close to it. Then draw the straight line you would get on a flat Mercator map and note the difference.
2. Trace the Trans-Alaska Pipeline from Prudhoe Bay to Valdez. Label the Brooks Range, Fairbanks, the Alaska Range and Prince William Sound, and sketch a cross-section of an above-ground support with its heat pipes.
3. Make a three-column chart, Flies, Floats, Flows, and list at least six goods in each, with one reason for each column at the top.

From history. The Berlin Airlift ran from June 1948 until September 30, 1949, though the Soviets lifted the blockade in May 1949. American and British crews, with help from other allies, flew about 278,000 flights and delivered about 2.3 million tons of food, coal and supplies; at its peak a plane landed in Berlin about every minute. An American pilot, Gail Halvorsen, began dropping candy to children from tiny handkerchief parachutes, and the "Candy Bomber" became a symbol of the airlift. About seventy American and British

airmen and support personnel died in accidents during the operation, along with a number of German civilians.

WORKED EXAMPLES

Example 1. Great-circle distances: Hong Kong to Anchorage about 8,160 km; Anchorage to Memphis about 5,060 km; Hong Kong to Memphis direct about 13,160 km. How much longer is the trip with a stop at Anchorage, in kilometers and as a percentage? Why is the stop so cheap in distance?

1. Via Anchorage: $8,160 + 5,060 = 13,220$ km.
2. Extra distance: $13,220 - 13,160 = 60$ km.
3. Percentage: $60 \div 13,160 \approx 0.0046$, about 0.5 percent.
4. In miles: $13,220 \text{ km} \times 0.621 \approx 8,210$ miles via Anchorage against about 8,170 miles direct.
5. Anchorage lies almost exactly on the great circle from Hong Kong to the American Midwest, which bends far north across the Pacific.

Answer: Only about 60 km (about 40 miles) longer, about 0.5 percent, because Anchorage sits nearly on the great-circle route. A freighter can refuel there and carry less fuel and more cargo on each leg.

Example 2. A smartphone in its box weighs 0.4 kg and sells for \$800. A kilogram of bananas sells for \$1.30. Suppose air freight across the Pacific costs \$4.00 per kilogram and sea freight in a refrigerated container \$0.20 per kilogram. Find the freight cost as a percentage of price for each good by each mode.

1. Phone by air: $0.4 \times \$4.00 = \1.60 ; $1.60 \div 800 = 0.002$, or 0.2 percent.
2. Phone by sea: $0.4 \times \$0.20 = \0.08 ; $0.08 \div 800 = 0.0001$, or 0.01 percent.
3. Bananas by air: $1 \times \$4.00 = \4.00 ; $4.00 \div 1.30 \approx 3.08$, or about 308 percent.
4. Bananas by sea: $1 \times \$0.20 = \0.20 ; $0.20 \div 1.30 \approx 0.154$, or about 15 percent.

Answer: Air freight adds only about 0.2 percent to the phone's price, but it would cost about three times the price of the bananas. Phones can fly; bananas float (in refrigerated ships).

Example 3. Suppose the Trans-Alaska Pipeline carries 500,000 barrels a day through a pipe 48 inches (1.219 m) across and 1,287 km long. (1 barrel = 0.159 m³.) Find the average speed of the oil and how many days a barrel takes from Prudhoe Bay to Valdez.

(Use the map or drawing “The 800-mile line from the Arctic coast to Valdez.” shown earlier in this lesson.)

1. Daily volume: $500,000 \times 0.159 = 79,500 \text{ m}^3 \text{ a day}$.
2. Pipe cross-section: radius 0.6095 m; area = $\pi \times 0.6095^2 \approx 1.167 \text{ m}^2$.
3. Speed: $79,500 \div 1.167 \approx 68,100 \text{ m a day} \approx 68.1 \text{ km a day} \approx 2.84 \text{ km/h}$ (about 1.8 mph).
4. Travel time: $1,287 \div 68.1 \approx 18.9 \text{ days}$.

Answer: The oil moves at about 2.8 km/h (about 1.8 mph), walking pace or slower, and takes about 19 days to travel the length of the line at that flow. (At its 1988 peak of about 2 million barrels a day, the oil moved about four times as fast.)

PRACTICE

1. **EASY** What was carried on the first paid air cargo flight in 1910, and between which two cities?
2. **EASY** About what share of world trade travels by sea by volume? About what share travels by air by weight and by value?
3. **EASY** Name three kinds of goods that usually fly and give the reason for each.
4. **EASY** Why does about half of the Trans-Alaska Pipeline run above the ground?
5. **MEDIUM** Convert 500,000 barrels a day to cubic meters a day and to U.S. gallons a day.
6. **MEDIUM** A Boeing 747-8 freighter carries about 130 tonnes. A container ship carries 20,000 TEU averaging 10 tonnes of cargo each. How many freighter loads would the ship’s cargo fill?
7. **MEDIUM** LNG takes up about 1/600 of the volume of the same gas at normal pressure. A large LNG carrier holds 174,000 m³ of liquid. About how much gas is that at normal pressure?
8. **MEDIUM** Explain why Anchorage is a major cargo airport although Alaska has few people.
9. **HARD** Find the volume of oil needed to fill the entire Trans-Alaska Pipeline (inside diameter 1.219 m, length 1,287 km), in cubic meters and in barrels.
10. **HARD** A Colombian rose grower sends 40,000 stems a week to Miami by air. A box of 300 stems weighs 12 kg. Air freight costs \$1.80 per kg. Find the weekly freight bill and the freight cost per stem. Why would the grower not ship roses by sea?
11. **HARD** Give two advantages and two disadvantages of moving oil by pipeline rather than by tanker truck or rail.
12. **CHALLENGE** In 1948–1949 the Berlin Airlift delivered about 2.3 million tons of supplies, most of it coal, by air. Using what you know about value-to-weight, explain why this

was an extraordinary use of air cargo, and what it shows about when the normal rules of transport cost give way.

COMMON MISTAKES

- Judging by weight alone. Air cargo is tiny by weight but large by value; always ask which measure a statistic uses.
- Drawing air routes as straight lines on a Mercator map. Long flights follow great circles, which curve toward the poles on most flat maps.
- Thinking oil races through pipelines. Oil in a large pipeline moves at about walking pace; pipelines win by carrying enormous volumes continuously, not by speed.

Make it a game · Fly, Float or Flow?. Make 30 cards, each naming a good: fresh tuna, iron ore, crude oil, smartphones, wheat, roses, natural gas, cars, insulin, coal, gold bars, sneakers, jet fuel, lumber, laptop chips, bananas, gasoline, live lobsters, furniture, water, etc. Draw a card and say “fly,” “float” or “flow” with one reason (value, urgency, perishability or form). One point for a defensible answer, two if you can name a real route or place (for example, “roses fly from Bogotá to Miami”). Play until the deck is gone.

Scripture. “For the king had at sea a navy of Tharshish with the navy of Hiram: once in three years came the navy of Tharshish, bringing gold, and silver, ivory, and apes, and peacocks.” (1 Kings 10:22, KJV)

Solomon’s fleet made a voyage of three years, so it carried only the most precious cargo: gold, silver and ivory, goods worth a great deal for their weight. The same rule decides what flies today: the longer or costlier the journey, the more valuable the cargo must be.

Practice answers

1. Silk (for the Morehouse-Martens department store), flown by Philip Parmalee in a Wright Model B from Dayton to Columbus, Ohio, on November 7, 1910.
2. Sea: about 80 percent by volume. Air: less than 1 percent by weight but roughly a third by value.
3. Examples: computer chips and electronics (high value per weight, urgent), fresh cut flowers or seafood (perishable), medicines and vaccines (valuable, perishable, urgent), urgent spare parts (a stopped factory loses money every hour), gold (very high value).
4. Warm oil would thaw the permafrost (permanently frozen ground) where it is rich in ice, and the ground would sink and break the pipe. Above-ground sections sit on supports with heat pipes that keep the ground frozen.
5. $500,000 \times 0.159 = 79,500 \text{ m}^3$ a day; $500,000 \times 42 = 21,000,000$ gallons a day.
6. Ship cargo: $20,000 \times 10 = 200,000$ tonnes. $200,000 \div 130 \approx 1,540$ freighter loads.
7. $174,000 \times 600 = 104,400,000 \text{ m}^3$, about 104 million cubic meters (about 3.7 billion cubic feet) of gas.
8. Anchorage lies almost on the great-circle routes between East Asia and North America (and is a reasonable stop on some Asia–Europe routes). Freighters stop to refuel and exchange cargo, so they can carry more freight and less fuel on each leg.

9. Area $\approx 1.167 \text{ m}^2$. Volume = $1.167 \times 1,287,000 \approx 1,502,000 \text{ m}^3$. In barrels: $1,502,000 \div 0.159 \approx 9.4$ million barrels.
10. Boxes: $40,000 \div 300 \approx 133.3$, so 134 boxes. Weight: $134 \times 12 = 1,608 \text{ kg}$. Freight: $1,608 \times \$1.80 \approx \$2,894$ a week, about $\$0.07$ per stem ($2,894 \div 40,000 \approx 0.072$). Roses wilt within days; a sea voyage plus port time would take too long, so speed is worth the cost.
11. Advantages: much lower cost per barrel over long distances; continuous flow with few workers; less traffic on roads; fewer accidents per barrel moved. Disadvantages: very high building cost; fixed route that cannot follow changing demand; carries only fluids; vulnerable to leaks, sabotage or political closure where it crosses borders; takes years to plan and build.
12. Coal has a very low value per ton and normally goes only by ship, barge or rail; flying it costs far more than it is worth. In Berlin the land and water routes were cut by the Soviet blockade, and the alternative was cold, hunger and the loss of the city to Soviet control. When safety, survival or national purpose is at stake, people will pay transport costs far above a good's market value; air was the only route geography and politics left open.

5.5 FINAL PROJECT: TRACE THE JOURNEY OF ONE PRODUCT TO YOUR HOME

OBJECTIVES

- Explain, using Leonard Read’s essay “I, Pencil” (1958), how even a simple product gathers materials and skills from many lands and why no single person knows how to make it.
- Trace one real product from raw materials to your home, stage by stage, naming the places, modes of transport, ports, straits and canals it passes, and drawing it on a world trade-flow map.
- Calculate total distance, transit time across time zones and the share of transport in a product’s price, and use the course’s main ideas (comparative advantage, choke points, containers, hubs) to explain the route.

Warm-up. Pick up an ordinary wooden pencil. Without looking anything up, list every material in it (there are at least six) and guess where in the world each might come from. Then turn over three things in your kitchen or closet and read the “Made in” labels. Write the countries on a slip of paper and put a pin or a sticky note on each country on a world map. Which ocean lies between each one and your home?

Video. Coming soon. “I, Pencil” by Leonard Read and how global supply chains work (a product’s journey from factory to port to store): search Hillsdale Studios (economics, free markets), Federal Reserve Bank of St. Louis (Econ Lowdown, global trade and supply chains), The Henry Ford (manufacturing and logistics); candidates (needs vetting): Maersk, Wendover Productions (supply chain logistics).

KEY TERMS

supply chain

The whole sequence of businesses, places and transport links that turn raw materials into a finished product in a customer’s hands.

intermodal journey

A trip using two or more modes of transport (truck, ship, train, plane) with the cargo staying in the same container or package.

distribution center

A large warehouse where goods arriving in bulk are sorted and sent out to stores or directly to customers.

lead time

The total time from placing an order to receiving the goods, including making, waiting, loading and travel.

landed cost

The full cost of a product once it arrives in the buyer's country: the factory price plus freight, insurance, duties and handling.

the last mile

The final step of delivery from a local warehouse or store to the customer's door, often the most costly per mile.

CORE IDEAS

The story. In December 1958 a small magazine called *The Freeman* printed an essay by Leonard E. Read, the founder of the Foundation for Economic Education in New York. It was written in the voice of an ordinary yellow pencil, a Mongol 482 made by the Eberhard Faber company, and it was called "I, Pencil." The pencil tells its family tree. Its wood is cedar from northern California and Oregon, cut by loggers and hauled by truck and rail to a mill in San Leandro, California. Its "lead" is not lead at all but graphite mined in Ceylon (now Sri Lanka), mixed with clay from Mississippi. Its eraser is made partly from rapeseed oil from the Dutch East Indies (now Indonesia), with pumice from Italy, held on by a band of brass. Coats of lacquer, glue and paint come from still other places. Then the pencil makes its famous claim: "Simple? Yet, not a single person on the face of this earth knows how to make me." Millions of people, most of whom never met, cooperated to make it, and no one directed them all.

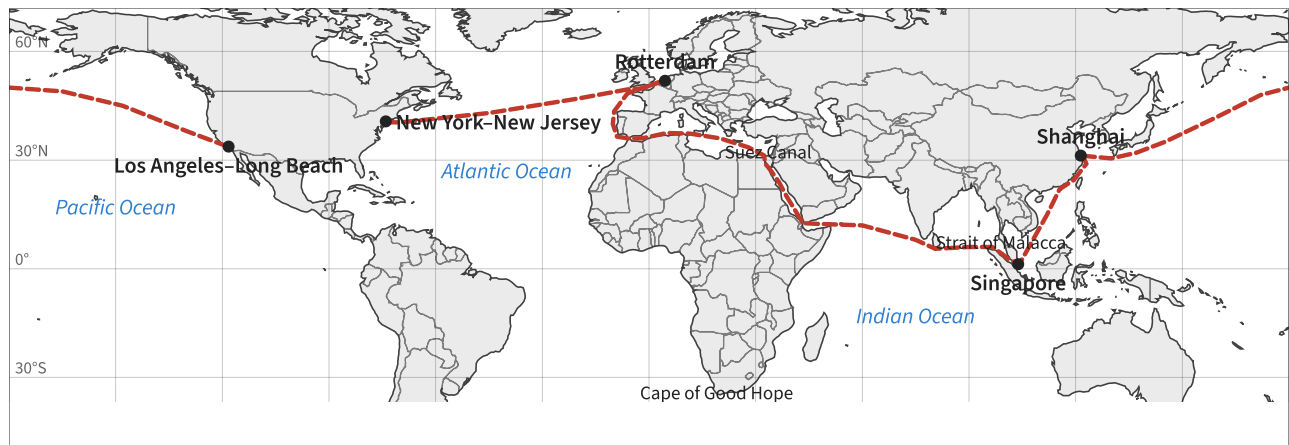
How it works. Every product you own has a journey like the pencil's, and this unit has given you the tools to trace it. Read the label and the company's own information to find where it was made. Ask what it is made of and where those materials lie (Unit 4). Ask why it was made in that place: what comparative advantage did the place have in skills, resources, land or labor (Lesson 5.1)? Find the nearest export port and its role, gateway or hub (Lesson 5.3). Follow the sea lane, and name every strait and canal on the way (Unit 3). Decide whether the product flew, floated or flowed (Lesson 5.4), and whether it traveled in a container (Lesson 5.2). Then follow it inland by rail and truck to a distribution center, a store and finally your door. A typical journey for shoes made in East Asia and sold in Chicago might run: factory to port by truck, a few days waiting in the terminal, about two weeks across the Pacific, a few days in Los Angeles or Long Beach, four or five days by train to Chicago, a stop in a warehouse, and a truck to the store. A month or more of travel adds only a small share to the shelf price, because the container made distance cheap.

The big idea. The modern trade map is the sum of countless journeys like these. Draw them all on one sheet and three great east-west highways stand out: across the Pacific between East Asia and North America; from East Asia through the Strait of Malacca, across the Indian Ocean and through the Suez Canal (or around the Cape of Good Hope) to Europe; and across the North Atlantic between Europe and North America. North-south flows bring oil from the Persian Gulf through the Strait of Hormuz, grain and soybeans from Brazil and the American Gulf Coast, iron ore from Australia and Brazil to China, and fruit and flowers from Latin America and Africa. When a choke point closes, the whole map feels it. In 2024, after attacks on ships in the Red Sea, many container lines sent their ships around the Cape of Good Hope instead of through Suez, adding thousands of miles and a week or more to the

voyage between Asia and Europe. The world's trade map is a living thing, and geography still draws its main lines.

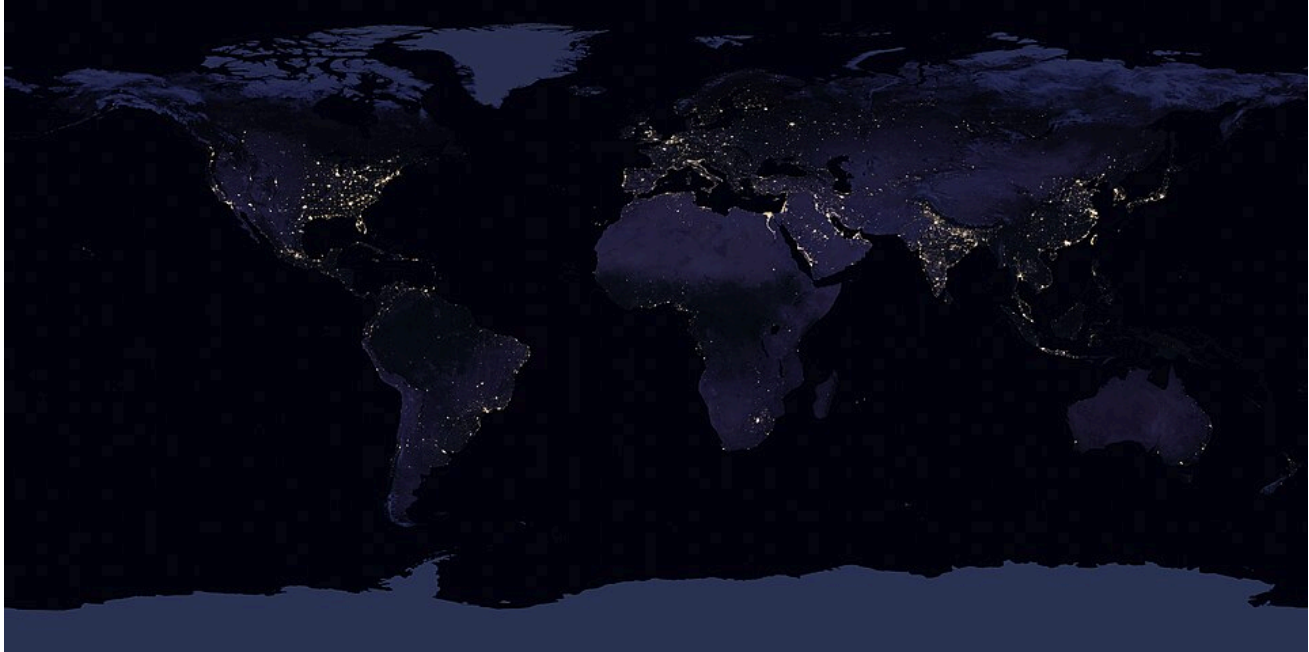
On the map. Your final project is to draw one product's journey on a world map like the one in this lesson, with each leg labeled by mode, distance and time. You will find that the map of your product looks like the map of the whole course. The caravans of the Silk Road (Unit 1) and the spice ships riding the monsoon (Unit 2) followed many of the same corridors that container ships and freighters use today: through Malacca, across the Arabian Sea, up the Red Sea and into the Mediterranean. The goods have changed from silk and pepper to chips and sneakers, and the time has shrunk from years to weeks, but the straits, the seas and the great ports at their ends are the ones God placed long before any merchant sailed.

Technology overcoming geography. Look back over the course and the thread is plain. The camel let merchants cross the desert; the dhow and the monsoon let them cross the Indian Ocean; the galleon crossed the Pacific; the clipper and the steamship shortened every voyage; the canal cut through land; the container, the giant ship and the automated port made distance almost free; the airplane made it fast; the pipeline made it continuous. Yet every one of these tools still bends to geography: to winds and currents, to the depth of a channel, the width of a strait, the reach of a river and the curve of a great circle. A wise student of commerce learns both lessons: what human skill has overcome, and what it never will. And a Christian student adds a third. The Scripture says God "hath made of one blood all nations of men" and "determined the times before appointed, and the bounds of their habitation." The variety of lands and the ties of trade between them are part of His ordering of the world, meant to bring peoples into contact, service and, Paul goes on to say, the seeking of God Himself.



The three great east-west container highways of the modern trade map, joining the ports of this unit. Most of the world's container trade moves along these lanes.

PICTURE STUDY



Earth at Night (the “Black Marble”), NASA Earth Observatory, from data collected by the Suomi NPP satellite (VIIRS instrument), 2016 composite (released 2017); the first global Black Marble was released in 2012 · Composite satellite image assembled from many cloud-free nighttime passes · NASA Earth Observatory (public domain); image by Joshua Stevens using Suomi NPP VIIRS data from Miguel Román, NASA Goddard Space Flight Center

NASA’s “Black Marble” images were made by stitching together many nighttime views from a weather satellite that can sense very faint light. The result shows where people have built cities, roads, ports and industries, and where they have not.

Read it like a trade map. The brightest coasts are lined with ports; the bright river valleys (the Nile, the Rhine, the Yangtze) are old trade corridors; the dark stretches are the deserts, mountains, forests and polar lands that trade has always gone around. In some images the lights of fishing fleets and offshore oil fields show up on the sea itself.

Look closely

- Find the Nile. Why is it a thin bright line in a dark land?
- Find the coast of East Asia from Shanghai to Hong Kong, and the coasts of Western Europe and the eastern United States. What do these bright coasts have in common?
- Find the darkest large areas on land. Name the deserts, forests or mountains they match.
- Can you trace any bright line that looks like a highway or railroad crossing a continent?

Talk about it

1. Which of the four ports in Lesson 5.3 can you find by their lights? What lies behind each one inland?

2. How does this image support the idea that geography still shapes where people live and trade?
3. What can a night image not tell you about trade?

PROJECT: THE PRODUCT-JOURNEY MAP

This is the final project of the course. You will choose one real product in your home and trace its journey from raw materials to your door as accurately as you can, then draw that journey on a world map and present it. Session 1 is research, Session 2 is map-making, and Session 3 is for your presentation and the course final exam (provided separately).

Choose something with a clear label and a traceable origin: a pair of sneakers, a bag of coffee, a bunch of bananas, a can of tuna, a bottle of olive oil, a cotton T-shirt, a smartphone, a box of tea or a wooden toy. Simple products are easier to trace well; complex ones (like the phone) need you to choose two or three key parts.

You will need

- The product (or its label and packaging)
- A large world outline map (poster size, or two printed sheets taped together) and an atlas or online map
- Colored pencils or markers (one color for each mode: sea, air, rail, truck, pipeline)
- Ruler, string (for measuring on a globe), calculator
- Index cards or sticky notes for leg labels

Steps

1. Identify: record the product, brand, “Made in” country and, if you can find it, the city or region of the factory (company websites often list factories or origins).
2. Materials: list the two to four main materials and where each most likely comes from (for example, cotton from Texas, India or Uzbekistan; coffee from Brazil, Colombia, Vietnam or Ethiopia). Note your source or your reasoning.
3. Explain the place: in two or three sentences, explain the comparative advantage of the place where the product was made or grown (climate, soil, resources, skills, wages, port access).
4. Route: list each leg of the journey from raw material to your home: start, end, mode (truck, rail, ship, air, pipeline), approximate distance in km and miles, and approximate time. Include the export port, every strait and canal the ship passes, the import port, the inland route and the distribution center.
5. Draw: plot the route on your world map, color-coded by mode, with arrows. Label every port, strait and canal and put a small card on each leg with its distance and days.
6. Calculate: total distance, total transit time (add waiting time in ports and warehouses), and an estimate of transport cost per unit as a percentage of the price (use the methods in Lessons 5.2 and 5.4).
7. Risk: name the one choke point or link that, if closed, would most delay your product, and describe the alternative route.

8. Write a one-page essay answering: Why did this product come from where it did, by the route it did? What did geography decide, and what did technology overcome?
9. Present: give a five-minute talk to your family or class using the map.

Tips

- Use rounded, sourced figures and say “about.” A careful estimate with reasons is better than a precise number you cannot defend.
- For sea distances, use a port-distance calculator or measure along the sea lane on a globe with string; do not measure straight across land.
- If the company will not say which port it uses, choose the most likely one and explain why (the nearest large container port to the factory, and the gateway nearest your home).

Check your work

- My map shows every leg of the journey, color-coded by mode, with ports, straits and canals labeled.
- My distances, times and cost share are calculated and explained.
- My essay explains the route with comparative advantage, choke points, containers and hubs.
- I named a real risk on the route and an alternative.

MAP NOTEBOOK

1. Draw a “family tree” for the pencil from “I, Pencil,” with the pencil in the center and a branch to each material and the place it came from.
2. On a world outline map, draw the three great east-west container highways from this lesson’s figure and label the straits and canals on each.
3. Make a timeline bar for your project product, with each leg of its journey as a colored segment proportional to the days it takes. Which segment is longest: travel or waiting?

From history. Leonard Read wrote “I, Pencil” to show what Adam Smith had called the division of labor and what the economist Friedrich Hayek, in a 1945 essay, called the use of knowledge spread among many people. The essay became famous again in 1980, when Milton Friedman held up a pencil in the television series *Free to Choose* and retold its story. Pencil-making itself has moved since 1958: much of the world’s pencil manufacturing has shifted to other countries, an example of comparative advantage changing over time.

WORKED EXAMPLES

Example 1. A pair of sneakers travels from a factory near Shanghai to a store in Chicago. Legs: truck to the port, 150 km, 1 day; waiting at the terminal, 3 days; sea voyage to Los Angeles, 10,560 km, 13 days; port and customs at Los Angeles, 4 days; rail to Chicago, 3,200 km, 4 days; distribution center, 3 days; truck to the store, 50 km, 1 day. Find the total distance in km and miles, the total time, and the share of time spent moving versus waiting.

(Use the map or drawing “The sea leg follows the transpacific highway.” shown earlier in this lesson.)

1. Distance: $150 + 10,560 + 3,200 + 50 = 13,960$ km; $\times 0.621 \approx 8,670$ miles.
2. Moving time: $1 + 13 + 4 + 1 = 19$ days.
3. Waiting time: $3 + 4 + 3 = 10$ days.
4. Total: $19 + 10 = 29$ days. Moving share: $19 \div 29 \approx 66$ percent; waiting share: $10 \div 29 \approx 34$ percent.

Answer: About 13,960 km (about 8,670 miles) in about 29 days, roughly two-thirds moving and one-third waiting in ports and warehouses.

Example 2. Ships between Shanghai and Rotterdam sail about 10,500 nautical miles through the Suez Canal, or about 14,000 nautical miles around the Cape of Good Hope. At 16 knots, how many extra days does the Cape route take? If a ship costs \$80,000 a day to run (fuel, crew, charter), what does the detour add for each voyage, and per TEU for a ship carrying 15,000 TEU?

1. Extra distance: $14,000 - 10,500 = 3,500$ nautical miles.
2. Extra time: $3,500 \div 16 \approx 219$ hours; $219 \div 24 \approx 9.1$ days.
3. Extra cost: $9.1 \times \$80,000 \approx \$728,000$ per voyage (before subtracting the Suez Canal toll the ship no longer pays).
4. Per TEU: $\$728,000 \div 15,000 \approx \49 .

Answer: About 9 extra days, about \$730,000 more per voyage, or about \$49 per TEU (less the canal toll saved). A large detour for the ship is still a small cost for each box, which is why trade continued even when Suez was avoided.

Example 3. A ship leaves Shanghai (UTC+8) at 6:00 p.m. local time on January 10 and sails for 13 days and 6 hours to Los Angeles (UTC−8 in winter). What is the local date and time of arrival in Los Angeles?

1. Add the voyage in Shanghai time: January 10, 6:00 p.m. + 13 days = January 23, 6:00 p.m.; + 6 hours = January 24, 12:00 midnight (00:00).
2. Time difference: from UTC+8 to UTC−8 is 16 hours; Los Angeles is 16 hours behind Shanghai.
3. Subtract 16 hours: January 24, 00:00 − 16 hours = January 23, 8:00 a.m.
4. Check: a ship crossing the International Date Line eastbound sets its calendar back one day, which is why it arrives on a calendar date earlier than the Shanghai-time count.

Answer: 8:00 a.m. on January 23, Los Angeles time.

PRACTICE

1. **EASY** Who wrote “I, Pencil,” and in what year? What is its main claim?
2. **EASY** Name the three great east-west container routes of the modern trade map.
3. **EASY** List the straits and canal that a container ship passes, in order, between Singapore and Rotterdam by the Suez route.
4. **EASY** Define landed cost and the last mile.
5. **MEDIUM** A T-shirt sells for \$20. Its factory price was \$4.00, ocean freight \$0.05, inland freight and handling \$0.25, and a 15 percent import duty on the factory price. Find the landed cost and the share of the retail price that went to all transport.
6. **MEDIUM** Bananas from Guayaquil, Ecuador, bound for the U.S. East Coast pass through which canal? Why do they travel by refrigerated ship and not by air?
7. **MEDIUM** A ship crosses the Pacific in 13 days at 18 knots. If it slows to 15 knots to save fuel, how many days does the 5,700-nautical-mile voyage take?
8. **MEDIUM** Match each historical trade with its unit and give its date: Zhang Qian’s mission west; Zheng He’s voyages; the founding of the Dutch East India Company; the Manila galleons; the opening of the Suez Canal.
9. **HARD** Using the course, explain in a paragraph why the sea route replaced the Silk Road for most long-distance trade between China and Europe, and why that remains true in the age of the railroad and the airplane.
10. **HARD** Choose one choke point (Malacca, Hormuz, Bab-el-Mandeb, Suez, Panama or Gibraltar). Name a kind of good that depends on it, the alternative route if it closed, and the main cost of that alternative.
11. **HARD** A coffee importer in New Jersey buys beans from Santos, Brazil. The sea leg is about 5,000 nautical miles at 16 knots; port time is 3 days at each end; trucking to the roaster takes 1 day. What is the total lead time in days? Express the sea distance in km.
12. **CHALLENGE** Write a short essay (about 200 words): “Geography is destiny” or “Technology has conquered geography.” Which statement better describes the modern trade map?

Use at least three examples from the course and give the strongest point on the other side.

COMMON MISTAKES

- Measuring sea routes as straight lines across land. Ships follow sea lanes through straits and canals; use a port-distance tool or measure along the water.
- Counting only travel time. Waiting in ports, customs and warehouses is often a third or more of the total lead time.
- Assuming the “Made in” country supplied the materials. A product is often assembled in one country from materials and parts from many others.

Make it a game · Route Relay. One player names a product and its origin (for example, “coffee from Santos, Brazil” or “a laptop from Shanghai”) and a destination city. The players take turns adding one leg at a time: the next port, strait, canal, train or truck stop, with its mode. A wrong or impossible leg (crossing land by ship, skipping a required canal) loses the turn. The player who completes the journey to the front door scores a point. Check routes on a world map. Play five products.

Scripture. “And hath made of one blood all nations of men for to dwell on all the face of the earth, and hath determined the times before appointed, and the bounds of their habitation;” (Acts 17:26, KJV)

Paul spoke these words in Athens, a city of merchants and philosophers. The nations are one family, placed by God in lands of different gifts. Every pencil, cup of coffee and pair of shoes that crosses the sea is a small reminder that we depend on one another, and on the Creator who set the bounds of every land and sea.

Practice answers

1. Leonard E. Read, in 1958 (in *The Freeman*). No single person knows how to make even a simple pencil; it is made by the cooperation of many people in many lands, coordinated by trade rather than by any one planner.
2. Transpacific (East Asia–North America), Asia–Europe (through Malacca and Suez or around the Cape), and transatlantic (Europe–North America).
3. Strait of Malacca (northwest from Singapore), Bab-el-Mandeb, the Suez Canal, the Strait of Gibraltar, and the Strait of Dover (English Channel).
4. Landed cost: the full cost of a product on arrival in the buyer’s country (factory price plus freight, insurance, duties and handling). The last mile: the final delivery step from a local warehouse or store to the customer’s door.
5. Duty: $0.15 \times 4.00 = \$0.60$. Landed cost: $4.00 + 0.05 + 0.25 + 0.60 = \4.90 . Transport: $0.05 + 0.25 = \$0.30$, which is $0.30 \div 20 = 1.5$ percent of the retail price.
6. The Panama Canal. Bananas are cheap per kilogram, so air freight would cost more than the fruit; they are picked green and kept cool on a ship (a refrigerated container or reefer ship), so a voyage of a week or two is acceptable.

7. $5,700 \div 15 = 380$ hours; $380 \div 24 \approx 15.8$ days, about 2.6 days longer than at 18 knots (13.2 days).
8. Zhang Qian: about 138 BC (Unit 1). Zheng He: 1405–1433 (Unit 2). VOC: 1602 (Unit 2). Manila galleons: 1565–1815 (Unit 2). Suez Canal: 1869 (Unit 3).
9. Answers will vary. A ship carries far more cargo per crew member and per unit of energy than camels, carts or trains; the sea needs no road, no oasis and no tolls at every border; the monsoon, better ships and later steam and containers made sea transport ever cheaper. Railways across Asia (such as China–Europe freight trains) are faster than ships but carry far less and cost more per box; airplanes are fastest but costliest. So the sea carries the bulk, with rail and air for time-sensitive or high-value goods.
10. Example: Hormuz; crude oil and LNG from the Persian Gulf to Asia and Europe; alternatives are limited to pipelines across Saudi Arabia to the Red Sea and across the UAE to Fujairah on the Gulf of Oman, which carry only part of the flow, so the main cost would be much less supply and sharply higher prices. (Other correct choke-point answers are acceptable, for example Suez, with the Cape of Good Hope as the alternative at a cost of about 3,500 extra nautical miles and more than a week.)
11. Sea: $5,000 \div 16 = 312.5$ hours ≈ 13.0 days. Total: $13.0 + 3 + 3 + 1 = 20$ days. Distance: $5,000 \times 1.852 = 9,260$ km.
12. Answers will vary. A strong essay uses specific examples (for example, the container cutting loading costs from about \$5.83 to 16 cents a ton; Yangshan's offshore port overcoming a shallow site; Anchorage's position on the great circle; Malacca and Hormuz still channeling trade; the Cape detour of 2024) and reaches a balanced judgment: technology has made distance cheap but has not moved the straits, rivers, harbors and resources, so geography still draws the main lines of the map. It fairly states the other side's best point.

UNIT 5 TEST

Answer each question. Show your work for every calculation, include units, and give both metric and U.S. units where asked. Use complete sentences for explanations. The test is worth 100 points.

1. (6 pts) Who published the wine-and-cloth example of comparative advantage, in what year, and in what book? Which country in the example had the absolute advantage in both goods?
2. (8 pts) Country X needs 4 hours to make a chair and 2 hours to make a basket. Country Y needs 6 hours for a chair and 6 hours for a basket. Find each country's opportunity cost of one chair (in baskets) and state which country has the comparative advantage in chairs and which in baskets.
3. (8 pts) Using Ricardo's numbers (England: cloth 100, wine 120 worker-years; Portugal: cloth 90, wine 80), show that complete specialization raises total output above 2 cloth and 2 wine, and name a terms-of-trade rate at which both countries gain.
4. (6 pts) Describe the voyage of the *Ideal X* (date, ports, cargo) and explain in one or two sentences why it mattered.
5. (6 pts) A ship carries 4,200 forty-foot containers and 2,600 twenty-foot containers. What is its load in TEU?
6. (8 pts) The sea route from Shanghai to Los Angeles is about 5,700 nautical miles. How many days does the crossing take at 19 knots? Express the distance in kilometers and statute miles.
7. (6 pts) Explain the difference between a port's site and its situation, using Shanghai's Yangshan port as your example.
8. (8 pts) A hub port reports 40 million TEU. If 75 percent of the moves are transshipment (each transshipped box counted once off and once on), how many TEU of gateway moves did it handle, and how many actual TEU of transshipped cargo?
9. (6 pts) Name the port that is (a) Europe's largest, at the mouth of the Rhine and Maas; (b) the great transshipment hub at the southern end of the Strait of Malacca; (c) the largest gateway complex in the United States. Give one engineering work that helped each.
10. (6 pts) Classify each good as most likely to fly, float or flow, with a one-word reason: crude oil from Prudhoe Bay to Valdez; iron ore from Australia to China; fresh roses from Bogotá to Miami; computer chips from Taiwan to California; natural gas from Texas to Europe; furniture from Vietnam to Ohio.
11. (8 pts) A laptop in its box weighs 2.5 kg and sells for \$1,000. Air freight costs \$4.50 per kg and sea freight \$0.15 per kg. Find the freight cost as a percentage of price by each mode. Then do the same for a 20-kg bag of rice that sells for \$30.
12. (6 pts) Why is Anchorage, Alaska, one of the world's busiest cargo airports? Why does much of the Trans-Alaska Pipeline run above ground?
13. (8 pts) A bag of coffee travels: truck from a farm in Colombia to the Pacific port of Buenaventura, 400 km, 1 day; waiting in port, 3 days; sea voyage to New Jersey

through the Panama Canal, 4,600 km, 8 days; port and customs, 3 days; truck to a roaster, 100 km, 1 day; roasting and warehouse, 5 days; truck to your town, 300 km, 1 day. Find total distance (km and miles), total time, and the percentage of time spent moving.

14. (10 pts) Essay (about 250 words): Using at least four ideas from this unit (comparative advantage, the container, ports and hubs, what flies, floats and flows, choke points), explain why an ordinary product in your home most likely came from where it did, by the route it did. Include one real cost of world trade to some group of people and one way geography still limits trade.

UNIT PROJECT: THE PRODUCT-JOURNEY MAP

Trace one real product from its raw materials to your home and present it as a large, color-coded world map. Mark every leg of the journey by mode (sea, air, rail, truck, pipeline), label every port, strait and canal, and attach a card to each leg with its distance in km and miles and its time in days. Beside the map, include your research notes and sources, a calculation sheet (total distance, total lead time with moving and waiting shares, and transport cost as a share of price), and a one-page essay explaining why the product came from where it did, by the route it did.

Finish with a short “risk box” naming the one choke point or link whose closure would most delay your product and the alternative route, and present the whole project in a five-minute talk.

- **Accuracy:** Places, ports, straits, canals and modes are real and correctly located; distances and times are reasonable and sourced or explained.
- **Calculations:** Total distance (both units), lead time with moving and waiting shares, and transport cost share are computed correctly with work shown.
- **Explanation:** The essay uses comparative advantage, containers, ports and hubs, choke points and fly-float-flow reasoning to explain the route, and fairly names both gains and costs of trade.
- **Craft and presentation:** The map is neat, color-coded, uncluttered and easy to read; the talk is clear, organized and within five minutes.

Answer key

1. David Ricardo, 1817, *On the Principles of Political Economy and Taxation*. Portugal had the absolute advantage in both cloth and wine.
2. X: 1 chair = $4 \div 2 = 2$ baskets. Y: 1 chair = $6 \div 6 = 1$ basket. Y has the comparative advantage in chairs (lower cost, 1 basket); X has it in baskets (X's basket costs 0.5 chair against Y's 1 chair). X has the absolute advantage in both.
3. England, 220 worker-years all in cloth: 2.2 cloth. Portugal, 170 worker-years all in wine: 2.125 wine. Total 2.2 cloth and 2.125 wine, more than 2 and 2. Any rate between 0.83 and 1.125 wine per cloth works, for example 1 cloth for 1 wine.
4. On April 26, 1956, Malcom McLean's converted tanker *Ideal X* sailed from Port Newark, New Jersey, to Houston with 58 containers (trailer bodies) on deck. It showed that cargo could be

loaded in standard boxes by crane, cutting loading costs from about \$5.83 to about 16 cents a ton and turning ships around far faster.

5. $4,200 \times 2 + 2,600 \times 1 = 8,400 + 2,600 = 11,000$ TEU.
6. $5,700 \div 19 = 300$ hours = 12.5 days. $5,700 \times 1.852 \approx 10,560$ km; $5,700 \times 1.151 \approx 6,560$ miles.
7. Site is the physical character of the place; situation is its position relative to other places. Shanghai's situation at the mouth of the Yangtze, with a vast hinterland of people and factories, is excellent, but its site (shallow, silty river docks) was poor for the largest ships. China built Yangshan on offshore islands with deep water, linked by the 32.5-km Donghai Bridge (opened 2005), keeping the situation while fixing the site.
8. Transshipment moves: $0.75 \times 40 = 30$ million TEU; gateway moves: $40 - 30 = 10$ million TEU. Actual transshipped cargo: $30 \div 2 = 15$ million TEU.
9. (a) Rotterdam: the Nieuwe Waterweg (1872), Europoort and Maasvlakte 2 (2013). (b) Singapore: land reclamation and the new Tuas port. (c) Los Angeles-Long Beach: the San Pedro breakwater (begun 1899) and the Alameda Corridor (2002).
10. Crude oil: flow (liquid; the Trans-Alaska Pipeline). Iron ore: float (bulk, low value). Roses: fly (perishable). Chips: fly (high value per weight, urgent). Natural gas: float as LNG (gas must cross the ocean, chilled to a liquid). Furniture: float (bulky, low value per weight, in containers).
11. Laptop by air: $2.5 \times 4.50 = \$11.25$, 1.1 percent; by sea: $2.5 \times 0.15 = \$0.375$, about 0.04 percent. Rice by air: $20 \times 4.50 = \$90$, 300 percent; by sea: $20 \times 0.15 = \$3.00$, 10 percent. The laptop can fly; the rice must float.
12. Anchorage lies almost on the great-circle routes between East Asia and North America, so freighters stop to refuel and exchange cargo with only a tiny detour. Much of the pipeline runs above ground on supports with heat pipes because warm oil would thaw ice-rich permafrost and the ground would sink and damage the pipe.
13. Distance: $400 + 4,600 + 100 + 300 = 5,400$ km; $\times 0.621 \approx 3,350$ miles. Moving: $1 + 8 + 1 + 1 = 11$ days. Waiting and processing: $3 + 3 + 5 = 11$ days. Total 22 days; moving share $11 \div 22 = 50$ percent.
14. Answers will vary. A full-credit essay names a real product and origin; explains the origin by comparative advantage (climate, resources, skills, wages, port access); describes the route by mode, naming real ports and choke points; explains why the container and economies of scale made the trip cheap; correctly says whether the product flew, floated or flowed and why; names a real cost (for example, workers in industries facing import competition, or longshoremen displaced by containers) fairly; and identifies a geographic limit (a strait, canal depth, great-circle distance, weather or a port's hinterland). Grade on accuracy (4), use of unit ideas (4) and clarity (2).

MIDTERM EXAM

Units 1-3 · 100 minutes

You have 100 minutes. A calculator is allowed; no notes, maps or textbook. Use these values unless a problem gives others: 1° of latitude = 111 km; 1° of longitude = $111 \times \cos(\text{latitude})$ km; 1 km = 0.621 mile; 1 nautical mile = 1.852 km = 1.151 miles; 1 knot = 1 nautical mile per hour = 1.852 km/h; 1 m = 3.281 ft; 1 barrel = 159 L = 42 U.S. gallons; $1 \text{ m}^3 = 1,000 \text{ L} = 264.2 \text{ U.S. gallons}$.

How points are earned. On calculations, write the setup, show the arithmetic with units, and give the answer with its unit (in both km and miles when asked) and one sentence saying what it means; a correct method earns partial credit even if a number slips. Short answers are graded on accurate, specific facts (names, places, dates). The three essays (Problems 10, 15 and 25) are graded on a clear thesis, accurate evidence from more than one side, and a reasoned conclusion; the grading points for each are listed with its answer.

The exam has 25 problems worth a total of **100 points**.

1. (4 pts) **Identification.** Who was Zhang Qian? In a short paragraph tell who sent him and about when, what his mission was, what happened to him, and why the lesson says his mission “failed at its purpose and succeeded beyond anything the emperor had imagined.”
2. (2 pts) **Map reasoning.** Without a map, describe the natural barriers that ring China on the east, north and southwest, and explain why the Han road to the west ran through the Hexi Corridor. Name the mountains and the desert that border the corridor.
3. (4 pts) Explain step by step how an oasis at the edge of the Tarim Basin gets its water. Define *alluvial fan* and *karez* in your answer, and explain why oases, and therefore the caravan roads, lie in strings along the foot of the mountains.
4. (5 pts) Dunhuang is at about 40.1° N , 94.7° E and Kashgar at about 39.5° N , 76.0° E . (a) Estimate the straight-line distance between them in km and miles, treating the north-south and east-west distances as legs of a right triangle and using the average latitude for the longitude scale. (b) The southern route around the Taklamakan is about 1,950 km. How many times longer is the road than the straight line? (c) A caravan travels the southern route at 30 km a day and rests one day for every five days of marching. How many days does the trip take?
5. (5 pts) Model: carrying one 200 kg camel load 2,500 km costs 250 silver coins (feed, driver, tolls and losses). A load of iron bars is worth 50 coins where it is bought; a load of silk is worth 25,000 coins. (a) For each, find the carrying cost as a percentage of the starting value and the lowest price that covers costs at the far end. (b) Find the value per kilogram of each and how many times greater silk’s is. (c) Use the term *value density* to explain the result, and explain why horses were the great exception to the rule.
6. (3 pts) **Identification.** The Silk Road carried skills, faiths and disease as well as goods. Name: (a) the Byzantine emperor to whom monks brought smuggled silkworm eggs about AD 552; (b) the battle of 751, between Abbasid and Tang armies, traditionally

linked to papermaking reaching Samarkand; (c) the monk of the Church of the East who reached Chang'an in 635; (d) the Genoese port in Crimea where plague struck the besieging Mongol army in 1346.

7. (4 pts) Model of tolls: before the Mongol conquests a caravan crosses the lands of 6 rulers, each taking 10% of the value of the cargo that remains. Under the Mongols it pays a single tax of 5%. The cargo is worth 2,000 silver coins at the start. (a) How much value is left at the end in each case? (b) What percentage of the cargo is lost to tolls in each case? (c) Explain in one or two sentences what this shows about the Pax Mongolica.
8. (3 pts) Define *yam*, *paiza* and *ortoq*. Then, in one sentence, say why an honest account of the Mongol peace must begin with its cost, giving one specific example.
9. (5 pts) Model: move 60 tonnes of goods from China to the Mediterranean. Overland: 3,000 km at 30 km a day; each camel carries 200 kg; one driver handles 5 camels. By sea: 5,000 km at an average of 125 km a day in one ship with a crew of 20. Costs: 1 coin per man-day, 1 coin per camel-day, and 20 coins per day for the ship itself. (a) Find the camels, drivers, days, man-days and camel-days for the caravan, and the days and man-days for the ship. (b) Find the total cost of each and the cost per tonne delivered. (c) Give each route in miles, and explain why the longer route is cheaper.
10. (6 pts) **Essay.** Older textbooks said the Ottoman Turks “closed” the road to Asia; others credit Vasco da Gama’s voyage of 1498 with ending the Silk Road. Weigh at least four causes of the decline of overland trade after the 1300s, decide which mattered most, and note how overland trade survived in new forms.
11. (4 pts) Explain why the winds of the northern Indian Ocean reverse with the seasons. Name the two monsoons with their approximate months, say which direction each carried a ship between India and Arabia or Africa, and explain why the monsoon is especially strong in this ocean.
12. (3 pts) One isba on a kamal is $\frac{1}{224}$ of a full circle. A pilot sailing for Calicut (about 11.25° N) measures the corrected height of the Pole Star as 8 isba. What is his latitude? About how far north or south of Calicut’s latitude is he, in km and miles, and what should he do to reach Calicut?
13. (4 pts) (a) A dhow sails from Muscat to Zanzibar, about 3,950 km (2,450 miles), averaging 6 knots day and night on the northeast monsoon. About how many days does it take? (b) Kilwa lies about 1,350 km (840 miles) north of Sofala, the port for the gold of the Zimbabwe plateau. Explain why Arabian ships seldom sailed to Sofala themselves and how this made Kilwa rich. Use the term *break-of-bulk point*.
14. (4 pts) The *History of Ming* gives the largest treasure ship as 44 zhang long (1 zhang $\approx$ 3.1 m). Many naval historians estimate the largest ships at about 70 m instead. (a) Give both lengths in meters and feet, and compare each with Columbus’s *Santa María* (about 18 m). (b) Name one piece of physical evidence that some ships were very large, and state the honest conclusion about the ships’ size.
15. (6 pts) **Essay.** After Zheng He’s seventh voyage (1431–1433) the Ming court ended the treasure fleets. Some writers call this one of history’s great mistakes; others think it was a sensible choice for the Ming. Weigh the evidence on both sides, judging the decision by what the Ming court knew and faced at the time, and give your conclusion.

16. (4 pts) Model risk: a VOC voyage has a 3-in-4 chance of returning, and a returning voyage pays back 2 times the money invested. Investor A puts 800 guilders into one voyage. Investor B puts 200 guilders into each of four voyages that succeed or fail independently. Find each investor's expected return and the chance that each loses everything. What does this show about the joint-stock company?
17. (3 pts) Explain how geography made the Dutch monopoly of nutmeg and cloves possible, what the VOC did at Banda in 1621, and how the monopoly was finally broken.
18. (4 pts) (a) A westbound galleon covers about 14,900 km from Acapulco to Manila in 95 days. A returning galleon covers about 15,000 km in 150 days. Find each average speed in km per day and in knots, and give each distance in miles. (b) Explain, using the wheel of North Pacific winds and currents, why the return route ran far to the north, and name the man who found it in 1565.
19. (4 pts) (a) Tomé Pires wrote that whoever is lord of Malacca has his hand on the throat of Venice. Explain what he meant. (b) A tanker bound from the Persian Gulf to Japan avoids Malacca by the Lombok Strait, adding about 1,600 km. Give the extra distance in miles. At 12 knots, how many extra days does it sail, and what is the extra cost at \$35,000 a day? (c) Why does the very largest tanker use Lombok anyway?
20. (4 pts) About 20 million barrels of oil a day passed the Strait of Hormuz in 2023–2024. The EIA estimated about 2.6 million barrels a day of unused bypass pipeline capacity. If the strait were closed and all of that capacity were used: (a) what percent of the flow could still reach the sea? (b) How much would be stranded, in barrels, liters and U.S. gallons per day? (c) How many 2-million-barrel VLCC loads is the stranded oil each day? (d) Saudi Arabia's East–West pipeline ends at Yanbu. Which choke points must its oil still pass?
21. (4 pts) Explain the two-layer flow in the Bosphorus and in the Strait of Gibraltar: which way the surface and deep water move in each, and why, using salinity. Then describe how Luigi Ferdinando Marsigli discovered the Bosphorus undercurrent in 1679–1680.
22. (4 pts) A lock chamber on the original Panama locks is about 305 m long and 33.5 m wide. Suppose it lowers a ship 9.0 m. (a) What volume of water drains out of the chamber in one lockage, in cubic meters, liters and U.S. gallons? (b) If 30 ships a day each draw two such volumes of fresh water from Gatun Lake, how much lake water is used per day? (c) Why did the dry year of 2023–2024 force the canal authority to limit ships?
23. (2 pts) **Geography reasoning.** Explain why the Suez Canal could be dug at sea level with no locks, but the successful Panama Canal needed locks and a lake 26 m (85 ft) above the sea.
24. (3 pts) The Great Belt route takes ships up to about 15 m draft under a bridge with about 65 m clearance. The Drogden channel of the Øresund has no bridge above it but only about 8 m of water. Ignoring safety margins, which route can each ship use? Ship X: draft 13 m, air draft 60 m. Ship Y: draft 7.5 m, air draft 68 m. Ship Z: draft 9 m, air draft 66 m. Then identify the Sound Toll in one sentence.
25. (6 pts) **Essay.** A strait is a risk to trade when much traffic depends on it, it is narrow enough to be threatened, and the alternatives are poor. Using figures from the course, compare the Strait of Malacca, the Strait of Hormuz and the Bab-el-Mandeb on these

three tests, and rank them from greatest to least risk to world oil supply. Describe recent events neutrally and give reasons for your ranking.

Answer key

1. Zhang Qian was a Han palace officer sent west about 138 BC by Emperor Wu of Han to find the Yuezhi and make an alliance against the Xiongnu nomads. The Xiongnu captured him and held him more than ten years; he escaped west to Dayuan (Ferghana) and Kangju (Samarkand country) and reached the Yuezhi in Bactria, who had no wish to fight. Captured again on the way home, he escaped in 126 BC and reached Chang'an with his wife and Ganfu; only two of more than a hundred men returned. **Failed:** no alliance was made. **Succeeded:** his eyewitness report, preserved in Sima Qian's *Shiji*, described Ferghana's horses, Parthia and Bactria, and Chinese goods reaching Bactria through India. Emperor Wu acted on it: he drove the Xiongnu from the Hexi Corridor (by 121 BC), founded frontier commanderies and sent silk embassies west, opening the Han road to the west.
Grading: 1 pt sender/date; 1 pt purpose (Yuezhi alliance vs. Xiongnu); 1 pt journey/captivity; 1 pt why the result mattered.
2. China is walled by the Pacific on the east, the Gobi and steppe on the north, and the Tibetan Plateau and Himalaya on the southwest. The one easy door west is the Hexi (Gansu) Corridor, a strip of oases about 1,000 km (600 miles) long, fed by snowmelt from the **Qilian Mountains** on one side with the **Gobi** on the other. Its oases gave caravans water, food and pasture a few days apart, and it leads to Dunhuang at the edge of the Tarim Basin.
Grading: 1 pt barriers; 1 pt corridor explanation with Qilian and Gobi.
3. (1) The basin gets very little rain, but the surrounding mountains (Tian Shan, Kunlun, Pamirs) catch snow; in spring snow and glaciers melt and feed rivers that rush down to the foot of the range. (2) There each river drops its gravel in an **alluvial fan**, a fan-shaped spread of gravel and sand, and much of its water sinks in. (3) Lower down, where gravel gives way to finer soil, the groundwater rises again in springs; that band of springs, fields and orchards is the oasis, and below it the rivers wither into the sand. (4) A **karez** is a gently sloping underground tunnel, dug with a line of vertical shafts, that carries groundwater by gravity from the mountain foot to the fields without losing it to evaporation (used at Turpan; called a qanat in Persia). Because oases form wherever mountain water meets the plain, they lie in strings along the mountain foot, and the caravan roads simply ran from one to the next.
Grading: 1 pt snowmelt source; 1 pt alluvial fan and springs; 1 pt karez; 1 pt strings/roads.
4. (a) North-south: $40.1 - 39.5 = 0.6^\circ \times 111 \approx 67$ km. Average latitude 39.8° , $\cos 39.8^\circ \approx 0.768$; east-west: $94.7 - 76.0 = 18.7^\circ \times 111 \times 0.768 \approx 1,595$ km. Distance $\approx \sqrt{(67^2 + 1,595^2)} \approx \mathbf{1,596 \text{ km (about 990 miles)}}$. (b) $1,950 \div 1,596 \approx \mathbf{1.2 \text{ times}}$; the road bends to follow the oases at the foot of the Kunlun instead of crossing the sand. (c) Marching days $1,950 \div 30 = 65$; rest days $65 \div 5 = 13$; total **78 days** (77 if no rest day is counted after arrival; either earns full credit) (about $2\frac{1}{2}$ months) for about 1,950 km (1,210 miles).
Grading: 2 pts (a); 1 pt (b); 2 pts (c).
5. (a) Iron: $250 \div 50 \times 100 = \mathbf{500\%}$; it must sell for at least $50 + 250 = \mathbf{300 \text{ coins}}$, six times its starting price. Silk: $250 \div 25,000 \times 100 = \mathbf{1\%}$; it must sell for at least **25,250 coins**. (b) Iron $50 \div 200 = 0.25$ coin/kg; silk $25,000 \div 200 = 125$ coins/kg; silk is **500 times** greater. (c) Value density is value per unit of weight. Each day on the road costs the same whatever the load is worth, so only high-value-density goods (silk, spices, gems, precious metals) could bear months of overland transport; heavy, cheap goods like grain, timber and iron could not. Horses were the exception because they carried themselves, and the Han and Tang needed

tens of thousands of them for cavalry.

Grading: 2 pts (a); 1 pt (b); 2 pts (c).

6. (a) **Justinian**; (b) the battle of the **Talas River**; (c) **Alopen**; (d) **Caffa**.

Grading: ¾ pt each.

7. (a) Before: $2,000 \times 0.9^6 = 2,000 \times 0.531 \approx$ **1,063 coins** left. Under the Mongols: $2,000 \times 0.95 =$ **1,900 coins** left. (b) Before: about 937 coins lost, about **47%**; after: 100 coins, **5%**, more than nine times less. (c) Trade costs include tolls and danger, not only distance. When one power held almost the whole route, tolls and risk fell sharply even though the deserts and mountains were unchanged, so trade and travel flourished.

Grading: 2 pts (a); 1 pt (b); 1 pt (c).

8. **Yam**: the Mongol network of relay stations with fresh horses, food and lodging for official messengers and pass-holders (organized under Ögedei). **Paiza**: a gold, silver or wood tablet carried by officials and envoys as a passport and order, entitling the bearer to protection and supplies at the stations. **Ortoq**: a partnership in which Mongol nobles invested with (often Muslim or Uyghur) merchants who traded for them and shared the profits. **Cost**: the peace was built on conquest and terror; for example, after the governor of Otrar killed Genghis Khan's merchants in 1218, Mongol armies took Bukhara and Samarkand (1220) and massacred whole populations at Merv and Nishapur (1221). (Baghdad's sack in 1258 is also acceptable.)

Grading: ½ pt each definition; 1½ pts cost with example.

9. (a) Caravan: $60,000 \text{ kg} \div 200 =$ **300 camels**; $300 \div 5 =$ **60 drivers**; $3,000 \div 30 =$ **100 days**; $60 \times 100 =$ **6,000 man-days**; $300 \times 100 =$ **30,000 camel-days**. Ship: $5,000 \div 125 =$ **40 days**; $20 \times 40 =$ **800 man-days** (about 7½ times less labor). (b) Caravan: $6,000 + 30,000 =$ **36,000 coins**, $36,000 \div 60 =$ **600 coins per tonne**. Ship: $800 + 20 \times 40 = 800 + 800 =$ **1,600 coins**, about **27 coins per tonne**; the ship is about 22 times cheaper per tonne. (c) $3,000 \text{ km} \approx 1,860 \text{ miles}$; $5,000 \text{ km} \approx 3,110 \text{ miles}$. The ship needs no animals, its crew does not grow in proportion to its cargo (economies of scale), and the wind does the work of moving it while water holds it up, so even a route two-thirds longer costs far less. (This is a model, but it agrees with Adam Smith's wagon-and-ship comparison of 1776.)

Grading: 2 pts (a); 2 pts (b); 1 pt (c).

10. **Model answer.** The overland trade weakened for several reasons. After 1260 the Mongol Empire split into rival khanates, ending the single authority that had kept tolls low and roads safe. The plague of the 1340s killed huge numbers along the routes and in their cities. The Yuan fell in 1368, and the Ming faced north against the steppe. Timur wrecked cities such as Baghdad and Delhi. The Ottomans took Constantinople (1453) and Caffa (1475), but the Turks did not so much close the road as tax it: the trade now passed through strong Muslim states (Mamluks, Ottomans, later Safavids) and Venice at the European end, and each hand raised the price. The deepest cause was the arithmetic of transport: a ship carried a hundred tonnes or more with a small crew and no animals, so once da Gama opened the Cape Route in 1498 Europe could reach India with no middleman at all, and the Portuguese soon held Goa, Malacca and Hormuz. So the political troubles weakened the road, but the cheaper sea route is what made the shift permanent. Overland trade adapted rather than vanished: Persian silk still went by caravan to Aleppo and Bursa, tea caravans ran to Kyakhta after 1727, railways reached Samarkand in 1888, and China-Europe freight trains run today for valuable, urgent goods.

Grading (6 pts): 1 pt each for four accurate causes (up to 4); 1 pt for a reasoned judgment of which mattered most (sea-route cost is the expected answer, but a well-argued alternative earns credit); 1 pt for what survived.

11. Land heats and cools faster than water. In the northern summer Asia grows hot, warm air rises over India and the lands to the north, pressure falls, and moist ocean air flows in: the **southwest monsoon**, about **June to September**, strong, wet and stormy, carrying ships from Arabia and Africa toward India. In winter Asia cools, cold heavy air spreads outward, and the **northeast monsoon** blows dry and steady from about **November to March**, carrying ships from India toward Arabia and East Africa. Calmer, changeable weeks lie between. The monsoon is especially strong here because a huge continent, Asia, sits across the ocean's whole northern side; no other ocean has that.
Grading: 1 pt land-sea heating; 1 pt each monsoon with months and direction; 1 pt why strongest here.
12. One isba = $360^\circ \div 224 \approx 1.607^\circ$; $8 \times 1.607^\circ \approx \mathbf{12.9^\circ \text{ N}}$ (the pole's height equals the latitude). He is $12.86 - 11.25 \approx 1.6^\circ$, exactly one isba, **north** of Calicut: $1.6 \times 111 \approx \mathbf{178 \text{ km (about 111 miles)}}$. He should sail south until the Pole Star stands at 7 isba (Calicut's latitude) and then run east along that latitude to landfall.
Grading: 1 pt latitude; 1 pt distance in km and miles; 1 pt what to do.
13. (a) $6 \times 1.852 = 11.1 \text{ km/h}$; $\times 24 \approx 267 \text{ km a day}$; $3,950 \div 267 \approx \mathbf{15 \text{ days}}$ of sailing. (b) The monsoon weakens to the south. A dhow from Arabia could ride the northeast monsoon to Kilwa, but going on to Sofala and back would usually make it miss the southwest wind home and lose a whole year. So cargo changed hands at Kilwa: its own merchants carried gold and ivory up from Sofala and sold them to the northern ships. Kilwa was a **break-of-bulk point**, a place where cargo must be moved from one kind of transport (here, one set of ships) to another, and it grew rich as the middleman, with its great mosque, the palace of Husuni Kubwa and its own copper coins.
Grading: 1 pt (a); 3 pts (b).
14. (a) Ming figure: $44 \times 3.1 = \mathbf{136 \text{ m (about 448 ft)}}$, about **7.6** times the Santa María. Modern estimate: **70 m (about 230 ft)**, about $70 \div 18 \approx \mathbf{3.9}$ times. (b) A rudder post about 11 m (36 ft) long dug up in 1957 at the site of the Nanjing shipyard. Honest conclusion: the fleets were the largest the world had yet seen, but the exact size of the biggest ship is uncertain; the Ming figure was compiled long afterward and many doubt a wooden ship of 136 m could sail well.
Grading: 2 pts (a); 1 pt evidence; 1 pt conclusion.
15. **Model answer.** The voyages had served the Yongle Emperor's purposes: proclaiming the power and legitimacy of a ruler who took the throne by civil war, bringing envoys to send tribute, gathering luxuries, and punishing enemies such as the pirate Chen Zuyi. After Yongle died in 1424, officials argued that the fleets cost a fortune while the empire faced the Mongols on its northern frontier and was rebuilding the Grand Canal and the new capital at Beijing. Geography supports them: China's great dangers came over land from the north, and its food and wealth moved by river and canal, so the sea seemed a luxury. The fleets also followed old merchant routes and opened no new trade; the sea ban on private trade remained law. On the other side, ending the voyages gave up a sea presence that no rival could match: within a century Portuguese ships were in the same ports (Malacca 1511, Hormuz 1515), and Chinese private traders were left without state support. A fair conclusion: given the Ming's real threats and costs, the decision was reasonable in its own time, but it shows that sea power is a choice a nation must keep making, and its long-run price was high.
Grading (6 pts): 2 pts for the court's reasons (cost, Mongol threat, canal/capital, sea ban); 2 pts for the case that it was costly (Portuguese arrival, lost presence); 1 pt for judging by the standards and knowledge of the time; 1 pt for a clear, supported conclusion either way.
16. A: expected return $(3/4) \times (2 \times 800) = \mathbf{1,200 \text{ guilders}}$; chance of losing everything $1/4 = \mathbf{25\%}$. B: each voyage $(3/4) \times (2 \times 200) = 300$, and $4 \times 300 = \mathbf{1,200 \text{ guilders}}$; B loses

everything only if all four fail: $(1/4)^4 = 1/256 \approx 0.4\%$. The expected returns are equal, but spreading money over many voyages almost removes the chance of ruin. A joint-stock company such as the VOC (1602), funding many voyages with money from more than a thousand investors, did this for all of them at once.

Grading: 1 pt each expected return and ruin chance (A and B, 3 pts); 1 pt meaning.

17. Clove trees grew wild only on five small islands of the northern Moluccas (Ternate, Tidore, Moti, Makian, Bacan), and nutmeg and mace only in the tiny Banda Islands, so a power that held these few remote islands could control the whole supply. In 1621 Governor-General Jan Pieterszoon Coen invaded Banda: the Bandanese were killed, executed, starved or enslaved; of about 15,000 people perhaps a thousand remained, and the groves were given to Dutch planters worked by enslaved laborers. (The VOC also concentrated cloves on Ambon and cut down trees elsewhere.) The monopoly was broken by geography too: in 1770 the Frenchman Pierre Poivre had seedlings smuggled to Mauritius, and the spices spread to Zanzibar, Ceylon, Penang and the West Indies (Grenada).

Grading: 1 pt each part.

18. (a) Westbound: $14,900 \div 95 \approx 157 \text{ km a day}$; $\div 24 \approx 6.5 \text{ km/h} \div 1.852 \approx 3.5 \text{ knots}$; $14,900 \text{ km} \approx 9,250 \text{ miles}$. Eastbound: $15,000 \div 150 = 100 \text{ km a day}$; $\approx 4.2 \text{ km/h} \approx 2.25 \text{ knots}$; $15,000 \text{ km} \approx 9,320 \text{ miles}$. (b) The North Pacific turns clockwise: the northeast trade winds and North Equatorial Current run west near the tropic (good for the outward run along about 13° N), the Kuroshio runs north along Asia, the westerlies and North Pacific Current run east in the middle latitudes, and the California Current runs south along North America. A ship sailing east in the tropics fights the trades, so **Andrés de Urdaneta** took the *San Pedro* north to about $39^\circ\text{--}40^\circ \text{ N}$ into the westerlies, crossed the ocean, sighted California and followed the coast south to Acapulco.

Grading: 2 pts (a); 2 pts (b).

19. (a) Malacca was the door through which the spices of the East passed to the Indian Ocean and on to Venice; whoever held that narrow strait could squeeze the spice trade that had made Venice rich. (b) $1,600 \text{ km} \approx 990 \text{ miles}$. $12 \times 1.852 = 22.2 \text{ km/h}$; $1,600 \div 22.2 \approx 72 \text{ hours} = 3.0 \text{ days}$; $3.0 \times \$35,000 \approx \$105,000$ per voyage. (c) Parts of the Malacca channel are only about 25 m deep, limiting ships to about 20.5 m draft (Malaccamax); the Lombok Strait is more than 150 m deep.

Grading: 1 pt (a); 2 pts (b); 1 pt (c).

20. (a) $2.6 \div 20 = 13\%$. (b) $20 - 2.6 = 17.4 \text{ million barrels a day}$; $\times 159 \text{ L} \approx 2.77 \text{ billion liters}$; $\times 42 \approx 731 \text{ million gallons}$. (c) $17.4 \div 2 \approx 8.7 \text{ VLCC loads a day}$. (d) Yanbu is on the Red Sea, so its oil must pass either northward through the **Suez Canal** or southward through the **Bab-el-Mandeb**.

Grading: 1 pt each part.

21. **Bosporus**: the Black Sea receives the Danube, Dnieper, Don and other great rivers and has more fresh water than it evaporates, so lighter, fresher water flows out at the surface toward the Sea of Marmara, while heavier, saltier Mediterranean water creeps in along the bottom toward the Black Sea. **Gibraltar**: the Mediterranean, in a hot, dry climate, loses more by evaporation than rivers and rain supply, so Atlantic water pours in at the surface and saltier, denser Mediterranean water flows out along the bottom over the Camarinal Sill. **Marsigli** lowered weighted lines with floats and found the deep water moving north; he weighed surface and deep water and found the deep water heavier because saltier; then he built a tank divided by a wall with holes, salt water on one side and fresh on the other, and watched the salt water slide along the bottom while the fresh flowed over the top. He published in Rome in 1681, one of the first real experiments in oceanography.

Grading: 1½ pts Bosporus; 1½ pts Gibraltar; 1 pt Marsigli.

22. (a) $305 \times 33.5 \times 9.0 \approx \mathbf{92,000 \text{ m}^3}$ = about **92 million liters** $\approx 92,000 \times 264.2 \approx \mathbf{24.3 \text{ million gallons}}$. (b) $30 \times 2 \times 92,000 \approx \mathbf{5.5 \text{ million m}^3}$ (about 5.5 billion liters, about 1.46 billion gallons) a day. (c) Every lockage drains fresh water from Gatun Lake to the sea; in a dry year rain did not refill the lake fast enough, so the authority limited the number and draft of ships. (The newer locks of 2016 use water-saving basins.)
Grading: 2 pts (a); 1 pt (b); 1 pt (c).
23. At Suez the land is low, flat desert and shallow lakes, and the Mediterranean and Red Sea stand at nearly the same level, so a sea-level channel works. At Panama the isthmus is covered with rain forest, crossed by the flood-prone Chagres River and backed by a mountain ridge; de Lesseps's sea-level attempt (from 1881) was beaten by landslides, floods and disease. The Americans dammed the Chagres at Gatun to make a lake 26 m above the sea, so ships climb by locks into the lake, cross the divide on it and through the Culebra Cut, and step back down to the other ocean.
Grading: 1 pt Suez; 1 pt Panama.
24. **Ship X:** Great Belt only ($13 < 15$ and $60 < 65$; too deep for Drogden). **Ship Y:** Drogden only ($68 > 65$ bars the bridge; $7.5 < 8$ fits Drogden). **Ship Z:** neither ($66 > 65$ bars the bridge; $9 > 8$ is too deep for Drogden). **Sound Toll:** a toll Denmark charged foreign ships passing the Øresund at Helsingør from 1429 (begun by King Eric of Pomerania) until 1857, when the maritime nations paid a lump sum to end it; it helped pay for Kronborg Castle.
Grading: ½ pt each ship (1½ pts); 1½ pts Sound Toll.
25. **Model answer.** *Malacca* carries the most oil, about 23 million barrels a day (2023), and more than 80,000 ship passages a year, and its Phillips Channel is only about 2.8 km wide; but piracy fell after the coastal states' coordinated patrols from 2004, and real alternatives exist: the Lombok Strait (deep enough for the largest tankers) and the Sunda Strait, at a cost of a few extra days, plus pipelines across Myanmar. *Hormuz* carries about 20 million barrels a day, about one-fifth of world consumption, plus about one-fifth of world LNG trade; it is about 39 km wide with lanes about 3 km wide, lies between Iran and Oman, and was the scene of the Tanker War (1984–1988). Its alternatives are poor: only about 2.6 million barrels a day of spare pipeline capacity, about 13% of the flow. The *Bab-el-Mandeb* carried about 8.7 million barrels a day in 2023; it is about 29 km wide; from November 2023 the Houthi movement in western Yemen attacked merchant ships, saying it acted over the war in Gaza, and traffic through the strait and Suez fell by roughly half in 2024. Its alternative, the Cape of Good Hope, is long (about 3,500 nautical miles more to northern Europe) but real. A reasonable ranking: **Hormuz first** (large flow, poor alternatives), **Bab-el-Mandeb second** (actually disrupted, but with a workable detour), **Malacca third** (largest flow but good alternatives). Other rankings earn credit if supported by the three tests.
Grading (6 pts): 1 pt each for accurate traffic, width and alternatives across the three straits (3 pts); 1 pt neutral, accurate description of events; 2 pts for a ranking clearly argued from the evidence.

FINAL EXAM

Units 1-5 · 120 minutes

You have 120 minutes. A calculator is allowed; no notes, maps or textbook. The exam is cumulative, with most of its points on Units 4 and 5. Use these values unless a problem gives others: 1° of latitude = 111 km; 1° of arc on a great circle = 111.2 km; $\cos c = \sin \varphi_1 \sin \varphi_2 + \cos \varphi_1 \cos \varphi_2 \cos \Delta\lambda$; 1 km = 0.621 mile; 1 nautical mile = 1.852 km = 1.151 miles; 1 knot = 1.852 km/h; 1 barrel = 159 L = 0.159 m^3 = 42 U.S. gallons; 1 acre = 0.4047 ha; 1 short ton = 2,000 lb.

How points are earned. On calculations, write the setup, show the arithmetic with units, and give the answer with its unit (in both km and miles when asked) and a sentence saying what it means; a correct method earns partial credit even if a number slips. Short answers are graded on accurate, specific facts. The three essays (Problems 12, 19 and 21) are graded on a clear thesis, accurate evidence from more than one side, and a reasoned conclusion; the grading points for each are listed with its answer.

The exam has 28 problems worth a total of **100 points**.

1. (2 pts) Why did caravans carry silk across Asia but almost never grain? Answer in two or three sentences using the term *value density*.
2. (5 pts) Lisbon is at about 38.7° N , 9.1° W and Calicut at about 11.25° N , 75.8° E . (a) Find the great-circle distance in km and miles. (b) Why could Vasco da Gama's ships not follow anything like this path, and what route did they take? (c) Although the sea route to India was far longer than the great circle, explain why it soon became the cheaper way to bring pepper to Europe.
3. (3 pts) Zheng He's fleets and the Arab dhows alike lived by the monsoon calendar. In what season did a Ming fleet sail from the Fujian coast toward Malacca and India, in what season did it come home, and why did the fleet keep a depot at Malacca? Name each monsoon.
4. (3 pts) Explain the "silver for silk" trade of the Manila galleons: where the silver came from, why China wanted it, what went back, and why historians often date a truly worldwide trade from 1571.
5. (3 pts) A tanker carries crude from Ras Tanura, Saudi Arabia, to Japan by the usual route. Name in order the two great straits it passes, and name the alternative strait it would use if the second were blocked. If about 20 million barrels a day pass the first strait and the world uses about 100 million barrels a day, what share of world use is that?
6. (4 pts) Before the Panama Canal, a ship from New York to San Francisco sailed about 22,500 km around Cape Horn; through the canal the voyage is about 9,500 km. (a) How much shorter is the canal route in km, miles and percent? (b) How many days does it save for a ship at 15 knots? (c) Name two people whose work against disease or on engineering made the canal possible, with what each did.
7. (2 pts) What is the Montreux Convention (1936), and why do the Turkish Straits matter so much to the grain trade of the Black Sea?

8. (3 pts) Seawater holds about 35 g of dissolved salts per kilogram, and about 78% of that is sodium chloride. How many kilograms (and metric tonnes) of seawater must evaporate in a saltern to make 1 tonne of common salt? Name the two other geographic sources of salt besides the sea, with one real example of each.
9. (3 pts) (a) An azalai of 600 camels carries 4 slabs of 30 kg on each camel from Taoudenni to Timbuktu, about 660 km (410 miles), at 33 km a day. How many tonnes of salt does it carry and how many days does the trip take? (b) Explain why Timbuktu grew where it did, using the terms *complementarity* and *break-of-bulk point*.
10. (4 pts) (a) Use the quantity equation $M \times V = P \times Y$. Suppose over some decades the quantity of money doubles, the speed of spending stays the same, and the quantity of goods sold rises 25%. By what percentage does the price level change? (b) Suppose a price index rose from 100 to 250 in 50 years. What steady yearly rate of increase is this, and about how long did prices take to double?
11. (3 pts) **Identification.** Briefly identify the Cerro Rico of Potosí, Viceroy Francisco de Toledo and the mita, and trace in words the legal route by which Potosí silver reached Seville.
12. (6 pts) **Essay.** Prices in Spain rose roughly fourfold during the 1500s, and prices rose across Europe. Was American silver the main cause of the price revolution? Present the evidence for the silver explanation and the critics' evidence fairly, and reach a conclusion.
13. (5 pts) Weber's triangle: ore field O, coalfield C and market M. Distances: O-C = 50 km, C-M = 120 km, O-M = 90 km. Freight costs \$0.10 per ton-kilometer, and 1 tonne of iron must reach the market. (a) In the early 1800s, 1 tonne of iron took 2 tonnes of ore and 4 tonnes of coal. Find the freight cost per tonne of iron at each corner. (b) Later, with better furnaces, it takes 1.5 tonnes of ore and 1 tonne of coal. Recalculate. (c) Explain what changed and connect it to the real move of steelworks.
14. (3 pts) (a) Name two British coalfields and the industrial city that grew on each. (b) A packhorse carried about 1/8 tonne of coal; a canal horse pulled a barge of about 30 tonnes. A mill needs 900 tonnes of coal a month. How many packhorse loads and how many barge loads is that, and how many packhorses did one canal horse replace?
15. (3 pts) Explain why oil is found where it is, naming the source rock, reservoir rock, cap rock and trap, and describing how gas, oil and water arrange themselves. Then explain what kind of trap made Spindletop (1901) and how it links to Lesson 4.1.
16. (4 pts) (a) A VLCC loads 2 million barrels at Ras Tanura for Ningbo, China, about 6,000 nautical miles. How long is the voyage at 15 knots? Give the distance in km and miles and the cargo in liters and U.S. gallons. (b) An LNG carrier holds 170,000 m³ of LNG, which expands about 600 times when warmed to gas. How many days of gas does one cargo supply for a city using 6 million m³ a day? (c) In one sentence, why do pipelines suit some geography and tankers other geography?
17. (3 pts) A wheat farmer on the Great Plains harvests 320 acres at 45 bushels per acre (1 bushel = 60 lb = 27.2 kg). Find the harvest in bushels, short tons and metric tonnes, and the yield in tonnes per hectare. Then explain in one sentence why the world's breadbaskets lie on mid-latitude grasslands.

18. (3 pts) (a) A copper mine processes 1,000,000 tonnes of ore at 0.5% copper and recovers 88% of it. How much copper does it produce, and how many tonnes of ore are mined per tonne of copper? (b) USGS estimates for 2024 put world rare-earth mine output at about 390,000 tonnes and China's at about 270,000. What is China's share? Why are rare earths hard to supply even though they are not truly rare?
19. (6 pts) **Essay.** Geographers call it *resource concentration* when most of a resource, or of its processing, comes from one or a few places. Compare resource concentration with a sea-lane choke point from Unit 3, using rare earths and one strait as examples. Weigh how serious the risk is and what buyers can do about it, in neutral terms.
20. (5 pts) Two countries make grain and cloth. In Country A one unit of grain takes 40 worker-days and one unit of cloth 60; in Country B grain takes 30 and cloth 20. A has 100 worker-days and B has 50, and before trade each makes 1 grain and 1 cloth. (a) Which country has the absolute advantage in each good? (b) Find each country's opportunity cost of grain and of cloth, and name each comparative advantage. (c) If each specializes completely, how much of each good does the pair make, and what is the gain? (d) Show that a trade of 1 grain for 1 cloth leaves both better off.
21. (7 pts) **Essay.** The container made distance cheap. Weigh fairly the gains of cheap container shipping and the real costs it brought to particular workers and places. Use specific evidence from the course, connect your answer to the transport cost Ricardo left out of his example, and reach a balanced judgment.
22. (4 pts) (a) A container ship carries 4,200 forty-foot containers and 2,100 twenty-foot containers. What is its load in TEU, and what percentage of an 11,000-TEU rating is used? (b) The sea route from Shanghai to Los Angeles is about 5,700 nautical miles. Give it in km and miles, and find the crossing time at 16 knots and at 12 knots (slow steaming).
23. (2 pts) Distinguish a port's *site* from its *situation*, using Shanghai and Yangshan as your example. Then classify Singapore and Los Angeles-Long Beach as a gateway port or a transshipment hub, with a reason for each.
24. (2 pts) A hub port reports 30 million TEU in a year. Suppose 85% of these moves are transshipment, so each transshipped box is counted twice (off one ship, onto another). How many TEU of moves are transshipment and how many gateway? How many TEU of actual cargo passed through the port in all?
25. (3 pts) Suppose air freight across the Pacific costs \$4.50 per kg and sea freight \$0.25 per kg. Find the freight cost as a percentage of price by each mode for: a laptop weighing 2 kg and selling for \$1,000; a 10 kg sack of potatoes selling for \$8; and a 1 kg box of fresh roses selling for \$60. Which should fly, and why?
26. (3 pts) (a) Suppose the Trans-Alaska Pipeline (cross-section about 1.167 m^2 , length about 1,287 km or 800 miles) carries 600,000 barrels a day (1 barrel = 0.159 m^3). Find the average speed of the oil in km/h and mph and the days a barrel takes from Prudhoe Bay to Valdez. (b) Why is Anchorage one of the world's busiest cargo airports?
27. (4 pts) A container of toys leaves Shanghai (UTC+8) at 10:00 a.m. local time on January 5, bound for Rotterdam (UTC+1 in winter) by way of the Suez Canal, about 10,500 nautical miles. (a) Give the distance in km and miles and the time at sea at 16 knots, in days and hours. (b) If the voyage takes exactly 27 days and 8 hours, what is the local

date and time of arrival in Rotterdam? (c) Name in order the straits and canal the ship passes after leaving the South China Sea.

28. (2 pts) **Identification.** What is “I, Pencil,” who wrote it and when, and what is its main point? Name two of the places the pencil’s materials came from.

Answer key

- Every day on the road cost the same (feed, drivers, tolls) whatever a 200 kg camel load was worth. Silk had high **value density** (great value per kilogram), so carrying costs added only a small share to its price; grain was heavy and cheap, so carrying costs would have multiplied its price many times and no distant buyer would pay it.
Grading: 1 pt fixed cost per load; 1 pt correct use of value density.
- (a) $\Delta\lambda = 9.1 + 75.8 = 84.9^\circ$. $\sin 38.7^\circ \times \sin 11.25^\circ \approx 0.625 \times 0.195 \approx 0.122$; $\cos 38.7^\circ \times \cos 11.25^\circ \times \cos 84.9^\circ \approx 0.780 \times 0.981 \times 0.089 \approx 0.068$. $\cos c \approx 0.190$, so $c \approx 79.0^\circ$. Distance $\approx 79.0 \times 111.2 \approx$ **8,790 km (about 5,460 miles)**. (b) The great circle crosses Europe, the Mediterranean, Arabia and Persia; there was no sea passage through them (the Suez Canal did not exist until 1869). Da Gama sailed from Lisbon far out into the Atlantic, around the Cape of Good Hope, up the East African coast to Malindi, and across the Arabian Sea with the monsoon to Calicut (1497–1498). (c) Ships carried large cargoes with small crews and no animals, the wind did the work, and the pepper passed through no middleman’s hands (no Arab shippers, Egyptian customs or Venetian merchants), so the long way around was the cheap way around.
Grading: 2 pts (a); 1½ pts (b); 1½ pts (c).
- The fleet gathered in autumn and sailed in **winter on the northeast monsoon** (about November–March) to Champa, Java and the Strait of Malacca; it came home in **summer on the southwest monsoon** (about June–September). Malacca lies where the monsoon systems of the Indian Ocean and the South China Sea meet, so the fleet stored goods in its fortified depot there and waited for the wind to change before crossing to Ceylon and Calicut or heading home.
Grading: 1 pt outward; 1 pt return; 1 pt Malacca.
- Silver came from Potosí in Peru (today Bolivia) and from Zacatecas and Guanajuato in Mexico, and sailed from Acapulco to Manila. China wanted it because in the 1570s and 1580s the Ming began requiring many taxes to be paid in silver, and silver was worth more in China, measured against gold, than in Europe or America. Chinese junks from Fujian brought silk, porcelain and lacquer to Manila to meet it. In 1571 Legazpi founded Manila, and from then American silver reached China directly across the Pacific, joining all the heavily populated continents in one trade.
Grading: 1 pt source; 1 pt China’s demand; 1 pt goods back and 1571.
- First the **Strait of Hormuz**, then the **Strait of Malacca** (with the Singapore Strait); the alternative is the **Lombok Strait** (or the Sunda Strait, which is narrower and shallower). Share: $20 \div 100 =$ **20%**, about one-fifth of world use.
Grading: 1 pt each.
- (a) $22,500 - 9,500 =$ **13,000 km (about 8,070 miles)**, $13,000 \div 22,500 \approx$ **58%** shorter. (b) $15 \times 1.852 = 27.8$ km/h; $13,000 \div 27.8 \approx 468$ hours $\approx$ **19.5 days**. (c) Any two: Carlos Finlay and Walter Reed showed that mosquitoes carry yellow fever; William Gorgas drained pools, screened and fumigated until yellow fever was gone from the Canal Zone by 1906; John Stevens built the railroad system to haul away spoil; George Washington Goethals finished the canal (opened 15 August 1914).
Grading: 1½ pts (a); 1½ pts (b); 1 pt (c).

7. The Montreux Convention gives Turkey control of the Turkish Straits (Bosporus, Sea of Marmara, Dardanelles), guarantees free passage to merchant ships in peacetime and limits warships (in 2022 Turkey closed them to warships of the warring states, as it allows). The straits are the Black Sea's only sea door, so grain ships from Ukraine, Russia and the other Black Sea ports must pass Istanbul; about 33 million tonnes of Ukrainian grain and food left this way under the 2022–2023 agreement.

Grading: 1 pt each.

8. Salt per kg of seawater: $35 \times 0.78 = 27.3$ g. Seawater needed: $1,000,000 \text{ g} \div 27.3 \text{ g/kg} \approx$ **36,600 kg, about 36.6 tonnes** (about 40 short tons). Other sources: **rock salt (halite)** beds, e.g., Taghaza or Taoudenni in the Sahara, Wieliczka in Poland, Hallstatt, Cheshire or the Gulf Coast salt domes; and **brine springs and wells**, e.g., Lüneburg, Droitwich or Zigong in Sichuan.

Grading: 1½ pts calculation; 1½ pts sources with examples.

9. (a) $600 \times 4 \times 30 \text{ kg} = 72,000 \text{ kg} =$ **72 tonnes**; $660 \div 33 =$ **20 days**. (b) The Sahara had salt but no gold and little food; the lands to the south had gold (Bambuk and Bure) and grain but almost no salt, so each region had what the other lacked (**complementarity**). Timbuktu stood near the great bend of the Niger, where the desert met the water; camels did poorly in the wet south and boats could not cross the sand, so goods were unloaded from camels and reloaded onto river boats there, a **break-of-bulk point**, which grew into a city.

Grading: 1 pt (a); 2 pts (b).

10. (a) $P = M \times V \div Y$, so P changes by a factor of $2 \times 1 \div 1.25 = 1.6$: prices rise **60%**. (b) Yearly factor = $2.5^{(1/50)}$; $\ln 2.5 \approx 0.916$, $\div 50 \approx 0.0183$, $e^{0.0183} \approx 1.0185$, so about **1.85% a year**. Doubling time by the rule of 70: $70 \div 1.85 \approx$ **38 years**.

Grading: 2 pts each part.

11. **Cerro Rico**: the “Rich Hill” above Potosí (city at about 4,090 m, 13,420 ft) where silver was found in 1545; by the 1590s the greatest silver source in the world. **Toledo**: Viceroy of Peru who reached Potosí in 1572 and rebuilt the system with mercury amalgamation (mercury from Huancavelica), the Kari Kari reservoirs and water-powered mills, and the mita. **Mita**: a rotating forced-labor draft, adapted from an Inca system, sending about 13,000 Andean men a year to the mines; many suffered and died, and people at the time condemned it. **Route**: llamas and mules to Arica on the Pacific; ship to Callao and on to Panama; mules across the isthmus to Portobelo; the treasure fleet to Havana and then Seville (much was also smuggled out by Buenos Aires).

Grading: ½ pt each identification (1½); 1½ pts route.

12. **Model answer**. For silver: by Earl J. Hamilton's official count, about 17,000 tonnes of silver and 180 tonnes of gold reached Seville between 1503 and 1660, plus smuggling. Thinkers of the time saw the link: Martín de Azpilcueta (1556) noted that money was worth less where it was plentiful, and Jean Bodin (1568) named the abundance of gold and silver as the chief cause. The quantity equation, $M \times V = P \times Y$, shows that if money grows faster than goods and spending speed, prices must rise. *Critics*: prices had begun rising before the great silver imports; Europe's population was growing fast, raising demand for food; and kings such as Henry VIII debased their coins, which also raised prices. *Conclusion*: most historians see several causes working together, with silver an important one, especially in the later 1500s; the slow, steady rate (about 1–1½% a year) fits a long-run monetary push alongside population growth. Spain itself did not stay rich: silver paid for wars and foreign goods, and the crown defaulted in 1557, 1560, 1575 and 1596.

Grading (6 pts): 2 pts evidence for silver (data, contemporaries, equation); 2 pts critics' evidence (earlier rise, population, debasement); 2 pts balanced, supported conclusion.

13. (a) At C: ore $2 \times 50 = 100$ + iron $1 \times 120 = 120 \rightarrow 220$ t-km = **\$22.00**. At O: coal $4 \times 50 = 200$ + iron $1 \times 90 = 90 \rightarrow 290$ t-km = **\$29.00**. At M: ore $2 \times 90 = 180$ + coal $4 \times 120 = 480 \rightarrow 660$ t-km = **\$66.00**. Cheapest: the **coalfield**. (b) At C: ore $1.5 \times 50 = 75$ + iron $120 \rightarrow 195$ t-km = **\$19.50**. At O: coal $1 \times 50 = 50$ + iron $90 \rightarrow 140$ t-km = **\$14.00**. At M: ore $1.5 \times 90 = 135$ + coal $1 \times 120 = 120 \rightarrow 255$ t-km = **\$25.50**. Cheapest: the **ore field**. (c) Coal is a weight-losing material; when it was the heaviest input, the least-cost site was on the coalfield (Britain's industrial cities, the Ruhr, Pittsburgh). As coal per tonne of iron fell, its pull weakened; and as local ores ran out and ore came by sea, the least-cost point moved to the coast, where ships unload ore and coal side by side (IJmuiden, Dunkirk, Pohang).
Grading: 2 pts (a); 2 pts (b); 1 pt (c).
14. (a) Any two: Lancashire – Manchester; South Staffordshire – Birmingham and the Black Country; Yorkshire – Sheffield; Scottish Central Belt – Glasgow; Northumberland and Durham – Newcastle; South Wales – Cardiff. (b) $900 \div 0.125 = \mathbf{7,200}$ **packhorse loads**; $900 \div 30 = \mathbf{30}$ **barge loads**; $30 \div 0.125 = \mathbf{240}$ **packhorses** per canal horse.
Grading: 1 pt (a); 2 pts (b).
15. Oil and gas form from buried plant and animal matter in fine-grained **source rock**, then creep upward because they are lighter than water, filling the pore spaces of porous **reservoir rock** (sandstone or limestone). They escape unless a **trap**, such as an anticline, a fault or the flank of a salt dome, holds them beneath a **cap rock** they cannot pass (shale or salt). In the trap they sort by weight: gas on top, oil in the middle, water below. Spindletop near Beaumont, Texas, was drilled into the flank of a buried **salt dome**: salt (rock salt, halite, Lesson 4.1) pushed up from below made the trap.
Grading: 2 pts trap anatomy and sorting; 1 pt Spindletop.
16. (a) $6,000 \div 15 = 400$ hours $\approx \mathbf{16.7}$ **days**; $6,000 \times 1.852 \approx \mathbf{11,100}$ **km**; $6,000 \times 1.151 \approx \mathbf{6,900}$ **miles**; $2,000,000 \times 159 \text{ L} = \mathbf{318}$ **million liters**; $\times 42 = \mathbf{84}$ **million gallons**. (b) $170,000 \times 600 = 102$ million m^3 ; $102 \div 6 = \mathbf{17}$ **days**. (c) A pipeline is cheap to run but fixed in place, so it suits large, steady flows over land between a field and a fixed buyer (Trans-Alaska, Druzhba); a tanker costs more per mile but can sail to any port that pays, so it suits crossing oceans and changing customers.
Grading: 2 pts (a); 1 pt (b); 1 pt (c).
17. $320 \times 45 = \mathbf{14,400}$ **bushels**; $\times 60 = 864,000$ lb = **432 short tons**; $14,400 \times 27.2 = 391,680$ kg $\approx \mathbf{392}$ **tonnes**; $320 \times 0.4047 \approx 129.5$ ha, so $392 \div 129.5 \approx \mathbf{3.0}$ **t/ha**. Centuries of grass roots built deep, dark soils (chernozem, prairie soils) on flat land with warm, long summer days and moderate rain, enough for grain but often too little for forest.
Grading: 2 pts calculation; 1 pt explanation.
18. (a) $1,000,000 \times 0.005 = 5,000$ t; $\times 0.88 = \mathbf{4,400}$ **t of copper**; $1,000,000 \div 4,400 \approx \mathbf{227}$ **t of ore** per tonne. (b) $270,000 \div 390,000 \approx \mathbf{69\%}$ (China refines about 90%). The elements are scattered, occur together, and are so alike chemically that separating them takes hundreds of steps, so processing, not only the deposit, controls supply.
Grading: 1½ pts (a); 1½ pts (b).
19. **Model answer.** A choke point concentrates *routes*; resource concentration concentrates *sources*. Hormuz carries about one-fifth of world oil use, with bypass pipelines able to take only about 13% of its flow. Rare earths are similar: as of the mid-2020s China mines roughly 70% and refines about 90%, and in 2025 it added export licensing rules for several rare earths and magnets, which matter for neodymium magnets in electric motors, drones, phone speakers and wind turbines. In both cases trouble in one place affects buyers everywhere. The differences matter too: a strait can be closed in a day but rarely stays closed for long, and ships can sometimes detour (the Cape, Lombok); a processing advantage takes years to match, but rare earths are not truly rare, so new mines and plants can be built (Mountain

Pass in California was once the leading source; Australia and the United States are expanding). Buyers respond the same way to both: second routes or sources, stockpiles (like Joseph's stored grain or national oil reserves), and new technology. A fair conclusion: concentration is a real risk that rewards diversification, but it is a risk to be managed, not a cause for panic.

Grading (6 pts): 2 pts accurate figures for both examples; 2 pts likenesses and differences weighed; 1 pt responses (sources, stockpiles, routes); 1 pt neutral, reasoned conclusion.

20. (a) B needs fewer worker-days for both ($30 < 40$, $20 < 60$): **B has the absolute advantage in both.** (b) A: 1 grain costs $40 \div 60 \approx 0.67$ cloth; 1 cloth costs 1.5 grain. B: 1 grain costs $30 \div 20 = 1.5$ cloth; 1 cloth costs ≈ 0.67 grain. **A's comparative advantage is grain; B's is cloth.** (c) A makes $100 \div 40 = 2.5$ grain; B makes $50 \div 20 = 2.5$ cloth. Before: 2 grain and 2 cloth; after: 2.5 and 2.5, a gain of **0.5 grain and 0.5 cloth** with the same workers. (d) After trading 1 for 1, A has 1.5 grain and 1 cloth (0.5 grain more than before); B has 1 grain and 1.5 cloth (0.5 cloth more). Both gain; any rate between 0.67 and 1.5 cloth per grain would work.

Grading: 1 pt (a); 2 pts (b); 1 pt (c); 1 pt (d).

21. **Model answer.** *Gains:* before the container, break-bulk loading cost about \$5.83 a ton (1956); the *Ideal X* was loaded for about 16 cents, roughly 36 times less. Ships that spent a week in port now spent a day; theft and breakage fell; standard ISO boxes moved by ship, train and truck without unpacking; ships grew from 58 boxes to about 24,000 TEU with crews of about 25. Freight became a tiny share of the price of shoes or televisions, so families everywhere got cheaper goods, exporting countries (especially in East Asia) gained jobs and rising incomes, and comparative advantage could work across oceans: Ricardo's gains from trade exist only when transport costs less than the gain from specializing, and the container shrank that cost almost to zero. *Costs:* longshore work, a proud trade for generations, shrank to a fraction of its size; the piers of Manhattan, Brooklyn, San Francisco and London emptied and dock neighborhoods lost their reason to exist; factory towns facing new competition from abroad bore real losses. Unions won pay guarantees for some, and many found new work, but not all. *Judgment:* the gains were broad and very large, while the costs were concentrated on particular workers and places; a fair account names both, and the student may argue for policies that ease such changes or for leaving them to the market, as long as the argument rests on the evidence.

Grading (7 pts): 2 pts specific gains with figures; 2 pts specific costs; 1 pt link to Ricardo/transport cost; 2 pts balanced, supported judgment.

22. (a) $4,200 \times 2 + 2,100 \times 1 = 8,400 + 2,100 = \mathbf{10,500 \text{ TEU}}$; $10,500 \div 11,000 \approx \mathbf{95.5\%}$. (b) $5,700 \times 1.852 \approx \mathbf{10,560 \text{ km}}$; $5,700 \times 1.151 \approx \mathbf{6,560 \text{ miles}}$. At 16 knots: $5,700 \div 16 \approx 356 \text{ h} \approx \mathbf{14.8 \text{ days}}$. At 12 knots: $5,700 \div 12 = 475 \text{ h} \approx \mathbf{19.8 \text{ days}}$, about 5 days longer.

Grading: 1½ pts (a); 2½ pts (b).

23. **Site** is the physical place itself (depth, shelter, land); **situation** is location relative to other places. Shanghai has a matchless situation at the mouth of the Yangtze, whose basin holds hundreds of millions of people and many factories, but a poor site: silt made its old docks too shallow, so it built Yangshan Deep-Water Port (2005) offshore, linked by the 32.5 km Donghai Bridge. **Singapore** is a transshipment hub: it sits where the Strait of Malacca meets the South China Sea, and most of its boxes arrive on one ship and leave on another. **Los Angeles-Long Beach** is a gateway: most of its boxes enter or leave the United States by rail and truck (e.g., the Alameda Corridor).

Grading: 1 pt site/situation; 1 pt classifications.

24. Transshipment moves: $0.85 \times 30 = \mathbf{25.5 \text{ million TEU}}$; gateway moves: $30 - 25.5 = \mathbf{4.5 \text{ million TEU}}$. Actual transshipped cargo: $25.5 \div 2 = 12.75 \text{ million TEU}$; actual cargo in all:

$12.75 + 4.5 = \mathbf{17.25 \text{ million TEU}}$.

Grading: 1 pt moves; 1 pt actual cargo.

25. Laptop: air \$9.00 = **0.9%**; sea \$0.50 = **0.05%**. Potatoes: air \$45.00 = **about 560%**; sea \$2.50 $\approx$ **31%**. Roses: air \$4.50 = **7.5%**; sea \$0.25 $\approx$ **0.4%**. The laptop can fly (high value-to-weight; fast delivery costs little); the roses fly because they are perishable and a weeks-long voyage would ruin them; the potatoes, cheap and heavy, must float.

Grading: 2 pts percentages; 1 pt reasoning.

26. (a) Daily volume: $600,000 \times 0.159 = 95,400 \text{ m}^3$. Speed: $95,400 \div 1.167 \approx 81,700 \text{ m a day} \approx 81.7 \text{ km/day} \approx \mathbf{3.4 \text{ km/h (about 2.1 mph)}}$. Time: $1,287 \div 81.7 \approx \mathbf{15.8 \text{ days}}$. (b) Air routes follow great circles, and the great circle from Hong Kong or Shanghai to the American Midwest bends far north across the Pacific, passing close to Anchorage; freighters stop there to refuel and swap cargo at almost no extra distance, so they can carry less fuel and more cargo.

Grading: 2 pts (a); 1 pt (b).

27. (a) $10,500 \times 1.852 \approx \mathbf{19,450 \text{ km}}$; $10,500 \times 1.151 \approx \mathbf{12,090 \text{ miles}}$; $10,500 \div 16 \approx 656 \text{ hours} \approx \mathbf{27 \text{ days } 8 \text{ hours}}$. (b) Jan 5, 10:00 a.m. + 27 days = Feb 1, 10:00 a.m.; + 8 hours = Feb 1, 6:00 p.m. Shanghai time. Rotterdam is 7 hours behind: **11:00 a.m., February 1**, Rotterdam time. (c) Singapore Strait and **Strait of Malacca; Bab-el-Mandeb; Suez Canal; Strait of Gibraltar; Strait of Dover** (English Channel) to Rotterdam.

Grading: 1½ pts (a); 1 pt (b); 1½ pts (c).

28. An essay by Leonard E. Read, published in *The Freeman* in December 1958, told in the voice of an ordinary pencil. Its point: millions of people in many lands, most of whom never met and no one of whom directed the rest, cooperate to make even a simple product, and “not a single person on the face of this earth knows how to make me.” Materials (any two): cedar from northern California and Oregon (milled at San Leandro); graphite from Ceylon (Sri Lanka); clay from Mississippi; rapeseed oil from the Dutch East Indies (Indonesia); pumice from Italy.

Grading: 1 pt author/date/point; 1 pt two places.