within sight of land, stopping at villages or other landfalls at night. Open-ocean Phoenician sailors ventured farther from shore, but stayed within sight of land and sometimes traveled at night. They steered by observing the constellations and the North Star. In the ancient world, the North Star was called the Phoenician Star. This is one of the earliest historical references to using the North Star for navigation.

UNDERWATER ARCHAEOLOGY

Very few drawings of ancient ships have survived, and those that have lack construction details. Yet today we have a good idea of what Greek and Phoenician ships looked like, how builders put them together, the types of cargo they carried, and other details. Furthermore, every sunken ship is a time capsule for the era in which it sank. Much of what we know about ancient cultures comes from what we've found in old shipwrecks. This is possible thanks to the science of underwater archaeology.

Archaeology is the scientific study of fossils, antiquities, and artifacts relating to past human cultures and activities. By necessity it is a methodical science that records every detail of an ancient find before moving and preserving it. This is important because archaeologists learn as much (sometimes more) from the relationships of objects to each other as from the objects themselves.

Underwater archaeology applies the same science to human fossils, antiquities, and artifacts found under water. This typically means ancient shipwrecks, sunken cities, and other archaeological sites under water. Marine archaeology is sometimes known as archaeological oceanography. Scientists commonly use both terms.

Institute of Nautical Archaeology

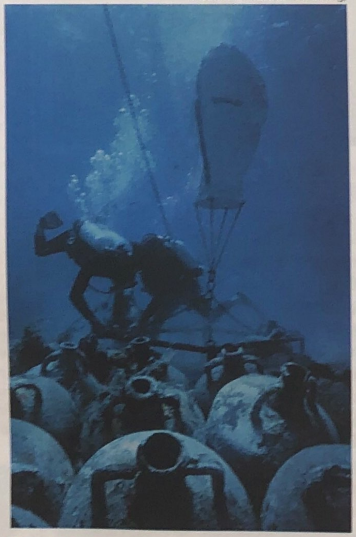

Figure 2-5

Underwater archaeology.

Much of what we know about ancient cultures comes from what we've found in old shipwrecks. This is possible thanks to the science of underwater archaeology.

As you may imagine, underwater archaeology can be quite demanding. Scientists must meet archaeology's exacting requirements in an extreme environment. This means they must do so using scuba diving, submersibles, or ROVs (Remotely Operated Vehicle), or a combination of these. Archaeologists must not only do this under water, but they must determine the best scientific methods to apply to each wreck—no two are exactly the same.

Early in the 20th century, hard-hat divers simply grabbed artifacts, which is salvage—not archaeology. This unscientific approach did not effectively study the finds and did more damage than good by causing the loss of significant potential information. In the late 1950s and early 1960s, Peter Throckmorton and George Bass conducted the first detailed, legitimate underwater archaeology on ancient wrecks in the Mediterranean. By the end of the 1960s, underwater archaeology had become an established and accepted archaeological discipline.

Ancient Polynesian Explorations and Discoveries

What was the significance of early Polynesian seafaring?

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Imagine you're on Hawaii. You cut down a tree, hollow it out, add a sail, load in some food and water, and then set out on the ocean headed for Tahiti, more than 3,200 kilometers (2,000 miles) away. It will take weeks, you have no navigation tools except your eyes, ears, and nose, and you're not sure what the weather will be. By modern standards, to even attempt this would seem absurd and foolhardy.

Yet, based on the findings of archaeologists and anthropologists, between 2000 and 500 B.C.—while European cultures were sailing within sight of shore—Polynesian seafarers in the South Pacific were doing exactly this. They routinely crossed thousands of kilometers of open ocean in canoes crafted with stone, bone, and coral tools.

It's theorized that Polynesians built these canoes from tree trunks or planks sewn together with fiber rope. They sealed cracks and seams with tree sap. For open-ocean stability, they either attached an outrigger for shorter voyages, or, for longer trips, they lashed together two canoes with crossbeams and a deck. These crafts had sails. The Polynesians paddled them when there was no wind.

Figure 2-6

Polynesian vessels.

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Incredibly, these crafts were seaworthy enough to voyage the distance from Hawaii to Tahiti—more than 3,200 kilometers (2,000 miles). Although they didn't carry as much as the ships used by European explorers and traders, the Polynesian ships were faster.

The significance of Polynesian seafaring is that it is the earliest known regular, long-distance, open-ocean seafaring beyond sight of land. Archaeologists think that the Polynesians spread eastward from Fiji, Tonga, and Samoa, settling islands in an area of about 26 million square kilometers (10 million square miles). It's estimated that it took more than 1,000 years for the area to be fully settled. By the time Europeans reached the Pacific Ocean in the 1500s, most of the habitable islands had been settled by Polynesians for hundreds of years.

Figure 2-7

The extent of Polynesian seafaring.

The significance of Polynesian seafaring is that it is the earliest known regular, long-distance, open-ocean seafaring beyond sight of land. Archaeologists think that the Polynesians spread eastward from Fiji, Tonga, and Samoa, settling islands in an area of about 26 million square kilometers (10 million square miles). It's estimated that it took more than 1,000 years for the area to be fully settled.

Ancient Greek Exploration and Discoveries

How did ancient explorers navigate near shore and in the open ocean?

What major ocean discovery is credited to the Greek Pytheas?

What two major contributions are credited to the Greek Eratosthenes?

What were the significances of the maps of Herodotus, Strabo, and Ptolemy?

If you've ever been out of sight of land on the ocean or a large lake, you know how difficult navigation can be. The sun and waves give you some directional clues, but these aren't steady or precise. Yet for seafaring to cross large expanses from one small point to another (from a port to an island), navigation is essential.

The Egyptians and other early ancient explorers probably stayed close to shore. They used references on shore to navigate. This kind of navigation is called piloting. As seafaring advanced, ancient explorers learned to use the sun, constellations, the North Star, and sea conditions to help them find their way on the open ocean. They learned to look for cloud patterns that form over islands and to watch for shore birds. It's even thought that they could smell land animals and plants some distance at sea.

It was primarily the ancient Greeks who first used mathematical principles and developed sophisticated maps for seafaring. By applying their advancements in early science and mathematics, this culture contributed to understanding the ocean in many ways. For example, although Western civilization would "lose" the knowledge during the Middle Ages, the Greeks knew that the Earth is a sphere, not flat.

While exploring the Mediterranean and the adjacent Atlantic up to modern-day Great Britain, the Greek Pytheas noted that he could predict tides in the Atlantic based on the phases of the moon. You'll learn more about how the moon creates tides in Chapter 10. Pytheas' major ocean discovery, however, was determining how far north or south you are from the North Star. He did this by measuring the angle between the horizon and the North Star. This significantly improved navigation.

Figure 2-8a

The Greek Pytheas.

While exploring the Mediterranean and the adjacent Atlantic up to modern-day Great Britain, the Greek Pytheas noted that he could predict tides in the Atlantic based on the phases of the moon. Pytheas' major ocean discovery, however, was determining how far north or south you are from the North Star. He did this by measuring the angle between the horizon and the North Star. This significantly improved navigation.

About 150 years later, Eratosthenes (c. 264-194 B.C.) made two major contributions that furthered Pytheas' work. Eratosthenes calculated the Earth's circumference and invented the first latitude/longitude system. This is a system of imaginary grid lines on the Earth, used for navigation and mapping. Eratosthenes' system was irregular because he deliberately ran his gridlines through important landmarks. It wasn't until about 127 B.C. that another Greek, Hipparchus, invented the regular grid system that we use today. You'll learn more about this system shortly.

Figure 2-8b

Eratosthenes invents latitude and longitude.

Eratosthenes invented the first latitude/longitude system. This is a system of imaginary grid lines on the Earth, used for navigation and mapping. Eratosthenes' system was irregular because he deliberately ran his gridlines through important landmarks.

Early seafarers, including the Greeks, began gathering navigational information and writing it down as early maps. In about 450 B.C., Herodotus published a detailed history of Greece's struggles with the Persian Empire. This work included a map that is signifi-

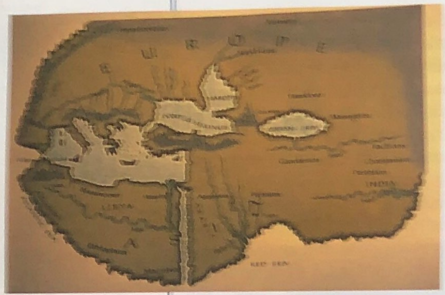

Figure 2-9

The world according to Herodotus, 450 B.C.

Early seafarers, including the Greeks, began gathering navigational information and writing it down as early maps. In about 450 B.C., Herodotus published a detailed history recording Greece's struggles with the Persian Empire. This work included a map that is significant because it was one of the earliest published maps of the world the Greeks knew. Although no known copies have survived, it has been reconstructed based on surviving descriptions.

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As sailors from Greece, Rome, and other cultures continued their exploration, they returned from their voyages with more information for mapping. Strabo (63 B.C.–24 A.D.) was a Greek historian, geographer, and philosopher. He published a 17-book work called *Geographic*. It described the peoples of the world the Greeks knew, and their histories. *Geographic* contained a map that was significant because it demonstrated the Greek's expanding knowledge, and its accuracy, about the world.

The next significant Greek map came from Ptolemy (c. 100-168 A.D.), an astronomer, mathematician, physicist, and geographer, in about 150 A.D. Ptolemy's map was significant because it showed a portion of the Earth as a sphere on flat paper. It was also significant because it improved on Hipparchus' latitude/longitude system. It did this by dividing the grid into degrees, minutes, and seconds of the arc. This is the latitude/longitude system still in use today. Although none of Ptolemy's maps have survived, it has been recreated from descriptions.

Jim Siebold

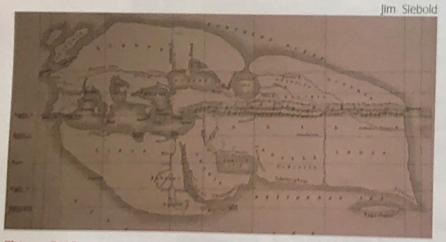

Figure 2-10

The world according to Strabo, c. 35 B.C.

As sailors from Greece, Rome, and other cultures continued their exploration, they returned from their voyages with more information for mapping. Strabo gathered that information and developed a map expanding knowledge, and its accuracy, about the world.

Figure 2-11

Ptolemy's Earth as a sphere.

The Greek Ptolemy developed the first known map to show a portion of the Earth as a sphere on flat paper.

MEASURING THE SIZE OF THE EARTH—ANCIENT GREEK STYLE

Imagine it's 200 B.C. and you want to make an accurate map. To do this, you need to know the circumference of the Earth. There are no satellites, surveying tools, or similar modern tools, so how do you do it? Can it even be done?

Eratosthenes did it by using basic geometry. Although his original work was lost long ago, his accomplishment survives through the works of other authors. It's thought his calculations went like this:

Eratosthenes knew that when a line crosses two parallel lines, the angles formed at the intersection of one line will always equal the angles formed at the intersection of the other line. Therefore, Eratosthenes determined he needed to measure the distance and angles between two parallel lines striking the Earth's surface. This would tell him the number of degrees of the Earth's circumference that the distance represents.

Figure 2-12

Eratosthenes of Cyrene, 276 B.C.-194 B.C.

Figure 2-13

First, Eratosthenes needed two parallel lines that intersected with the Earth's surface. For these, he decided to use the sun's rays. He probably knew that technically sun rays are not parallel. But, the sun is so far away that for his practical purposes, they were close enough to parallel to be accurate.

Next, Eratosthenes needed to know when sunlight was striking the Earth squarely so he would have one of his two lines perpendicular to the Earth. That would be when the sun was directly overhead. He had heard of a deep well in Syene, Egypt into which, at noon on the longest day of the year, sunlight shone directly to the water at the bottom. That told him when the sun's rays gave him the parallel lines he needed. The well would be one line and the rays coming down anywhere else could be the other, provided he could measure and determine an angle from it.

In another Egyptian city, Alexandria, he had noticed a vertical pole that cast a very slight shadow on the same day at the same time. This meant that the sun was not directly overhead in Alexandria when it was directly overhead in Syene. The vertical pole's shadow therefore formed the intersecting angle he needed. Eratosthenes measured the angle and found it to be 7.2°. Now all he needed was the distance from the pole to the well, which was estimated as (in modern measurements) 800 kilometers (500 miles). From there it was determining a ratio with basic algebra:

$$\frac{7.2^\circ}{800\text{ km}} = \frac{360^\circ}{\text{Earth circumference in km}}$$

The next step is to cross multiply:

$$7.2^\circ \times \text{Earth circumference in km} = 800\text{ km} \times 360^\circ$$

Then solve for the circumference:

$$\text{Earth circumference in km} = \frac{800\text{ km} \times 360^\circ}{7.2^\circ}$$

$$\text{Earth circumference in km} = \frac{288{,}000^\circ\text{ km}}{7.2^\circ}$$

$$\text{Earth circumference in km} = 40{,}000\text{ km (24,840 miles)}$$

The accepted measurement today using lasers, satellites, and other modern instruments is 40,032 km. Eratosthenes missed it by only 32 km (approximately 20 miles)! With the Earth's circumference in hand, Eratosthenes went on to invent the first latitude/longitude system.

Ironically, Ptolemy's later map, which used Hipparchus' improved latitude/longitude system, was based on an *inaccurate* Earth size. Ptolemy's map underestimated the Earth's circumference. His estimate became widely accepted and survived to Columbus' day. Columbus believed he had reached the west coast of Asia when he reached the Caribbean because he thought the Earth was smaller than it is.