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ALEXANDER JONES
LIBA TAUB

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20

GREEK AND GRECO-ROMAN GEOGRAPHY

Klaus Geus

The Greek term "geography" was coined rather late, probably by Eratosthenes, the famous polymath and librarian of Alexandria, in the late third century BCE. It superseded the older expression *gês periodos*, which means "traveling along the edges of the Earth," i.e. "description of the known world (according to a map)" or, in some contexts, simply "map." It seems that *gês periodos* was the title of nearly all the works with geographical content before Eratosthenes (e.g. those of Anaximander, Eudoxus, or Dicaearchus). That it took until the heyday of Hellenistic times to find a more suitable term for regional and topographical studies attests to the fact that the Greeks and Romans did not consider "geography" a discipline sui generis. To be sure, ancient authors never tired of emphasizing that spatial knowledge was important for generals, politicians, merchants, and even for philosophers and the like, but geography was never studied for its own sake; geographical knowledge always served another practical or ancillary purpose.

We are not informed why Eratosthenes felt compelled to use *geôgraphia* for his work. He may have thought that the term *gês periodos* was adequate only for the description of the coasts and borders of the world, but not for the description of its entirety, or he may have been inspired by a word play of Herodotus (4.36) – but his aim in coining the new term is clear: *geography* should mean also, and primarily, cartography. A geographer was a scholar who "dared" (Agath. 1.1 [*Geographi graeci minores*, ed. Müller (henceforth "GGM"), II 471]; Eustathius *Commentary on Dionysius Periegetes* [GGM II 208]; cf. Strabo 1.1.1) to draw a map of all parts of the known world. In this vein the word geography was used throughout antiquity, e.g. by Ptolemy in his famous work *Geôgraphikê Hyphêgêsis* (*Introduction to geography*). For the ancients, a geographer was basically a cartographer.

It is consistent with this line of thinking that Eratosthenes considered as the first geographers not Homer or Hesiod but Anaximander and Hecataeus, who had indeed drawn maps. Of course, this was a break with tradition, which commonly named Homer the "proteus heuretês" ("first

inventor") of every discipline (cf., e.g., the lengthy discussion in chapters 1 and 2 of Strabo's first book). But Eratosthenes demonstrated that most of Homer's geographical and topographical information was false, or at least questionable, combatting the view of Homer as the founder of geography with the acerbic statements "that poets only want to entertain and not to teach" (Strabo 1.1.10; cf. 1.2.3) and "that one will find where Odysseus wandered when you find the cobbler who sewed up the hide of winds" (Strabo 1.2.5; cf. Eustathius 1645 [*ad Homeri Odysseam* 10.19]).

In spite of that, much interesting and reliable spatial information permeates Homer's works, which were composed in Asia Minor in the second half of the eighth century BCE. At that time the Greek colonization had started from Miletus, and Homer may have even heard about lands and peoples in the western Mediterranean or along the Atlantic coasts. But this geographical knowledge was superimposed by layers and elements of mythology such as the Elysian Fields or the Grove of Persephone, located at the fringes of the known world (*Od.* 4.563; 10.508–12). Scanning through the *Iliad* and *Odyssey*, we can extract Homer's worldview as follows: the "limitless Earth" is a circular plane, surrounded by the Okeanos, the "soft flowing" and "deep" river (*Iliad* 14.245 f.; 18.607; 20.7; *Odyssey* 11.157; cf. Strabo 1.1.7). The eternal sky rests like an arch on columns, supported by the giant Atlas in the west, and encompasses the lands and seas of the Earth. At its center rises Mount Olympos, where the Greek gods dwell (cf. *Odyssey* 1.52 ff.).

Homer's worldview was accepted by his younger contemporary Hesiod (ca. 700 BCE) with only a few modifications. Like Homer, Hesiod made the Earth encircled by Okeanos, which he vividly called "back-flowing" and "all-circling" (*Theogony* 242, 959, 983). But for him, the flat Earth has roots and is no longer limitless. Above and beneath the disk two hemispheres converge at the horizon and form a self-contained universe, the *kosmos* (Hesiod *Theogony* 728, 807; cf. *Works and Days* 19). Later poets adhere to this basic concept. Like Homer and Hesiod, they deemed the Earth to be a flat disk. But according to Pindar and the Attic tragedians, the *omphalos*, the "navel" or center of the world, was no longer Mount Olympus, but Delphi, or, more exactly, the Delphic oracle (cf. Pindar, *Pythian* 4.74; fr. 54 = Strabo 9.3.6; Pausanias 10.10.3; Bacchylides 4.4; Aeschylus *Eumenides* 40).

Later, the so-called Presocratics, in their search for causes of certain phenomena, had a more "rational" or, one may even say, more "scientific" approach to explaining the world. Modern scholars distinguish two branches of Presocratics, the "Ionians" and the "Italians." Such a distinction is justified not only by the regional distribution of their protagonists but also in regards to the content of their works: these groups disagreed fundamentally in their cosmological and geographical concepts.

The earliest Presocratics hailed from Ionia in Asia Minor. As already mentioned, the Greek colonization started from here. Its metropolis Miletus was an international center of the exchange of goods and

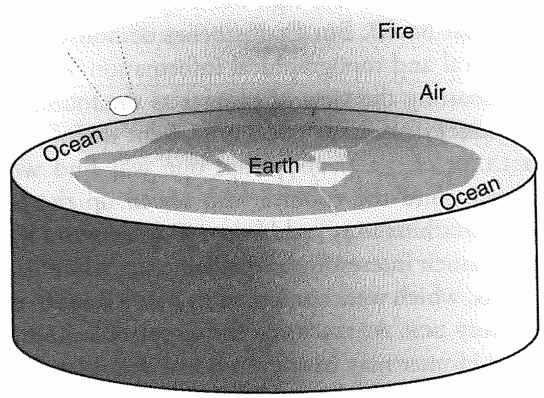

Figure 20.1. The cosmology of Anaximander.

information. Hence, it was not by accident that the first thinkers who tried to put together a coherent picture of the world were based there. Yet, since their knowledge of the world was still rather limited in geographical scope, the Ionians used geometrical models and arguments such as symmetry and analogy, as they had already done in their cosmological theories, in order to move into yet unknown, uncharted territory.

Anaximander (first half of the sixth century BCE), allegedly the pupil of Thales, thought of the Earth as a drum, floating in the middle of the *kosmos*. The height of this cylinder is one-third of its diameter. All peoples live on the top surface of this drum, which is surrounded by the world river Okeanos (see esp. *VS* 12 A 10 and 11; fig. 20.1).

Ancient sources agree that Anaximander was the first who "dared" to draw a map of the world (Agathemerus 1.1 = *VS* 12 A 6). There is no reason to doubt this since Anaximander also worked in the adjacent field of astronomy and is cited as the inventor of the gnomon and the globe, two instruments also essential for geographers. His basic conception for the map is in accordance with that of Homer. Anaximander seemingly made an effort to integrate even the parts of the Earth into his map that were unknown or inaccessible to the Greeks at his time. Despite the fact that Anaximander's map is more about geometry than geography, his idea of using numbers and ratios for the construction of the world map was a key innovation in ancient geographical thought.

Anaximander's disciple Anaximenes (ca. 585–525 BCE) also described the Earth as a flat disk hovering in the air. Sun and Moon float like leaves around it. Interestingly, Anaximenes explained the alternation between day and night as a movement of the heavenly bodies which disappear behind a huge mountain range in the north, called the Rhipaean Mountains, at regular intervals (*VS* 13 A 7; cf. A 14).

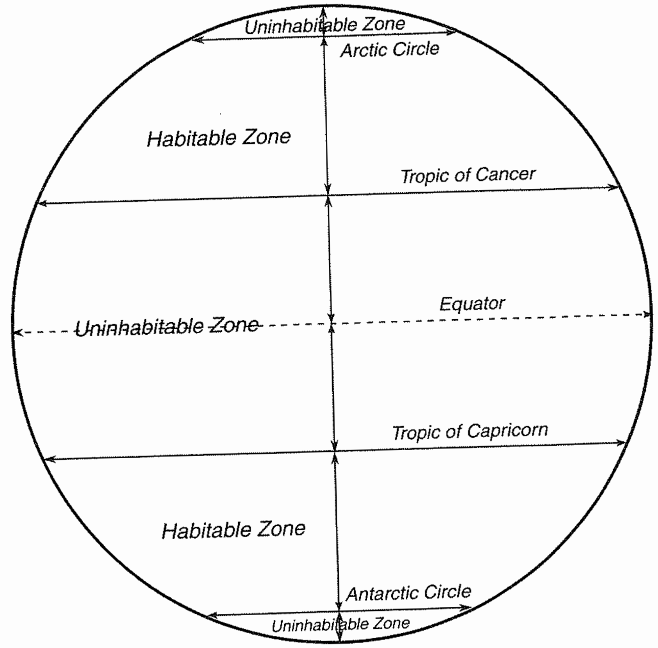

Figure 20.2. The system of five geographical zones. The equation of the zones' boundaries with the tropic and arctic circles is probably later than Parmenides.

The cosmology of Anaximander and Anaximenes exhibits the same basic features that we have found in the archaic poets. They were so common that the idea of a flat Earth was ascribed to other thinkers from Asia Minor as well, such as Thales, Anaxagoras, Democritus, Hecataeus, Herodotus, and Ephorus. One may even call the flat-Earth theory a dogma of Ionian thought.

In contrast, philosophers of Magna Graecia, such as the Pythagoreans and the Eleatic philosophers, took a different stance in cosmology and geography. They advanced a new theory: that of the sphericity of the Earth. Nevertheless, we find some differences between the various "Italian" schools. The Pythagoreans contended that the Earth, a "counter-Earth" (*antichthon*), the sun, the moon, and the five known planets rotate around a central fire. In this, the Pythagoreans were probably more influenced by speculation about ideal forms and numbers than by actual experience.

Parmenides, the founder of the Eleatic school, remained true to his basic philosophical conviction that all being is "all at once, one and continuous." He proposed that the *kosmos* must have the most perfect form, the sphere (*VS* 28 B1, B8; Diogenes Laertius 8.48 = *VS* 28 A44; cf. Diogenes Laertius 9.21). Later doxographers ascribe to Parmenides also other astronomical and geographical ideas (cf., e.g., Diogenes Laertius 9.23). He divided the Earth into "belts" (called *klimata*) running around the surface of the Earth (Figure 20.2). According to Parmenides there are five belts or zones, three uninhabitable – two cold ones around the poles and a hot one around the equator – and two habitable ones in between. Parmenides' contention that there are not one but two habitable zones on the Earth was revolutionary: other regions exist on the surface of the Earth where mankind can live. This idea fathered a new term: *oikoumenê*, i.e. "inhabited" or "known world," as opposed to the "whole Earth" (*gê*).

Parmenides' model of the world remained popular until the end of antiquity. Although subsequent voyages of Greek mariners extended beyond the equator, establishing that the equatorial belt was in fact inhabited, the notion of an uninhabitable zone persisted as late as Ptolemy, who asserts in his *Almagest* that no one from his part of the world had reached the equator so that the question of habitability was open. The authority of Aristotle and the poems of Aratus and Vergil helped to canonize the notion of the hot, impassable zone at the equator. Theory, not autopsy, won the day.

The idea of the spherical Earth advanced by the Pythagoreans and the Eleatics had, at first, only minor repercussions on the Ionian Presocratics in the east. Hecataeus of Miletus (ca. 500 BCE), whom Eratosthenes considered to be the first geographer, integrated the known geographical data into his work. He also attached a map to his text. But Hecataeus' map was an improvement over Anaximander's older map only in a limited sense. Like all Ionians Hecataeus considered the Earth to be a disk surrounded by the Okeanos. And like Anaximander, Hecataeus used geometrical figures in order to structure his map; for example, he drafted Sicily as a triangle (Figure 20.3).

Despite the enormous growth of geographical information at the end of the sixth century BCE, the basic geographical conception of the world had not changed much. The *oikoumenê* was still considered an "island" in the Okeanos. Hecataeus' contribution consisted mainly in updating Anaximander's map and in adding some new data.

We have only a few reports about maps in the period immediately after Hecataeus. We can surely assume that expanded and modified versions were made following the Ionian model. The Ionians, like the Italian Presocratics, distinguished the inhabited from the uninhabitable world, inscribing an oblong rectangle in a circle. This part of the world was also called – just like the inhabited zones in Parmenides' model – *oikoumenê*, "inhabited (world)." But the arguments that the Earth is a sphere and not a disk could no longer be ignored by the end of the classical period. By the time of Plato and Aristotle at the latest, such a view was prevalent within the scientific community (see, e.g., Plin. *NH* 2.64.160).

The geographical conception of the historian Ephorus (ca. 405–330 BCE) also gained currency. The famous geographer Strabo (ca. 64 BCE–23 CE) and the Christian monk Cosmas Indicopleustes (sixth century CE) both reported how the historian Ephorus made use of a rectangular map (Strabo 1.2.28; Cosmas *Topographia* 2.148). In the fourth book of his *Histories* Ephorus

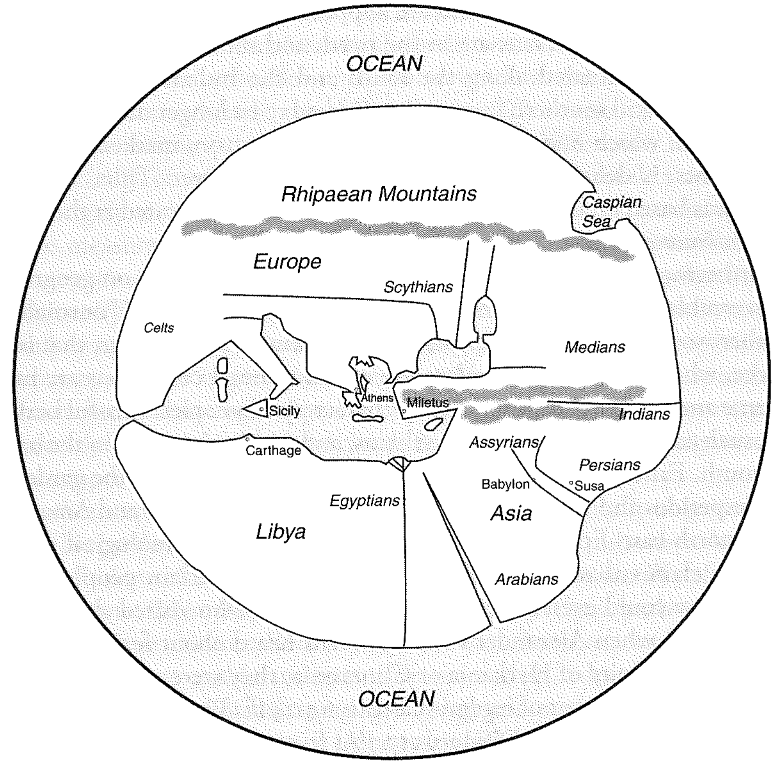

Figure 20.3. Modern reconstruction of the map of Hecataeus.

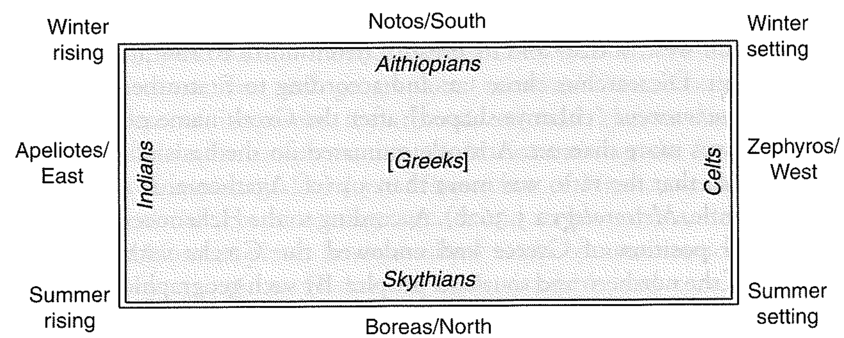

Figure 20.4. Schematic reconstruction of the world map of Ephorus.

sketched out the *oikoumenê* in the traditional form of a rectangle (where the south is on top, see Figure 20.4).

Ephorus equated each side and angle of the rectangle with cardinal directions, expressed as winds and astronomical points, namely where the sun rises and sets on the days of the summer and winter solstice. Each side is also associated with peoples who are supposed to inhabit regions of great extent. While the Skythians are in the north and the Celts in the west, the Aithiopians are situated along the south and the Indians along the east. The northern and southern lines are considered to be longer than the eastern and western, which underlines the fact that the horizon, marked by certain fixed points, is defined with respect to a Greek observer. Thus, Ephorus' model was based on the old concept that the Greeks are located at the center of the *oikoumenê*.

Furthermore, an influence of the ethnographical tradition on geography is discernible here. In a view of the Earth like that of Ephorus, "normality," in other words "order" and "civilization," dominate at its center, that is, in Greece, whereas towards the edges the environmental conditions are more extreme and give rise to simplistically characterized peoples. Blissful barbarians, such as the Hyperboreans, Skythians, and Aithiopians, live in the north and south. Fantastic lands stretch out far to the west and east: the garden of the Hesperides and Erytheia lie in the west, India in the east, and Amazonia in the north-east. Ephorus seems to owe much to this ethnological model, when he claims that the *oikoumenê* is bounded by certain peoples. Such a worldview could even influence the first Greeks who visited these lands. For example, when Alexander's Macedonians heard about female warriors living in the vicinity of Hyrkania or Chorasmia, they were quick to identify them with the Amazons of legend (Curtius 6.5.24 ff.; Plutarch *Alexander* 46; Arrian *Anabasis* 4.15.4; cf. Diodorus 17.77.1 ff. et al.).

But let us return to the more "scientific" geographers. As already mentioned, in the years after Hecataeus, geographers quarreled over the size of the *oikoumenê*, which was represented as a rectangle by the majority. Democritus proposed a ratio of 3:2 for the ratio between the *oikoumenê*'s length (from west to east) and its breadth (from north to south); Eudoxus preferred 2:1; Dicaearchus chose 3:2; and according to Eratosthenes – who called the *oikoumenê* "chlamys-shaped" after the Greek name of a type of cloak – it was more than 2:1. Aristotle estimated on the basis of data from land and sea that the ratio was more than 5:3 (cf. Agathemerus 1.2; Strabo 1.4.5; Aristotle, *Meteorology* 2.5, 362b). According to the Hellenocentric view, the central position of Greece had endowed the Greeks with the best qualities of the northern and southern peoples. By such geographical reasoning, Aristotle could derive a legitimate claim for Greek supremacy over the "barbarians" (cf. Aristotle *Politics* 1.6, 1255a–b; 3.14, 1285a).

Aristotle was also one of the first to inform us about attempts to measure the circumference of the Earth, and cites unknown "mathematicians" (Eudoxus?) for the figure 400,000 stades (*De Caelo* 2.14, 298a15). Some years later, Archimedes (287–212 BCE) shortened it to 300,000 stades (*Arenarius* 1.8), which was still much too high, since these numbers are equivalent to about 63,000 or 47,000 km instead of about 40,000 km.

The man who put the measurement of the circumference of the Earth onto a scientific, i.e. mathematical, basis was Eratosthenes of Cyrene (276–194 BCE), the versatile scholar and head of the famous library of Alexandria. Eratosthenes' method (see esp. Cleomedes 1.7.51–110) was based on a simple proportion: he equated the difference between the astronomically observed latitudes of two places – Alexandria and Syene, lying roughly on the same meridian – with their known terrestrial interval, i.e. the measured distance on the ground. By this means, he arrived at an accurate estimation of the circumference of the Earth (assuming that he used the "itinerary" stade of 157.5, his calculation circumference – 250,000×157.5 – arrived at 39,375 km). Eratosthenes also drew a new map of the *oikoumenê*, which was a major improvement on the older maps with their speculative elements and characteristic appeal to principles of analogy and symmetry. He was also the first to draw parallel circles and meridians and to integrate them into a proper system.

In other respects too, his approach was more geometrically objective than that of his predecessors. The cornerstones of his map consisted no longer of peoples (Indians, Celts, etc.) whose geographical extent was ill defined, but of important cities (Carthage, Meroe, etc.) and landmarks (Pillars of Herakles, Cape Notou Keras, etc.). It was, however, only one step. Eratosthenes was unable to determine more than a handful of parallels (and even fewer meridians) running through some of the most important cities of early Hellenistic times (Alexandria, Rhodes, Byzantion, Carthage, Massalia [i.e. Marseille], Gades [i.e. Cadiz]). Thus, since these cities were chosen for their civil prominence or for other nongeographical reasons, they formed no fully abstract and geometrical set of coordinates. Hence, the modus operandi of Eratosthenes must not be judged as a complete break with geographical tradition, but as a compromise between ideal and reality.

Later astronomers and geographers criticized Eratosthenes for his extensive use of itineraries (i.e. records of road systems) and *periploi* (analogous documents for sea routes) in determining the latitudes and meridians of important locations. Hipparchus of Nicaea, working in the latter half of the second century BCE, is said to have demanded that the relative positions of places be determined solely by astronomical observations (cf. frs. 35, 26, 39 Dicks). As understandable and correct as such a demand was, it was one which simply could not be carried out in ancient times. Only a handful of locations had ever been measured astronomically. The preserved fragments make it clear that Hipparchus tried neither to condemn everything Eratosthenes proposed nor to replace Eratosthenes' geographical system with his own. Rather, Hipparchus' criticism was aimed mostly at particular cartographical aspects of Eratosthenes' geography. In consequence, he advised his readers to use the older Ionian maps (cf. fr. 14 Dicks) since in his view they represented a standing hypothesis that Eratosthenes had failed to prove incorrect.

Hipparchus' work, aptly entitled "Against the *Geography* of Eratosthenes," was a commentary on Eratosthenes from an astronomical point of view. This view is confirmed by Strabo (2.1.41 = test. F Dicks):

> Therefore, for Hipparchus who was not writing a geographical treatise, but was making a critical examination of the statements made by Eratosthenes in his *Geography*, it would have been fitting for him to have gone into further details of correction.

After Eratosthenes, Greek scholars went separate ways. Some, like Posidonius (ca. 135–51 BCE), were interested in physics (a part of philosophy) and wrote about geological matters; some, like Agatharchides (ca. 200–after 131 BCE), Polybius (ca. 200–120 BCE), and Artemidorus (first century BCE), produced ethnographical accounts about peoples and regions of the *oikumenê*; some, like Pseudo-Skymnus (second century BCE) and Dionysius of Alexandria (also called Periegetes; early second centry CE), rehashed spatial information for a broader audience by putting it into verse. None of them produced a new map of the world (Strabo 2.4.1).

Even Strabo (64/63 BCE–ca. 24 CE), who wrote a huge "geographical" (in the modern sense) work in seventeen books, never drafted a map. Accordingly, he refers to his own work as *chôrographia*, *periêgêsis*, *periodos gês*, and *periodeia tês chôras* (3.4.5; 6.1.2; 9.5.14). The only exception seems to come at the beginning of his third book (Strabo 3.1.1), where he indeed speaks about *geôgraphia*, but he clearly means by this the earlier cartographical efforts like that of Eratosthenes, which he had discussed in Books 1–2. Hence, a better title for Strabo's work would be "chorography" instead of "geography." As the titles of the works of Pomponius Mela and Pappus of Alexandria, which employ *chôrographia* rather than *geôgraphia*, show, the term "chorography" was used in antiquity for a comprehensive description of the whole world in a *non-cartographical* mode. Strabo's work, in fact, contains a thorough description of the entire *oikoumenê* which overlaps to a large extent with the *Imperium Romanum* of Augustan times. He advanced and discussed cartographical theories on the Okeanos, the three continents, the *klimata*, and the five zones as important elements of *oikoumenê*. But by imposing on this rich material other spatial, political, and ethnographical concepts (for example, Hellenes and barbarians, or centers and periphery) for every region, Strabo's work gained a new outlook, one that we nowadays would not hesitate to call "geographical."

But again, this was not how the ancients would have described it. A final hint can be detected in the famous definition of geography at the beginning of the *Introduction to "Geography"* (*geôgraphikê hyphêgêsis*) written by the famous astronomer Claudius Ptolemy (Klaudios Ptolemaios) around 150 CE:

> Geography is an imitation through drafting (*dia graphês*) of the entire known part of the world together with the things which are, broadly speaking, connected with it. It differs from chorography . . .

The phrase "together with the things which are, broadly speaking, connected with it" surely allows for some margin of interpretation, but Ptolemy was entirely concerned with producing maps, especially the "world-map," in his *Introduction to "Geography."*

By eliminating all political, historical, and ethnographical aspects and data (2.1.8) that he found in his source material (called "research derived from travel," *historia periodikê*, i.e. *periploi* and itineraries; 1.2.2; 1.4 tit.; cf. 1.5.2; 1.6.1; 7.7.4), Ptolemy arguably produced the most influential work in the history of geography. His methods and goals, expounded in detail in the first book, are clear and distinctly explained. The major part of his *Geography* consists of a catalog of no less than 8,000 localities with 6,300 pairs of coordinates of latitudes and longitudes. The geographical work of Ptolemy is an impressive demonstration of applied mathematics. In addition to this, it introduced some long-lasting cartographical innovations such as the north-at-top orientation of modern maps and the use of symbols. Ptolemy's advancements are important not only in terms of the enormous increase in the quantity of information represented, there is also a truly astonishing qualitative shift, in that unlike the former cartographers Anaximander, Hecataeus, and Eratosthenes, Ptolemy did not need to fall back on geometrical figures and estimates of distances to draft a map of the *oikoumenê*.

At this point, Greek geography, the foster child of geometry, appeared likely to emancipate itself as a discipline in its own right. But Ptolemy's groundbreaking work was not taken up by any later scientist in antiquity. In fact, it was almost completely forgotten in late antiquity and the Middle Ages, only to be rediscovered in the Byzantine Empire in the thirteenth century, and in the Latin world only at the beginning of the fifteenth. Why such an ingenious work as Ptolemy's fell into oblivion is hard to fathom. There was probably more than one reason. Apart from the required mathematical expertise, the technical difficulties in producing maps, and the costs of copying the long text and the maps, we may also point to the little-known fact that Ptolemy's work was epitomized by later authors. For example, while describing the Sasanian empire, the Latin historian Ammianus Marcellinus (*History* 23.6) clearly drew on a list of regions which was organized according to the structure of Ptolemy's *Geography*; and Pappus of Alexandria (fourth century CE) wrote a *Chôrographia oikumenikê* (*Description of the "oikumenê"*), extant in Armenian under the title *Ašxarhac'oyc'* (i.e. "worldview"), which is seemingly an abbreviated version of Ptolemy's work. The fact is that world maps played a much smaller role in antiquity than today. For orienting and navigating, the Greeks and Romans used other means, especially *periploi* and itineraries. Accordingly, geography in its original sense, "the art of drafting maps," never found much resonance with the Greeks and Romans.

21

GREEK OPTICS

A. Mark Smith

Although it can be fairly said that, as a science in the modern sense, Greek optics had its wellsprings in ray theory, three caveats are in order. First, the goal of Greek optics was to explain vision, not the physics of light, so the classical ray represented a path for sight, not light.[1] On that account, second, Greek optics must be evaluated within the broader context of concurrent epistemological thought. Finally, the dearth of contemporaneous sources makes it difficult to trace the development of Greek optics with any confidence. These caveats in mind, we shall begin with an overview of the evolution of ray theory from its presumed beginnings around 400 BCE to its culmination in the later second century CE. Next, we shall discuss various models of visual perception formulated over roughly the same period, taking into account underlying physical, physiological, and psychological issues. We shall then narrow our focus upon mathematical optics. The resulting account will reflect the tripartite analytic structure that evolved over the period between Euclid (ca. 300 BCE) and Ptolemy (ca. 160 CE). Accordingly, we shall examine the development of optics proper first (involving unimpeded visual radiation), then of catoptrics (involving fully broken or reflected visual radiation), and, last, of dioptrics (involving partially broken or refracted visual radiation).

HISTORICAL OVERVIEW

Precisely when and why the ray concept was developed is a matter of speculation, but its origins probably lie in the early fourth century BCE and certainly no later than mid-century. Aristotle, for instance, includes optics among the "more physical" of the mathematical sciences in *Physics* 2.2, and

[1] On this point, see Gérard Simon, *Le regard, l'être et l'apparence dans l'optique de l'antiquité* (Paris: Seuil, 1988).